Chapter 18—Predictive Method for Freeways

18.1. INTRODUCTION

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

The predictive method for freeways provides a structured methodology to estimate the expected average crash frequency (in total, by crash type, or by crash severity) for a freeway with known characteristics. Crashes involving vehicles of all types are included in the estimate. The predictive method can be applied to an existing freeway, a design alternative for an existing freeway, a new freeway, or for alternative traffic volume projections. An estimate can be made of expected average crash frequency for a prior time period (i.e., what did or would have occurred) or a future time period (i.e., what is expected to occur). The development of the predictive method in this chapter is documented by Bonneson et al. (1).

This chapter presents the following information about the predictive method for freeways:

- A concise overview of the predictive method.
- Definitions of the facility types and site types addressed by the predictive method.
- A step-by-step description of the predictive method.
- Details for dividing a freeway facility into individual evaluation sites.
- Safety performance functions (SPFs) for freeways.
- Crash modification factors (CMFs) for freeways.
- Severity distribution functions (SDFs) for freeways.
- Limitations of the predictive method.
- Sample problems illustrating the application of the predictive method.

18.2. OVERVIEW OF THE PREDICTIVE METHOD

The predictive method provides an 18-step procedure to estimate the expected average crash frequency (in total, by crash type, or by crash severity) for a roadway network, facility, or site. A site is a freeway segment or a freeway speed-change lane. A freeway speed-change lane is an uncontrolled terminal between a ramp and a freeway. A facility consists of a contiguous set of individual sites. A facility is defined by the surrounding land use, roadway cross section, and degree of access. A roadway network consists of a number of contiguous facilities.

The predictive method is used to estimate the expected number of crashes for an individual site. This estimate can be summed for all sites to compute the expected number of crashes for the entire facility or network. The estimate represents a given time period of interest (in years) during which the geometric design and traffic control features are unchanged and traffic volumes are known or forecasted. The expected average crash frequency is obtained by dividing the expected number of crashes by the number of years during the time period of interest. The estimate is obtained by combining the prediction from the predictive model with observed crash data using the Empirical Bayes (EB) Method.

The predictive models used in this chapter are described in detail in Section 18.3. The variables that comprise the predictive models include a series of subscripts to describe precisely the conditions to which they apply. These subscripts are described in detail in later sections of this chapter. For this section, it is sufficient to use "place-holder" subscripts such as *w*, *x*, *y*, *z*, and *m*. The subscript *w* is a place-holder for specific site-type subscripts that define the equation's application (e.g., it is replaced with "*fs*" when needed to indicate that the equation applies to a freeway segment). Similarly, *x* is a place-holder for segment cross-section subscripts, *y* is a place-holder for crash-type subscripts, *z* is a place holder for crash severity, and *m* is a place-holder for a specific geometric design or traffic control feature.

The predictive models used in this chapter to determine the predicted average crash frequency are of the general form shown in Equation 18-1.

$$N_{p,w,x,y,z} = N_{spf,w,x,y,z} \times \left(CMF_{1,w,x,y,z} \times CMF_{2,w,x,y,z} \times \ldots \times CMF_{m,w,x,y,z}\right) \times C_{w,x,y,z} \tag{18-1}$$

Where:

$N_{p,\,w,\,x,\,y,\,z}$ = predicted average crash frequency for a specific year for site type *w*, cross section or control type *x*, crash type *y*, and severity *z* (crashes/yr);

$N_{spf,\,w,\,x,\,y,\,z}$ = predicted average crash frequency determined for base conditions of the SPF developed for site type *w*, cross section or control type *x*, crash type *y*, and severity *z* (crashes/yr);

$CMF_{m,\,w,\,x,\,y,\,z}$ = crash modification factors specific to site type *w*, cross section or control type *x*, crash type *y*, and severity *z* for specific geometric design and traffic control feature *m*; and

$C_{w,\,x\,y,\,z}$ = calibration factor to adjust SPF for local conditions for site type *w*, cross section or control type *x*, crash type *y*, and severity *z*.

The predictive models provide estimates of the predicted average crash frequency in total, by crash type, or by crash severity. A default distribution of crash type is included in the predictive method. It is used with the predictive models to quantify the crash frequency for each of several crash types. The models predict fatal-and-injury crash frequency and property-damage-only crash frequency. A severity distribution function is available to further quantify the crash frequency by the following severity levels: fatal, incapacitating injury, non-incapacitating injury, and possible injury.

18.3. FREEWAYS—DEFINITIONS AND PREDICTIVE MODELS

This section provides the definitions of the facility and site types discussed in this chapter. It also describes the predictive models for each of the site types.

18.3.1. Definition of Freeway Facility and Site Types

The predictive method in this chapter applies to the following freeway facilities:

- rural freeway segment with four to eight lanes,
- urban freeway segment with four to ten lanes, and
- freeway speed-change lanes associated with entrance ramps and exit ramps.

Freeways have fully-restricted access control and grade separation with all intersecting roadways. Freeways are accessed only through grade-separated interchanges. Roads having at-grade access should be analyzed as rural highways or urban or suburban arterials. These facility types are addressed in Chapters 10, 11, and 12.

The terms "freeway" and "road" are used interchangeably in this chapter and apply to all freeways independent of official state designation or local roadway designation.

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

Table 18-1 identifies the urban freeway segment configurations for which SPFs have been developed. A second set of SPFs have been developed for rural freeway segments with four, six, or eight lanes (they are not shown in the table, but use the same nomenclature). The SPFs are used to estimate the predicted average crash frequency by crash type and crash severity. These estimates are added to yield the total predicted average crash frequency for an individual site. The predictions include both travel directions combined.

Table 18-1. Urban Freeway Segment SPFs

Site Type (w)	Cross Section (x) [a]	Crash Type (y)	Crash Severity (z)	SPF
Freeway segments (*fs*)	Four-lane divided (*4*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf,\,fs,\,4,\,mv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,fs,\,4,\,mv,\,pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf,\,fs,\,4,\,sv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,fs,\,4,\,sv,\,pdo}$
	Six-lane divided (*6*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf,\,fs,\,6,\,mv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,fs,\,6,\,mv,\,pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf,\,fs,\,6,\,sv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,fs,\,6,\,sv,\,pdo}$
	Eight-lane divided (*8*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf,\,fs,\,8,\,mv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,fs,\,8,\,mv,\,pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf,\,fs,\,8,\,sv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,fs,\,8,\,sv,\,pdo}$
	Ten-lane divided (*10*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf,\,fs,\,10,\,mv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,fs,\,10,\,mv,\,pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf,\,fs,\,10,\,sv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,fs,\,10,\,sv,\,pdo}$

[a] The term "divided" indicates that opposing directions of travel are separated by use of a non-traversable median (i.e., a depressed median, a depressed median with barrier, or a flush-paved median with barrier).

The freeway segment is defined as follows:

- *Four-lane freeway segment (4)*—a length of roadway consisting of four through lanes with a continuous cross section providing two directions of travel in which the opposing travel lanes are physically separated by either distance or a barrier.

- *Six-lane freeway segment (6)*—a length of roadway consisting of six through lanes with a continuous cross section providing two directions of travel in which the opposing travel lanes are physically separated by either distance or a barrier.
- *Eight-lane freeway segment (8)*—a length of roadway consisting of eight through lanes with a continuous cross section providing two directions of travel in which the opposing travel lanes are physically separated by either distance or a barrier.
- *Ten-lane freeway segment (10)*—a length of roadway consisting of ten through lanes with a continuous cross section providing two directions of travel in which the opposing travel lanes are physically separated by either distance or a barrier.

Table 18-2 identifies the urban speed-change lane configurations for which SPFs have been developed. A second set of SPFs have been developed for rural speed-change lanes with four, six, or eight lanes (they are not shown in the table, but use the same nomenclature). The SPFs are used to estimate the predicted average crash frequency by crash severity. These estimates are added to yield the total predicted average crash frequency for an individual site.

Table 18-2. Urban Freeway Speed-Change Lane SPFs

Site Type (*w*)	Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	SPF
Speed-change lanes (*sc*)	Ramp entrance to four-lane divided (*4EN*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\, sc,\, 4EN,\, at,\, fi}$
			Property damage only (*pdo*)	$N_{spf,\, sc,\, 4EN,\, at,\, pdo}$
	Ramp entrance to six-lane divided (*6EN*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\, sc,\, 6EN,\, at,\, fi}$
			Property damage only (*pdo*)	$N_{spf,\, sc,\, 6EN,\, at,\, pdo}$
	Ramp entrance to eight-lane divided (*8EN*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\, sc,\, 8EN,\, at,\, fi}$
			Property damage only (*pdo*)	$N_{spf,\, sc,\, 8EN,\, at,\, pdo}$
	Ramp entrance to ten-lane divided (*10EN*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\, sc,\, 10EN,\, at,\, fi}$
			Property damage only (*pdo*)	$N_{spf,\, sc,\, 10EN,\, at,\, pdo}$
	Ramp exit from four-lane divided (*4EX*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\, sc,\, 4EX,\, at,\, fi}$
			Property damage only (*pdo*)	$N_{spf,\, sc,\, 4EX,\, at,\, pdo}$
	Ramp exit from six-lane divided (*6EX*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\, sc,\, 6EX,\, at,\, fi}$
			Property damage only (*pdo*)	$N_{spf,\, sc,\, 6EX,\, at,\, pdo}$
	Ramp exit from eight-lane divided (*8EX*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\, sc,\, 8EX,\, at,\, fi}$
			Property damage only (*pdo*)	$N_{spf,\, sc,\, 8EX,\, at,\, pdo}$
	Ramp exit from ten-lane divided (*10EX*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\, sc,\, 10EX,\, at,\, fi}$
			Property damage only (*pdo*)	$N_{spf,\, sc,\, 10EX,\, at,\, pdo}$

The speed-change lane cross section is defined as a ramp entrance (*nEN*) or ramp exit (*nEX*) with *n* lanes. The variable *n* is used to describe the number of through lanes in the portion of freeway adjacent to the speed-change lane *plus* those freeway lanes in the opposing travel direction. This approach to describing the speed-change lane cross section is used for consistency with that used for freeway segment SPFs. The variable *n* is not intended to describe the number of lanes in the speed-change lane.

18.3.2. Predictive Model for Freeway Segments

In general, a predictive model is used to compute the predicted average crash frequency for a site. It combines the SPF, CMFs, and a calibration factor. The predicted quantity can describe crash frequency in total, by crash type, or by crash severity. This section describes the predictive model for freeway segments. The next section describes the predictive model for speed-change lanes.

The predictive model for freeway segments is used to estimate the predicted average frequency of segment crashes (i.e., the estimate does not include speed-change-lane-related crashes). Speed-change-lane-related crashes are defined in Section 18.3.3 and estimated using the predictive method described in that section.

The predictive model for freeway segments is presented in Equation 18-2. This equation consists of four terms, where each of Equation 18-3 to Equation 18-6 correspond to one term.

$$N_{p,fs,n,at,as} = N_{p,fs,n,mv,fi} + N_{p,fs,n,sv,fi} + N_{p,fs,n,mv,pdo} + N_{p,fs,n,sv,pdo} \tag{18-2}$$

$$\begin{aligned} N_{p,fs,n,mv,fi} = {} & C_{fs,ac,mv,fi} \times N_{spf,fs,n,mv,fi} \times \left(CMF_{1,fs,ac,mv,fi} \times \ldots \times CMF_{m,fs,ac,mv,fi}\right) \\ & \times \left(CMF_{1,fs,ac,at,fi} \times \ldots \times CMF_{m,fs,ac,at,fi}\right) \end{aligned} \tag{18-3}$$

$$\begin{aligned} N_{p,fs,n,sv,fi} = {} & C_{fs,ac,sv,fi} \times N_{spf,fs,n,sv,fi} \times \left(CMF_{1,fs,ac,sv,fi} \times \ldots \times CMF_{m,fs,ac,sv,fi}\right) \\ & \times \left(CMF_{1,fs,ac,at,fi} \times \ldots \times CMF_{m,fs,ac,at,fi}\right) \end{aligned} \tag{18-4}$$

$$\begin{aligned} N_{p,fs,n,mv,pdo} = {} & C_{fs,ac,mv,pdo} \times N_{spf,fs,n,mv,pdo} \times \left(CMF_{1,fs,ac,mv,pdo} \times \ldots \times CMF_{m,fs,ac,mv,pdo}\right) \\ & \times \left(CMF_{1,fs,ac,at,pdo} \times \ldots \times CMF_{m,fs,ac,at,pdo}\right) \end{aligned} \tag{18-5}$$

$$\begin{aligned} N_{p,fs,n,sv,pdo} = {} & C_{fs,ac,sv,pdo} \times N_{spf,fs,n,sv,pdo} \times \left(CMF_{1,fs,ac,sv,pdo} \times \ldots \times CMF_{m,fs,ac,sv,pdo}\right) \\ & \times \left(CMF_{1,fs,ac,at,pdo} \times \ldots \times CMF_{m,fs,ac,at,pdo}\right) \end{aligned} \tag{18-6}$$

Where:

$N_{p,fs,n,y,z}$ = predicted average crash frequency of a freeway segment with *n* lanes, crash type *y* (*y* = *sv*: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only, *as*: all severities) (crashes/yr);

$N_{spf,fs,n,y,z}$ = predicted average crash frequency of a freeway segment with base conditions, *n* lanes, crash type *y* (*y* = *sv*: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr);

$CMF_{m,fs,ac,y,z}$ = crash modification factor for a freeway segment with any cross section *ac*, feature *m*, crash type *y* (*y* = *sv*: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only); and

$C_{fs,ac,y,z}$ = calibration factor for freeway segments with any cross section *ac*, crash type *y* (*y* = *sv*: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only).

Equation 18-2 shows that freeway segment crash frequency is estimated as the sum of four components: fatal-and-injury multiple-vehicle crash frequency, fatal-and-injury single-vehicle crash frequency, property-damage-only multiple-vehicle crash frequency, and property-damage-only single-vehicle crash frequency.

Different CMFs are used in Equation 18-3 to Equation 18-6. The first term in parentheses in each equation recognizes that the influence of some features is unique to each crash type. In contrast, the second term in parentheses in these equations recognizes that some features have a similar influence on all crash types. All CMFs are unique to crash severity.

Equation 18-3 and Equation 18-4 are used to estimate the fatal-and-injury crash frequency. Equation 18-5 and Equation 18-6 are used to estimate the property-damage-only crash frequency.

The SPFs for freeway segments are presented in Section 18.6.1. The associated CMFs are presented in Section 18.7.1. Similarly, the associated SDFs are presented in Section 18.8. A procedure for establishing the value of the calibration factor is described in Section B.1 of Appendix B .

18.3.3. Predictive Model for Freeway Speed-Change Lanes

The predictive model for speed-change lanes is used to compute the predicted average crash frequency for a speed-change lane. Speed-change-related crashes include all crashes that are located between the gore point and the taper point of a speed-change lane and that involve vehicles (a) in the speed-change lane or (b) in the freeway lanes on the same side of the freeway as the speed-change lane.

The predictive model for ramp entrance speed-change lanes is presented in Equation 18-7. This equation consists of two terms, where each of Equation 18-8 and Equation 18-9 correspond to one term.

$$N_{p,sc,nEN,at,as} = N_{p,sc,nEN,at,fi} + N_{p,sc,nEN,at,pdo} \tag{18-7}$$

$$\begin{aligned} N_{p,sc,nEN,at,fi} = {} & C_{sc,EN,at,fi} \times N_{spf,sc,nEN,at,fi} \times \left(CMF_{1,sc,nEN,at,fi} \times \ldots \times CMF_{m,sc,nEN,at,fi}\right) \\ & \times \left(CMF_{1,sc,ac,at,fi} \times \ldots \times CMF_{m,sc,ac,at,fi}\right) \end{aligned} \tag{18-8}$$

$$\begin{aligned} N_{p,sc,nEN,at,pdo} = {} & C_{sc,EN,at,pdo} \times N_{spf,sc,nEN,at,pdo} \times \left(CMF_{1,sc,nEN,at,pdo} \times \ldots \times CMF_{m,sc,nEN,at,pdo}\right) \\ & \times \left(CMF_{1,sc,ac,at,pdo} \times \ldots \times CMF_{m,sc,ac,at,pdo}\right) \end{aligned} \tag{18-9}$$

Where:

$N_{p,\,sc,\,nEN,\,at,\,z}$ = predicted average crash frequency of ramp entrance speed-change lane on a freeway with *n* lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only, *as*: all severities) (crashes/yr);

$N_{spf,\,sc,\,nEN,\,at,\,z}$ = predicted average crash frequency of a ramp entrance speed-change lane on a freeway with base conditions, *n* lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr);

$CMF_{m,\,sc,\,x,\,at,\,z}$ = crash modification factor for a speed-change lane with feature *m*, cross section *x* (*x* = *nEN*: ramp entrance adjacent to a freeway with *n* lanes, *nEX*: ramp exit adjacent to a freeway with *n* lanes, *ac*: any cross section), all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only); and

$C_{sc,\,EN,\,at,\,z}$ = calibration factor for a ramp entrance speed-change lane with all crash types *at* and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only).

The predictive model for ramp exit speed-change lanes is presented in Equation 18-10. This equation consists of two terms, where each of Equation 18-11 and Equation 18-12 correspond to one term.

$$N_{p,sc,nEX,at,as} = N_{p,sc,nEX,at,fi} + N_{p,sc,nEX,at,pdo} \tag{18-10}$$

$$N_{p,sc,nEX,at,fi} = C_{sc,EX,at,fi} \times N_{spf,sc,nEX,at,fi} \times \left(CMF_{1,sc,nEX,at,fi} \times \ldots \times CMF_{m,sc,nEX,at,fi}\right) \times \left(CMF_{1,sc,ac,at,fi} \times \ldots \times CMF_{m,sc,ac,at,fi}\right) \quad (18\text{-}11)$$

$$N_{p,sc,nEX,at,pdo} = C_{sc,EX,at,pdo} \times N_{spf,sc,nEX,at,pdo} \times \left(CMF_{1,sc,nEX,at,pdo} \times \ldots \times CMF_{m,sc,nEX,at,pdo}\right) \times \left(CMF_{1,sc,ac,at,pdo} \times \ldots \times CMF_{m,sc,ac,at,pdo}\right) \quad (18\text{-}12)$$

Where:

$N_{p,\, sc,\, nEX,\, at,\, z}$ = predicted average crash frequency of ramp exit speed-change lane on a freeway with *n* lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only, *as*: all severities) (crashes/yr);

$N_{spf,\, sc,\, nEX,\, at,\, z}$ = predicted average crash frequency of a ramp exit speed-change lane on a freeway with base conditions, *n* lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr); and

$C_{sc,\, EX,\, at,\, z}$ = calibration factor for a ramp exit speed-change lane with all crash types *at* and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only).

Equation 18-7 and Equation 18-10 show that speed-change lane crash frequency is estimated as the sum of two components: predicted average fatal-and-injury crash frequency and predicted average property-damage-only crash frequency.

Different CMFs are used in Equation 18-8, Equation 18-9, Equation 18-11, and Equation 18-12. The first term in parentheses in each equation recognizes that the influence of some features is unique to each speed-change lane type. In contrast, the second term in parentheses in these equations recognizes that some features have a similar influence on both speed-change lane types. All CMFs are unique to crash severity.

The SPFs for speed-change lanes are presented in Section 18.6.2. The associated CMFs are presented in Section 18.7.2. Similarly, the associated SDFs are presented in Section 18.8. A procedure for establishing the value of the calibration factor is described in Section B.1 of Appendix B.

18.4. PREDICTIVE METHOD FOR FREEWAYS

This section describes the predictive method for freeways. It consists of two sections. The first section provides a step-by-step description of the predictive method. The second section describes the geometric design features, traffic control features, and traffic volume data needed to apply the predictive method.

18.4.1. Step-by-Step Description of the Predictive Method

The predictive method for freeways is shown in Figure 18-1. Applying the predictive method yields an estimate of the expected average crash frequency (in total, by crash type, or by crash severity) for a freeway facility or network. The predictive models described in this chapter are applied in Steps 9, 10, and 11 of the predictive method. The information needed to apply each step is provided in this section.

