Chapter 19—Predictive Method for Ramps

19.1. INTRODUCTION

This chapter presents the predictive method for ramps used to connect two or more roadways at an interchange. The method is also applicable to collector-distributor (C-D) roadways that connect with ramps and one or more roadways at an interchange. A general introduction to the *Highway Safety Manual* (HSM) predictive method is provided in Part C—Introduction and Applications Guidance.

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

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

- a concise overview of the predictive method,
- the definitions of the site types addressed by the predictive method,
- a step-by-step description of the predictive method,
- details for dividing a ramp into individual evaluation sites,.
- safety performance functions (SPFs) for ramps,
- crash modification factors (CMFs) for ramps,
- severity distribution functions (SDFs) for ramps,
- limitations of the predictive method, and
- sample problems illustrating the application of the predictive method.

19.2. OVERVIEW OF THE PREDICTIVE METHOD

The predictive method provides an 18-step procedure to estimate the expected average crash frequency (in total, by crash type, or by crash severity) for an entire ramp or C-D road. The gore point of the speed-change lane is used to define the beginning (or ending) point of a ramp or C-D road.

The predictive method is used to evaluate an entire ramp, C-D road, or site. A site is a ramp segment, a C-D road segment, or crossroad ramp terminal. A crossroad ramp terminal is a controlled terminal between a ramp and a crossroad. A crossroad speed-change lane (i.e., an uncontrolled terminal between a ramp and a crossroad) is not addressed by the method.

The predictive method is applicable to ramps or C-D roads in the vicinity of an interchange. The interchange may connect a freeway and a crossroad (service interchange) or two freeways (system interchange). The method is applicable to ramps and C-D roads that are one-way roadways.

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

The predictive models used in this chapter are described in detail in Section 19.3. The variables that comprise the predictive models include a series of subscripts to describe precisely the conditions to which they apply. These subscripts are described in detail in later sections of this chapter. For this section, it is sufficient to use "place-holder" subscripts such as *w*, *x*, *y*, *z*, and *m*. The subscript *w* is a place-holder for specific site-type subscripts that define the equation's application (e.g., it is replaced with "*rps*" when needed to indicate that the equation applies to a ramp segment). Similarly, *x* is a place-holder for segment cross-section or intersection control-type subscripts, *y* is a place-holder for crash-type subscripts, *z* is a place holder for crash severity, and *m* is a place-holder for a specific geometric design or traffic control feature.

The predictive models used in this chapter to determine the predicted average crash frequency are of the general form shown in Equation 19-1.

$$N_{p,w,x,y,z} = N_{spf,w,x,y,z} \times \left(CMF_{1,w,x,y,z} \times CMF_{2,w,x,y,z} \times \ldots \times CMF_{m,w,x,y,z} \right) \times C_{w,x,y,z} \tag{19-1}$$

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.

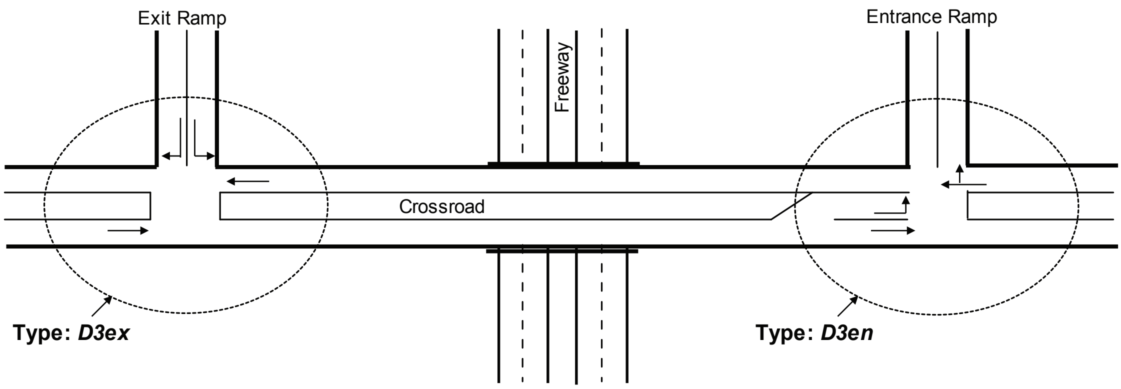
19.3. RAMPS—DEFINITIONS AND PREDICTIVE MODELS

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

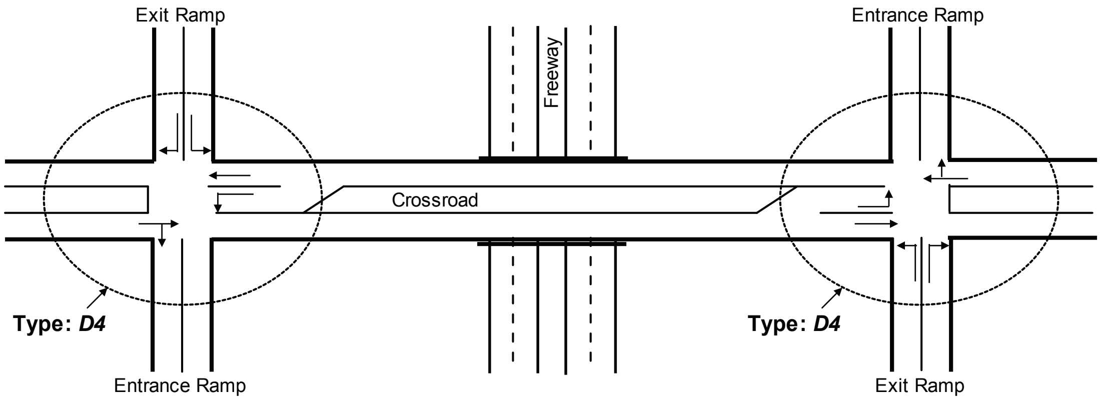
19.3.1. Definition of Ramp Site Types

The predictive method in this chapter applies to the following site types: entrance ramp segment with one or two lanes, exit ramp segment with one or two lanes, C-D road segment with one or two lanes, and crossroad ramp terminal. Connector ramp segments are represented using one of these site types.

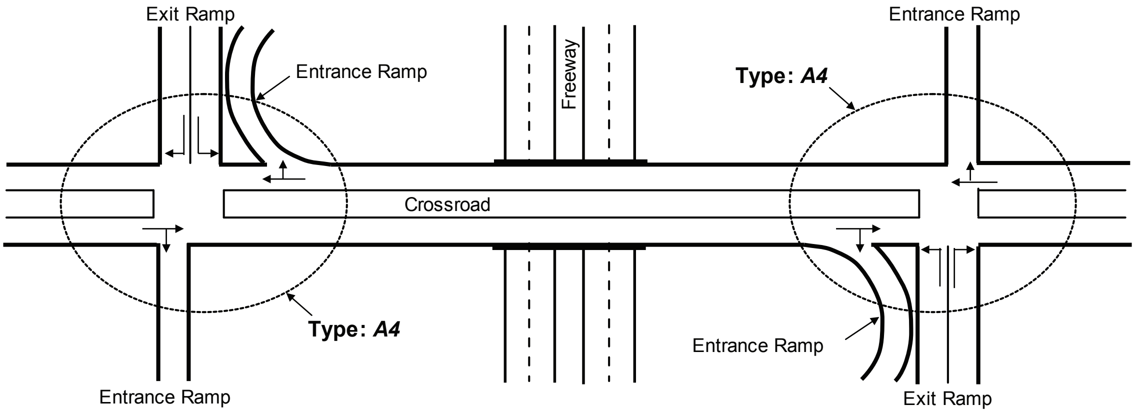
There are many different configurations of crossroad ramp terminal used at interchanges. For this reason, the definition of "site type" is broadened when applied to crossroad ramp terminals to be specific to each configuration. The more common configurations are identified in Figure 19-1.



a. Three-Leg Ramp Terminal with Diagonal Exit or Entrance Ramp (*D3ex* and *D3en*)

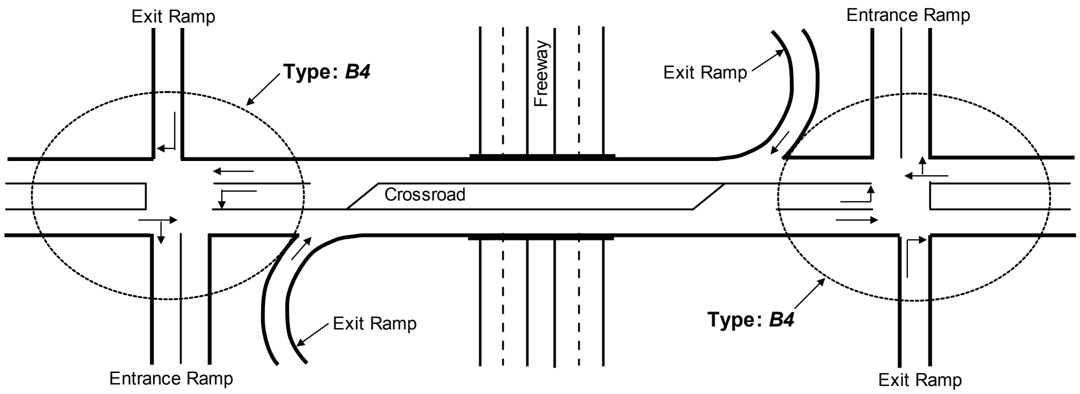


b. Four-Leg Ramp Terminal with Diagonal Ramps (*D4*)