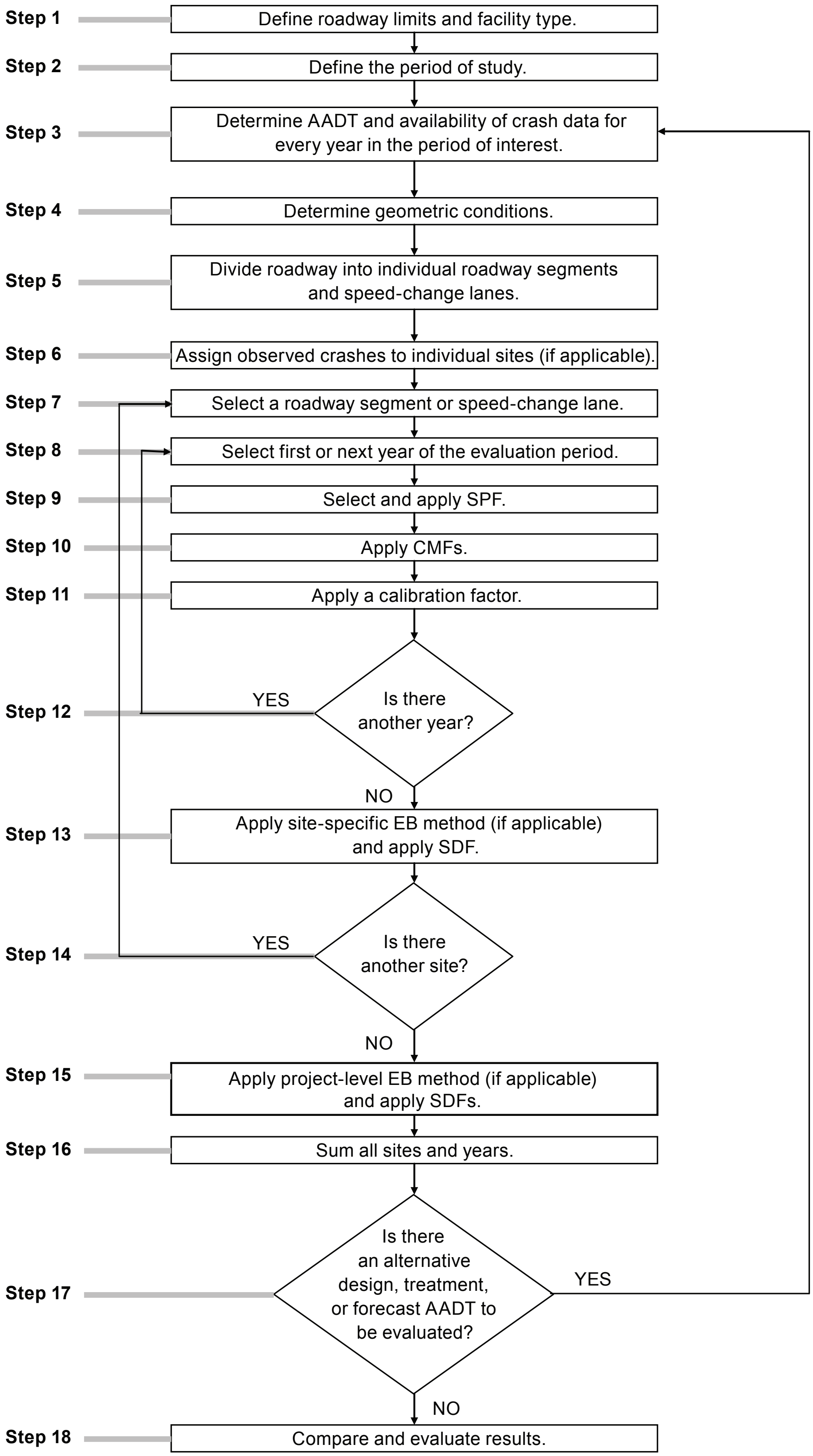


Figure 18-1. The HSM Predictive Method

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

The following discussion explains the details of each step of the method, as applied to freeways.

Step 1—Define the limits of the project.
A project can be a freeway network, a freeway facility, or a site. A site is either a speed-change lane or a homogeneous freeway segment. A site is further categorized by its cross section. A description of the specific site types is provided in Section 18.3.1.

The project limits are defined in this step. They will depend on the purpose of the study. The study may be limited to one specific site or to a group of contiguous sites. Alternatively, the limits can be expanded to include a very long corridor for the purposes of network screening (as discussed in Chapter 4). For comparative analysis of design alternatives, the project limits should be the same for all alternatives.

The analyst should identify (or establish) a reference line for the freeway. This line is defined as the inside edge of traveled way for the roadbed serving traffic moving in the increasing milepost direction. All lengths along the roadway are determined using this line. The location of the reference line is shown in subsequent figures (e.g., Figure 18-6). Locations along this line are specified using a linear referencing system, and are identified using the label "milepost *X*," where the number for *X* has units of miles (e.g., milepost 1.4).

Step 2—Define the period of interest.
The *study period* is defined as the consecutive years for which an estimate of the expected average crash frequency is desired. The *crash period* is defined as the consecutive years for which observed crash data are available. The *evaluation period* is defined as the combined set of years represented by the study period and crash period. Every year in the evaluation period is evaluated using the predictive method. All periods are measured in years.

If the EB Method is not used, then the study period is the same as the evaluation period. The EB Method is discussed in more detail in Step 3.

If the EB Method is used and the crash period is not fully included in the study period, then the predictive models need to be applied to the study years *plus* each year of the crash period not represented in the study period. In this situation, the evaluation period includes the study period and any additional years represented by the crash data but not in the study period. For example, let the study period be defined as the years 2010, 2011, and 2012. If crash data are available for 2008, 2009, and 2010, then the evaluation period is 2008, 2009, 2010, 2011, and 2012.

The study period can represent either a past time period or a future time period. Whether the predictive method is used for a past or future period depends upon the purpose of the study. The study period may be:

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

Step 3—For the study period, determine the availability of annual average daily traffic (AADT) volumes and, for an existing project, the availability of observed crash data (to determine whether the EB Method is applicable).
Traffic volume data are acquired in this step. Also, a decision is made whether the EB Method will be applied. If it will be applied, then it must also be decided whether the site-specific or project-level EB Method will be applied. If the EB Method will be applied, then the observed crash data are also acquired in this step.

Determining Traffic Volumes
The SPFs used in Step 9 (and some CMFs in Step 10) include annual average daily traffic (AADT) volume as a variable. For a past period, the AADT volume may be determined by using automated recorder data or estimated by a sample survey. For a future period, the AADT volume may be a forecast estimate based on appropriate land use planning and traffic volume forecasting models.

For each freeway segment, the following five AADT values are required:

(1) the AADT volume of the freeway segment,

(2) the AADT volume of the nearest entrance ramp upstream of the segment for the increasing milepost travel direction,

(3) the AADT volume of the nearest entrance ramp upstream of the segment for the decreasing milepost travel direction,

(4) the AADT volume of the nearest exit ramp downstream of the segment for the increasing milepost travel direction, and

(5) the AADT volume of the nearest exit ramp downstream of the segment for the decreasing milepost travel direction.

For each ramp entrance speed-change lane, two values are required. They include the AADT volume of the freeway segment and the AADT volume of the ramp.

For each ramp exit speed-change lane, only the AADT volume of the freeway segment is required. The AADT volume of the ramp is not needed.

The AADT volumes are needed for each year of the evaluation period. The AADT volume for a given year represents an annual average daily 24-hour traffic volume. The freeway segment AADT volume is a two-way volume (i.e., the total of both travel directions). Each ramp AADT volume represents a one-way volume.

In many cases, it is expected that AADT data will not be available for all years of the evaluation period. In that case, an estimate of AADT volume for each missing year is interpolated or extrapolated, as appropriate. If there is not an established procedure for doing this, the following rules may be applied within the predictive method to estimate the AADT volumes for years when such data are not available. If these rules are applied, the fact that some AADT volumes are estimated should be documented with the analysis results.

- If AADT volume is available for only a single year, that same volume is assumed to apply to all years of the evaluation period.

- If two or more years of AADT data are available, the AADT volumes for intervening years are computed by interpolation.
- The AADT volumes for years before the first year for which data are available are assumed to be equal to the AADT volume for that first year.
- The AADT volumes for years after the last year for which data are available are assumed to be equal to the AADT volume for that last year.

Determining Availability of Observed Crash Data
Where an existing site (or an alternative condition for an existing site) is being considered, the EB Method can be used to obtain a more reliable estimate of the expected average crash frequency. The EB Method is applicable when crash data are available for the entire project or for its individual sites. Crash data may be obtained directly from the jurisdiction's crash report system. At least two years of crash data are desirable to apply the EB Method. The EB Method (and criteria to determine whether the EB Method is applicable) is presented in Section B.2 in Appendix B.

The EB Method can be applied at the site-specific level or at the project level. At the site-specific level, crash data are assigned to specific sites in Step 6. The site-specific EB Method is applied in Step 13. At the project level, crash data are assigned to a group of sites (typically because they cannot be assigned to individual sites). The project-level EB Method is applied in Step 15. In general, the best results will be obtained if the site-specific EB Method is used. Guidance to determine whether the site-specific or project-level EB Method is applicable is presented in Section B.2.2 in Appendix B.

Step 4—Determine geometric design features, traffic control features, and site characteristics for all sites in the project limits.
A range of data is needed to apply a predictive model. These data are used in the SPFs and CMFs to estimate the predicted average crash frequency for the selected site and year. These data represent the geometric design features, traffic control features, and traffic demand characteristics that have been found to have some relationship to safety. These data are needed for each site in the project limits. They are needed for the study period and, if applicable, the crash period. The specific data, and means by which they are measured or obtained, is described in Section 18.4.2.

Step 5—Divide the roadway into sites.
Using the information from Step 1 and Step 4, divide the freeway into individual sites consisting of individual homogeneous freeway segments and speed-change lanes. The procedure for dividing the freeway into individual segments is provided in Section 18.5.

Step 6—Assign observed crashes to the individual sites (if applicable).
Step 6 applies if it was determined in Step 3 that the site-specific EB Method is applicable. If the site-specific EB Method is not applicable, then proceed to Step 7. In this step, the observed crash data are assigned to the individual sites. Specific criteria for assigning crashes to individual sites are presented in Section B.2.3 in Appendix B.

Step 7—Select the first or next individual site in the project limits. If there are no more sites to be evaluated, proceed to Step 15.
Steps 7 through 14 are repeated for each site within the project limits identified in Step 1.

Any site can be selected for evaluation because each site is considered to be independent of the other sites. However, good practice is to select the sites in an orderly manner, such as in the order of their physical occurrence in the direction of increasing milepost.

Step 8—For the selected site, select the first or next year in the period of interest. If there are no more years to be evaluated for that site, proceed to Step 13.
Steps 8 through 12 are repeated for each year in the evaluation period for the selected site.

The individual years of the evaluation period are analyzed one year at a time because the SPFs and some CMFs are dependent on AADT volume, which may change from year to year.

Step 9—For the selected site and the selected year, determine and apply the appropriate SPF.
The SPF determines the predicted average crash frequency for a site with features that match the SPF's base conditions. The SPFs (and their base conditions) are described in Section 18.6.

Determine the appropriate SPF for the selected site based on its site type and cross section (or traffic control). This SPF is then used to compute the crash frequency for the selected year using the AADT volume for that year, as determined in Step 3.

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs.
Collectively, the CMFs are used in the predictive model to adjust the SPF estimate from Step 9 so that the resulting predicted average crash frequency accurately reflects the geometric design and traffic control features of the selected site. The available CMFs are described in Section 18.7.

All CMFs presented in this chapter have the same base conditions as the SPFs in this chapter. *Only the CMFs presented in Section 18.7 may be used as part of the predictive method described in this chapter*.

For the selected site, determine the appropriate CMFs for the site type, geometric design features, and traffic control features present. The CMF's designation by crash type and severity must match that of the SPF with which it is used (unless indicated otherwise in the CMF description). The CMFs for the selected site are calculated using (a) the AADT volume determined in Step 3 for the selected year and (b) the geometric design and traffic control features determined in Step 4.

Multiply the result from Step 9 by the appropriate CMFs.

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
The SPFs and CMFs in this chapter have each been developed with data from specific jurisdictions and time periods. Calibration to local conditions will account for any differences between these conditions and those present at the selected sites. A calibration factor is applied to each SPF in the predictive method. Detailed guidance for the development of calibration factors is included in Section B.1 of Appendix B.

Multiply the result from Step 10 by the calibration factor to obtain the predicted average crash frequency.

Step 12—If there is another year to be evaluated in the evaluation period for the selected site, return to Step 8. Otherwise, proceed to Step 13.
This step creates a loop from Step 8 through Step 12 that is repeated for each year of the evaluation period for the selected site.

Step 13—Apply the site-specific EB Method (if applicable) and apply SDFs.
The site-specific EB Method combines the predicted average crash frequency computed in Step 11 with the observed crash frequency of the selected site. It produces a more statistically reliable estimate of the site's expected average crash frequency. The procedure for applying the site-specific EB Method is provided in Section B.2.4 of Appendix B.

The decision to apply the site-specific EB Method was determined in Step 3. If the EB Method is not used, then the estimate of expected average crash frequency for each year of the study period is limited to the predicted average crash frequency for that year, as computed in Step 11.

If the EB Method is used, then the expected average crash frequency is equal to the estimate obtained from the EB Method. An estimate is obtained for each year of the crash period (i.e., the period for which the observed crash data are available). The individual years of the crash period are analyzed one year at a time because the SPFs and some CMFs are dependent on AADT volume, which may change from year to year.

Apply the site-specific EB Method to a future time period, if appropriate.
Section B.2.6 in Appendix B provides a procedure for converting the estimates from the EB Method to any years in the study period that are not represented in the crash period (e.g., future years). This approach gives consideration to any differences in traffic volume, geometry, or traffic control between the study period and the crash period. This procedure yields the expected average crash frequency for each year of the study period.

Apply the severity distribution functions (SDFs), if desired.
The SDFs can be used to compute the expected average crash frequency for each of the following severity levels: fatal, incapacitating injury, non-incapacitating injury, and possible injury. Each SDF includes variables that describe the geometric design and traffic control features of a site. In this manner, the computed distribution gives consideration to the features present at the selected site. The SDFs are described in Section 18.8. They can benefit from being updated based on local data as part of the calibration process. Detailed guidance for the development of the SDF calibration factor is included in Section B.1.4 of Appendix B.

Apply the crash type distribution, if desired.
Each predictive model includes a default distribution of crash type. This distribution can be used to compute the expected average crash frequency for each of ten crash types (e.g., head-on, fixed object). The distribution is presented in Section 18.6. It can benefit from being updated based on local data as part of the calibration process.

Step 14—If there is another site to be evaluated, return to Step 7; otherwise, proceed to Step 15.
This step creates a loop from Step 7 through Step 14 that is repeated for each site of interest.

Step 15—Apply the project-level EB Method (if applicable) and apply SDFs.
The activities undertaken during this step are the same as undertaken for Step 13 but they occur at the project level (i.e., network or facility). They are based on estimating the project-level predicted average crash frequency. This crash frequency is computed for each year during the crash period. It is computed as the sum of the predicted average crash frequency for all sites (as computed in Step 11).

The project-level EB Method combines the project-level predicted average crash frequency with the observed crash frequency for all sites within the project limits. It produces a more statistically reliable estimate of the project-level expected average crash frequency. The procedure for applying the project-level EB Method is provided in Section B.2.5 of Appendix B.

The decision to apply the project-level EB Method was determined in Step 3. If this method is not used, then the project-level expected average crash frequency for each year of the study period is limited to the project-level predicted average crash frequency for that year, as computed in Step 11.

If the EB Method is used, then the project-level expected average crash frequency is equal to the estimate obtained from the EB Method. An estimate is obtained for each year of the crash period (i.e., the period for which the observed crash data are available). The individual years of the crash period are analyzed one year at a time because the SPFs and some CMFs are dependent on AADT volume, which may change from year to year.

Apply the project-level EB Method to a future time period, if appropriate.
Follow the same guidance as provided in Step 13 using the estimate from the project-level EB Method.

Apply the severity distribution functions, if desired.
Follow the same guidance as provided in Step 13 using the estimate from the project-level EB Method.

Apply the crash type distribution, if desired.
Follow the same guidance as provided in Step 13 using the estimate from the project-level EB Method.

Step 16—Sum all sites and years in the study to estimate the total crash frequency.
One outcome of the predictive method is the total expected average crash frequency. The term “total” indicates that the estimate includes all crash types and severities. It is computed from an estimate of the total expected number of

crashes, which represents the sum of the total expected average crash frequency for each site and for each year in the study period. The total expected number of crashes during the study period is calculated using Equation 18-13:

$$N^{*}_{e,aS,ac,at,as} = \sum_{j=1}^{n_s}\left(\sum_{i=1}^{all\ sites} N_{e,fs(i),n,at,as,j} + \sum_{i=1}^{all\ sites} N_{e,sc(i),nEN,at,as,j} + \sum_{i=1}^{all\ sites} N_{e,sc(i),nEX,at,as,j}\right) \quad (18\text{-}13)$$

Where:

$N^{*}_{e,\,aS,\,ac,\,at,\,as}$ = total expected number of crashes for all sites *aS* and all years in the study period (includes all cross sections *ac*, all crash types *at*, and all severities *as*) (crashes);

n_s = number of years in the study period (yr);

$N_{e,\,fs(i),\,n,\,at,\,as,\,j}$ = expected average crash frequency of freeway segment *i* with *n* lanes for year *j* (includes all crash types *at* and all severities *as*) (crashes/yr);

$N_{e,\,sc(i),\,nEN,\,at,\,as,\,j}$ = expected average crash frequency of ramp entrance speed-change lane *i* on a freeway with *n* lanes for year *j* (includes all crash types *at* and all severities *as*) (crashes/yr); and

$N_{e,\,sc(i),\,nEX,\,at,\,as,\,j}$ = expected average crash frequency of ramp exit speed-change lane *i* on a freeway with *n* lanes for year *j* (includes all crash types *at* and all severities *as*) (crashes/yr).

Equation 18-13 is used to compute the total expected number of crashes estimated to occur in the project limits during the study period. The summation of crashes by type and severity for each site and year is not shown in mathematic terms (but it is implied by the subscripts *at* and *as*).

Equation 18-14 is used to estimate the overall expected average crash frequency within the project limits during the study period.

$$N_{e,aS,ac,at,as} = \frac{N^{*}_{e,aS,ac,at,as}}{n_s} \quad (18\text{-}14)$$

Where:

$N_{e,\,aS,\,ac,\,at,\,as}$ = overall expected average crash frequency for all sites *aS* and all years in the study period (includes all cross sections *ac*, all crash types *at*, and all severities *as*) (crashes/yr).

Step 17—Determine if there is an alternative design, treatment, or forecast AADT to be evaluated.
Steps 3 through 17 are repeated as appropriate for the same project limits but for alternative conditions, treatments, periods of interest, or forecast AADT volumes.

Step 18—Evaluate and compare results.
The predictive method is used to provide a statistically reliable estimate of the expected average crash frequency (in total, or by crash type and severity) for the specified project limits, study period, geometric design and traffic control features, and known or estimated AADT volume.

18.4.2. Data Needed to Apply the Predictive Method

The input data needed for the predictive models are identified in this section. These data represent the geometric design features, traffic control features, and traffic demand characteristics that have been found to have some relationship to safety. They are identified by bullet in this section and are listed in Table B-2 of Appendix B.

The input data are needed for each site in the project limits. Criteria for defining site boundaries are described in Section 18.5.

There are several data identified in this section that describe a length along the roadway (e.g., segment length, curve length, weaving section length, etc.). *All of these lengths are measured along the reference line*, which is the inside edge of traveled way in the increasing milepost direction of travel. Points that do not lie on the reference line must be projected onto the reference line (along a perpendicular line if the alignment is straight, or along a radial line if the alignment is curved) to facilitate length determination. These dimensions can be obtained from field measurements, a plan set, or aerial photographs.

The input data needed for the predictive models include the following:

- *Number of through lanes*—For a freeway segment, use the total number of through lanes (in both directions of travel). For a speed-change lane, use the number of through lanes in the portion of freeway adjacent to the speed-change lane *plus* those freeway lanes in the opposing travel direction. Rural freeways are limited to eight lanes. Urban freeways are limited to ten lanes. A segment with a lane-add (or lane-drop) taper is considered to have the same number of through lanes as the roadway just downstream of the lane-add (or lane-drop) taper. This guidance is shown in Figure 18-2.

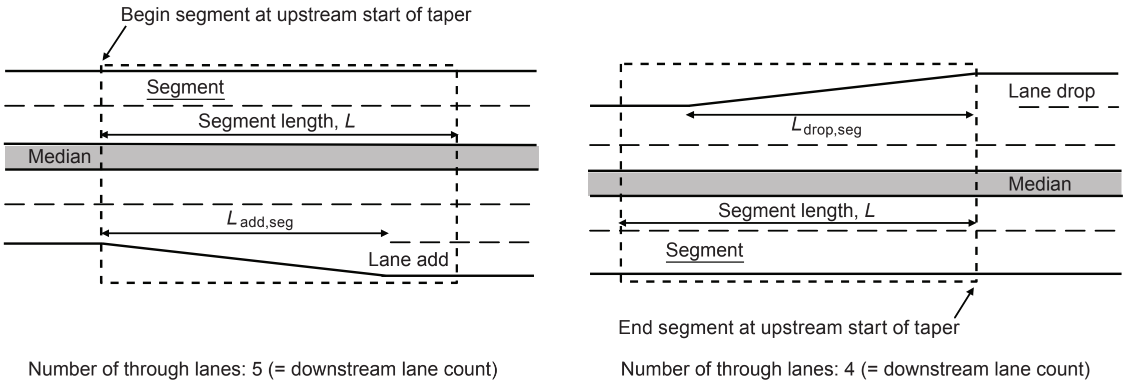


Figure 18-2. Through-Lane Count in Segments with Lane Add or Lane Drop

Do not include any high-occupancy vehicle (HOV) lanes or managed lanes.

Do not include any auxiliary lanes that are associated with a weaving section, unless the weaving section length exceeds 0.85 mi (4,500 ft). If this length is exceeded, then the auxiliary lane is counted as a through lane that starts as a lane-add ramp entrance and ends as a lane-drop ramp exit.

Do not include the speed-change lane that is associated with a ramp that merges with (or diverges from) the freeway, unless its length exceeds 0.30 mi (1,600 ft). If this length is exceeded, then the speed-change lane is counted as a through lane that starts as a lane-add ramp entrance and ends as a lane drop by taper (or starts as a lane add by taper and ends as a lane-drop ramp exit).

- *Length of freeway segment, and length of speed-change lane (if present)*—Speed-change lane length is measured from the gore point to the taper point. Figure 18-3 illustrates these measurement points for a ramp entrance and a ramp exit speed-change lane with the parallel and taper design, respectively.

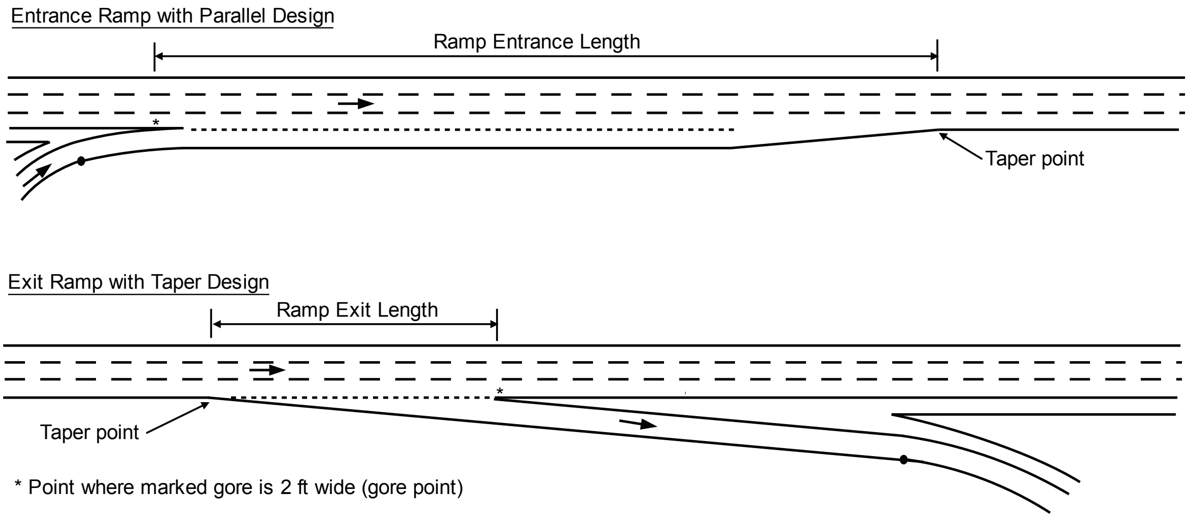
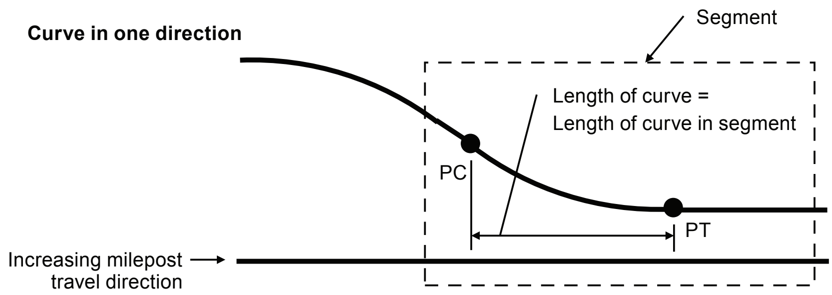


Figure 18-3. Freeway Speed-Change Lane Length

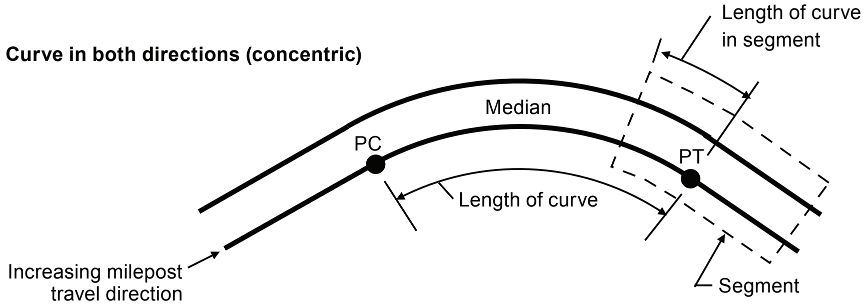
- *Presence of a horizontal curve on one or both roadbeds*—If a curve is present, then the three data elements in the following list are needed. Guidelines for obtaining these data are provided in Figure 18-4.
  - *Length of curve*—Curve length is measured along the reference line from the point where the tangent ends and the curve begins (i.e., the PC) to the point where the curve ends and the tangent begins (PT). If the curve PC and PT do not lie on the reference line, then they must be projected onto this line and the curve length measured between these projected points along the reference line.

    If the curve has spiral transitions, then measure from the "effective" PC point to the "effective" PT point. The effective PC point is located midway between the TS and SC, where the TS is the point of change from tangent to spiral and the SC is the point of change from spiral to circular curve. The effective PT is located midway between the CS and ST, where CS is the point of change from circular curve to spiral and ST is the point of change from spiral to tangent.
  - *Radius of curve*—Radius is measured separately for each roadbed curve. The line used to define curve radius is the inside edge of the traveled way. This line is established separately on each roadbed. If the curve has spiral transitions, then use the radius of the central circular portion of the curve.
  - *Length of curve in segment*—The length of the curve within the boundaries of the segment (or speed-change lane). This length cannot exceed the segment length or the curve length.



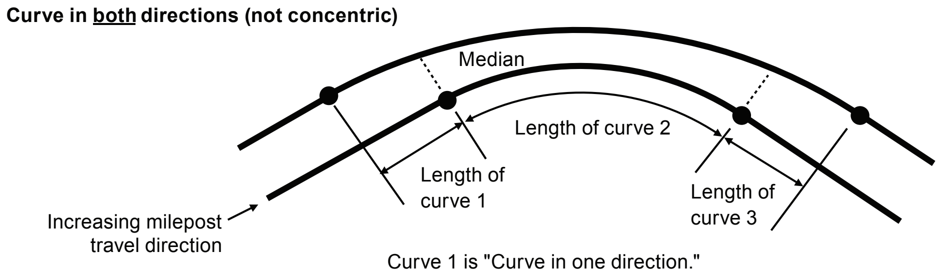
Rules
1. Roadbed in increasing milepost travel direction is basis of curve length measurement.
2. Curve length is measured along the inside edge of traveled way.
3. Radius is measured for curved roadbed.
4. Radius is measured to inside edge of traveled way.

Note: Curve is shown to be fully in segment, but could also be only partially in segment.



Rules
1. Roadbed in increasing milepost travel direction is basis of curve length measurement.
2. Curve length is measured along the inside edge of traveled way.
3. Radius is measured for both roadbeds.
4. Radius is measured to inside edge of traveled way.

Note: Curve is shown to be only partially in segment, but could also be fully in segment.



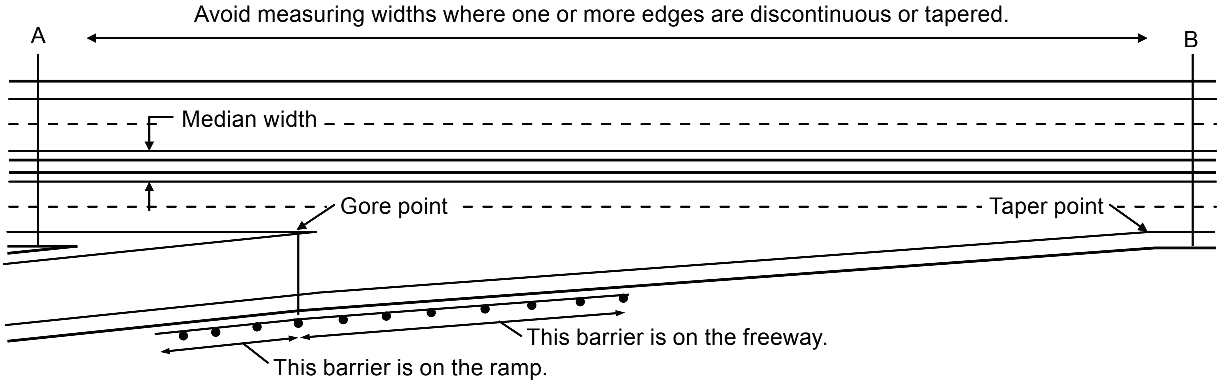
Curve 1 is "Curve in one direction."
Curve 2 is "Curve in both directions."
Curve 3 is "Curve in one direction."

Rules
1. Disaggregate into multiple curved pieces, where one or both roadbeds are curved in each piece.
2. If one roadbed is curved, use rules for "Curve in one direction."
3. If both roadbeds are curved, use rules for "Curve in both directions (concentric)."

Note: Roadbeds are shown to curve in same direction; however, these rules also apply when curves are in the opposite direction.

Figure 18-4. Curve Length and Radius Measurements

- *Widths of lanes, outside shoulders, inside shoulders, and median*—The first three elements represent an average for both roadbeds. These widths should be measured where the cross section is constant, such as along line A or B shown in Figure 18-5. They should not be measured where one or more edges are discontinuous or tapered. If a width varies along the segment or speed-change lane (but not enough to justify beginning a new segment), then compute the length-weighted average width. Rules for defining segment boundaries are provided in Section 18.5.2.
  - *Lane width*—This width is computed as an average for all through lanes.
  - *Shoulder width*—This width represents only the paved width.
  - *Median width*—This width is measured between the edges of the traveled way for the two roadways in the opposite direction of travel, including the width of the inside shoulders, if they are present.



Measure lane, shoulder, and median widths in areas with constant cross section. Measure along a line such as line A or line B. If necessary, move the line off the subject segment to the nearest point with constant cross section.

Figure 18-5. Measurement of Cross Section Data Elements

- *Length of rumble strips on the inside (or median) shoulder and on the outside (or roadside) shoulder*—Measured separately for each shoulder type and travel direction.
- *Length of (and offset to) the barrier in the median and the barrier on the roadside*—Measured for each short piece of barrier. Offset is also measured for barrier that continues for the length of the segment or speed-change lane (and beyond). Each piece is represented once for a site. Barrier length is measured along the reference line. Offset is measured from the nearest edge of traveled way to the barrier face.

  Figure 18-6 illustrates these measurements for two barrier elements protecting a sign support in a median with width W_m and adjacent to shoulders with width W_{is}. Each barrier element has a portion of its length that is parallel to the roadway and a portion of its length that is tapered from the roadway. One way to evaluate these elements is to separate them into four pieces, as shown in Figure 18-6. Each piece is represented by its average offset $W_{off,\,in,\,i}$ and length $L_{ib,\,i}$. Alternatively, the analyst may recognize that the offset is the same for pieces 1 and 4 and for pieces 2 and 3. In this case, each pair can be combined by adding the two lengths (e.g., $L_{ib,\,1} + L_{ib,\,4}$) and using the common offset.

  A barrier is associated with the freeway if the offset from the near edge of traveled way is 30 ft or less. Barrier adjacent to a ramp but also within 30 ft of the freeway traveled way should also be associated with the freeway. The determination of whether a barrier is adjacent to a speed-change lane or a ramp is based on the gore and taper points, as shown in Figure 18-5.

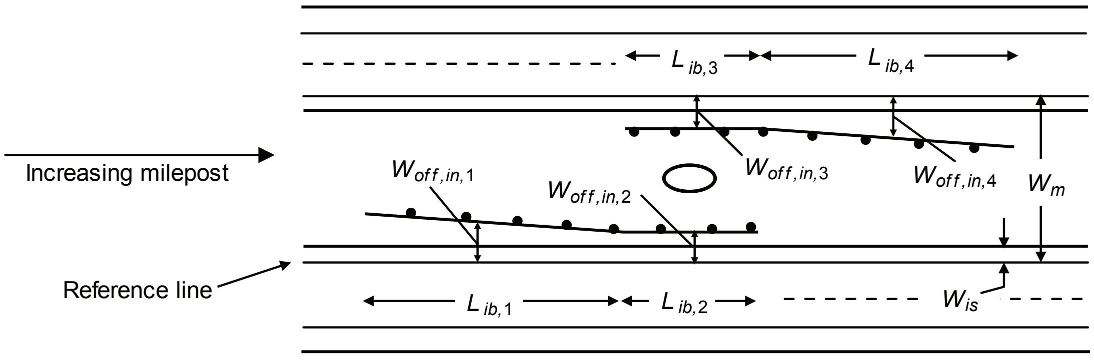


Figure 18-6. Barrier Variables

- Width of continuous median barrier, if present.
- *Presence and length of a Type B weaving section*—This weaving section has the following characteristics: (a) one of the two weaving movements can be made without making any lane changes, (b) the other weaving movement requires at most one lane change, and (c) the ramp entrance and ramp exit associated with the weaving section are located on the right side of the freeway. Typical Type B weaving sections are shown in Figure 18-7. Other weaving section types are addressed directly by the predictive method.
    - *Type B weaving section length*—This length is measured along the edge of the freeway traveled way from the gore point of the ramp entrance to the gore point of the next ramp exit, as shown in Figure 18-7. The gore point is located where the pair of solid white pavement edge markings that separate the ramp from the freeway main lanes are 2.0 ft apart. If the markings do not extend to a point where they are 2.0 ft apart, then the gore point is found by extrapolating both markings until the extrapolated portion is 2.0 ft apart. If the measured gore-to-gore distance exceeds 0.85 mi (4,500 ft), then a weaving section is not considered to exist. Rather, the entrance ramp is a "lane add" and the exit ramp is a "lane drop."
    - *Length of weaving section located* **in the segment***, between the segment's begin and end points*—This length cannot exceed the length of the segment. This length cannot exceed the length of the weaving section.

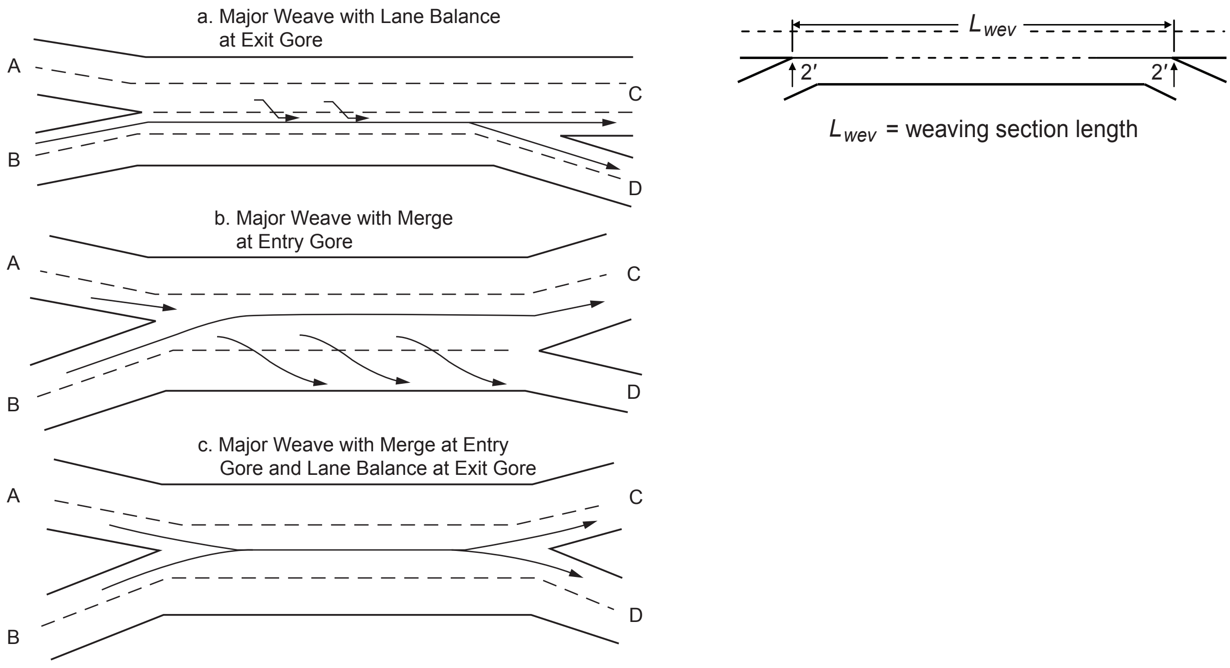


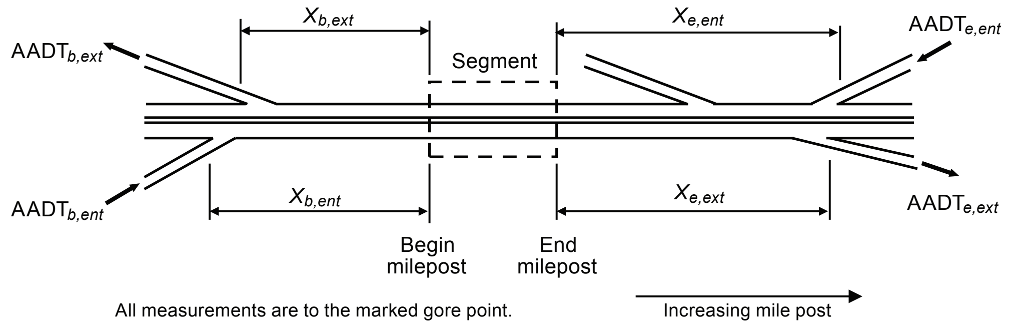
Figure 18-7. Type B Weaving Section and Length

- Distance to nearest upstream entrance ramp in each travel direction.
- Measure this distance from the segment boundary to the ramp gore point, along the freeway's solid white pavement edge marking that intersects the gore point. The distance to the nearest upstream entrance ramp in each travel direction is shown in Figure 18-8 using the two variables $X_{b, ent}$ and $X_{e, ent}$. If the ramp entrance is located in the segment, then the corresponding distance is equal to 0.0 mi. If the ramp does not exist or is located more than 0.5 mi from the segment, then this distance can be set to a large value (i.e., 999) in the predictive method to obtain the correct results.

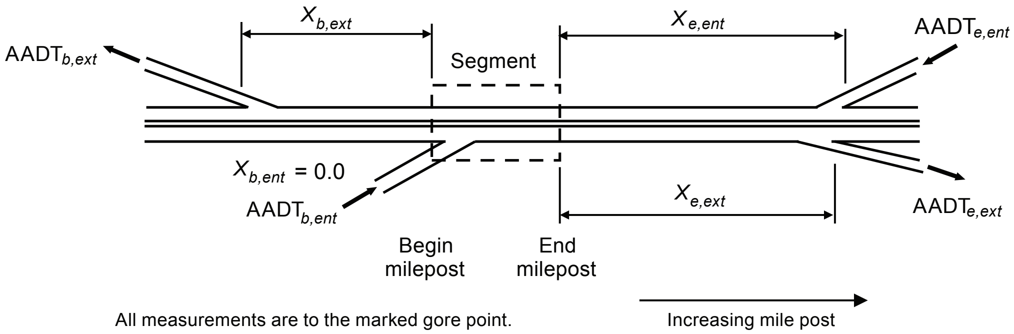
  The gore point is located where the pair of solid white pavement edge markings that separate the ramp from the freeway main lanes are 2.0 ft apart. If the markings do not extend to a point where they are 2.0 ft apart, then the gore point is found by extrapolating both markings until the extrapolated portion is 2.0 ft apart.

  Upstream *exit* ramps are not of direct interest, and data are not needed for them if they exist in the vicinity of the segment. Figure 18-8a shows an upstream exit ramp serving travel in the decreasing milepost direction. This ramp is not of interest to the evaluation of the subject segment.

- Distance to nearest downstream exit ramp in each travel direction. The measurement technique is the same as for upstream entrance ramps. This distance is shown in Figure 18-8 using the two variables $X_{b, ext}$ and $X_{e, ext}$. Downstream *entrance* ramps are not of direct interest, and their data are not needed.



a. All Ramps External to the Segment



b. Three Ramps External to the Segment and One Ramp in the Segment

Figure 18-8. Distance to Nearest Ramp

- *Clear zone width*—This width is measured from the edge of traveled way to typical limits of vertical obstruction (e.g., non-traversable slope, fence line, utility poles) along the roadway. The *Roadside Design Guide* (1) provides detailed information about roadside features that define this width.

  The clear zone width includes the outside shoulder. It is measured for both travel directions. If this width varies along the segment, then use the estimated length-weighted average clear zone width (excluding the portion of the segment with barrier). Do not consider roadside barrier when determining the clear zone width for the predictive method. Barrier location and influence is addressed in other CMFs. If the segment has roadside barrier on both sides for its entire length, then the clear zone width will not influence the model prediction, and any value can be used as a model input (e.g., 30 ft).

- This guidance is illustrated in Figure 18-9 where the clear zone is shown to be established by a fence line that varies in offset from the edge of traveled way. A length-weighted width is appropriate for this situation. The lone tree and the guardrail are not considered in the determination of clear zone width.