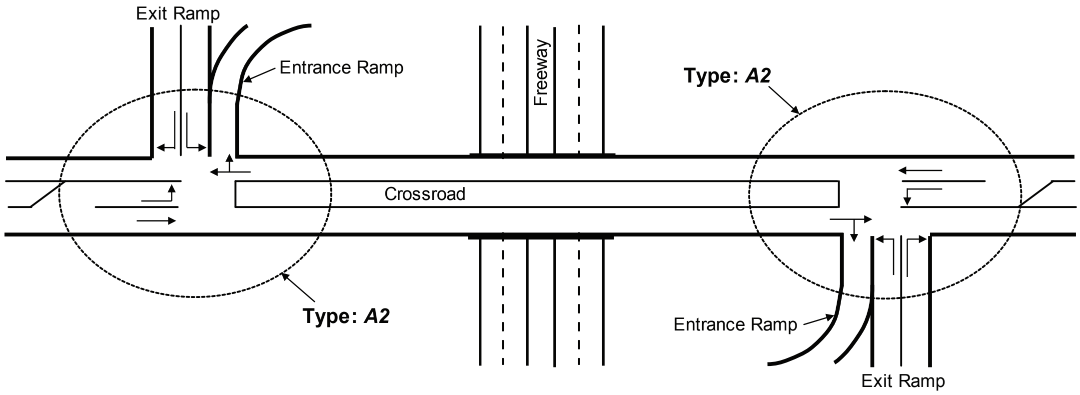


c. Four-Leg Ramp Terminal at Four-Quadrant Partial Cloverleaf A (*A4*)

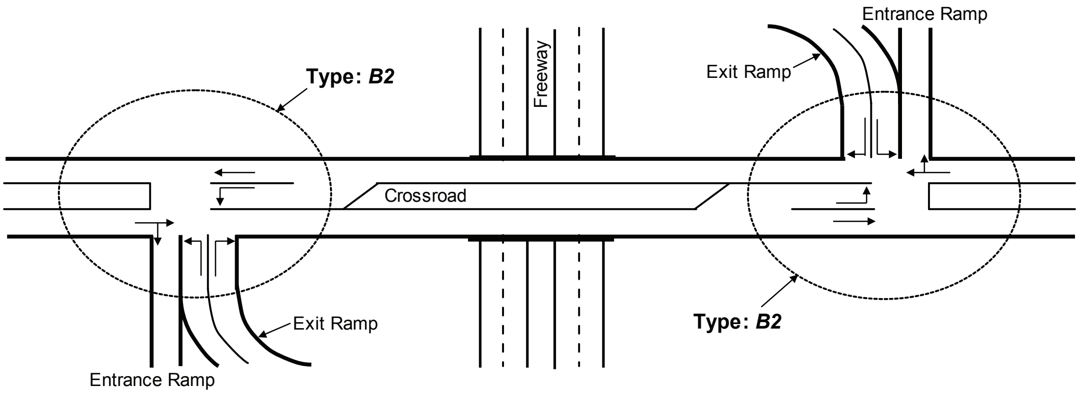
Figure 19-1. Ramp Terminal Configurations



d. Four-Leg Ramp Terminal at Four-Quadrant Partial Cloverleaf B (*B4*)



e. Three-Leg Ramp Terminal at Two-Quadrant Partial Cloverleaf A (*A2*)



f. Three-Leg Ramp Terminal at Two-Quadrant Partial Cloverleaf B (*B2*)

Figure 19-1. Ramp Terminal Configurations (continued)

Differences among the terminals shown Figure 19-1 reflect the number of ramp legs, number of left-turn movements, and location of crossroad left-turn storage (i.e., inside or outside of the interchange). Although not shown, control type (i.e., signalized or stop controlled) is also an important factor in characterizing a crossroad ramp terminal.

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

Table 19-1 identifies the urban ramp and C-D road segment configurations for which SPFs have been developed. A second set of SPFs have been developed for rural ramps and C-D road segments with one lane (they are not shown in the table, but use the same nomenclature). The SPFs are used to estimate the predicted average crash frequency by crash type and crash severity. These estimates are added to yield the total predicted average crash frequency for an individual site.

Table 19-1. Urban Ramp and Collector-Distributor Road Segment SPFs

Site Type (w)	Cross Section (x)	Crash Type (y)	Crash Severity (z)	SPF
Ramp segments (*rps*)	One-lane entrance ramp (*1EN*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf, rps, 1EN, mv, fi}$
			Property damage only (*pdo*)	$N_{spf, rps, 1EN, mv, pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf, rps, 1EN, sv, fi}$
			Property damage only (*pdo*)	$N_{spf, rps, 1EN, sv, pdo}$
	Two-lane entrance ramp (*2EN*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf, rps, 2EN, mv, fi}$
			Property damage only (*pdo*)	$N_{spf, rps, 2EN, mv, pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf, rps, 2EN, sv, fi}$
			Property damage only (*pdo*)	$N_{spf, rps, 2EN, sv, pdo}$
	One-lane exit ramp (*1EX*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf, rps, 1EX, mv, fi}$
			Property damage only (*pdo*)	$N_{spf, rps, 1EX, mv, pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf, rps, 1EX, sv, fi}$
			Property damage only (*pdo*)	$N_{spf, rps, 1EX, sv, pdo}$
	Two-lane exit ramp (*2EX*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf, rps, 2EX, mv, fi}$
			Property damage only (*pdo*)	$N_{spf, rps, 2EX, mv, pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf, rps, 2EX, sv, fi}$
			Property damage only (*pdo*)	$N_{spf, rps, 2EX, sv, pdo}$
C-D road segments (*cds*)	One-lane C-D road (*1*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf, cds, 1, mv, fi}$
			Property damage only (*pdo*)	$N_{spf, cds, 1, mv, pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf, cds, 1, sv, fi}$
			Property damage only (*pdo*)	$N_{spf, cds, 1, sv, pdo}$
	Two-lane C-D road (*2*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf, cds, 2, mv, fi}$
			Property damage only (*pdo*)	$N_{spf, cds, 2, mv, pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf, cds, 2, sv, fi}$
			Property damage only (*pdo*)	$N_{spf, cds, 2, sv, pdo}$

The ramp segment and C-D road segment are defined as follows:

- *One-lane segment*—a length of roadway consisting of one through lane with a continuous cross section providing one direction of travel.
- *Two-lane segment*—a length of roadway consisting of two through lanes with a continuous cross section providing one direction of travel.

Table 19-2 identifies the urban crossroad ramp terminal configurations for which SPFs have been developed for three-leg terminals with a diagonal exit ramp. A second set of SPFs have been developed for rural three-leg terminals with either stop control, or signal control and two, three, or four lanes on the crossroad (they are not shown in the table, but use the same nomenclature). The SPFs are used to estimate the predicted average crash frequency by crash severity. These estimates are added to yield the total predicted average crash frequency for an individual site.

Table 19-2. Urban Crossroad Ramp Terminal SPFs for Three-Leg Terminals with a Diagonal Exit Ramp

Site Type (w)	Cross Section and Control Type (x)	Crash Type (y)	Crash Severity (z)	SPF
Three-leg terminals with diagonal exit ramp (*D3ex*),	One-way stop control; 2, 3, or 4 lane crossroad (*ST*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\ w,\ ST,\ at,\ fi}$
			Property damage only (*pdo*)	$N_{spf,\ w,\ ST,\ at,\ pdo}$
	Signal control, 2-lane crossroad (*SG2*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\ w,\ SG2,\ at,\ fi}$
			Property damage only (*pdo*)	$N_{spf,\ w,\ SG2,\ at,\ pdo}$
	Signal control, 3-lane crossroad (*SG3*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\ w,\ SG3,\ at,\ fi}$
			Property damage only (*pdo*)	$N_{spf,\ w,\ SG3,\ at,\ pdo}$
	Signal control, 4-lane crossroad (*SG4*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\ w,\ SG4,\ at,\ fi}$
			Property damage only (*pdo*)	$N_{spf,\ w,\ SG4,\ at,\ pdo}$
	Signal control, 5-lane crossroad (*SG5*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\ w,\ SG5,\ at,\ fi}$
			Property damage only (*pdo*)	$N_{spf,\ w,\ SG5,\ at,\ pdo}$
	Signal control, 6-lane crossroad (*SG6*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\ w,\ SG6,\ at,\ fi}$
			Property damage only (*pdo*)	$N_{spf,\ w,\ SG6,\ at,\ pdo}$

One set of urban SPFs (and one set of rural SPFs) for the configurations shown in Table 19-2 have also been developed for each of the following six site types (they also use the same nomenclature shown in the table).

- Three-leg terminals with diagonal entrance ramp (*D3en*),
- Four-leg terminals with diagonal ramps (*D4*),
- Four-leg terminals at four-quadrant partial cloverleaf A (*A4*),
- Four-leg terminals at four-quadrant partial cloverleaf B (*B4*),
- Three-leg terminals at two-quadrant partial cloverleaf A (*A2*),
- Three-leg terminals at two-quadrant partial cloverleaf B (*B2*).