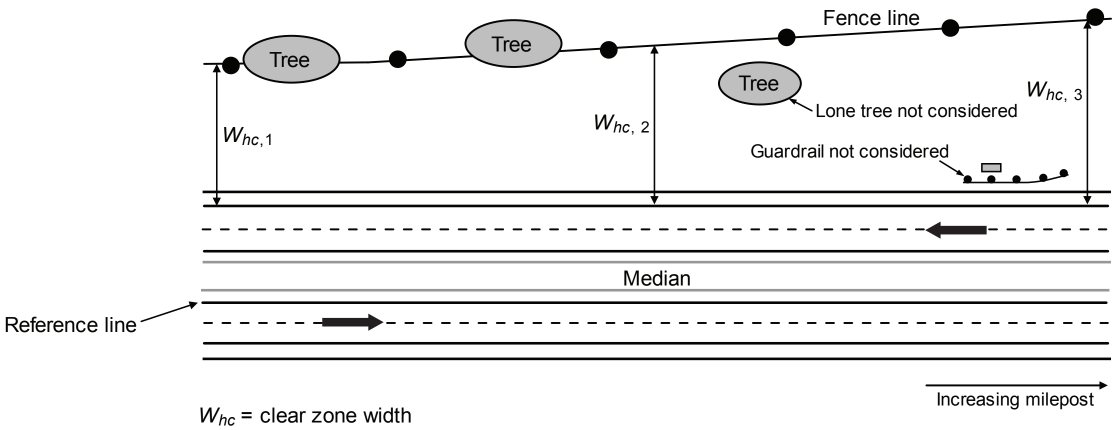


Figure 18-9. Clear Zone Width Considerations

- *Proportion of freeway AADT volume that occurs during hours where the lane volume exceeds 1,000 vehicles per hour per lane (veh/h/ln)*—The lane volume for hour i LV_i is computed as $LV_i = HV_i/n$ where HV_i is the volume during hour i (i = 1, 2, 3, ... 24) and n is the number of through lanes. The desired proportion P_{hv} is computed as $P_{hv} = (\Sigma\, HV_i^*)/AADT$ where $\Sigma\, HV_i^*$ is the sum of the volume during each hour where the lane volume exceeds 1,000 veh/h/ln. The *AADT*, *HV*, and n variables include both freeway travel directions. These data will typically be obtained from the continuous traffic counting station that (1) is nearest to the subject freeway and (2) has similar traffic demand and peaking characteristics. A default value can be computed as $P_{hv} = 1.0 - \exp(1.45 - 0.000124 \times AADT/n)$. If the value computed is less than 0.0, then it is set to 0.0.

- Freeway AADT volume, upstream entrance ramp AADT volume, downstream exit ramp AADT volume.

18.5. ROADWAY SEGMENTS AND SPEED-CHANGE LANES

This section consists of three subsections. The first subsection defines freeway segments and speed-change lanes. The second subsection provides guidelines for segmenting the freeway facility. The assignment of crashes to sites is discussed in the last subsection.

18.5.1. Definition of Freeway Segment and Speed-Change Lane

When using the predictive method, the freeway within the defined project limits is divided into individual sites. A site is either a homogeneous freeway segment or a speed-change lane. A facility consists of a contiguous set of individual sites. A roadway network consists of a number of contiguous facilities.

A speed-change lane site is defined as the section of roadway area located (a) between the marked gore and taper points of a ramp merge or diverge area, and (b) on the same side of the freeway as the merge or diverge area. The location of the gore and taper points is identified in Figure 18-3.

Three freeway segments are shown schematically in Figure 18-10. They are labeled *Fr* in the figure. The presence of a speed-change lane adjacent to a freeway segment requires a reduction in the effective length of the freeway segment. This reduction is used to account for the crashes assigned to the speed-change lane. The equation for computing the "effective" segment length is shown in the bottom of Figure 18-10 for a freeway segment with one ramp entrance and one ramp exit.

Two speed-change lanes are shown schematically in Figure 18-10. The speed-change lane associated with an entrance ramp is labeled *SCen* and that associated with an exit ramp exit is labeled SC_{ex}.

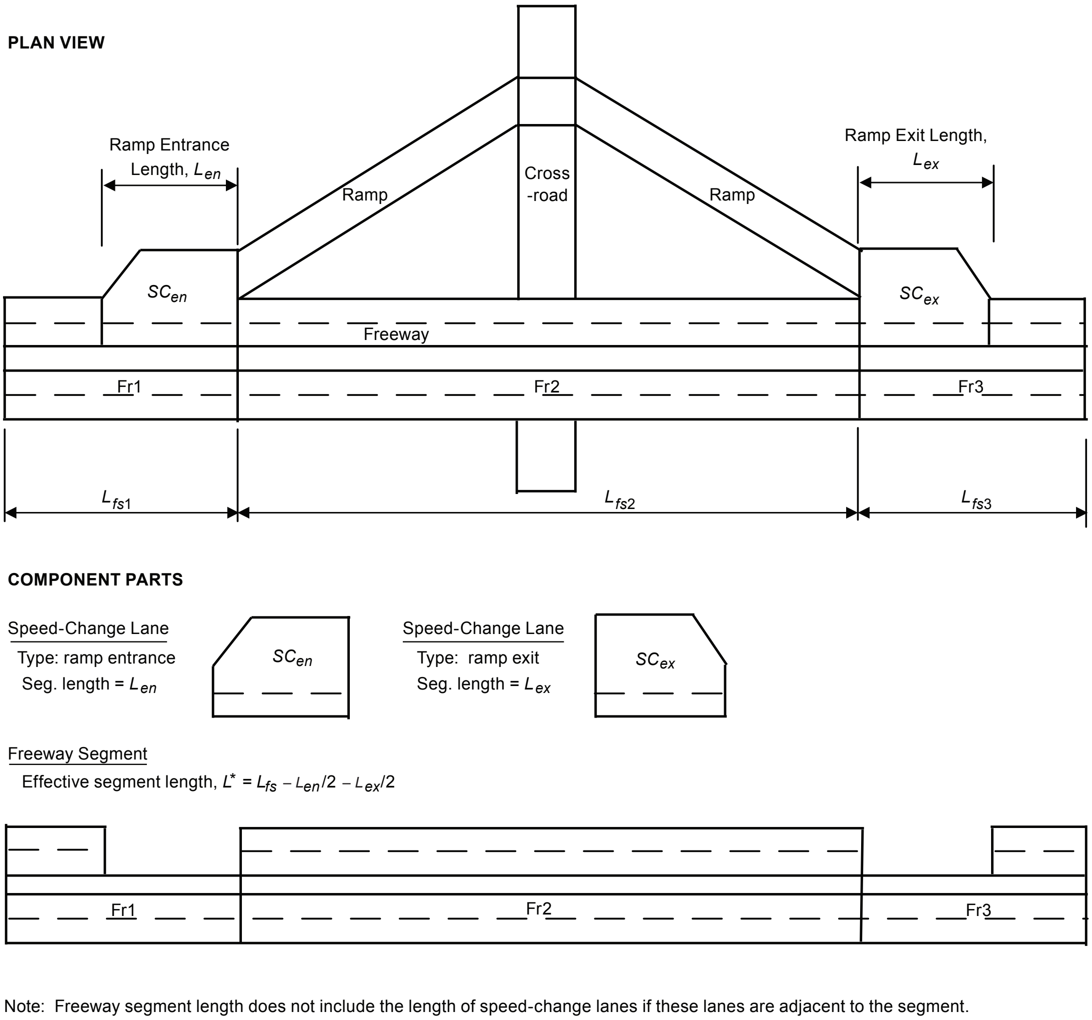


Figure 18-10. Illustrative Freeway Segments and Speed-Change Lanes

18.5.2 Segmentation Process

A speed-change lane site begins at the gore (or taper) point and ends at the associated taper (or gore) point. These points are shown in Figure 18-3.

The segmentation process produces a set of segments of varying length, each of which is homogeneous with respect to characteristics such as traffic volume, key geometric design features, and traffic control features. A new homogeneous freeway segment begins where there is a change in at least one of the following characteristics of the freeway:

- *Number of through lanes*—Begin segment at the gore point if the lane is added or dropped at a ramp or C-D road. Begin segment at the upstream start of taper if the lane is added or dropped by taper. Guidance in this regard is described in the text accompanying Figure 18-2.

- *Lane width*—Measure the lane width at successive points along the roadway. Compute an average lane width for each point and round this average to the nearest 0.5 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 11.5 to 12.0 ft).
- *Outside shoulder width*—Measure the outside shoulder width at successive points along the roadway. Compute an average shoulder width for each point and round this average to the nearest 1.0 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 6 to 7 ft).
- *Inside shoulder width*—Measure the inside shoulder width at successive points along the roadway. Compute an average shoulder width for each point and round this average to the nearest 1.0 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 6 to 5 ft).
- *Median width*—Measure the median width at successive points along the roadway. Round the measured median width at each point to the nearest 10 ft. If the rounded value exceeds 90 ft, then set it to 90 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 30 to 20 ft).
- *Ramp presence*—Begin segment at the ramp gore point.
- *Clear zone width*—Measure the clear zone width at successive points along the roadway. Compute an average clear zone width for each point and round this average to the nearest 5 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 25 to 30 ft).

The presence of a horizontal curve does not necessarily define segment boundaries. This approach represents a difference from the process described in Chaper 10, where a curve does define segment boundaries.

Application of the "median width" segmentation criterion is shown in Figure 18-11. The freeway section in this figure is shown to consist of five segments. Segment 1 has a rounded median width of 70 ft. Segment 2 starts where the rounded median width first changes to 80 ft. Segment 3 begins at the point where the rounded median width first changes to 90 ft. Segment 4 begins where the rounded median width first changes to 80 ft. Segment 5 begins where the rounded median width first changes to 70 ft.

Guidance regarding the location of the lane, shoulder, and median width measurement points is provided in the text associated with Figure 18-5 in Section 18.4.2. Each width represents an average for the segment. Similarly, guidance associated with Figure 18-9 is used to determine the clear zone width for the segment. The rounded lane, shoulder, median, and clear zone width values are used solely to determine segment boundaries. Once these boundaries are determined, the unrounded values for the segment are then used for all subsequent calculations in the predictive method.

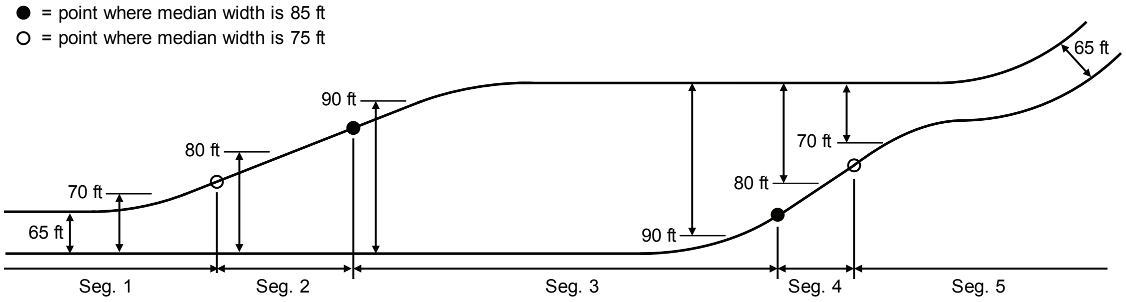


Figure 18-11. Segmentation for Varying Median Width

18.5.3. Crash Assignment to Sites

Observed crash counts are assigned to the individual sites to apply the site-specific EB Method. Any crashes that occur on the freeway are classified as speed-change-lane-related or segment-related crashes. The speed-change-lane-related crashes are assigned to the corresponding speed-change lane. The speed-change lane predictive model estimates the frequency of these crashes. The segment-related crashes are assigned to the corresponding freeway segment. The freeway segment predictive model estimates the frequency of these crashes. The procedure for assignment of crashes to individual sites is presented in Section B.2.3 in Appendix B.

18.6. SAFETY PERFORMANCE FUNCTIONS

When using the predictive method, the appropriate safety performance functions (SPFs) are used to estimate the predicted average crash frequency of a site with base conditions. Each SPF was developed as a regression model using observed crash data for a set of similar sites as the dependent variable. The SPFs, like all regression models, estimate the value of the dependent variable as a function of a set of independent variables. The independent variables for the freeway segment SPFs include the segment AADT volume, segment length, and area type (i.e., rural or urban). The independent variables for the speed-change lane SPFs include the AADT volume of the freeway, speed-change lane length, and area type. The SPFs in this chapter are summarized in Table 18-3.

Table 18-3. Freeway Safety Performance Functions

Site Type (*w*)	Cross Section (*x*)	Crash Type (*y*)	SPF Equations
Freeway segments (*fs*)	*n* lanes (*n*)	Multiple vehicle (*mv*)	Equation 18-15
		Single vehicle (*sv*)	Equation 18-18
Speed-change lanes (*sc*)	Ramp entrance, *n* lanes (*nEN*)	All types (*at*)	Equation 18-20
	Ramp exit, *n* lanes (*nEX*)	All types (*at*)	Equation 18-22

A detailed discussion of SPFs and their use in the HSM is presented in Sections 3.5.2 and C.6.3 of the *Highway Safety Manual*.

Some transportation agencies may have performed statistically sound studies to develop their own jurisdiction-specific SPFs. These SPFs may be substituted for the SPFs presented in this chapter. Criteria for the development of SPFs for use in the predictive method are addressed in the calibration procedure presented in Section B.1.2 in Appendix B.

Each SPF has an associated overdispersion parameter k. The overdispersion parameter provides an indication of the statistical reliability of the SPF. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. This parameter is used in the EB Method that is discussed in Section B.2 in Appendix B.

18.6.1. Safety Performance Functions for Freeway Segments

The SPFs for freeway segments are presented in this section. Specifically, SPFs are provided for freeway segments with 4, 6, 8, or 10 through lanes (total of both travel directions). The range of AADT volume for which these SPFs are applicable is shown in Table 18-4. Application of the SPFs to sites with AADT volumes substantially outside these ranges may not provide reliable results.

Table 18-4. Applicable AADT Volume Ranges for SPFs

Area Type	Cross Section (Through Lanes) (*x*)	Applicable AADT Volume Range (veh/day)
Rural	4	0 to 73,000
	6	0 to 130,000
	8	0 to 190,000
Urban	4	0 to 110,000
	6	0 to 180,000
	8	0 to 270,000
	10	0 to 310,000

The SPFs described in this section are directly applicable to segments with an even number of through lanes. They can be extended to the evaluation of segments with 5, 7, or 9 lanes using the following procedure. If a freeway segment has X total lanes that represent Y lanes in one direction and Z lanes in the opposite direction (i.e., $X = Y + Z$) and Y is not equal to Z, then it is recommended that the segment be evaluated twice. One evaluation would be conducted where the number of lanes is equal to $2 \times Y$ and one evaluation would be conducted where the number of lanes is equal to $2 \times Z$. All other inputs to the SPFs would be unchanged between evaluations. The two estimates of predicted average crash frequency obtained in this manner are then averaged to obtain the best estimate of the predicted average crash frequency for the subject segment.

Other types of freeway segments may be found on freeways, but they are not addressed by the predictive model described in this chapter.

Multiple-Vehicle Crashes

The base conditions for the SPFs for multiple-vehicle crashes on freeway segments are presented in the following list of the variables defined in Section 18.4.2:

- Length of horizontal curve — 0.0 mi (i.e., not present)
- Lane width — 12 ft
- Inside shoulder width (paved) — 6 ft
- Median width — 60 ft
- Length of median barrier — 0.0 mi (i.e., not present)
- Number of hours where volume exceeds 1,000 veh/h/ln — None
- Distance to nearest upstream ramp entrances — More than 0.5 mi from segment
- Distance to nearest downstream ramp exits — More than 0.5 mi from segment
- Length of Type B weaving section — 0.0 mi (i.e., not present)

The SPFs for multiple-vehicle crashes on freeway segments are represented using the following equation:

$$N_{spf,fs,n,mv,z} = L^* \times \exp(a + b \times \ln[c \times AADT_{fs}]) \tag{18-15}$$

with

$$L^* = L_{fs} - \left(0.5 \times \sum_{i=1}^{2} L_{en,seg,i}\right) - \left(0.5 \times \sum_{i=1}^{2} L_{ex,seg,i}\right) \tag{18-16}$$

Where:

$N_{spf,fs,n,mv,z}$ = predicted average multiple-vehicle crash frequency of a freeway segment with base conditions, n lanes, and severity z ($z = fi$: fatal and injury, pdo: property damage only) (crashes/yr);

L^* = effective length of freeway segment (mi);

L_{fs} = length of freeway segment (mi);

$L_{en,seg,i}$ = length of ramp entrance i adjacent to subject freeway segment (mi);

$L_{ex,seg,i}$ = length of ramp exit i adjacent to subject freeway segment (mi);

a, b = regression coefficients;

c = AADT scale coefficient; and

$AADT_{fs}$ = AADT volume of freeway segment (veh/day).

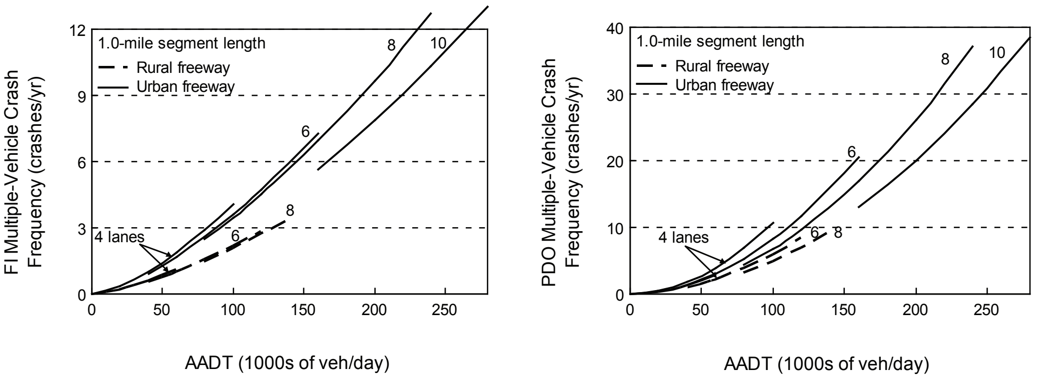
The calculation of the "effective length of freeway segment" was discussed in the text associated with Figure 18-10. The variable $L_{en, seg, i}$ represents the length of the speed-change lane located between the start and end points of the adjacent freeway segment. This length cannot exceed the length of the segment or the length of the ramp entrance speed-change lane. Similarly, the variable $L_{ex, seg, i}$ represents the length of the speed-change lane located between the start and end points of the adjacent freeway segment.

The summation terms in Equation 18-16 recognize the potential for there to be as many as two ramp entrances (and two ramp exits) adjacent to a freeway segment. If there are two ramp entrances, then they will be serving opposing directions of travel. If there are two ramp exits, then they will be serving opposing directions of travel.

The SPF coefficients and the inverse dispersion parameter are provided in Table 18-5. The SPFs are illustrated in Figure 18-12.

Table 18-5. SPF Coefficients for Multiple-Vehicle Crashes on Freeway Segments

Crash Severity (z)	Area Type	Number of Through Lanes (n)	SPF Coefficient a	b	c	Inverse Dispersion Parameter $K_{fs, n, mv, z}$ (mi^{-1})
Fatal and injury (fi)	Rural	4	–5.975	1.492	0.001	17.6
		6	–6.092	1.492	0.001	17.6
		8	–6.140	1.492	0.001	17.6
	Urban	4	–5.470	1.492	0.001	17.6
		6	–5.587	1.492	0.001	17.6
		8	–5.635	1.492	0.001	17.6
		10	–5.842	1.492	0.001	17.6
Property damage only (pdo)	Rural	4	–6.880	1.936	0.001	18.8
		6	–7.141	1.936	0.001	18.8
		8	–7.329	1.936	0.001	18.8
	Urban	4	–6.548	1.936	0.001	18.8
		6	–6.809	1.936	0.001	18.8
		8	–6.997	1.936	0.001	18.8
		10	–7.260	1.936	0.001	18.8



a. Fatal-and-Injury Crash Frequency

b. Property-Damage-Only Crash Frequency

Figure 18-12. Graphical Form of the SPFs for Multiple-Vehicle Crashes on Freeway Segments

The value of the overdispersion parameter associated with the SPFs for freeway segments is determined as a function of the segment length. This value is computed using Equation 18-17.

$$k_{fs,n,mv,z} = \frac{1.0}{K_{fs,n,mv,z} \times L^{*}} \tag{18-17}$$

Where:

$k_{fs,\,n,\,mv,\,z}$ = overdispersion parameter for freeway segments with *n* lanes, multiple-vehicle crashes *mv*, and severity *z*; and

$K_{fs,\,n,\,mv,\,z}$ = inverse dispersion parameter for freeway segments with *n* lanes, multiple-vehicle crashes *mv*, and severity *z* (mi^{-1}).

The inverse dispersion parameter for segments with even numbers of lanes is provided in Table 18-5. A procedure is described in Section B.2.7 in Appendix B for using these parameters to estimate the overdispersion parameter for segments with an odd number of lanes.

The crash frequency obtained from Equation 18-15 can be multiplied by the proportions in Table 18-6 to estimate the predicted average multiple-vehicle crash frequency by crash type category.

Table 18-6. Default Distribution of Multiple-Vehicle Crashes by Crash Type for Freeway Segments

		Proportion of Crashes by Severity	
Area Type	**Crash Type Category**	**Fatal and Injury**	**Property Damage Only**
Rural	Head-on	0.018	0.004
	Right-angle	0.056	0.030
	Rear-end	0.630	0.508
	Sideswipe	0.237	0.380
	Other multiple-vehicle crashes	0.059	0.078
Urban	Head-on	0.008	0.002
	Right-angle	0.031	0.018
	Rear-end	0.750	0.690
	Sideswipe	0.180	0.266
	Other multiple-vehicle crashes	0.031	0.024

Single-Vehicle Crashes

The base conditions for the SPFs for single-vehicle crashes on freeway segments are presented in the following list: The variables are defined in Section 18.4.2.

- Length of horizontal curve 0.0 mi (i.e., not present)
- Lane width 12 ft
- Inside shoulder width (paved) 6 ft
- Median width 60 ft
- Length of median barrier 0.0 mi (i.e., not present)
- Number of hours where volume exceeds 1,000 veh/h/ln None
- Outside shoulder width (paved) 10 ft
- Length of shoulder rumble strip 0.0 mi (i.e., not present)

- Clear zone width 30 ft
- Length of outside barrier 0.0 mi (i.e., not present)

The SPFs for single-vehicle crashes on freeway segments are represented with the following equation:

$$N_{spf,fs,n,sv,z} = L^{*} \times \exp(a + b \times \ln[c \times AADT_{fs}]) \tag{18-18}$$

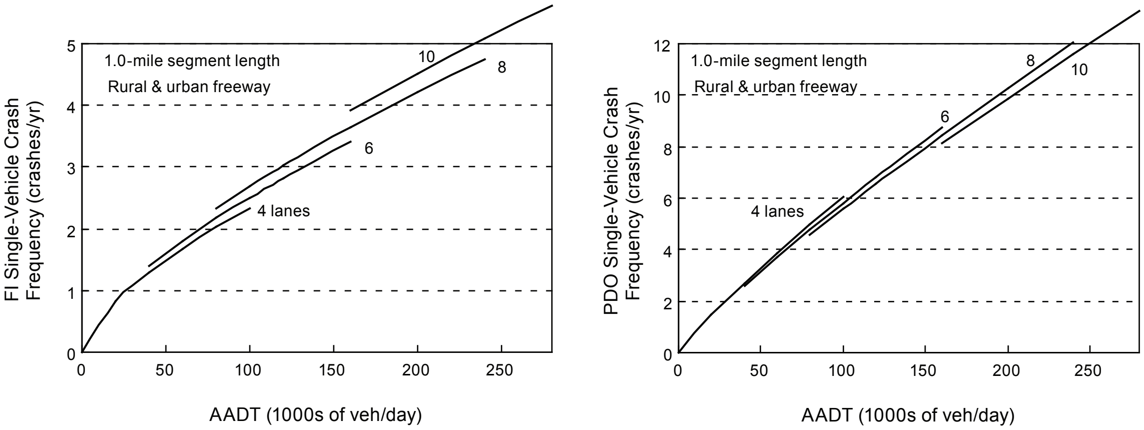
Where:

$N_{spf,fs,n,sv,z}$ = predicted average single-vehicle crash frequency of a freeway segment with base conditions, *n* lanes, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr).

The SPF coefficients and the inverse dispersion parameter are provided in Table 18-7. The SPFs are illustrated in Figure 18-13.

Table 18-7. SPF Coefficients for Single-Vehicle Crashes on Freeway Segments

Crash Severity (*z*)	Area Type	Number of Through Lanes (*n*)	SPF Coefficient *a*	SPF Coefficient *b*	SPF Coefficient *c*	Inverse Dispersion Parameter $K_{fs,n,sv,z}$ (mi^{-1})
Fatal and injury (*fi*)	Rural	4	–2.126	0.646	0.001	30.1
		6	–2.055	0.646	0.001	30.1
		8	–1.985	0.646	0.001	30.1
	Urban	4	–2.126	0.646	0.001	30.1
		6	–2.055	0.646	0.001	30.1
		8	–1.985	0.646	0.001	30.1
		10	–1.915	0.646	0.001	30.1
Property damage only (*pdo*)	Rural	4	–2.235	0.876	0.001	20.7
		6	–2.274	0.876	0.001	20.7
		8	–2.312	0.876	0.001	20.7
	Urban	4	–2.235	0.876	0.001	20.7
		6	–2.274	0.876	0.001	20.7
		8	–2.312	0.876	0.001	20.7
		10	–2.351	0.876	0.001	20.7



a. Fatal-and-Injury Crash Frequency

b. Property-Damage-Only Crash Frequency

Figure 18-13. Graphical Form of the SPFs for Single-Vehicle Crashes on Freeway Segments

The value of the overdispersion parameter associated with the SPFs for freeway segments is determined as a function of the segment length. This value is computed using Equation 18-19.

$$k_{fs,n,sv,z} = \frac{1.0}{K_{fs,n,sv,z} \times L^*} \qquad (18\text{-}19)$$

Where:

$k_{fs,\,n,\,sv,\,z}$ = overdispersion parameter for freeway segments with n lanes, single-vehicle crashes sv, and severity z; and

$K_{fs,\,n,\,sv,\,z}$ = inverse dispersion parameter for freeway segments with n lanes, single-vehicle crashes sv, and severity z (mi^{-1}).

The inverse dispersion parameter for segments with even numbers of lanes is provided in Table 18-7. A procedure is described in Section B.2.7 in Appendix B for using these parameters to estimate the overdispersion parameter for segments with odd numbers of lanes.

The crash frequency obtained from Equation 18-18 can be multiplied by the proportions in Table 18-8 to estimate the predicted average single-vehicle crash frequency by crash type category.

Table 18-8. Default Distribution of Single-Vehicle Crashes by Crash Type for Freeway Segments

		Proportion of Crashes by Severity	
Area Type	**Crash Type Category**	**Fatal and Injury**	**Property Damage Only**
Rural	Crash with animal	0.010	0.065
	Crash with fixed object	0.567	0.625
	Crash with other object	0.031	0.125
	Crash with parked vehicle	0.024	0.023
	Other single-vehicle crashes	0.368	0.162
Urban	Crash with animal	0.004	0.022
	Crash with fixed object	0.722	0.716
	Crash with other object	0.051	0.139
	Crash with parked vehicle	0.015	0.016
	Other single-vehicle crashes	0.208	0.107

18.6.2. Safety Performance Functions for Speed-Change Lanes

The SPFs for freeway speed-change lanes are presented in this section. SPFs are provided for ramp entrances and ramp exits adjacent to freeways with 4, 6, 8, or 10 through lanes. The SPFs for speed-change lanes are applicable to the same freeway AADT volume ranges that are listed in Table 18-4. Application to sites with AADT volumes substantially outside these ranges may not provide reliable results.

The SPFs described in this section are directly applicable to speed-change lanes adjacent to freeways with an even number of through lanes. They can be extended to the evaluation of speed-change lanes adjacent to freeways with 5, 7, and 9 lanes using the procedure described in Section 18.6.1.

Ramp-Entrance Speed-Change Lanes

The base conditions for the SPFs for ramp-entrance speed-change lanes are presented in the following list of the variables defined in Section 18.4.2:

■ Length of horizontal curve	0.0 mi (i.e., not present)
■ Lane width	12 ft
■ Inside shoulder width (paved)	6 ft
■ Median width	60 ft
■ Length of median barrier	0.0 mi (i.e., not present)
■ Number of hours where volume exceeds 1,000 veh/h/ln	None

The SPFs for ramp entrance speed-change lanes are represented using the following equation:

$$N_{spf,sc,nEN,at,z} = L_{en} \times \exp(a + b \times \ln[c \times AADT_{fs}]) \tag{18-20}$$

Where:

$N_{spf,\,sc,\,nEN,\,at,\,z}$ = predicted average crash frequency of a ramp entrance speed-change lane on a freeway with base conditions, n lanes, all crash types at, and severity z ($z = fi$: fatal and injury, pdo: property damage only) (crashes/yr); and

L_{en} = length of ramp entrance (mi).

The SPF coefficients and the inverse dispersion parameter are provided in Table 18-9. The variable n is used in this table to describe the number of through lanes in the portion of freeway adjacent to the speed-change lane *plus* those freeway lanes in the opposing travel direction. This approach to describing the speed-change lane cross section is used for consistency with that used for freeway segment SPFs. The variable n is not intended to describe the number of lanes in the speed-change lane.

Table 18-9. SPF Coefficients for Ramp-Entrance-Related Crashes in Speed-Change Lanes

Crash Severity (z)	Area Type	Number of Through Lanes (n)	SPF Coefficient a	b	c	Inverse Dispersion Parameter $K_{sc,\,nEN,\,at,\,z}$ (mi^{-1})
Fatal and injury (fi)	Rural	4	–3.894	1.173	0.0005	26.1
		6	–4.154	1.173	0.0005	26.1
		8	–4.414	1.173	0.0005	26.1
	Urban	4	–3.714	1.173	0.0005	26.1
		6	–3.974	1.173	0.0005	26.1
		8	–4.234	1.173	0.0005	26.1
		10	–4.494	1.173	0.0005	26.1
Property damage only (pdo)	Rural	4	–2.895	1.215	0.0005	24.8
		6	–3.097	1.215	0.0005	24.8
		8	–3.299	1.215	0.0005	24.8
	Urban	4	–2.796	1.215	0.0005	24.8
		6	–2.998	1.215	0.0005	24.8
		8	–3.200	1.215	0.0005	24.8
		10	–3.402	1.215	0.0005	24.8

The SPFs are illustrated in Figure 18-14. The ramp entrance CMF is combined with this SPF to create the trend lines shown in the figure. This CMF is a function of entrance ramp volume and the speed-change lane length. These variables in combination do not readily lend themselves to the specification of a representative base condition. For this reason, the CMF is combined with the SPF for the graphical presentation. The ramp entrance CMF is described in Section 18.7.2.

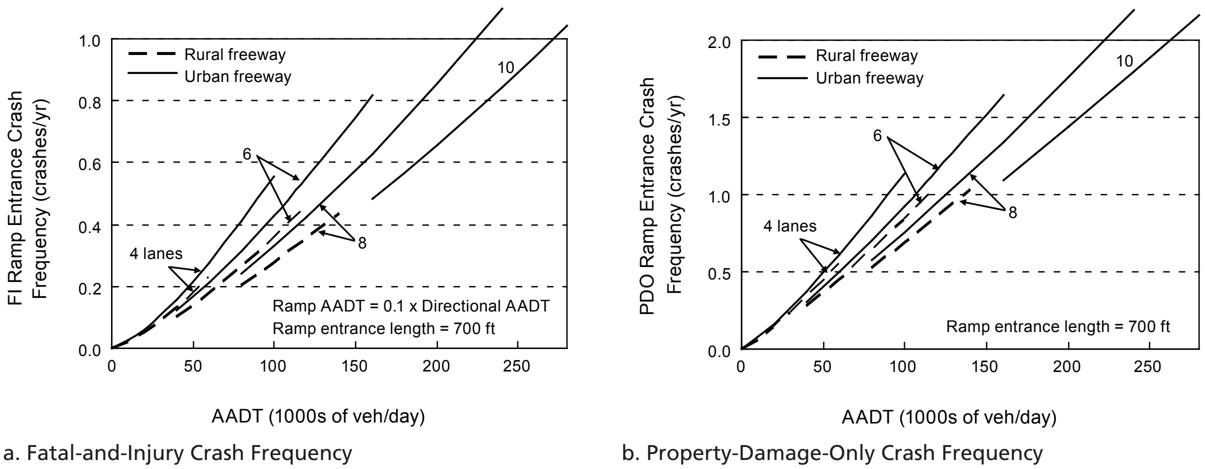


Figure 18-14. Graphical Form of the SPFs for Ramp Entrance Speed-Change Lanes

The value of the overdispersion parameter associated with the SPFs for ramp-entrance speed-change lanes is determined as a function of the speed-change lane length. This value is computed as:

$$k_{sc,nEN,at,z} = \frac{1.0}{K_{sc,nEN,at,z} \times L_{en}} \tag{18-21}$$

Where:

$k_{sc,\,nEN,\,at,\,z}$ = overdispersion parameter for ramp entrance speed-change lane on a freeway with *n* lanes, all crash types *at*, and severity *z*; and

$K_{sc,\,nEN,\,at,\,z}$ = inverse dispersion parameter for ramp entrance speed-change lane on a freeway with *n* lanes, all crash types *at*, and severity *z* (mi^{-1}).

The inverse dispersion parameter for speed-change lanes adjacent to freeways with 4, 6, 8, or 10 through lanes is provided in Table 18-9. A procedure is described in Section B.2.7 in Appendix B for using these parameters to estimate the overdispersion parameter for speed-change lanes adjacent to freeways with 5, 7, or 9 lanes.

The crash frequency obtained from Equation 18-20 can be multiplied by the proportions in Table 18-10 to estimate the predicted average ramp-entrance-related crash frequency by crash type or crash type category. These proportions are based on ramp-entrance speed-change lane crashes. They do not include crashes associated with a ramp entrance that adds a lane to the cross section.

Table 18-10. Default Distribution of Ramp-Entrance-Related Crashes by Crash Type

			Proportion of Crashes by Severity	
Area Type	**Crash Type**	**Crash Type Category**	**Fatal and Injury**	**Property Damage Only**
Rural	Multiple vehicle	Head-on	0.021	0.004
		Right-angle	0.032	0.013
		Rear-end	0.351	0.260
		Sideswipe	0.128	0.242
		Other multiple-vehicle crash	0.011	0.040
	Single vehicle	Crash with animal	0.000	0.009
		Crash with fixed object	0.245	0.296
		Crash with other object	0.021	0.070
		Crash with parked vehicle	0.021	0.000
		Other single-vehicle crashes	0.170	0.066
Urban	Multiple vehicle	Head-on	0.004	0.001
		Right-angle	0.019	0.016
		Rear-end	0.543	0.530
		Sideswipe	0.133	0.252
		Other multiple-vehicle crash	0.017	0.015
	Single vehicle	Crash with animal	0.000	0.002
		Crash with fixed object	0.194	0.129
		Crash with other object	0.019	0.036
		Crash with parked vehicle	0.004	0.003
		Other single-vehicle crashes	0.067	0.016

Ramp Exit Speed-Change Lanes

The base conditions for the SPFs for ramp-exit speed-change lanes are the same as those for ramp entrance speed-change lanes, as described in the preceding subsection.

The SPFs for ramp exit speed-change lanes are represented using the following equation:

$$N_{spf,sc,nEX,at,z} = L_{ex} \times \exp(a + b \times \ln[c \times AADT_{fs}]) \tag{18-22}$$

Where:

$N_{spf,\,sc,\,nEX,\,at,\,z}$ = predicted average crash frequency of a ramp exit speed-change lane on a freeway with base conditions, *n* lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr); and

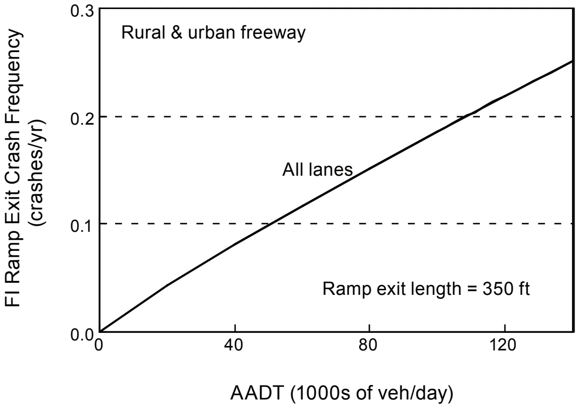
L_{ex} = length of ramp exit (mi).

The SPF coefficients and the inverse dispersion parameter are provided in Table 18-11. The variable *n* is used in this table to describe the number of through lanes in the portion of freeway adjacent to the speed-change lane *plus* those freeway lanes in the opposing travel direction.

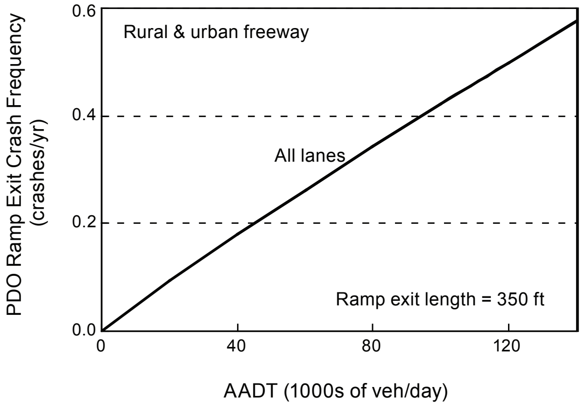
Table 18-11. SPF Coefficients for Ramp-Exit-Related Crashes in Speed-Change Lanes

Crash Severity (z)	Area Type	Number of Through Lanes (n)	SPF Coefficient a	SPF Coefficient b	SPF Coefficient c	Inverse Dispersion Parameter $K_{sc,\, nEX,\, at,\, z}$
Fatal and injury (fi)	Rural	4, 6, 8	–2.679	0.903	0.0005	1.78
	Urban	4, 6, 8, 10	–2.679	0.903	0.0005	1.78
Property damage only (pdo)	Rural	4, 6, 8	–1.798	0.932	0.0005	1.58
	Urban	4, 6, 8, 10	–1.798	0.932	0.0005	1.58

The SPFs are illustrated in Figure 18-15. The ramp exit CMF is combined with the fatal-and-injury SPF to create the trend lines shown in the figure for fatal-and-injury crashes. This CMF is a function of the speed-change lane length. This variable (in combination with the SPF length variable) does not readily lend itself to the specification of a representative base condition. For this reason, the CMF is combined with the SPF for the graphical presentation. The ramp exit CMF is described in Section 18.7.2.



a. Fatal-and-Injury Crash Frequency



b. Property-Damage-Only Crash Frequency

Figure 18-15. Graphical Form of the SPFs for Ramp Exit Speed-Change Lanes

The overdispersion parameter associated with the SPFs for ramp exit speed-change lanes is computed as follows:

$$k_{sc,nEX,at,z} = \frac{1.0}{K_{sc,nEX,at,z}} \tag{18-23}$$

Where:

$k_{sc,\, nEX,\, at,\, z}$ = overdispersion parameter for ramp exit speed-change lane on a freeway with n lanes, all crash types at, and severity z; and

$K_{sc,\, nEX,\, at,\, z}$ = inverse dispersion parameter for ramp exit speed-change lane on a freeway with n lanes, all crash types at, and severity z.

The inverse dispersion parameter for speed-change lanes adjacent to freeways with 4, 6, 8, or 10 through lanes is provided in Table 18-11. A procedure is described in Section B.2.7 in Appendix B for using these parameters to estimate the overdispersion parameter for speed-change lanes adjacent to freeways with 5, 7, or 9 lanes.

The crash frequency obtained from Equation 18-22 can be multiplied by the proportions in Table 18-12 to estimate the predicted average ramp-exit-related crash frequency by crash type or crash type category. These proportions are based on ramp-exit speed-change lane crashes. They do not include crashes associated with a ramp exit that drops a lane from the cross section.

Table 18-12. Default Distribution of Ramp-Exit-Related Crashes by Crash Type

			Proportion of Crashes by Severity	
Area Type	**Crash Type**	**Crash Type Category**	**Fatal and Injury**	**Property Damage Only**
Rural	Multiple vehicle	Head-on	0.000	0.000
		Right-angle	0.015	0.000
		Rear-end	0.463	0.304
		Sideswipe	0.104	0.243
		Other multiple-vehicle crash	0.000	0.009
	Single vehicle	Crash with animal	0.000	0.061
		Crash with fixed object	0.224	0.235
		Crash with other object	0.030	0.061
		Crash with parked vehicle	0.000	0.017
		Other single-vehicle crashes	0.164	0.070
Urban	Multiple vehicle	Head-on	0.005	0.002
		Right-angle	0.011	0.012
		Rear-end	0.549	0.565
		Sideswipe	0.158	0.138
		Other multiple-vehicle crash	0.016	0.016
	Single vehicle	Crash with animal	0.000	0.007
		Crash with fixed object	0.196	0.207
		Crash with other object	0.016	0.030
		Crash with parked vehicle	0.000	0.000
		Other single-vehicle crashes	0.049	0.023

18.7. CRASH MODIFICATION FACTORS

This section describes the CMFs applicable to the SPFs presented in Section 18.6. These CMFs were calibrated along with the SPFs. They are summarized in Table 18-13.

Many of the CMFs in Table 18-13 are developed for specific site types, cross sections, crash types, or crash severities. This approach was undertaken to make the predictive model sensitive to the geometric design and traffic control features of specific sites with specific cross sections, in terms of their influence on specific crash types and severities. The subscripts for each CMF variable indicate the sites, cross sections, crash types, and severities to which each CMF is applicable. The subscript definitions are provided in the table footnote. In some cases, a CMF is applicable to several site types, cross sections, crash types, or severities. In these cases, the subscript retains the generic letter w, x, y, or z, as appropriate. The discussion of these CMFs in Section 18.7.1 or 18.7.2 identifies the specific site types, cross sections, crash types, or severities to which they apply.

As indicated in Table 18-13, some of the CMFs apply to both freeway segments and speed-change lanes. These CMFs are presented in Section 18.7.1 and referenced in Section 18.7.2. For some of the CMFs, supplemental calculations must be performed before the CMF value can be computed. For example, to apply the median width CMF, the proportion of the segment length having inside barrier and the length-weighted average barrier offset (as measured from the edge of the inside shoulder) must be computed. Procedures for supplemental calculations are described in Section 18.7.3.