For the purposes of evaluation, a crossroad ramp terminal's "site type" is defined in terms of its configuration. The terminal configurations addressed in the predictive method are shown in Figure 19-1. These terminals are further categorized by crossroad cross section and the type of traffic control used at the terminal. Stop-controlled terminals have a stop sign on the ramp approach to the intersection, and no stop or yield sign on the crossroad approaches. Signal-controlled terminals have traffic signals on the ramp and crossroad approaches.

19.3.2. Predictive Model for Ramp Segments

In general, a predictive model is used to compute the predicted average crash frequency for a site. It combines with the SPF, CMFs, and a calibration factor. The predicted quantity can describe crash frequency in total, by crash type, or by crash severity. This section describes the predictive model for ramp and C-D road segments. The next section describes the predictive model for crossroad ramp terminals.

The predictive model for ramp and C-D road segments is used to estimate the predicted average crash frequency of segment crashes (i.e., the estimate does not include ramp-terminal-related crashes). Segment crashes include crashes that occur in the segment and either (a) away from the crossroad ramp terminal or (b) within the limits of the crossroad ramp terminal but not related to the terminal. That is, the predictive model estimate includes crashes that would occur regardless of whether the crossroad ramp terminal is present.

The predictive model for entrance ramps (and connector ramps at service interchanges that serve motorists traveling from the crossroad to the freeway) is presented in Equation 19-2. This equation consists of four terms, where each of Equation 19-3 to Equation 19-6 correspond to one term.

$$N_{p,rps,nEN,at,as} = N_{p,rps,nEN,mv,fi} + N_{p,rps,nEN,sv,fi} + N_{p,rps,nEN,mv,pdo} + N_{p,rps,nEN,sv,pdo} \tag{19-2}$$

$$\begin{aligned} N_{p,rps,nEN,mv,fi} = {} & C_{rps,EN,mv,fi} \times N_{spf,rps,nEN,mv,fi} \times \left(CMF_{1,rps,ac,mv,fi} \times \ldots \times CMF_{m,rps,ac,mv,fi}\right) \\ & \times \left(CMF_{1,rps,ac,at,fi} \times \ldots \times CMF_{m,rps,ac,at,fi}\right) \end{aligned} \tag{19-3}$$

$$\begin{aligned} N_{p,rps,nEN,sv,fi} = {} & C_{rps,EN,sv,fi} \times N_{spf,rps,nEN,sv,fi} \times \left(CMF_{1,rps,ac,sv,fi} \times \ldots \times CMF_{m,rps,ac,sv,fi}\right) \\ & \times \left(CMF_{1,rps,ac,at,fi} \times \ldots \times CMF_{m,rps,ac,at,fi}\right) \end{aligned} \tag{19-4}$$

$$\begin{aligned} N_{p,rps,nEN,mv,pdo} = {} & C_{rps,EN,mv,pdo} \times N_{spf,rps,nEN,mv,pdo} \times \left(CMF_{1,rps,ac,mv,pdo} \times \ldots \times CMF_{m,rps,ac,mv,pdo}\right) \\ & \times \left(CMF_{1,rps,ac,at,pdo} \times \ldots \times CMF_{m,rps,ac,at,pdo}\right) \end{aligned} \tag{19-5}$$

$$\begin{aligned} N_{p,rps,nEN,sv,pdo} = {} & C_{rps,EN,sv,pdo} \times N_{spf,rps,nEN,sv,pdo} \times \left(CMF_{1,rps,ac,sv,pdo} \times \ldots \times CMF_{m,rps,ac,sv,pdo}\right) \\ & \times \left(CMF_{1,rps,ac,at,pdo} \times \ldots \times CMF_{m,rps,ac,at,pdo}\right) \end{aligned} \tag{19-6}$$

Where:

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

$C_{rps,\,EN,\,y,\,z}$ = calibration factor for entrance ramp segments with any lanes, crash type *y* (*y* = *sv*: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only);

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

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

The predictive model for exit ramps (and connector ramps at service interchanges that serve motorists traveling from the freeway to the crossroad) is identical to that for entrance ramps except that the subscript "EX" is substituted for "EN" in Equation 19-2 to Equation 19-6.

Equation 19-2 shows that entrance ramp segment crash frequency is estimated as the sum of four components: fatal-and-injury multiple-vehicle crash frequency, fatal-and-injury single-vehicle crash frequency, property-damage-only multiple-vehicle crash frequency, and property-damage-only single-vehicle crash frequency.

Different CMFs are used in Equation 19-3 to Equation 19-6. The first terms in parentheses in each equation recognizes that the influence of some features is unique to each crash type. In contrast, the second term in parentheses in these equations recognizes that some features have a similar influence on all crash types. All CMFs are unique to crash severity.

Equation 19-3 and Equation 19-4 are used to estimate the fatal-and-injury crash frequency. Equation 19-5 and Equation 19-6 are used to estimate the property-damage-only crash frequency.

The predictive model for C-D roads (and connector ramps at system interchanges) is presented in Equation 19-7. This equation consists of four terms, where each of Equation 19-8 to Equation 19-11 correspond to one term.

$$N_{p,cds,n,at,as} = N_{p,cds,n,mv,fi} + N_{p,cds,n,sv,fi} + N_{p,cds,n,mv,pdo} + N_{p,cds,n,sv,pdo} \tag{19-7}$$

$$N_{p,cds,n,mv,fi} = C_{cds,ac,mv,fi} \times N_{spf,cds,n,mv,fi} \times \left(CMF_{1,cds,ac,mv,fi} \times \ldots \times CMF_{m,cds,ac,mv,fi}\right) \times \left(CMF_{1,cds,ac,at,fi} \times \ldots \times CMF_{m,cds,ac,at,fi}\right) \tag{19-8}$$

$$N_{p,cds,n,sv,fi} = C_{cds,ac,sv,fi} \times N_{spf,cds,n,sv,fi} \times \left(CMF_{1,cds,ac,sv,fi} \times \ldots \times CMF_{m,cds,ac,sv,fi}\right) \times \left(CMF_{1,rps,ac,at,fi} \times \ldots \times CMF_{m,rps,ac,at,fi}\right) \tag{19-9}$$

$$N_{p,cds,n,mv,pdo} = C_{cds,ac,mv,pdo} \times N_{spf,cds,n,mv,pdo} \times \left(CMF_{1,cds,ac,mv,pdo} \times \ldots \times CMF_{m,cds,ac,mv,pdo}\right) \times \left(CMF_{1,cds,ac,at,pdo} \times \ldots \times CMF_{m,cds,ac,at,pdo}\right) \tag{19-10}$$

$$N_{p,cds,n,sv,pdo} = C_{cds,ac,sv,pdo} \times N_{spf,cds,n,sv,pdo} \times \left(CMF_{1,cds,ac,sv,pdo} \times \ldots \times CMF_{m,cds,ac,sv,pdo}\right) \times \left(CMF_{1,cds,ac,at,pdo} \times \ldots \times CMF_{m,cds,ac,at,pdo}\right) \tag{19-11}$$

Where:

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

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

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

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

The interpretation of these equations is similar to that described previously for ramp entrance segments.

The SPFs for ramp and C-D road segments are presented in Section 19.6.1. The associated CMFs are presented in Section 19.7.1. Similarly, the associated SDFs are presented in Section 19.8.1. A procedure for establishing the value of the calibration factor is described in Section B.1 of Appendix B.

19.3.3. Predictive Model for Ramp Terminals

The predictive model for crossroad ramp terminals is used to compute the predicted average crash frequency for a crossroad ramp terminal. Terminal-related crashes include (a) all crashes that occur within the limits of the intersection (i.e., at-intersection crashes) and (b) crashes that occur on the ramp or crossroad legs and are attributed to the presence of an intersection (i.e., intersection-related crashes).

The predictive model for one-way stop-controlled crossroad ramp terminals is presented in Equation 19-12. This equation consists of two terms, where each of Equation 19-13 and Equation 19-14 correspond to one term.

$$N_{p,w,ST,at,as} = N_{p,w,ST,at,fi} + N_{p,w,ST,at,pdo} \tag{19-12}$$

$$N_{p,w,ST,at,fi} = C_{aS,ST,at,fi} \times N_{spf,w,ST,at,fi} \times \left(CMF_{1,aS,ST,at,fi} \times \ldots \times CMF_{m,aS,ST,at,fi}\right) \tag{19-13}$$

$$N_{p,w,ST,at,pdo} = C_{aS,ST,at,pdo} \times N_{spf,w,ST,at,pdo} \times \left(CMF_{1,aS,ST,at,pdo} \times \ldots \times CMF_{m,aS,ST,at,pdo}\right) \tag{19-14}$$

Where:

$N_{p, w, ST, at, z}$ = predicted average crash frequency of a stop-controlled crossroad ramp terminal of site type *w* (*w* = *D3ex*, *D3en*, *D4*, *A4*, *B4*, *A2*, *B2*), all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only, *as*: all severities) (crashes/yr);

$C_{aS, ST, at, z}$ = calibration factor for a stop-controlled crossroad ramp terminal (any site type *aS*) with all crash types *at* and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only);

$N_{spf, w, ST, at, z}$ = predicted average crash frequency of a one-way stop-controlled crossroad ramp terminal of site type *w* (*w* = *D3ex*, *D3en*, *D4*, *A4*, *B4*, *A2*, *B2*) with base conditions, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr); and

$CMF_{m, aS, ST, at, z}$ = crash modification factor for a stop-controlled crossroad ramp terminal (any site type *aS*) with feature *m*, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only).