Table 18-13. Freeway Crash Modification Factors and their Corresponding SPFs

Applicable SPF(s)	CMF Variable [a]	CMF Description	CMF Equations [b]
Freeway segments or speed-change lanes	$CMF_{1,\,w,\,x,\,y,\,z}$	Horizontal curve	Equation 18-24, Equation 18-40
	$CMF_{2,\,w,\,x,\,y,\,fi}$	Lane width	Equation 18-25, Equation 18-41
	$CMF_{3,\,w,\,x,\,y,\,z}$	Inside shoulder width	Equation 18-26, Equation 18-42
	$CMF_{4,\,w,\,x,\,y,\,z}$	Median width	Equation 18-27, Equation 18-43
	$CMF_{5,\,w,\,x,\,y,\,z}$	Median barrier	Equation 18-28, Equation 18-44
	$CMF_{6,\,w,\,x,\,y,\,z}$	High volume	Equation 18-29, Equation 18-45
Multiple-vehicle crashes on freeway segments	$CMF_{7,\,fs,\,ac,\,mv,\,z}$	Lane change	Equation 18-30
Single-vehicle crashes on freeway segments	$CMF_{8,\,fs,\,ac,\,sv,\,z}$	Outside shoulder width	Equation 18-35
	$CMF_{9,\,fs,\,ac,\,sv,\,fi}$	Shoulder rumble strip	Equation 18-36
	$CMF_{10,\,fs,\,ac,\,sv,\,fi}$	Outside clearance	Equation 18-38
	$CMF_{11,\,fs,\,ac,\,sv,\,z}$	Outside barrier	Equation 18-39
Ramp entrances	$CMF_{12,\,sc,\,nEN,\,at,\,z}$	Ramp entrance	Equation 18-46
Ramp exits	$CMF_{13,\,sc,\,nEX,\,at,\,z}$	Ramp exit	Equation 18-47

[a] Subscripts to the CMF variables use the following notation:
- Site type *w* (*w* = *fs*: freeway segment, *sc*: speed-change lane),
- Cross section *x* (*x* = *n*: n-lane freeway, *nEN*: ramp entrance speed-change lane adjacent to a freeway with *n* lanes, *nEX*: ramp exit speed-change lane adjacent to a freeway with *n* lanes, *ac*: any cross section),
- Crash type *y* (*y* = *sv*: single vehicle, *mv*: multiple vehicle, *at*: all types), and
- Severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only, *as*: all severities).

[b] Where two equations are listed, the first equation is applicable to freeway segments and the second equation is applicable to speed-change lanes.

18.7.1. Crash Modification Factors for Freeway Segments

The CMFs for geometric design and traffic control features of freeway segments are presented in this section. Several CMFs described in this section include a variable defining the proportion of the segment's length along which a particular feature (i.e., curve, rumble strip, barrier) is present. Guidance is offered herein for computing each proportion. The concept underlying this guidance is that the computed proportion should equal the total length of the feature summed over both roadbeds (excluding the length of the feature adjacent to speed-change lanes) divided by the total length of both roadbeds (excluding the length of speed-change lanes).

$CMF_{1,\,w,\,x,\,y,\,z}$—Horizontal Curve

Four CMFs are used to describe the relationship between horizontal curve geometry and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, specified number of lanes (*fs*, *n*, *mv*, *fi*);
- SPF for property-damage-only multiple-vehicle crashes, specified number of lanes (*fs*, *n*, *mv*, *pdo*);
- SPF for fatal-and-injury single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *fi*); and
- SPF for property-damage-only single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *pdo*).

The base condition is an uncurved (i.e., tangent) segment. The CMFs are described using the following equation:

$$CMF_{1,\,fs,\,ac,\,y,\,z} = 1.0 + a \times \left[\sum_{i=1}^{m} \left(\frac{5,730}{R_i^*} \right)^2 \times P_{c,\,i} \right] \tag{18-24}$$

Where:

$CMF_{1,fs,ac,y,z}$ = crash modification factor for horizontal curvature in a freeway segment with any cross section *ac*, crash type *y*, and severity *z*;

m = number of horizontal curves in the segment;

R_i^* = equivalent radius of curve *i* (= $[0.5/R_{a,i}^2 + 0.5/R_{b,i}^2]^{-0.5}$ if both roadbeds are curved, $R_{a,i}$ if only one roadbed is curved) (ft);

$R_{a,i}$ = radius of curve *i* in one roadbed (ft);

$R_{b,i}$ = radius of curve *i* in second roadbed (used if both roadbeds are curved) (ft); and

$P_{c,i}$ = proportion of effective segment length with curve *i*.

The coefficient for Equation 18-24 is provided in Table 18-14. Equation 18-24 is derived to recognize that more than one curve may exist in a segment and that a curve may be located only partially in the segment (and partially on an adjacent segment). The variable $P_{c,i}$ is computed as the ratio of the length of curve *i* in the segment to the length of the freeway segment L_{fs}. For example, consider a segment that is 0.5 mi long and a curve that is 0.2 mi long. If one-half of the curve is in the segment, then $P_{c,i} = 0.20$ (= 0.1/0.5). In fact, this proportion is the same regardless of the curve's length (provided that it is 0.1 mi or longer and 0.1 mi of this curve is located in the segment).

Table 18-14. Coefficients for Horizontal Curve CMF–Freeway Segments

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$CMF_{1,fs,ac,mv,fi}$	0.0172
		Property damage only (*pdo*)	$CMF_{1,fs,ac,mv,pdo}$	0.0340
	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{1,fs,ac,sv,fi}$	0.0719
		Property damage only (*pdo*)	$CMF_{1,fs,ac,sv,pdo}$	0.0626

Details regarding the measurement of radius, curve length, and other variables associated with this CMF are provided in Section 18.4.2. The CMF is applicable to curves with a radius of 1,000 ft or larger.

$CMF_{2,w,x,y,fi}$—Lane Width

Two CMFs are used to describe the relationship between average lane width and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, specified number of lanes (*fs*, *n*, *mv*, *fi*); and
- SPF for fatal-and-injury single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *fi*).

The base condition is a 12-ft lane width. The CMFs are described using the following equation:

$$CMF_{2,fs,ac,y,fi} = \begin{cases} \exp\left(a \times [W_l - 12]\right) & : \text{If } W_l < 13\,\text{ft} \\ b & : \text{If } W_l \geq 13\,\text{ft} \end{cases} \qquad (18\text{-}25)$$

Where:

$CMF_{2,fs,ac,y,fi}$ = crash modification factor for lane width in a freeway segment with any cross section *ac*, crash type *y*, and fatal-and-injury crashes *fi*; and

W_l = lane width (ft).

The coefficients for Equation 18-25 are provided in Table 18-15. In fact, the coefficient values are the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs. The CMF is discontinuous, breaking at a lane width of 13 ft. The CMF is applicable to lane widths in the range of 10.5 to 14 ft.

Table 18-15. Coefficients for Lane Width CMF–Freeway Segments

				CMF Coefficients	
Cross Section (*x*)	**Crash Type (*y*)**	**Crash Severity (*z*)**	**CMF Variable**	*a*	*b*
Any cross section (*ac*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$CMF_{2, fs, ac, mv, fi}$	–0.0376	0.963
	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{2, fs, ac, sv, fi}$	–0.0376	0.963

$CMF_{3,\ w, x, y, z}$—Inside Shoulder Width

Four CMFs are used to describe the relationship between average inside shoulder width and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, specified number of lanes (*fs*, *n*, *mv*, *fi*);
- SPF for property-damage-only multiple-vehicle crashes, specified number of lanes (*fs*, *n*, *mv*, *pdo*);
- SPF for fatal-and-injury single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *fi*); and
- SPF for property-damage-only single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *pdo*).

The base condition is a 6-ft inside shoulder width. The CMFs are described using the following equation:

$$CMF_{3,fs,ac,y,z} = \exp\left(a \times [W_{is} - 6]\right) \tag{18-26}$$

Where:

$CMF_{3, fs, ac, y, z}$ = crash modification factor for inside shoulder width in a freeway segment with any cross section *ac*, crash type *y*, and severity *z*; and

W_{is} = paved inside shoulder width (ft).

The coefficient for Equation 18-26 is provided in Table 18-16. For a given severity, the coefficient values are the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs. The CMF is applicable to shoulder widths in the range of 2 to 12 ft.

Table 18-16. Coefficients for Inside Shoulder Width CMF–Freeway Segments

Cross Section (*x*)	**Crash Type (*y*)**	**Crash Severity (*z*)**	**CMF Variable**	**CMF Coefficient (*a*)**
Any cross section (*ac*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$CMF_{3, fs, ac, mv, fi}$	–0.0172
		Property damage only (*pdo*)	$CMF_{3, fs, ac, mv, pdo}$	–0.0153
	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{3, fs, ac, sv, fi}$	–0.0172
		Property damage only (*pdo*)	$CMF_{3, fs, ac, sv, pdo}$	–0.0153

$CMF_{4,\ w, x, y, z}$—Median Width

Four CMFs are used to describe the relationship between median width and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, specified number of lanes (*fs*, *n*, *mv*, *fi*);
- SPF for property-damage-only multiple-vehicle crashes, specified number of lanes (*fs*, *n*, *mv*, *pdo*);

- SPF for fatal-and-injury single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *fi*); and
- SPF for property-damage-only single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *pdo*).

The base condition is a 60-ft median width, a 6-ft inside shoulder width, and no barrier present in the median. The CMFs are described using the following equation:

$$CMF_{4,\,fs,ac,y,z} = \left(1.0 - P_{ib}\right) \times \exp\left(a \times [W_m - 2 \times W_{is} - 48]\right) + P_{ib} \times \exp\left(a \times [2 \times W_{icb} - 48]\right) \tag{18-27}$$

Where:

$CMF_{4,\,fs,\,ac,\,y,\,z}$ = crash modification factor for median width in a freeway segment with any cross section *ac*, crash type *y*, and severity *z*;

P_{ib} = proportion of effective segment length with a barrier present in the median (i.e., inside);

W_m = median width (measured from near edges of traveled way in both directions) (ft); and

W_{icb} = distance from edge of inside shoulder to barrier face (ft).

The coefficient for Equation 18-27 is provided in Table 18-17. These CMFs are derived to be applicable to a segment that has median barrier present along some portion of the segment. Guidance for computing the variables P_{ib} and W_{icb} is provided in Section 18.7.3.

Table 18-17. Coefficients for Median Width CMF–Freeway Segments

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$CMF_{4,\,fs,\,ac,\,mv,\,fi}$	–0.00302
		Property damage only (*pdo*)	$CMF_{4,\,fs,\,ac,\,mv,\,pdo}$	–0.00291
	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{4,\,fs,\,ac,\,sv,\,fi}$	0.00102
		Property damage only (*pdo*)	$CMF_{4,\,fs,\,ac,\,sv,\,pdo}$	–0.00289

The CMF is applicable to median widths of 9 ft or more, W_{icb} values in the range of 0.75 to 17 ft, and shoulder widths in the range of 2 to 12 ft. If the median width exceeds 90 ft, then 90 ft should be used for W_m in Equation 18-27.

$CMF_{5,\,w,\,x,\,y,\,z}$—Median Barrier

Four CMFs are used to describe the relationship between median barrier presence and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, specified number of lanes (*fs*, *n*, *mv*, *fi*);
- SPF for property-damage-only multiple-vehicle crashes, specified number of lanes (*fs*, *n*, *mv*, *pdo*);
- SPF for fatal-and-injury single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *fi*); and
- SPF for property-damage-only single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *pdo*).

The base condition is no barrier present in the median. The CMFs are described using the following equation:

$$CMF_{5,\,fs,ac,y,z} = \left(1.0 - P_{ib}\right) \times 1.0 + P_{ib} \times \exp\left(\frac{a}{W_{icb}}\right) \tag{18-28}$$

Where:

$CMF_{5,\, fs,\, ac,\, y,\, z}$ = crash modification factor for median barrier in a freeway segment with any cross section *ac*, crash type *y*, and severity *z*.

The coefficient for Equation 18-28 is provided in Table 18-18. For a given severity, the coefficient values are the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs. Guidance for computing the variables P_{ib} and W_{icb} is provided in Section 18.7.3.

Table 18-18. Coefficients for Median Barrier CMF–Freeway Segments

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$CMF_{5,\, fs,\, ac,\, mv,\, fi}$	0.131
		Property damage only (*pdo*)	$CMF_{5,\, fs,\, ac,\, mv,\, pdo}$	0.169
	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{5,\, fs,\, ac,\, sv,\, fi}$	0.131
		Property damage only (*pdo*)	$CMF_{5,\, fs,\, ac,\, sv,\, pdo}$	0.169

The CMF is applicable to W_{icb} values in the range of 0.75 to 17 ft. This CMF is applicable to cable barrier, concrete barrier, guardrail, and bridge rail.

$CMF_{6,\, w,\, x,\, y,\, z}$—High Volume

As volume nears capacity, average freeway speed tends to decrease and headway is reduced. Logically, these changes have some influence on crash characteristics, including crash frequency, crash type, and crash severity. This CMF was developed to provide some sensitivity to volume variation during the average day and specifically to those peak hours where traffic volume is likely to be near (or in excess of) capacity.

A statistic was developed to describe the degree of volume concentration during peak hours of the average day. It represents the proportion of the AADT that occurs during hours where the volume exceeds 1,000 vehicles per hour per lane (veh/h/ln). It has a value of zero if the volume on the associated segment does not exceed the threshold value for any hour of the day. It has a value of one if the volume during each hour of the average day exceeds the threshold value. In general, its value is large when hourly volumes are continuously high or when there is a peak few hours with an exceptionally large volume.

Typical freeway speed-volume relationships show that the average speed tends to drop as flow rates increase beyond 1,000 veh/h/ln. This trend suggests that drivers reduce their speed to improve their comfort and safety as their headway gets shorter than 3.6 s/veh (= 3,600/1,000).

Four CMFs are used to describe the relationship between volume concentration and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, specified number of lanes (*fs*, *n*, *mv*, *fi*);
- SPF for property-damage-only multiple-vehicle crashes, specified number of lanes (*fs*, *n*, *mv*, *pdo*);
- SPF for fatal-and-injury single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *fi*); and
- SPF for property-damage-only single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *pdo*).

The base condition is no hours having a volume that exceeds 1,000 veh/h/ln. The CMFs are described using the following equation:

$$CMF_{6,\, fs,\, ac,\, y,\, z} = \exp\left(a \times P_{hv}\right) \qquad (18\text{-}29)$$

Where:

$CMF_{6,fs,ac,y,z}$ = crash modification factor for high volume in a freeway segment with any cross section *ac*, crash type *y*, and severity *z*; and

P_{hv} = proportion of AADT during hours where volume exceeds 1,000 veh/h/ln.

The coefficient for Equation 18-29 is provided in Table 18-19. The CMF is applicable to P_{hv} values in the range of 0.0 to 1.0.

Table 18-19. Coefficients for High Volume CMF–Freeway Segments

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$CMF_{6,fs,ac,mv,fi}$	0.350
		Property damage only (*pdo*)	$CMF_{6,fs,ac,mv,pdo}$	0.283
	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{6,fs,ac,sv,fi}$	–0.0675
		Property damage only (*pdo*)	$CMF_{6,fs,ac,sv,pdo}$	–0.611

$CMF_{7,fs,ac,mv,z}$—Lane Change

Two CMFs are used to describe the relationship between lane change activity and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, specified number of lanes (*fs*, *n*, *mv*, *fi*); and
- SPF for property-damage-only multiple-vehicle crashes, specified number of lanes (*fs*, *n*, *mv*, *pdo*).

The base condition is no significant lane changing due to ramp entry or exit. More specifically, the base condition is no ramp entrance or ramp exit within 0.5 mi of the segment. The CMFs are described using the following equations:

$$CMF_{7,fs,ac,mv,z} = \left(0.5\times f_{wev,inc}\times f_{lc,inc}\right) + \left(0.5\times f_{wev,dec}\times f_{lc,dec}\right) \tag{18-30}$$

with

$$f_{wev,inc} = \left(1.0 - P_{wevB,inc}\right)\times 1.0 + P_{wevB,inc}\times \exp\left(\frac{a}{L_{wev,inc}}\right) \tag{18-31}$$

$$f_{wev,dec} = \left(1.0 - P_{wevB,dec}\right)\times 1.0 + P_{wevB,dec}\times \exp\left(\frac{a}{L_{wev,dec}}\right) \tag{18-32}$$

$$\begin{aligned} f_{lc,inc} = &\left(1.0 + \frac{\exp\left(-b\times X_{b,ent} + d\times \ln\left[c\times AADT_{b,ent}\right]\right)}{b\times L_{fs}}\times\left[1.0 - \exp\left(-b\times L_{fs}\right)\right]\right) \\ &\times\left(1.0 + \frac{\exp\left(-b\times X_{e,ext} + d\times \ln\left[c\times AADT_{e,ext}\right]\right)}{b\times L_{fs}}\times\left[1.0 - \exp\left(-b\times L_{fs}\right)\right]\right) \end{aligned} \tag{18-33}$$

$$f_{lc,\,dec} = \left(1.0 + \frac{\exp\left(-b \times X_{e,ent} + d \times \ln\left[c \times AADT_{e,ent}\right]\right)}{b \times L_{fs}} \times \left[1.0 - \exp\left(-b \times L_{fs}\right)\right]\right) \times \left(1.0 + \frac{\exp\left(-b \times X_{b,ext} + d \times \ln\left[c \times AADT_{b,ext}\right]\right)}{b \times L_{fs}} \times \left[1.0 - \exp\left(-b \times L_{fs}\right)\right]\right) \tag{18-34}$$

Where:

$CMF_{7,\,fs,\,ac,\,mv,\,z}$ = crash modification factor for lane changes in a freeway segment with any cross section *ac*, multiple-vehicle crashes *mv*, and severity *z*;

$f_{lc,\,inc}$ = lane change adjustment factor for travel in increasing milepost direction;

$f_{lc,\,dec}$ = lane change adjustment factor for travel in decreasing milepost direction;

$f_{wev,\,inc}$ = weaving section adjustment factor for travel in increasing milepost direction;

$f_{wev,\,dec}$ = weaving section adjustment factor for travel in decreasing milepost direction;

$P_{wevB,\,inc}$ = proportion of segment length within a Type B weaving section for travel in increasing milepost direction;

$P_{wevB,\,dec}$ = proportion of segment length within a Type B weaving section for travel in decreasing milepost direction;

$L_{wev,\,inc}$ = weaving section length for travel in increasing milepost direction (may extend beyond segment boundaries) (mi);

$L_{wev,\,dec}$ = weaving section length for travel in decreasing milepost direction (may extend beyond segment boundaries) (mi);

$X_{b,\,ent}$ = distance from segment begin milepost to nearest upstream entrance ramp gore point, for travel in increasing milepost direction (mi);

$X_{b,\,ext}$ = distance from segment begin milepost to nearest downstream exit ramp gore point, for travel in decreasing milepost direction (mi);

$X_{e,\,ent}$ = distance from segment end milepost to nearest upstream entrance ramp gore point, for travel in decreasing milepost direction (mi);

$X_{e,\,ext}$ = distance from segment end milepost to nearest downstream exit ramp gore point, for travel in increasing milepost direction (miles);

$AADT_{b,\,ent}$ = AADT volume of entrance ramp located at distance $X_{b,\,ent}$ (veh/day);

$AADT_{b,\,ext}$ = AADT volume of exit ramp located at distance $X_{b,\,ext}$ (veh/day);

$AADT_{e,\,ent}$ = AADT volume of entrance ramp located at distance $X_{e,\,ent}$ (veh/day); and

$AADT_{e,\,ext}$ = AADT volume of exit ramp located at distance $X_{e,\,ext}$ (veh/day).

The coefficients for Equation 18-31 to Equation 18-34 are provided in Table 18-20.

Table 18-20. Coefficients for Lane Change CMF–Freeway Segments

Cross Section (x)	Crash Type (y)	Crash Severity (z)	CMF Variable	CMF Coefficients a	b	c	d
Any cross section (ac)	Multiple vehicle (mv)	Fatal and injury (fi)	$CMF_{7,fs,ac,mv,fi}$	0.175	12.56	0.001	–0.272
		Property damage only (pdo)	$CMF_{7,fs,ac,mv,pdo}$	0.123	13.46	0.001	–0.283

If the segment is in a Type B weaving section, then the length of the weaving section is an input to the CMF. The variables for weaving section length (i.e., $L_{wev,inc,}$ $L_{wev,dec}$) in Equation 18-31 and Equation 18-32 are intended to reflect the degree to which the weaving activity is concentrated along the freeway. The sign of the coefficient in these two equations indicates that the lane change CMF value will increase if the segment is in a Type B weaving section. The amount of this increase is inversely related to the length of the weaving section. Guidance for determining if a weaving section is Type B is provided in Section 18.4.

The variables $P_{wevB,inc}$ and $P_{wevB,dec}$ in Equation 18-31 and Equation 18-32, respectively, are computed as the ratio of the length of the weaving section in the segment to the length of the freeway segment L_{fs}. If the segment is wholly located in the weaving section, then this variable is equal to 1.0.

The X and $AADT$ variables describe the distance to (and volume of) the four nearest ramps to the subject segment. Two of the ramps of interest are on the side of the freeway with travel in the increasing milepost direction. One ramp on this side of the freeway is upstream of the segment, and one ramp is downstream of the segment. Similarly, one ramp on the other side of the freeway is upstream of the segment and one ramp is downstream. Only those entrance ramps that contribute volume to the subject segment are of interest. Hence, a downstream entrance ramp is not of interest. For similar reasons, an upstream exit ramp is not of interest.

The lane change CMF is applicable to any segment in the vicinity of one or more ramps. It is equally applicable to segments in a weaving section (regardless of the weaving section type) and segments in a non-weaving section (i.e., segments between an entrance ramp and an exit ramp where both ramps have a speed-change lane). If the weaving section is Type B, then an additional adjustment is made using Equation 18-31 and Equation 18-32. The CMF is applicable to weaving section lengths between 0.10 and 0.85 mi. It is applicable to any value for the distance variable X and to the range of ramp AADTs in Table 19-4.

The two SPFs for predicting speed-change-related crash frequency (i.e., Equation 18-20 and Equation 18-22) are not used when evaluating a weaving section because the ramps that form the weaving section do not have a speed-change lane. As a result, the predicted crash frequency for the set of segments that comprise a weaving section will tend to be smaller than that predicted for a similar set of segments located in a non-weaving section but having entrance and exit ramps. This generalization will always be true for weaving sections that are not Type B. It may or may not hold for the Type B weaving section, depending on the length of the weaving section.

$CMF_{8,fs,ac,sv,z}$—Outside Shoulder Width

Two CMFs are used to describe the relationship between average outside shoulder width and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury single-vehicle crashes, specified number of lanes (fs, n, sv, fi); and
- SPF for property-damage-only single-vehicle crashes, specified number of lanes (fs, n, sv, pdo).

The base condition is a 10-ft outside shoulder width. The CMFs are described using the following equation:

$$CMF_{8,fs,ac,sv,z} = \left(1.0 - \sum_{i=1}^{m} P_{c,i} \times f_{c,i}\right) \times \exp\left(a \times [W_s - 10]\right) + \left(\sum_{i=1}^{m} P_{c,i} \times f_{c,i}\right) \times \exp\left(b \times [W_s - 10]\right) \qquad (18\text{-}35)$$

Where:

$CMF_{8,\,fs,\,ac,\,sv,\,z}$ = crash modification factor for outside shoulder width in a freeway segment with any cross section *ac*, single-vehicle crashes *sv*, and severity *z*; and

W_s = paved outside shoulder width (ft).

The coefficients for Equation 18-35 are provided in Table 18-21. The variable $P_{c,i}$ is computed as the ratio of the length of curve *i* in the segment to the effective length of the freeway segment L^*. The CMF is applicable to shoulder widths in the range of 4 to 14 ft. The "length of curve *i* in the segment" is computed as an average of two values: the length of curve *i* between the segment's begin and end mileposts for roadbed 1 and that for roadbed 2, where each value excludes the length of any coincident speed-change lane that may be present and where the value for a given roadbed is zero if that roadbed is not curved.

Table 18-21. Coefficients for Outside Shoulder Width CMF–Freeway Segments

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficients	
				a	*b*
Any cross section (*ac*)	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{8,\,fs,\,ac,\,sv,\,fi}$	–0.0647	–0.0897
		Property damage only (*pdo*)	$CMF_{8,\,fs,\,ac,\,sv,\,pdo}$	0.00	–0.0840

$CMF_{9,\,fs,\,ac,\,sv,\,fi}$—Shoulder Rumble Strips

One CMF is used to describe the relationship between shoulder rumble strip presence and predicted crash frequency. The SPF to which it applies is identified in the following list:

- SPF for fatal-and-injury single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *fi*).

The base condition is no shoulder rumble strips present. The CMF is described using the following equation:

$$CMF_{9,\,fs,ac,sv,\,fi} = \left(1.0 - \sum_{i=1}^{m} P_{c,\,i} \times f_{c,\,i}\right) \times f_{\tan} + \left(\sum_{i=1}^{m} P_{c,\,i} \times f_{c,\,i}\right) \times 1.0 \tag{18-36}$$

$$f_{\tan} = 0.5 \times \left([1.0 - P_{ir}] \times 1.0 + P_{ir} \times 0.811\right) + 0.5 \times \left([1.0 - P_{or}] \times 1.0 + P_{or} \times 0.811\right) \tag{18-37}$$

Where:

$CMF_{9,\,fs,\,ac,\,sv,\,fi}$ = crash modification factor for shoulder rumble strips in a freeway segment with any cross section *ac* and fatal-and-injury (*fi*) single-vehicle (*sv*) crashes;

f_{tan} = factor for rumble strip presence on tangent portions of the segment;

P_{ir} = proportion of effective segment length with rumble strips present on the inside shoulders; and

P_{or} = proportion of effective segment length with rumble strips present on the outside shoulders.

The proportion P_{ir} represents the proportion of the effective segment length with rumble strips present on the inside shoulders. It is computed by summing the length of roadway with rumble strips on the inside shoulder (excluding the length of any rumble strips adjacent to speed-change lanes) in *both* travel directions and dividing by twice the effective freeway segment length L^*. The proportion P_{or} represents the proportion of the effective segment length with rumble strips present on the outside shoulders. It is computed by summing the length of roadway with rumble strips on the outside shoulder (excluding the length of any rumble strips adjacent to speed-change lanes) in *both* travel directions and dividing by twice the effective freeway segment length L^*.

This CMF addresses shoulder rumble strip placement on curved and uncurved (i.e., tangent) segments. It has a value less than 1.0 on tangent segments with shoulder rumble strips suggesting that crash frequency is lowered by the presence of rumble strips. This trend was not found in the calibration data for curved segments.

$CMF_{10,\, fs,\, ac,\, sv,\, fi}$—Outside Clearance

One CMF is used to describe the relationship between average outside clearance and predicted crash frequency. The SPF to which it applies is identified in the following list:

- SPF for fatal-and-injury single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *fi*).

The base condition is a 30-ft clear zone, a 10-ft outside shoulder width, and no barrier present in the clear zone. The CMF is described using the following equation:

$$CMF_{10,\, fs, ac, sv, fi} = (1.0 - P_{ob}) \times \exp(-0.00451 \times [W_{hc} - W_s - 20]) + P_{ob} \times \exp(-0.00451 \times [W_{ocb} - 20]) \quad (18\text{-}38)$$

Where:

$CMF_{10,\, fs,\, ac,\, sv,\, fi}$ = crash modification factor for outside clearance in a freeway segment with any cross section *ac*, single-vehicle *sv*, fatal-and-injury *fi* crashes;

P_{ob} = proportion of effective segment length with a barrier present on the roadside (i.e., outside);

W_{hc} = clear zone width (ft); and

W_{ocb} = distance from edge of outside shoulder to barrier face (ft).

This CMF is derived to be applicable to a segment that has roadside barrier present along some portion of the segment. Guidance for computing the variables P_{ob} and W_{ocb} is provided in Section 18.7.3. The CMF is applicable to clear zone widths of 30 ft or less, W_{ocb} values in the range of 0.75 to 17 ft, and to shoulder widths in the range of 4 to 14 ft.

$CMF_{11,\, fs,\, ac,\, sv,\, z}$—Outside Barrier

Two CMFs are used to describe the relationship between outside barrier presence and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *fi*); and
- SPF for property-damage-only single-vehicle crashes, specified number of lanes (*fs*, *n*, *sv*, *pdo*).

The base condition is no barrier present in the clear zone. The CMFs are described using the following equation:

$$CMF_{11,\, fs, ac, sv, z} = (1.0 - P_{ob}) \times 1.0 + P_{ob} \times \exp\left(\frac{a}{W_{ocb}}\right) \quad (18\text{-}39)$$

Where:

$CMF_{11,\, fs,\, ac,\, sv,\, z}$ = crash modification factor for roadside barrier in a freeway segment with any cross section *ac*, single-vehicle crashes *sv*, and severity *z*.

The coefficient for Equation 18-39 is provided in Table 18-22. Guidance for computing the variables P_{ob} and W_{ocb} is provided in Section 18.7.3.

Table 18-22. Coefficients for Outside Barrier CMF–Freeway Segments

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{11, fs, ac, sv, fi}$	0.131
		Property damage only (*pdo*)	$CMF_{11, fs, ac, sv, pdo}$	0.169

The variable W_{ocb} represents the distance from the edge of outside shoulder to roadside barrier face. The value used for this variable in Equation 18-39 is an average for the segment. The CMF is applicable to W_{ocb} values in the range of 0.75 to 17 ft. This CMF is applicable to cable barrier, concrete barrier, guardrail, and bridge rail.

18.7.2. Crash Modification Factors for Speed-Change Lanes

The CMFs for geometric design and traffic control features of speed-change lanes are presented in this section.

$CMF_{1, w, x, y, z}$—Horizontal Curve

Four CMFs are used to describe the relationship between horizontal curve geometry and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury crashes, ramp entrance, freeway lanes *n* (*sc*, *nEN*, *at*, *fi*);
- SPF for property-damage-only crashes, ramp entrance, freeway lanes *n* (*sc*, *nEN*, *at*, *pdo*);
- SPF for fatal-and-injury crashes, ramp exit, freeway lanes *n* (*sc*, *nEX*, *at*, *fi*); and
- SPF for property-damage-only crashes, ramp exit, freeway lanes *n* (*sc*, *nEX*, *at*, *pdo*).

The base condition is an uncurved (i.e., tangent) alignment through the speed-change lane. The CMFs are described using the following equation:

$$CMF_{1,sc,ac,at,z} = 1.0 + a \times \left[\sum_{i=1}^{m} \left(\frac{5,730}{R_i} \right)^2 \times P_{c,i} \right] \tag{18-40}$$

Where:

$CMF_{1, sc, ac, at, z}$ = crash modification factor for horizontal curvature at a speed-change lane with any cross section *ac*, all crash types *at*, and severity *z*;

m = number of horizontal curves in the speed-change lane;

R_i = radius of curve *i* (ft); and

$P_{c, i}$ = proportion of speed-change lane length with curve *i*.

The coefficient for Equation 18-40 is provided in Table 18-23. The variable $P_{c, i}$ is computed as the ratio of the length of curve *i* in the speed-chanage lane to the length of the speed-change lane L_{en} or L_{ex}. Additional discussion of this CMF is provided in Section 18.7.1.

Table 18-23. Coefficients for Horizontal Curve CMF–Speed-Change Lanes

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{1, sc, ac, at, fi}$	0.0172
		Property damage only (*pdo*)	$CMF_{1, sc, ac, at, pdo}$	0.0340

$CMF_{2,\ w,\ x,\ y,\ fi}$—Lane Width

Two CMFs are used to describe the relationship between average lane width and predicted crash frequency. The SPFs to which it applies are identified in the following list:

- SPF for fatal-and-injury crashes, ramp entrance, freeway lanes *n* (*sc*, *nEN*, *at*, *fi*); and
- SPF for fatal-and-injury crashes, ramp exit, freeway lanes *n* (*sc*, *nEX*, *at*, *fi*).

The base condition is a 12-ft lane width. The CMF is described using the following equation:

$$CMF_{2,sc,ac,at,fi} = \begin{cases} \exp\left(-0.0376 \times [W_l - 12]\right) & : \text{If } W_l < 13\,\text{ft} \\ 0.963 & : \text{If } W_l \geq 13\,\text{ft} \end{cases} \tag{18-41}$$

Where:

$CMF_{2,\ sc,\ ac,\ at,\ fi}$ = crash modification factor for lane width at a speed-change lane with any cross section *ac*, all crash types *at*, and fatal-and-injury crashes *fi*; and

W_l = lane width (ft).

The CMF is applicable to lane widths in the range of 10.5 to 14 ft.

$CMF_{3,\ w,\ x,\ y,\ z}$—Inside Shoulder Width

Four CMFs are used to describe the relationship between average inside shoulder width and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury crashes, ramp entrance, freeway lanes *n* (*sc*, *nEN*, *at*, *fi*);
- SPF for property-damage-only crashes, ramp entrance, freeway lanes *n* (*sc*, *nEN*, *at*, *pdo*);
- SPF for fatal-and-injury crashes, ramp exit, freeway lanes *n* (*sc*, *nEX*, *at*, *fi*); and
- SPF for property-damage-only crashes, ramp exit, freeway lanes *n* (*sc*, *nEX*, *at*, *pdo*).

The base condition is a 6-ft inside shoulder width. The CMFs are described using the following equation:

$$CMF_{3,sc,ac,at,z} = \exp\left(a \times [W_{is} - 6]\right) \tag{18-42}$$

Where:

$CMF_{3,\ sc,\ ac,\ at,\ z}$ = crash modification factor for inside shoulder width at a speed-change lane with any cross section *ac*, all crash types *at*, and severity *z*; and

W_{is} = paved inside shoulder width (ft).

The coefficient for Equation 18-42 is provided in Table 18-24. The CMF is applicable to shoulder widths in the range of 2 to 12 ft.

Table 18-24. Coefficients for Inside Shoulder Width CMF–Speed-Change Lanes

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{3,\ sc,\ ac,\ at,\ fi}$	–0.0172
		Property damage only (*pdo*)	$CMF_{3,\ sc,\ ac,\ at,\ pdo}$	–0.0153

$CMF_{4,\ w,\ x,\ y,\ z}$—Median Width

Four CMFs are used to describe the relationship between median width and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury crashes, ramp entrance, freeway lanes *n* (*sc*, *nEN*, *at*, *fi*);
- SPF for property-damage-only crashes, ramp entrance, freeway lanes *n* (*sc*, *nEN*, *at*, *pdo*);
- SPF for fatal-and-injury crashes, ramp exit, freeway lanes *n* (*sc*, *nEX*, *at*, *fi*); and
- SPF for property-damage-only crashes, ramp exit, freeway lanes *n* (*sc*, *nEX*, *at*, *pdo*).

The base condition is a 60-ft median width, a 6-ft inside shoulder width, and no barrier present in the median. The CMFs are described using the following equation:

$$CMF_{4,\,sc,ac,at,z} = \left(1.0 - P_{ib}\right) \times \exp\left(a \times [W_m - 2 \times W_{is} - 48]\right) + P_{ib} \times \exp\left(a \times \ [2 \times W_{icb} - 48]\right) \tag{18-43}$$

Where:

$CMF_{4,\ sc,\ ac,\ at,\ z}$ = crash modification factor for median width at a speed-change lane with any cross section *ac*, all crash types *at*, and severity *z*;

P_{ib} = proportion of speed-change lane length with a barrier present in the median (i.e., inside);

W_m = median width (measured from near edges of traveled way in both directions) (ft); and

W_{icb} = distance from edge of inside shoulder to barrier face (ft).

The coefficient for Equation 18-43 is provided in Table 18-25. These CMFs are derived to be applicable to a speed-change lane that has median barrier present along some portion of its length. Guidance for computing the variables P_{ib} and W_{icb} is provided in Section 18.7.3.

Table 18-25. Coefficients for Median Width CMF–Speed-Change Lanes

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{4,\ sc,\ ac,\ at,\ fi}$	–0.00302
		Property damage only (*pdo*)	$CMF_{4,\ sc,\ ac,\ at,\ pdo}$	–0.00291

The CMF is applicable to median widths 9 ft or more, W_{icb} values in the range of 0.75 to 17 ft, and shoulder widths in the range of 2 to 12 ft. If the median width exceeds 90 ft, then 90 ft should be used for W_m in Equation 18-43.

$CMF_{5,\ w,\ x,\ y,\ z}$—Median Barrier

Four CMFs are used to describe the relationship between median barrier presence and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury crashes, ramp entrance, freeway lanes *n* (*sc*, *nEN*, *at*, *fi*);
- SPF for property-damage-only crashes, ramp entrance, freeway lanes *n* (*sc*, *nEN*, *at*, *pdo*);
- SPF for fatal-and-injury crashes, ramp exit, freeway lanes *n* (*sc*, *nEX*, *at*, *fi*); and
- SPF for property-damage-only crashes, ramp exit, freeway lanes *n* (*sc*, *nEX*, *at*, *pdo*).

The base condition is no barrier present in the median. The CMFs are described using the following equation:

$$CMF_{5,\,sc,ac,at,z} = (1.0 - P_{ib}) \times 1.0 + P_{ib} \times \exp\left(\frac{a}{W_{icb}}\right) \tag{18-44}$$

Where:

$CMF_{5,\,sc,\,ac,\,at,\,z}$ = crash modification factor for median barrier at a speed-change lane with any cross section *ac*, all crash types *at*, and severity *z*.

The coefficient for Equation 18-44 is provided in Table 18-26. Guidance for computing the variables P_{ib} and W_{icb} is provided in Section 18.7.3.

Table 18-26. Coefficients for Median Barrier CMF–Speed-Change Lanes

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{5,\,sc,\,ac,\,at,\,fi}$	0.131
		Property damage only (*pdo*)	$CMF_{5,\,sc,\,ac,\,at,\,pdo}$	0.169

The CMF is applicable to W_{icb} values in the range of 0.75 to 17 ft. This CMF is applicable to cable barrier, concrete barrier, guardrail, and bridge rail.

$CMF_{6,\,w,\,x,\,y,\,z}$—High Volume

Four CMFs are used to describe the relationship between volume concentration and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury crashes, ramp entrance, freeway lanes *n* (*sc*, *nEN*, *at*, *fi*);
- SPF for property-damage-only crashes, ramp entrance, freeway lanes *n* (*sc*, *nEN*, *at*, *pdo*);
- SPF for fatal-and-injury crashes, ramp exit, freeway lanes *n* (*sc*, *nEX*, *at*, *fi*); and
- SPF for property-damage-only crashes, ramp exit, freeway lanes *n* (*sc*, *nEX*, *at*, *pdo*).

The base condition is no hours having a volume that exceeds 1,000 veh/h/ln. The CMFs are described using the following equation:

$$CMF_{6,sc,\,ac,at,\,z} = \exp(a \times P_{hv}) \tag{18-45}$$

Where:

$CMF_{6,\,sc,\,ac,\,at,\,z}$ = crash modification factor for high volume at a speed-change lane with any cross section *ac*, all crash types *at*, and severity *z*; and

P_{hv} = proportion of AADT during hours where volume exceeds 1,000 veh/h/ln.

The coefficient for Equation 18-45 is provided in Table 18-27. Additional discussion of this CMF is provided in Section 18.7.1.

Table 18-27. Coefficients for High Volume CMF–Speed-Change Lanes

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{6,\,sc,\,ac,\,at,\,fi}$	0.350
		Property damage only (*pdo*)	$CMF_{6,\,sc,\,ac,\,at,\,pdo}$	0.283

$CMF_{12,\ sc,\ nEN,\ at,\ z}$—Ramp Entrance

Two CMFs are used to describe the relationship between ramp entrance geometry and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury crashes, ramp entrance, freeway lanes *n* (*sc*, *nEN*, *at*, *fi*); and
- SPF for property-damage-only crashes, ramp entrance, freeway lanes *n* (*sc*, *nEN*, *at*, *pdo*).

The CMFs are described using the following equation:

$$CMF_{12,\,sc,\,nEN,\,at,\,z} = \exp\left(a \times I_{left} + \frac{b}{L_{en}} + d \times \ln[c \times AADT_r]\right) \tag{18-46}$$

Where:

$CMF_{12,\ sc,\ nEN,\ at,\ z}$ = crash modification factor for ramp entrance geometry on a freeway with *n* lanes with all crash types *at* and severity *z*;

L_{en} = length of ramp entrance (mi);

I_{left} = ramp side indicator variable (= 1.0 if entrance or exit is on left side of through lanes, 0.0 if it is on right side); and

$AADT_r$ = AADT volume of ramp (veh/day).

The coefficients for Equation 18-46 are provided in Table 18-28.

Table 18-28. Coefficients for Ramp Entrance CMF–Speed-Change Lanes

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficients			
				a	*b*	*c*	*d*
Ramp entrance, *n* lanes (*nEN*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{12,\ sc,\ nEN,\ at,\ fi}$	0.594	0.0318	0.001	0.198
		Property damage only (*pdo*)	$CMF_{12,\ sc,\ nEN,\ at,\ pdo}$	0.824	0.0252	0.001	0.00

This CMF is applicable to a ramp entrance speed-change lane, as shown in Figure 18-10. The ramp entrance length is measured using the reference points identified in Figure 18-3.

The variable for ramp entrance length L_{en} in Equation 18-46 is intended to reflect the degree to which the lane-changing activity is concentrated along the ramp entrance. The CMF is applicable to ramp entrance lengths in the range of 0.04 to 0.30 mi (210 to 1,600 ft). It is applicable to the range of ramp AADTs in Table 19-4.

The indicator variable for ramp side I_{left} is associated with a positive coefficient. This sign indicates that a ramp entrance on the left side of the through lanes is associated with an increase in crash frequency, relative to one on the right side. The data used to calibrate this CMF represent freeways where ramp entrances are typically located on the right side.

$CMF_{13,\ sc,\ nEX,\ at,\ z}$—Ramp Exit

Two CMFs are used to describe the relationship between ramp exit geometry and predicted crash frequency. The SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury crashes, ramp exit, freeway lanes *n* (*sc*, *nEX*, *at*, *fi*); and
- SPF for property-damage-only crashes, ramp exit, freeway lanes *n* (*sc*, *nEX*, *at*, *pdo*).

The CMFs are described using the following equation:

$$CMF_{13,\,sc,\,nEX,\,at,\,z} = \exp\left(a \times I_{left} + \frac{b}{L_{ex}}\right) \tag{18-47}$$

Where:

$CMF_{13,\,sc,\,nEX,\,at,\,z}$ = crash modification factor for ramp exit geometry on a freeway with n lanes with all crash types at and severity z;

L_{ex} = length of ramp exit (mi); and

I_{left} = ramp side indicator variable (= 1.0 if entrance or exit is on left side of through lanes, 0.0 if it is on right side).

The coefficients for Equation 18-47 are provided in Table 18-29.