The seven site types (i.e., *D3ex*, *D3en*, *D4*, *A4*, *B4*, *A2*, *B2*) are shown in Figure 19-1.

Equation 19-12 shows that crossroad ramp terminal crash frequency is estimated as the sum of two components: predicted average fatal-and-injury crash frequency and predicted average property-damage-only crash frequency.

Different CMFs are used in Equation 19-13 and Equation 19-14. The term in parentheses in each equation recognizes that the influence of some features is unique to the type of control used at the terminal. All CMFs are unique to crash severity.

The predictive model for signal-controlled crossroad ramp terminals is presented in Equation 19-15. This equation consists of two terms, where each of Equation 19-16 and Equation 19-17 correspond to one term.

$$N_{p,\,w,\,SGn,\,at,\,as} = N_{p,\,w,\,SGn,\,at,\,fi} + N_{p,\,w,\,SGn,\,at,\,pdo} \tag{19-15}$$

$$N_{p,w,SGn,at,fi} = C_{aS,SG,at,fi} \times N_{spf,\,w,SGn,at,fi} \times \left(CMF_{1,aS,SGn,at,fi} \times \ldots \times CMF_{m,aS,SGn,at,fi}\right) \tag{19-16}$$

$$N_{p,w,SGn,at,pdo} = C_{aS,SG,at,pdo} \times N_{spf,\,w,SGn,at,pdo} \times \left(CMF_{1,aS,SGn,at,pdo} \times \ldots \times CMF_{m,aS,SGn,at,pdo}\right) \tag{19-17}$$

Where:

$N_{p,\,w,\,SGn,\,at,\,z}$ = predicted average crash frequency of a signal-controlled crossroad ramp terminal of site type *w* (*w* = *D3ex*, *D3en*, *D4*, *A4*, *B4*, *A2*, *B2*) with *n* crossroad lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only, *as*: all severities) (crashes/yr);

$C_{aS,\,SG,\,at,\,z}$ = calibration factor for a signal-controlled crossroad ramp terminal (any site type *aS*) with all crash types *at* and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only);

$N_{spf,\,w,\,SGn,\,at,\,z}$ = predicted average crash frequency of a signal-controlled crossroad ramp terminal of site type *w* (*w* = *D3ex*, *D3en*, *D4*, *A4*, *B4*, *A2*, *B2*) with base conditions, *n* crossroad lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr); and

$CMF_{m,\,aS,\,SGn,\,at,\,z}$ = crash modification factor for a signal-controlled crossroad ramp terminal (any site type *aS*) on a crossroad with *n* lanes, feature *m*, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only).

The SPFs for crossroad ramp terminals are presented in Section 19.6.2. The associated CMFs are presented in Section 19.7.2. Similarly, the associated SDFs are presented in Section 19.8.2. A procedure for establishing the value of the calibration factor is described in Section B.1 of Appendix B.

19.4. PREDICTIVE METHOD FOR RAMPS AND RAMP TERMINALS

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

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

The predictive method for ramps is shown in Figure 19-2. Applying the predictive method yields an estimate of the expected average crash frequency (in total, by crash type, or by crash severity) for an entire ramp or C-D road. The predictive models described in this chapter are applied in Steps 9, 10, and 11 of the predictive method. The information needed to apply each step is provided in this section.

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

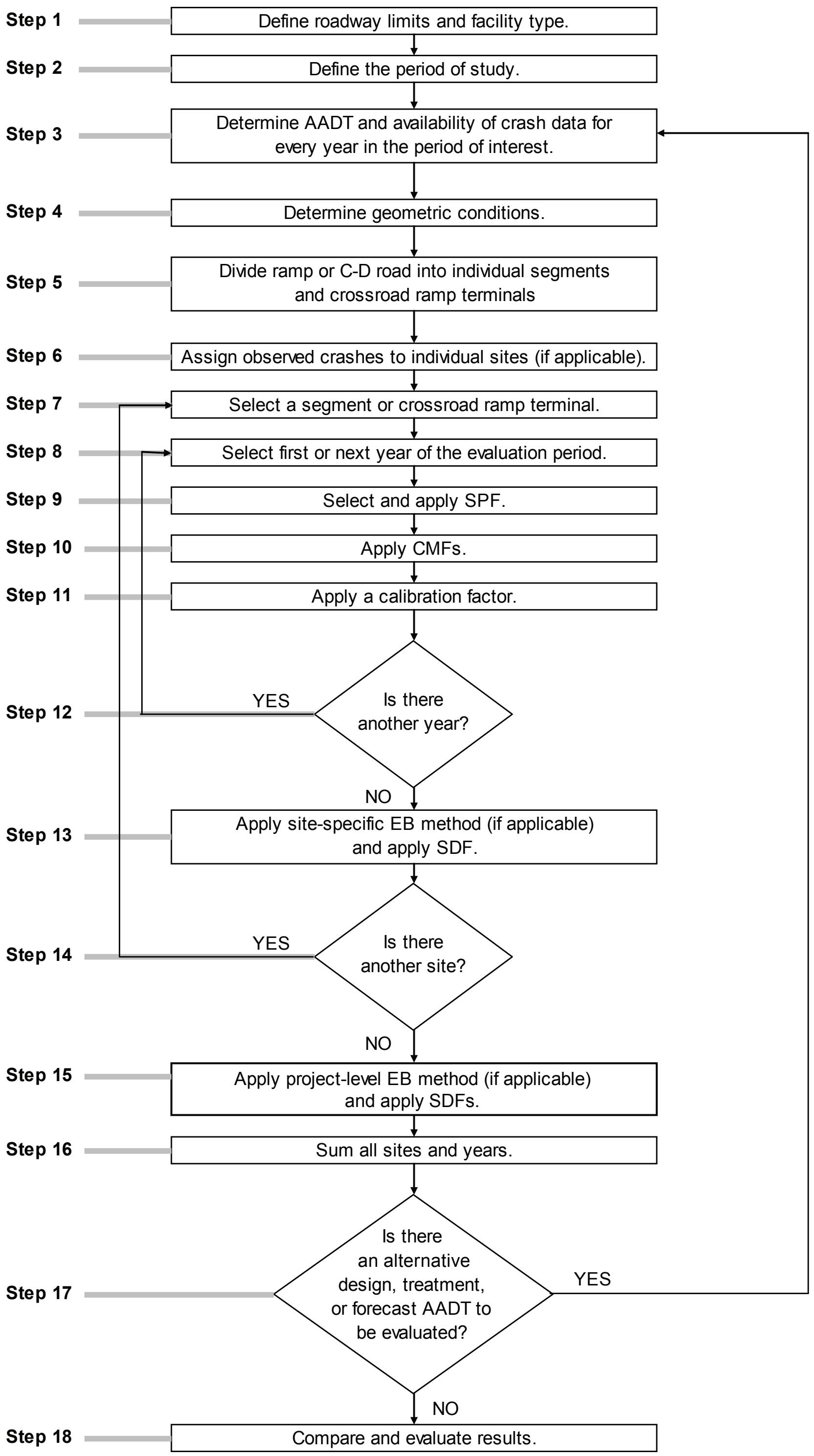


Figure 19-2. The HSM Predictive Method

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

Step 1—Define the limits of the project.
A project can be all of the ramps and C-D roads in the vicinity of an interchange, an entire ramp, an entire C-D road, or an individual site. A site is a crossroad ramp terminal, a homogeneous ramp segment, or a homogeneous C-D road segment. A site is further categorized by its cross section or control type. A description of the specific site types is provided in Section 19.3.1.

The project limits are defined in this step. They will depend on the purpose of the study. The study may be limited to one specific site, or to a group of contiguous sites. Alternatively, the limits can be expanded to include all of the ramps, C-D roads, and crossroad ramp terminals in the vicinity of an interchange. For comparative analysis of design alternatives, the project limits should be the same for all alternatives.

The analyst should identify (or establish) a reference line for each ramp and C-D road. This line is defined as the right edge of traveled way in the direction of travel. All lengths along the roadway are determined using this line. The location of the reference line is shown in subsequent figures (e.g., Figure 19-4). Locations along this line are specified using a linear referencing system, and are identified using the label "ramp-mile *X*," where the number for *X* has units of miles (e.g., ramp-mile 1.4).

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

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

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

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

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

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

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

The AADT volume of the ramp is needed for each ramp segment. The AADT volume of the C-D road is needed for the evaluation of each C-D road segment.

For each crossroad ramp terminal, one AADT value is needed for each intersecting leg. Thus, for a four-leg ramp terminal, the following values are needed: AADT volume of the crossroad leg "inside" the interchange, AADT volume of the crossroad leg "outside" of the interchange, AADT volume of the exit ramp, and AADT volume of the entrance ramp. The inside crossroad leg is the leg that is on the side of the ramp terminal nearest to the freeway. The outside crossroad leg is on the other side of the ramp terminal.