Table 18-29. Coefficients for Ramp Exit CMF–Speed-Change Lanes

Cross Section (x)	Crash Type (y)	Crash Severity (z)	CMF Variable	CMF Coefficients a	CMF Coefficients b
Ramp exit, n lanes (nEX)	All types (at)	Fatal and injury (fi)	$CMF_{13,\,sc,\,nEX,\,at,\,fi}$	0.594	0.0116
		Property damage only (pdo)	$CMF_{13,\,sc,\,nEX,\,at,\,pdo}$	0.824	0.00

This CMF is applied to a ramp exit speed-change lane, as shown in Figure 18-10. The ramp exit length is measured using the reference points identified in Figure 18-3.

The variable for ramp exit length L_{ex} in Equation 18-47 is intended to reflect the degree to which the lane-changing activity is concentrated along the ramp exit. The CMF is applicable to ramp exit lengths in the range of 0.02 to 0.30 mi (106 to 1600 ft).

The indicator variable for ramp side I_{left} is associated with a positive coefficient. This sign indicates that a ramp exit on the left side of the through lanes is associated with an increase in crash frequency, relative to one on the right side. The data used to calibrate this CMF represent freeways where ramp exits are typically located on the right side.

18.7.3. Supplemental Calculations to Apply Crash Modification Factors

Some of the CMFs in Section 18.7.1 and Section 18.7.2 require the completion of supplemental calculations before they can be applied to the SPFs in Section 18.6. These CMFs are:

- Median width,
- Median barrier,
- Outside clearance, and
- Outside barrier.

These four CMFs include variables that describe the presence of barrier in the median or on the roadside. These variables include barrier offset, length, and width.

Barrier offset represents a lateral distance measured from the near edge of the shoulder to the face of the barrier (i.e., it does not include the width of the shoulder). Barrier length represents the length of lane paralleled by a barrier; it is a total for both travel directions. For example, if the outside barrier extends for the length of the roadway on both sides of the roadway, then the outside barrier length equals twice the segment length.

Median barrier width represents either (a) the physical width of the barrier if only one barrier is used or (b) the lateral distance between barrier "faces" if two parallel barriers are provided in the median area. A barrier face is the side of the barrier that is exposed to traffic.

Two key variables that are needed for the evaluation of barrier presence are the inside barrier offset distance W_{icb} and the outside barrier offset distance W_{ocb}. As indicated in Equation 18-28 and Equation 18-39, this distance is included as a divisor in the exponential term. This relationship implies that the correlation between barrier distance and crash frequency is an inverse one (i.e., crash frequency decreases with increasing distance to the barrier). When multiple sections of barrier exist along the segment, a length-weighted average of the *reciprocal* of the individual distances is needed to properly reflect this inverse relationship. The length used to weight the average is the barrier length.

Additional key variables include the proportion of segment length with a barrier present in the median P_{ib} and the proportion of segment length with a barrier present on the roadside P_{ob}. Equations for calculating these proportions and the aforementioned distances are described in the following paragraphs.

The length of segment L used in the following equations is equal to the effective freeway segment L^* or speed-change lane length, L_{ex} or L_{en}, as appropriate for the CMF to which the calculated value will be applied. If the median width exceeds 90 ft, then 90 ft should be used for W_m in the following equations.

For segments or speed-change lanes with a continuous barrier centered in the median (i.e., symmetric median barrier), the following equations are used to estimate W_{icb} and P_{ib}.

$$W_{icb} = \frac{2 \times L}{\sum \frac{L_{ib,i}}{W_{off,in,i} - W_{is}} + \frac{2 \times L - \sum L_{ib,i}}{0.5 \times (W_m - 2 \times W_{is} - W_{ib})}} \tag{18-48}$$

$$P_{ib} = 1.0 \tag{18-49}$$

Where:

W_{icb} = distance from edge of inside shoulder to barrier face (ft);

L = length of segment (mi);

$L_{ib,\,i}$ = length of lane paralleled by inside barrier *i* (include both travel directions) (mi);

$W_{off,\,in,\,i}$ = horizontal clearance from the edge of the traveled way to the face of inside barrier *i* (ft);

W_{is} = paved inside shoulder width (ft);

W_m = median width (measured from near edges of traveled way in both directions) (ft); and

W_{ib} = inside barrier width (measured from barrier face to barrier face) (ft).

P_{ib} = proportion of segment length with a barrier present in the median (i.e., inside).

The first summation term "∑" in Equation 18-48 applies to short lengths of barrier in the median. It indicates that the ratio of barrier length $L_{ib,\,i}$ to clearance distance (= $W_{off,\,in,\,i} - W_{is}$) should be computed for each individual length of barrier that is found in the median along the segment (e.g., a barrier protecting a sign support). The continuous median barrier is not considered in this summation. Any clearance distance that is less than 0.75 ft should be set to 0.75 ft. Similarly, if the distance "$0.5 \times (W_m - 2 \times W_{is} - W_{ib})$" is less than 0.75 ft, then it should be set to 0.75 ft.

For segments or speed-change lanes with a continuous barrier adjacent to one roadbed (i.e., asymmetric median barrier), the following equations should be used to estimate W_{icb} and P_{ib}.

$$W_{icb} = \frac{2 \times L}{\dfrac{L}{W_{near} - W_{is}} + \sum \dfrac{L_{ib,i}}{W_{off,\,in,i} - W_{is}} + \dfrac{L - \sum L_{ib,i}}{W_m - 2 \times W_{is} - W_{ib} - W_{near}}} \tag{18-50}$$

$$P_{fs+sc,ac,at,K} = \frac{\exp(V_K)}{\dfrac{1.0}{C_{sdf,fs+sc}} + \exp(V_K) + \exp(V_A) + \exp(V_B)} \tag{18-51}$$

Where:

W_{near} = "near" horizontal clearance from the edge of the traveled way to the continuous median barrier (measure for both travel directions and use the smaller distance) (ft).

Similar to the previous guidance, the first summation term "∑" in Equation 18-50 applies to short lengths of barrier in the median. The ratio of barrier length L_{ib} to the clearance distance (= $W_{off,\,in,\,i} - W_{is}$) should be computed for each individual length of barrier that is found in the median along the segment. The continuous median barrier is not considered in this summation. Any clearance distance that is less than 0.75 ft should be set to 0.75 ft. Similarly, if the distance "$W_{near} - W_{is}$" or the distance "$W_m - 2 \times W_{is} - W_{ib} - W_{near}$" is less than 0.75 ft, then it should be set to 0.75 ft.

For segments or speed-change lanes with a depressed median and some short sections of barrier in the median (e.g., bridge rail), the following equations should be used to estimate W_{icb} and P_{ib}:

$$W_{icb} = \frac{\sum L_{ib,i}}{\sum \dfrac{L_{ib,i}}{W_{off,\,in,i} - W_{is}}} \tag{18-52}$$

$$P_{ib} = \frac{\sum L_{ib,i}}{2 \times L} \tag{18-53}$$

Any clearance distance (= $W_{off,\,in,\,i} - W_{is}$) that is less than 0.75 ft should be set to 0.75 ft. When a freeway segment is being evaluated, the proportion P_{ib} represents the proportion of the effective segment length with barrier present in the median. It is computed by summing the length of roadway with median barrier (excluding the length of any median barrier adjacent to speed-change lanes) in *both* travel directions and dividing by twice the effective freeway segment length L^*.

For segments or speed-change lanes with depressed medians without a continuous barrier or short sections of barrier in the median, the following equation should be used to estimate P_{ib}:

$$P_{ib} = 0.0 \tag{18-54}$$

As suggested by Equation 18-28, the calculation of W_{icb} is not required when $P_{ib} = 0.0$.

For segments or speed-change lanes with barrier on the roadside, the following equations should be used to estimate W_{ocb} and P_{ob}:

$$W_{ocb} = \frac{\sum L_{ob,i}}{\sum \frac{L_{ob,i}}{W_{off,o,i} - W_s}} \tag{18-55}$$

$$P_{ob} = \frac{\sum L_{ob,i}}{2 \times L} \tag{18-56}$$

Where:

W_{ocb} = distance from edge of outside shoulder to barrier face (ft);

$L_{ob,i}$ = length of lane paralleled by outside barrier *i* (include both travel directions) (mi);

$W_{off,o,i}$ = horizontal clearance from the edge of the traveled way to the face of outside barrier *i* (ft);

W_s = paved outside shoulder width (ft); and

P_{ob} = proportion of segment length with a barrier present on the roadside (i.e., outside).

Any clearance distance ($= W_{off,o,i} - W_s$) that is less than 0.75 ft should be set to 0.75 ft. When a freeway segment is being evaluated, the proportion P_{ob} represents the proportion of the effective segment length with barrier present on the roadside. It is computed by summing the length of roadway with roadside barrier (excluding the length of any roadside barrier adjacent to speed-change lanes) in *both* travel directions and dividing by twice the effective freeway segment length L^*.

For segments or speed-change lanes without barrier on the roadside, the following equation should be used to estimate P_{ob}:

$$P_{ob} = 0.0 \tag{18-57}$$

As suggested by Equation 18-39, the calculation of W_{ocb} is not required when $P_{ob} = 0.0$.

18.8. SEVERITY DISTRIBUTION FUNCTIONS

The severity distribution functions (SDFs) are presented in this section. They are used in the predictive model to estimate the expected average crash frequency for the following severity levels: fatal *K*, incapacitating injury *A*, non-incapacitating injury *B*, and possible injury *C*. Each SDF was developed as a regression model using observed crash data for a set of similar sites as the dependent variable. The SDF, like all regression models, estimates the value of the dependent variable as a function of a set of independent variables. The independent variables include various geometric features, traffic control features, and area type (i.e., rural or urban). The SDFs described in this section are equally applicable to freeway segments and speed-change lanes.

The general model form for the severity distribution prediction is shown in the following equation:

$$N_{e,w,x,y,j} = N_{e,w,x,y,fi} \times P_{w,ac,at,j} \tag{18-58}$$

Where:

$N_{e,w,x,y,j}$ = expected average crash frequency for site type *w*, cross section or control type *x*, crash type *y*, and severity level *j* (*j* = *K*: fatal, *A*: incapacitating injury, *B*: non-incapacitating injury, *C*: possible injury) (crashes/yr);

$N_{e,w,x,y,fi}$ = expected average crash frequency for site type *w*, cross section or control type *x*, crash type *y*, and fatal-and-injury crashes *fi* (crashes/yr); and

$P_{w,x,at,j}$ = probability of the occurrence of severity level *j* (*j* = *K*: fatal, *A*: incapacitating injury, *B*: non-incapacitating injury, *C*: possible injury) for all crash types *at* at site type *w* with cross section or control type *x*.

There is one SDF associated with each probability level *j* in the predictive model. An SDF predicts the probability of occurrence of severity level *j* for a crash based on various geometric design and traffic control features at the subject site. Each SDF also contains a calibration factor that is used to calibrate it to local conditions.

The SDFs for freeway segments and speed-change lanes are described by the following equations.

$$P_{fs+sc,ac,at,K} = \frac{\exp(V_K)}{\frac{1.0}{C_{sdf,fs+sc}} + \exp(V_K) + \exp(V_A) + \exp(V_B)} \quad (18\text{-}59)$$

$$P_{fs+sc,ac,at,A} = \frac{\exp(V_A)}{\frac{1.0}{C_{sdf,fs+sc}} + \exp(V_K) + \exp(V_A) + \exp(V_B)} \quad (18\text{-}60)$$

$$P_{fs+sc,ac,at,B} = \frac{\exp(V_B)}{\frac{1.0}{C_{sdf,fs+sc}} + \exp(V_K) + \exp(V_A) + \exp(V_B)} \quad (18\text{-}61)$$

$$P_{fs+sc,ac,at,C} = 1.0 - (P_K + P_A + P_B) \quad (18\text{-}62)$$

with

$$V_j = a + \left(b \times \frac{P_{ib} + P_{ob}}{2}\right) + (c \times P_{hv}) + \left(d \times \frac{P_{ir} + P_{or}}{2}\right) + \left(e \times \sum P_{c,i}\right) + (f \times W_l) + (g \times I_{rural}) \quad (18\text{-}63)$$

Where:

V_j = systematic component of crash severity likelihood for severity level *j*;

$C_{sdf,fs+sc}$ = calibration factor to adjust SDF for local conditions for freeway segments and speed-change lanes;

P_{ib} = proportion of segment length with a barrier present in the median (i.e., inside);

P_{ob} = proportion of segment length with a barrier present on the roadside (i.e., outside);

P_{hv} = proportion of AADT during hours where volume exceeds 1,000 veh/h/ln;

P_{ir} = proportion of segment length with rumble strips present on the inside shoulders;

P_{or} = proportion of segment length with rumble strips present on the outside shoulders;

$P_{c,\,i}$ = proportion of segment length with curve i;

W_l = lane width (ft);

I_{rural} = area type indicator variable (= 1.0 if area is rural, 0.0 if it is urban); and

a, b, c, d, e, f, g = regression coefficients.

The SDF coefficients in Equation 18-63 are provided in Table 18-30. Guidance for computing the variables P_{ib} and P_{ob} is provided in Section 18.7.3.

Table 18-30. SDF Coefficients for Freeway Segments and Speed-Change Lanes

		SDF Coefficients						
Severity Level (*j*)	**Variable**	*a*	*b*	*c*	*d*	*e*	*f*	*g*
Fatal (*K*)	V_K	–0.171	–0.388	–0.924	0.387	0.208	–0.261	0.492
Incapacitating injury (*A*)	V_A	–2.393	–0.325	–0.853	0.391	0.243	0.00	0.430
Non-incapacitating injury (*B*)	V_B	0.0732	–0.250	–0.872	0.135	0.131	–0.0464	0.208

The proportion of AADT during hours where the volume exceeds 1,000 veh/h/ln is computed using the average hourly volume distribution associated with the subject segment. This distribution will typically be computed using the data obtained from the continuous traffic counting station that (1) is nearest to the subject freeway and (2) has similar traffic demand and peaking characteristics. The SDF is applicable to P_{hv} values in the range of 0.0 to 1.0. Additional discussion of this variable is provided in Section 18.7.1 for the High Volume CMF.

When a freeway segment is being evaluated, the proportion P_{ir} is computed by summing the length of roadway with rumble strips on the inside shoulder (excluding the length of any rumble strips adjacent to speed-change lanes) in *both* travel directions and dividing by twice the effective freeway segment length L^*. When a freeway segment is being evaluated, the proportion P_{or} is computed by summing the length of roadway with rumble strips on the outside shoulder (excluding the length of any rumble strips adjacent to speed-change lanes) in *both* travel directions and dividing by twice the effective freeway segment length L^*.

The variable $P_{c,\,i}$ is computed as the ratio of the length of curve i in the segment to the effective length of the freeway segment L^*. For example, consider a segment that is 0.5 mi long and a curve that is 0.2 mi long. If one-half of the curve is in the segment, then $P_{c,\,i}$ = 0.20 (= 0.1/0.5). In fact, this proportion is the same regardless of the curve's length (provided that it is 0.1 mi or longer and 0.1 mi of this curve is located in the segment). When the SDF is applied to a speed-change lane, the variable $P_{c,\,i}$ is computed as the ratio of the length of curve i in the speed-chanage lane to the length of the speed-change lane L_{en} or L_{ex}. When the SDF is applied to a freeway segment, the "length of curve i in the segment" is computed as an average of two values: the length of curve i between the segment's begin and end mileposts for roadbed 1 and that for roadbed 2, where each value excludes the length of any coincident speed-change lane that may be present and where the value for a given roadbed is zero if that roadbed is not curved.

The SDF is applicable to lane widths in the range of 10.5 to 14 ft.

The sign of a coefficient in Table 18-30 indicates the change in the proportion of crashes associated with a change in the corresponding variable. For example, the negative coefficient associated with barrier presence indicates that the proportion of fatal K crashes decreases with an increase in the proportion of barrier present in the segment. A similar trend is indicated for barrier presence on incapacitating injury A crashes and non-incapacitating injury B crashes. By inference, the proportion of possible injury C crashes *increases* with an increase in the proportion of barrier present.

18.9. CALIBRATION OF THE SPFS AND SDFS TO LOCAL CONDITIONS

Crash frequencies, even for nominally similar freeway segments or speed-change lanes, can vary widely from one jurisdiction to another. Geographic regions differ markedly in climate, animal population, driver populations, crash-reporting threshold, and crash-reporting practices. These variations may result in some jurisdictions experiencing a different number of traffic crashes on freeways than others. Calibration factors are included in the methodology to allow transportation agencies to adjust the SPFs and SDFs to match actual local conditions.

The SPF calibration factors will have values greater than 1.0 for segments or speed-change lanes that, on average, experience more crashes than those used in the development of the SPFs. Similarly, the calibration factors for segments or speed-change lanes that experience fewer crashes on average than those used in the development of the SPFs will have values less than 1.0. The calibration procedures for SPFs are presented in Section B.1.1 of Appendix B .

The SDF calibration factors will have values greater than 1.0 for segments or speed-change lanes that, on average, experience more severe crashes than those used in the development of the SDFs. Similarly, the calibration factors for segments or speed-change lanes that experience fewer severe crashes on average than those used in the development of the SDFs will have values less than 1.0. The calibration procedures for SDFs are presented in Section B.1.4 of Appendix B.

Default values are also provided for the crash type distributions used in the methodology. These values can also be replaced with locally derived values. The derivation of these values is addressed in Section B.1.3 of Appendix B.

18.10. LIMITATIONS OF PREDICTIVE METHOD

The limitations of the predictive method which apply generally across all of the Part C chapters are discussed in Section C.8 of the *Highway Safety Manual*. This section discusses limitations of the predictive models described in this chapter.

The predictive method described in this chapter can be applied to the combinations of area type (rural or urban) and number of lanes that are listed in Section 18.6. The method can be extended to freeway segments with unequal number of lanes in opposing directions, but only if the number of lanes is within the ranges listed in Section 18.6.1 and varies by no more than one lane between the two travel directions.

The predictive method does not account for the influence of the following conditions on freeway safety:

- Freeways with 11 or more through lanes in urban areas,
- Freeways with 9 or more through lanes in rural areas,
- Freeways with continuous access high-occupancy vehicle (HOV) lanes.
- Freeways with limited access managed lanes that are buffer-separated from the general purpose lanes,
- Ramp metering,
- Use of safety shoulders as travel lanes,
- Toll plazas, and
- Reversible lanes.

The predictive method does not distinguish between barrier types (i.e., cable barrier, concrete barrier, guardrail, and bridge rail) in terms of their possible different influence on crash severity.

18.11. APPLICATION OF PREDICTIVE METHOD

The predictive method presented in this chapter is applied to a freeway facility by following the 18 steps presented in Section 18.4. Worksheets are provided in Appendix 18A for applying calculations in the predictive method. All computations of crash frequencies in these worksheets are conducted with values expressed to three decimal places. This level of precision is needed only for consistency in computations. In the last stage of computations, rounding the final estimates of expected average crash frequency to one decimal place is appropriate.

18.11.1. Freeways with Barrier-Separated Managed Lanes

The predictive method can be used to evaluate freeways with barrier-separated managed lanes. The managed lanes are considered to be part of the median (i.e., the median width is measured between the near edges of the traveled way for the general purpose lanes) and the managed lane's entry or exit points are treated as entrance or exit ramps, respectively, on the adjacent freeway. The average lane width is based on the general purpose lanes (i.e., the managed lanes are not considered). The shoulder width is measured from the edge of the traveled way of the general-purpose lanes. The barrier between the general purpose lanes and managed lanes is treated as median barrier.

The safety of the managed lanes is not addressed by this technique. The estimate of expected average crash frequency only includes crashes that occur in the general purpose lanes.

18.11.2. Freeways with Toll Facilities

The predictive method can be used to evaluate a freeway section that is part of toll facility provided that the section is sufficiently distant from the toll facility that the facility does not influence vehicle operation. The predictive method is not directly applicable to any portion of the freeway that (a) is in the immediate vicinity of a toll plaza, (b) is widened to accommodate vehicle movements through the toll plaza, (c) experiences toll-related traffic queues, or (d) experiences toll-related speed changes.

18.12. SUMMARY

The predictive method for freeways is applied by following the 18 steps of the predictive method presented in Section 18.4. It is used to estimate the expected average crash frequency for a series of contiguous sites, or a single individual site. If a freeway facility is being evaluated, then it is divided into a series of sites in Step 5 of the predictive method.

Predictive models are applied in Steps 9, 10, and 11 of the method. Each predictive model consists of a safety performance function (SPF), crash modification factors (CMFs), a severity distribution function (SDF), and calibration factors. The SPF is selected in Step 9. It is used to estimate the predicted average crash frequency for a site with base conditions. CMFs are selected in Step 10. They are combined with the estimate from the SPF to produce the predicted average crash frequency.

When observed crash data are available, the EB Method is applied in Step 13 or 15 of the predictive method to estimate the expected average crash frequency. The EB Method can be applied at the site-specific level in Step 13 or at the project level in Step 15. The choice of level will depend on (a) the required reliability of the estimate and (b) the accuracy with which each observed crash can be associated with an individual site. The EB Method is described in Section B.2 of Appendix B.

Optionally, SDFs are selected in Step 13. They can be used to estimate the average crash frequency for one or more crash severity levels (i.e., fatal, incapacitating injury, non-incapacitating injury, or possible injury crash). Optionally, the crash type distribution can be used in Step 13 to estimate the average crash frequency for one or more crash types (e.g., head-on, fixed object).

The SPF should be calibrated to the specific state or geographic region in which the project is located. Calibration accounts for differences in state or regional crash frequencies, relative to the states and regions represented in the data used to define the predictive models described in this chapter. The process for determining calibration factors for the predictive models is described in Section B.1 of Appendix B.