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

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

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

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

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

Step 4—Determine geometric design features, traffic control features, and site characteristics for all sites in the project limits.
A range of data is needed to apply a predictive model. These data are used in the SPFs and CMFs to estimate the predicted average crash frequency for the selected site and year. These data represent the geometric design features, traffic control features, and traffic demand characteristics that have been found to have some relationship to safety. These data are needed for each site in the project limits. They are needed for the study period and, if applicable, the crash period. The specific data, and means by which they are measured or obtained, is described in Section 19.4.2.

Step 5—Divide the roadway into sites.
Using the information from Step 1 and Step 4, the ramp or C-D road is divided into individual sites, consisting of individual homogeneous segments and ramp terminals. The procedure for dividing the ramp or C-D road into individual segments is provided in Section 19.5.

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

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

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

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

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

Step 9—For the selected site, determine and apply the appropriate SPF.
The SPF determines the predicted average crash frequency for a site whose features match the SPF's base conditions. The SPFs (and their base conditions) are described in Section 19.6.

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

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs.
Collectively, the CMFs are used in the predictive model to adjust the SPF estimate from Step 9 such that the resulting predicted average crash frequency accurately reflects the geometric design and traffic control features of the selected site. The available CMFs are described in Section 19.7.

All CMFs presented in this chapter have the same base conditions as the SPFs in this chapter. Only the CMFs presented in Section 19.7 may be used as part of the predictive method described in this chapter.

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

Multiply the result from Step 9 by the appropriate CMFs.

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

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

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

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

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

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

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

Apply the severity distribution functions (SDFs), if desired.
The SDFs can be used to compute the expected average crash frequency for each of the following severity levels: fatal, incapacitating injury, non-incapacitating injury, and possible injury. Each SDF includes variables that describe the geometric design and traffic control features of a site. In this manner, the computed distribution gives consideration to the features present at the selected site. The SDFs are described in Section 19.8. They can benefit from being updated based on local data as part of the calibration process. Detailed guidance for the development of the SDF calibration factor is included in Section B.1.4 of Appendix B.

Apply the crash type distribution, if desired.
Each predictive model includes a default distribution of crash type. This distribution can be used to compute the expected average crash frequency for each of ten crash types (e.g., head-on, fixed object). The distribution is presented in Section 19.6. It can benefit from being updated based on local data as part of the calibration process.

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

Step 15—Apply the project-level EB Method (if applicable) and apply SDFs.
The activities undertaken during this step are the same as undertaken for Step 13 but they occur at the project level (i.e., entire ramp, entire C-D road, or interchange). They are based on estimating the project-level predicted average

crash frequency. This crash frequency is computed for each year during the crash period. It is computed as the sum of the predicted average crash frequency for all sites (as computed in Step 11).

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

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

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

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

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

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

Step 16—Sum all sites and years in the study to estimate total crash frequency.
One outcome of the predictive method is the total expected average crash frequency. The term "total" indicates that the estimate includes all crash types and severities. It is computed from an estimate of the total expected number of crashes, which represents the sum of the total expected average crash frequency for each site and for each year in the study period. The total expected number of crashes during the study period is calculated using Equation 19-18:

$$N^*_{e,aS,ac,at,as} = \sum_{j=1}^{n_s}\left(\sum_{i=1}^{all\ sites} N_{e,rps(i),ac,at,as,j} + \sum_{i=1}^{all\ sites} N_{e,cds(i),ac,at,as,j} + \sum_{i=1}^{all\ sites} N_{e,w(i),ac,at,as,j}\right) \quad (19\text{-}18)$$

Where:

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

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

$N_{e,\,rps(i),\,ac,\,at,\,as,\,j}$ = expected average crash frequency of ramp segment *i* for year *j* (includes all cross sections *ac*, all crash types *at*, and all severities *as*) (crashes/yr);

$N_{e,\,cds(i),\,ac,\,at,\,as,\,j}$ = expected average crash frequency of C-D road segment *i* for year *j* (includes all cross sections *ac*, all crash types *at*, and all severities *as*) (crashes/yr); and

$N_{e,\,w(i),\,ac,\,at,\,as,\,j}$ = expected average crash frequency of crossroad ramp terminal *i* of site type *w(i)* (*w* = *D3ex*, *D3en*, *D4*, *A4*, *B4*, *A2*, *B2*) for year *j* (includes all control types *ac*, all crash types *at*, and all severities *as*) (crashes/yr).

Equation 19-18 is used to compute the total expected number of crashes estimated to occur in the project limits during the study period. The summation of crashes for each terminal type, cross section, control type, crash type, and severity for each site and year is not shown in mathematic terms, but it is implied by the subscripts *w*, *ac*, *at*, and *as*, respectively.

Equation 19-19 is used to estimate the overall expected average crash frequency within the project limits during the study period.

$$N_{e,aS,ac,at,as} = \frac{N^{*}_{e,aS,ac,at,as}}{n_s} \quad (19\text{-}19)$$

Where:

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

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

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

19.4.2. Data Needed to Apply the Predictive Method

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

The input data are needed for each site in the project limits. Criteria for defining site boundaries are described in Section 19.5.

The data are described in two subsections. The first subsection describes input data for ramp and C-D road segments. The second subsection describes input data for crossroad ramp terminals.

Features of Ramp and C-D Road Segments
The input data needed for ramp and C-D road segments is described in this subsection. There are several data identified in this section that describe a length along the roadway (e.g., segment length, curve length, weaving section length, etc.). *All of these lengths are measured along the reference line*, which is the right edge of traveled way in the direction of travel. Points that do not lie on the reference line must be projected onto the reference line (along a perpendicular line if the alignment is straight, or along a radial line if the alignment is curved) to facilitate length determination. These dimensions can be obtained from field measurements, a plan set, or aerial photographs.

- *Number of through lanes*—The total number of through lanes in the segment. Rural ramp segments are limited to one lane. Urban ramp segments are limited to two lanes. A segment with a lane-add (or lane-drop) taper is considered to have the same number of through lanes as the roadway just downstream of the lane-add (or lane-drop) taper. If the segment ends at a ramp terminal, then the number of through lanes is not based on the lane assignment, or lane markings, at the terminal.

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

Do not include any auxiliary lanes that are associated with a C-D road weaving section, unless the weaving section length exceeds 0.30 mi (1,600 ft). If this length is exceeded, then the auxiliary lane is counted as a through lane that starts as a lane-add ramp entrance and ends as a lane-drop ramp exit.

Do not include any auxiliary lanes that are developed as a turn bay (for queued vehicle storage) at the crossroad ramp terminal.

Do not include the speed-change lane that is associated with a second ramp that merges with (or diverges from) the subject ramp, unless its length exceeds 0.19 mi (1,000 ft). If this length is exceeded, then the speed-change lane is counted as a through lane that starts as a lane-add ramp entrance and ends as a lane drop by taper (or starts as a lane add by taper and ends as a lane-drop ramp exit).

This guidance is illustrated in Figure 19-3 using a portion of an exit ramp. The portion is shown to end at the crossroad ramp terminal. It consists of three segments. The first segment ends at the lane add section and has one lane. The second segment ends at the start of the bay taper and has two lanes. The third segment ends at the crossroad. Four lanes are shown at the downstream end of this segment, but two of the lanes are in turn bays and are not included in the determination of the number of through lanes for the segment. Thus, this segment is considered to have two lanes (= 4 – 2) for this application.

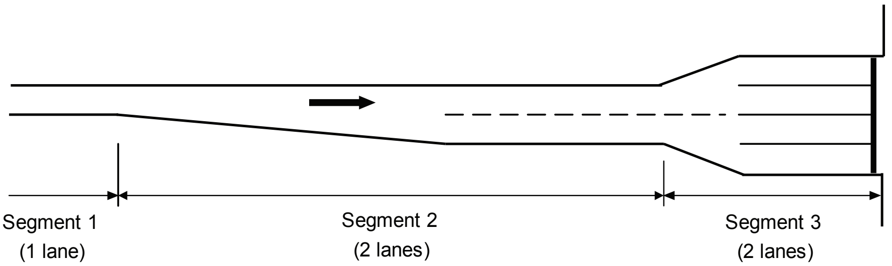


Figure 19-3. Determination of Number of Lanes for Ramp Segments

- Length of ramp or C-D road segment.
- *Average traffic speed on the freeway during off-peak periods of the typical day*—This speed is used to compute the speed for each curve (if any) that is present on the ramp. If better information is not available, then this speed can be estimated as the freeway's maximum speed limit.
- *Type of traffic control used at the crossroad ramp terminal to regulate intersecting traffic (none, yield, stop, signal)*—The term "None" is appropriate if the ramp intersects the crossroad as a speed-change lane or as a lane added (or lane dropped).
- *Presence of a horizontal curve prior to (or in) the subject segment*—Curves located prior to the segment influence the speed on the subject segment. For each curve located prior to (or in) the segment, the following data are needed:
  - *Length of curve*—Curve length is measured along the reference line from the point where the tangent ends and the curve begins (the PC) to the point where the curve ends and the tangent begins (the PT).

    If the curve has spiral transitions, then measure from the "effective" PC point to the "effective" PT point. The effective PC point is located midway between the TS and SC, where the TS is the point of change from tangent to spiral and the SC is the point of change from spiral to circular curve. The effective PT is located midway between the CS and ST, where CS is the point of change from circular curve to spiral and ST is the point of change from spiral to tangent.

    If the curve is continued from a curve on an intersecting alignment, then consider only the curve length on the subject alignment. For example, if the subject ramp diverges from another ramp and the curvature from the originating ramp continues into the subject ramp, then the curve on the subject ramp is considered to start at the beginning of the subject ramp (i.e., at the gore point).

- *Radius of curve*—The radius is defined by the right edge of traveled way. If the curve has spiral transitions, then use the radius of the central circular portion of the curve.
- *Length of curve in segment*—The length of the curve within the boundaries of the segment. This length cannot exceed the segment length or the curve length.
- *Ramp-mile of beginning of curve in direction of travel*—This value equals the distance from ramp-mile 0.0 to the point where the tangent ends and the curve begins. Ramp-mile locations are measured along the right edge of the ramp traveled way in the direction of travel (in the absence of tapers and speed-change lanes, this edge coincides with the right edge of traveled way). These locations are established for this application, and may or may not coincide with the mileposts (or stations) established for the ramp's design.

The gore point will often be used to define ramp-mile 0.0 for a ramp or C-D road. The gore point is located where the pair of solid white pavement edge markings that separate the ramp from the intersecting roadway are 2.0 ft apart. If the markings do not extend to a point where they are 2.0 ft apart, then the gore point is found by extrapolating both markings until the extrapolated portion is 2.0 ft apart. This point is shown in the top part of Figure 19-4.

For exit ramps and C-D roads that diverge from the freeway (and entrance ramps that diverge from the cross-road using a speed-change lane), ramp-mile 0.0 is located where the gore point projects onto the ramp reference line. The ramp reference line is defined as the right edge of the ramp traveled way.

For entrance ramps that intersect the crossroad, ramp-mile 0.0 is located where the ramp reference line intersects with the near edge of traveled way of the crossroad. This point is shown in the bottom part of Figure 19-4.

If two or more ramps merge such that there is a choice of two or more points at which ramp-mile 0.0 could be established for curves downstream of the merge point, then establish ramp-mile 0.0 for these curves on the ramp with the highest volume.

If the subject curve is preceded by a spiral transition, then measure to the "effective" curve beginning point. This point is located midway between the TS and SC, where the TS is the point of change from tangent to spiral and the SC is the point of change from spiral to circular curve.

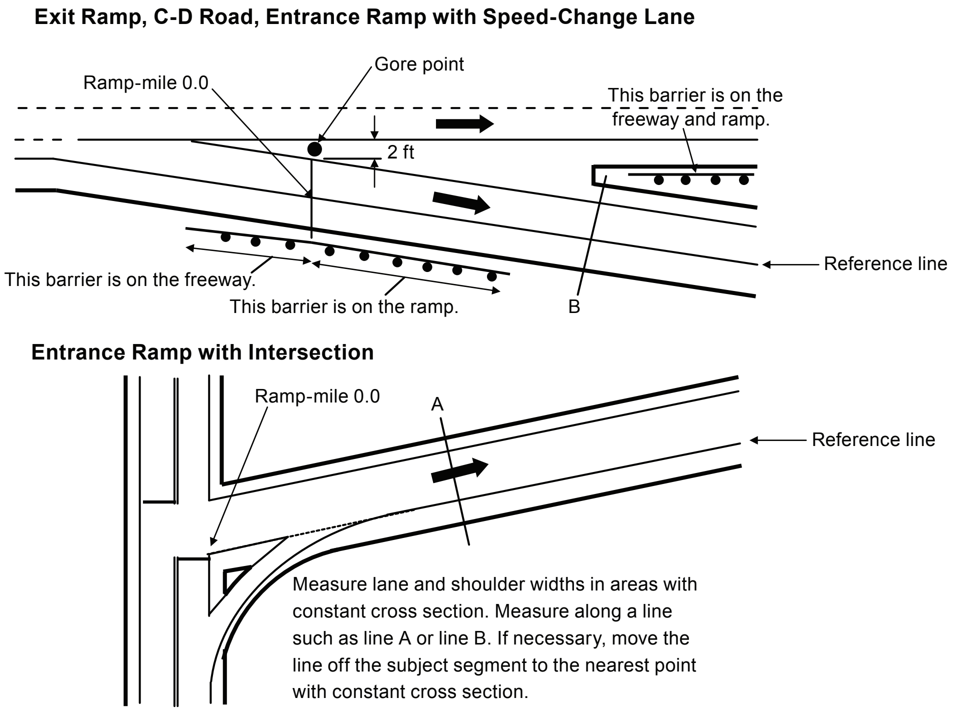


Figure 19-4. Starting Location on Ramps and C-D Roads

- *Widths of lanes, right shoulder, and left shoulder*—These elements represent an average for the segment. These widths should be measured where the cross section is constant, such as along line A or B shown in Figure 19-4. They should not be measured where one or more edges are discontinuous or tapered. If a width varies along the segment (but not enough to justify beginning a new segment), then compute the length-weighted average width. Rules for defining segment boundaries are provided in Section 19.5.2.
  - *Lane width*—This width is computed as an average for all through lanes.
  - *Shoulder width*—This width represents only the paved width.
- *Length of (and offset to) the right-side barrier and the left-side barrier*—Measured separately for each short piece of barrier and for barrier that continues for the length of the segment (and beyond). Each piece is represented once for a site. Barrier length is measured along the reference line. Offset is measured from the nearest edge of traveled way to the barrier face.

  Figure 19-5 illustrates these measurements for a barrier element protecting a sign support on the right side of a ramp with right shoulder width W_{rs}. The barrier element has a portion of its length that is parallel to the ramp and a portion of its length that is tapered away from the ramp. To evaluate this element, separate it into two pieces, as shown in Figure 19-5. Each piece is represented by its average offset $W_{off,\,r,\,i}$ and length $L_{rb,\,i}$. Barrier pieces with the same offset can be combined by adding their length and using their common offset.

  A barrier is associated with a ramp if its offset from the near edge of traveled way is 30 ft or less. Barrier adjacent to the freeway but also within 30 ft of the ramp traveled way should also be associated with the ramp. The determination of whether a barrier is adjacent to a freeway speed-change lane or a ramp is based on the gore point, as shown in Figure 19-4.

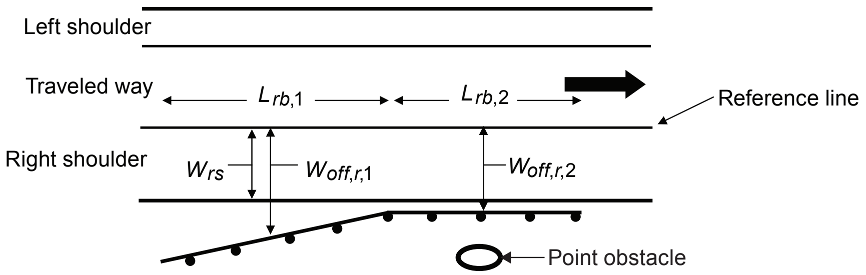


Figure 19-5. Barrier Variables

- Presence of an entrance speed-change lane (due to a second merging ramp)—If a speed-change lane is present, then the length of the speed-change lane *in the segment* is needed. Guidance for measuring this length is provided in the following list.
  - Speed-change lane length in the segment is measured between the segment's beginning and ending points. It cannot exceed the length of the segment, regardless of the length of the speed-change lane. It cannot exceed the length of the speed-change lane.
  - Speed-change lane length is measured along the edge of the subject ramp's traveled way from the gore point to the taper point. The gore point is located where the pair of solid white pavement edge markings that separate the subject ramp from the intersecting ramp are 2.0 ft apart. If the markings do not extend to a point where they are 2.0 ft apart, then the gore point is found by extrapolating both markings until the extrapolated portion is 2.0 ft apart. This point is shown in Figure 19-6.
  - The taper point is located where the outside edge marking of the intersecting ramp intersects the subject ramp's outside edge marking. It marks the point where the taper ends (or begins) as shown in Figure 19-6.

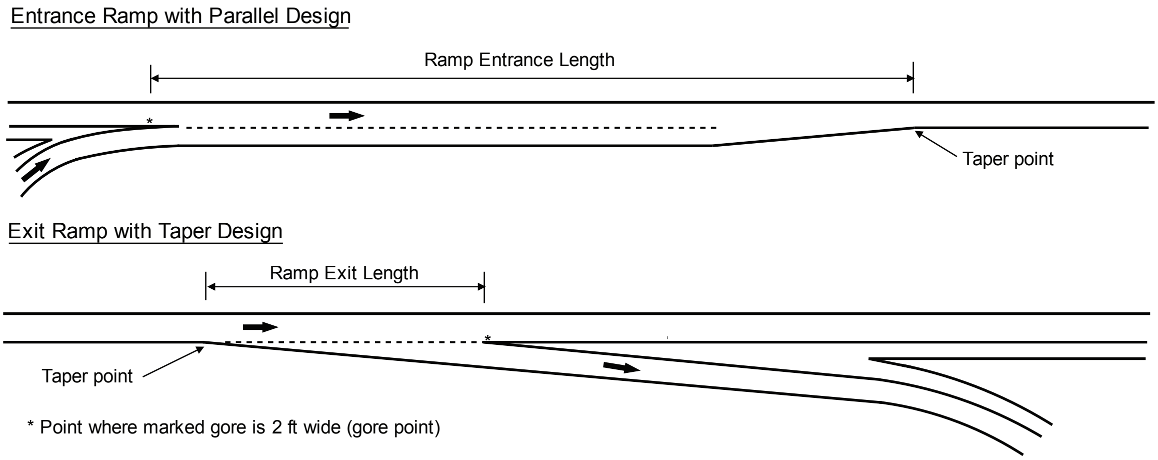


Figure 19-6. Speed-Change Lane Location on Ramps and C-D Roads

- *Presence of an exit speed-change lane (due to a second diverging ramp)*—If a speed-change lane is present, then the length of the speed-change lane *in the segment* is needed. Guidance for measuring this length is the same as for entrance speed-change lanes.
- *Lane added to the ramp or C-D road (not as a result of a second merging ramp)*—If a lane is added, then the length of the taper *in the segment* is needed. Guidance for measuring this length is provided in the following list:
  - *Length of taper in the segment*—This length is measured between the segment's beginning and ending points. This length cannot exceed the length of the segment. This length cannot exceed the taper length.
  - *Taper length*—This length is measured along the edge of the ramp traveled way from the point where the traveled way width first begins changing to the point where this width first stops changing. Traveled way width is measured between the solid white pavement edge lines.
- *Lane dropped from the ramp or C-D road (not as a result of a second diverging ramp)*—If a lane is dropped, then the length of the taper *in the segment* is needed. Guidance for measuring this length is the same as for the lane add case.
- *Presence of a weaving section on a C-D road segment*—If the segment is partially or wholly within a weaving section then the following data are needed:
  - *Weaving section length*—This length is measured along the edge of the C-D road traveled way from the gore point of the ramp entrance to the gore point of the next ramp exit, as shown in Figure 19-7. The gore point is located where the pair of solid white pavement edge markings that separate the ramp from the C-D road are 2.0 ft apart. If the markings do not extend to a point where they are 2.0 ft apart, then the gore point is found by extrapolating both markings until the extrapolated portion is 2.0 ft apart. If the measured gore-to-gore distance exceeds 0.30 mi (1,600 ft), then a weaving section is not considered to exist. Rather, the entrance ramp is a "lane add" and the exit ramp is a "lane drop."

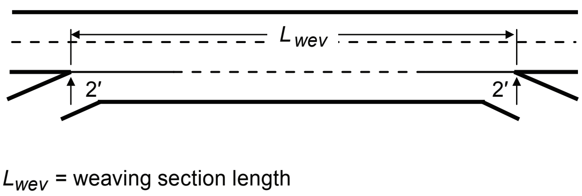


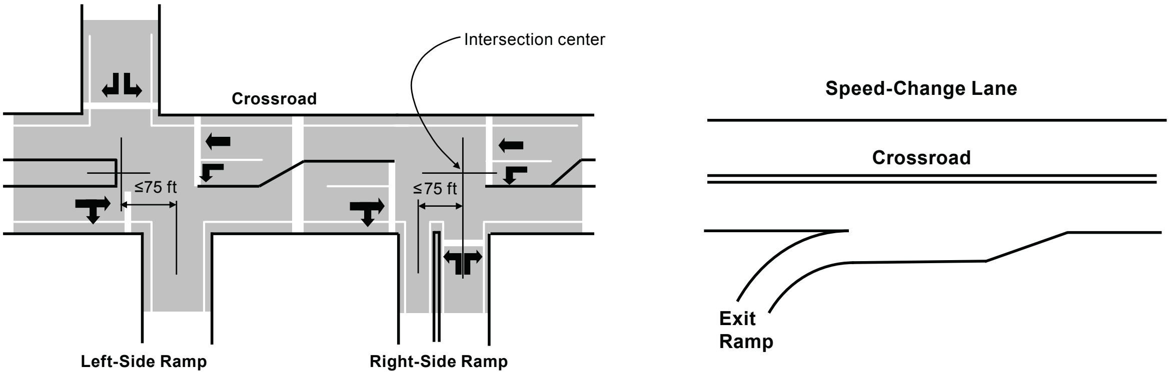
Figure 19-7. C-D Road Weaving Section Length

- *Length of weaving section located in the segment, between the segment's beginning and ending points*—This length cannot exceed the length of the segment. This length cannot exceed the length of the weaving section.

- Segment AADT volume.

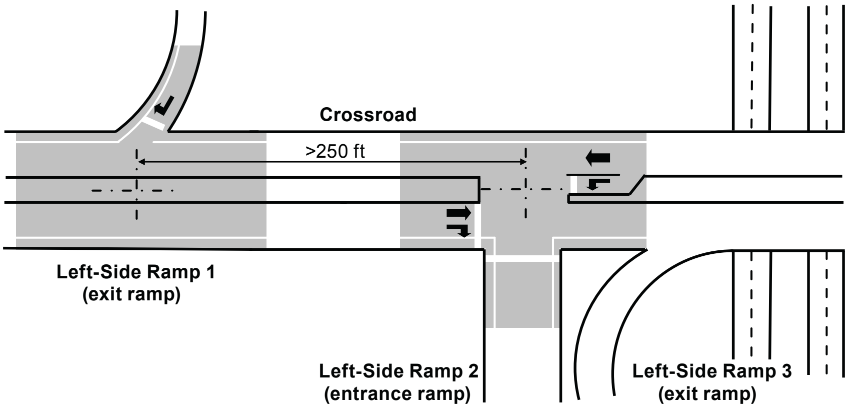
Features of Crossroad Ramp Terminals

The input data that describe a crossroad ramp terminal are described in this subsection. The phrase "crossroad ramp terminal" refers to a controlled terminal between the ramp and crossroad. This type of terminal is addressed by the predictive method. A terminal where the ramp merges with (or diverges from) the crossroad as a speed-change lane is not addressed by the predictive method. Figures 19-8a and 19-8b illustrate these two terminal types.



a. Four-Leg Intersection and Three-Leg Intersection

b. Speed-Change Lane



c. Two Three-Leg Intersections and a Speed-Change Lane

Figure 19-8. Illustrative Ramp Terminals

If the crossroad intersects two ramps that are relatively near one another, there may be some question as to whether the two ramps are part of one intersection or two separate intersections (for the purpose of applying the predictive method). The following guidance is offered to help with this decision; however, some engineering judgment may also be required.

If the centerlines of the two ramps are offset by 75 ft or less, and they are configured to function as one intersection, then both ramps are considered to be part of the same intersection. This point is illustrated in Figure 19-8a for the left-side ramp and the right-side ramp at an interchange. Two intersections are shown in this figure.

If the two ramps are offset by more than 250 ft, then each ramp terminal is considered to form a separate intersection. This point is illustrated in Figure 19-8c for the left-side ramps at a four-quadrant partial cloverleaf B interchange. Two intersections are shown in this figure.

Occasionally, the ramp offset is between 75 and 250 ft. In this situation, engineering judgment is required to determine whether the two ramps function as one or two intersections. Factors considered in making this determination will include the intersection control, traffic volume level, traffic movements being served (see Figure 19-1), channelization, average queue length, and pavement markings. Higher volume conditions often dictate that the two ramps are controlled as one signalized intersection. Ramp offsets in this range are typically avoided for new designs.

A description of the following geometric design and traffic control features is needed to use the CMFs associated with the predictive model for crossroad ramp terminals:

- Ramp terminal configuration, as described in Figure 19-1.
- *Ramp terminal control type (signal, one-way stop control, all-way stop control)*—The predictive models are calibrated to address signal control and one-way stop control, where the ramp is stop controlled. An interim predictive model is provided in Section 19.10 for all-way stop control.
- *Presence of a non-ramp public street leg at the terminal (signal control)*—This situation occurs occasionally. When it does, the public street leg is opposite from one ramp, and the other ramp either does not exist or is located at some distance from the subject ramp terminal such that it is not part of the terminal. This information is needed only for signalized terminals.
- *Exit ramp skew angle (one-way stop control)*—Skew angle equals 90 minus the intersection angle (in degrees). These angles are shown in Figure 19-9. The intersection angle is the acute angle between the crossroad centerline and a line along the center of an imaginary vehicle stopped at the end of the ramp (i.e., where it joins the crossroad). The vehicle is centered in the traveled way and behind the stop line. If vehicles can exit the ramp as left- or right-turn movements, then use a left-turning vehicle as the vehicle of reference. This information is needed only for terminals with one-way stop control. At a *B4* terminal configuration, the skew angle represents that for the diagonal exit ramp (not the loop exit ramp).

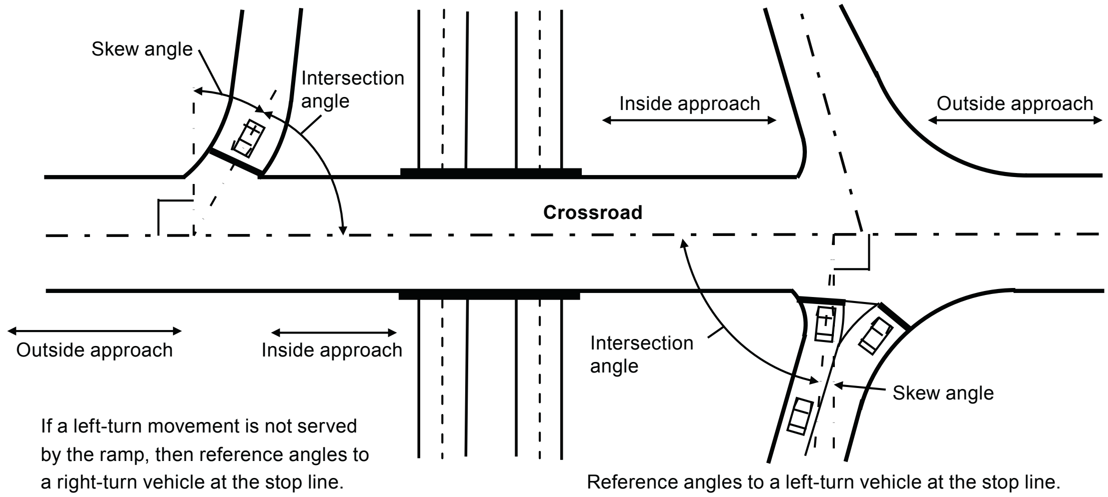


Figure 19-9. Exit Ramp Skew Angle

- *Distance to the next public street intersection on the outside crossroad leg*—This data element represents the distance between the subject ramp terminal and the nearest public street intersection located in a direction away from the freeway (measured along the crossroad from subject terminal center to intersection center).

- *Distance to the adjacent ramp terminal*—This data element represents the distance between the subject ramp terminal and the adjacent ramp terminal (measured along the crossroad from terminal center to terminal center). If there is no adjacent ramp terminal, then use the distance to the next public street intersection (located on the crossroad in the direction opposite to the intersection described in the previous bullet).
- *Presence of protected left-turn operation (signal control)*—This information is needed for each crossroad left-turn movement that exists at the terminal. An affirmative response is indicated if the left-turn operates as protected only. If it operates as permissive or protected-permissive, then the response is negative. This information is needed only for signalized terminals.
- *Exit ramp right-turn control type*—This information is needed only for the exit ramp (at terminals with an exit ramp). It is focused on the right-turn movement, which may have a different control type than the left-turn movement. Control types considered include: free flow, merge, yield, stop, and signal (where free-flow and merge operation are recognized to represent "no control"). The free-flow type is associated with an accepting (or auxiliary) lane on the crossroad for the right-turn movement. The merge type is associated with a speed-change lane for the right-turn movement.
- *Crossroad median width*—This width is measured along a line perpendicular to the centerline of the crossroad in the vicinity of the intersection. If no median exists, then a width of 0.0 ft is used in the predictive model. If a raised curb is present, then the width is measured from face-of-curb to face-of-curb. If a raised curb is not present, then the width is measured between the near edge of traveled way for the two opposing travel directions. If a left-turn bay is present, then the median width includes the width of the left-turn bay. It is measured from the lane line delineating the bay to the face-of-curb adjacent to (or the near edge of traveled way for) the opposing travel direction. If the median width is different on the two crossroad legs, then use an average of the two widths.
- *Number of through lanes on the inside crossroad approach*—Number of lanes (shared or exclusive) serving through traffic on the crossroad approach that is nearest to the freeway (i.e., the inside approach), as shown in Figure 19-9. This variable includes only lanes that continue through the intersection. Count the lanes along the crosswalk (or the logical location of the crosswalk if it is not marked).
- *Number of through lanes on the outside crossroad approach*—Number of lanes (shared or exclusive) serving through traffic on the crossroad approach that is more distant from the freeway (i.e., the outside approach), as shown in Figure 19-9. This variable includes only lanes that continue through the intersection. Count the lanes along the crosswalk (or the logical location of the crosswalk if it is not marked).
- *Number of lanes on the exit ramp leg at the terminal*—Lanes can serve any movement (left, right, or through). If right-turn channelization is provided, then count the lanes at the last point where all exiting movements are joined (i.e., count at the channelization gore point). All lanes counted must be fully developed for 100 ft or more before they intersect the crossroad. If a lane's development length is less than 100 ft, then it is not counted as a lane for this application. The lane (or lanes) associated with the loop exit ramp at a *B4* terminal configuration are *not* included in this count.
- *Presence of right-turn channelization on the inside crossroad approach (signal control)*—This channelization creates a turning roadway that serves right-turn vehicles. It is separated from the intersection by a triangular channelizing island (delineated by markings or raised curb). The gore point at the upstream end of the island must be within 200 ft of the downstream stop line for right-turn channelization to be considered "present." If this distance exceeds 200 ft, then the right-turn movement is served by a ramp roadway that is separate from the intersection (i.e., it should be evaluated as a ramp). The right-turn movement can be free-flow, stop, or yield controlled. This information is needed only for signalized terminals.
- *Presence of right-turn channelization on the outside crossroad approach (signal control)*—The guidance provided in the previous bullet also applies to this variable. It is needed only for signalized terminals.
- *Presence of right-turn channelization on the exit ramp approach (signal control)*—The guidance provided in the previous bullet also applies to this variable. It is needed only for signalized terminals. The presence of right-turn channelization on the loop exit ramp at a *B4* terminal configuration is *not* considered when determining this input data.

- *Presence of a left-turn lane (or bay) on the inside crossroad approach*—The lane (or bay) can have one or two lanes. A lane (or bay) is considered to be present when it (a) is for the exclusive use of a turn movement, (b) extends 100 ft or more back from the stop line, and (c) ends at the intersection stop line.
- *Presence of a left-turn lane (or bay) on the outside crossroad approach*—The guidance provided in the previous bullet also applies to this variable.
- *Width of left-turn lane (or bay) on the inside crossroad approach*—This variable represents the total width of all lanes that exclusively serve turning vehicles on the subject approach. It is measured from the near edge of traveled way of the adjacent through lane to the near lane marking (or curb face) that delineates the median.
- *Width of left-turn lane (or bay) on the outside crossroad approach*—The guidance provided in the previous bullet also applies to this variable.
- *Presence of a right-turn lane (or bay) on the inside crossroad approach*—The lane (or bay) can have one or two lanes. A lane (or bay) is considered to be present when it (a) is for the exclusive use of a turn movement, (b) extends 100 ft or more back from the stop line, and (c) satisfies one of the following rules:
    - If the bay or turn lane does not have island channelization at the intersection, then it must end at the intersection stop line.
    - If the bay or turn lane has island channelization at the intersection, then the bay or turn lane must have (a) stop, yield, or signal control at its downstream end, and (b) an exit gore point that is within 200 ft of the intersection.
- *Presence of a right-turn lane (or bay) on the outside crossroad approach*—The guidance provided in the previous bullet also applies to this variable.
- *Number of driveways on the outside crossroad leg (signal control)*—This number represents the count of unsignalized driveways on the outside crossroad leg and within 250 ft of the ramp terminal. The count is taken on both sides of the leg (i.e., it is a two-way total). The count should only include "active" driveways (i.e., those driveways with an average daily volume of 10 veh/day or more). This information is needed only for signalized terminals.
- *Number of public street approaches on the outside crossroad leg*—This number represents the count of unsignalized public street approaches on the outside crossroad leg and within 250 ft of the ramp terminal. The count is taken on both sides of the leg (i.e., it is a two-way total). If a public street approach is present at the terminal, then it is not counted for this entry. Rather, it is identified as being present using the "Presence of a non-ramp public street leg at the terminal" data that was discussed previously.
- *AADT volume for the inside crossroad leg, AADT volume for the outside crossroad leg, AADT volume for each ramp leg*—The inside crossroad leg is the leg that is on the side of the ramp terminal nearest to the freeway. The outside crossroad leg is on the other side of the ramp terminal. The AADT of the loop ramp at a terminal with a either an *A4* or *B4* configuration is not needed (or used in the calculations).

19.5. RAMP SEGMENTS AND RAMP TERMINALS

This section consists of three subsections. Section 19.5.1 defines ramp segments, C-D road segments, and crossroad ramp terminals. Section 19.5.2 provides guidelines for segmenting the ramp or C-D road. The assignment of crashes to sites is discussed in Section 19.5.3.

19.5.1. Definition of Ramp Segment and Ramp Terminal

When using the predictive method, the ramps and C-D roads within the defined project limits are divided into individual sites. A site is a homogeneous ramp segment, a homogeneous C-D road segment, or a crossroad ramp terminal.

Four ramps and one C-D road are shown in Figure 19-10. This figure represents one side of an interchange. Each ramp is shown to consist of one segment. The C-D road is divided into five segments. The ramp segments are labeled R_{en1}, R_{en2}, R_{ex3}, and R_{ex4}. The C-D road segments are labeled CD_1 to CD_5. Two of the C-D road segments include a speed-change lane with a ramp. A third C-D road segment includes two speed-change lanes associated with the two loop ramps. The C-D road is not shown to have a weaving section; however, the predictive models can address C-D roads with or without a weaving section.

One crossroad ramp terminal is shown in Figure 19-10. It is labeled "*In*" and is noted to have an influence area that extends 250 ft in each direction along the crossroad and ramps. The terminal has four legs—two crossroad legs and two ramp legs. Given the presence of the loop ramps, it is likely that this terminal serves only right-turn maneuvers to and from the crossroad.

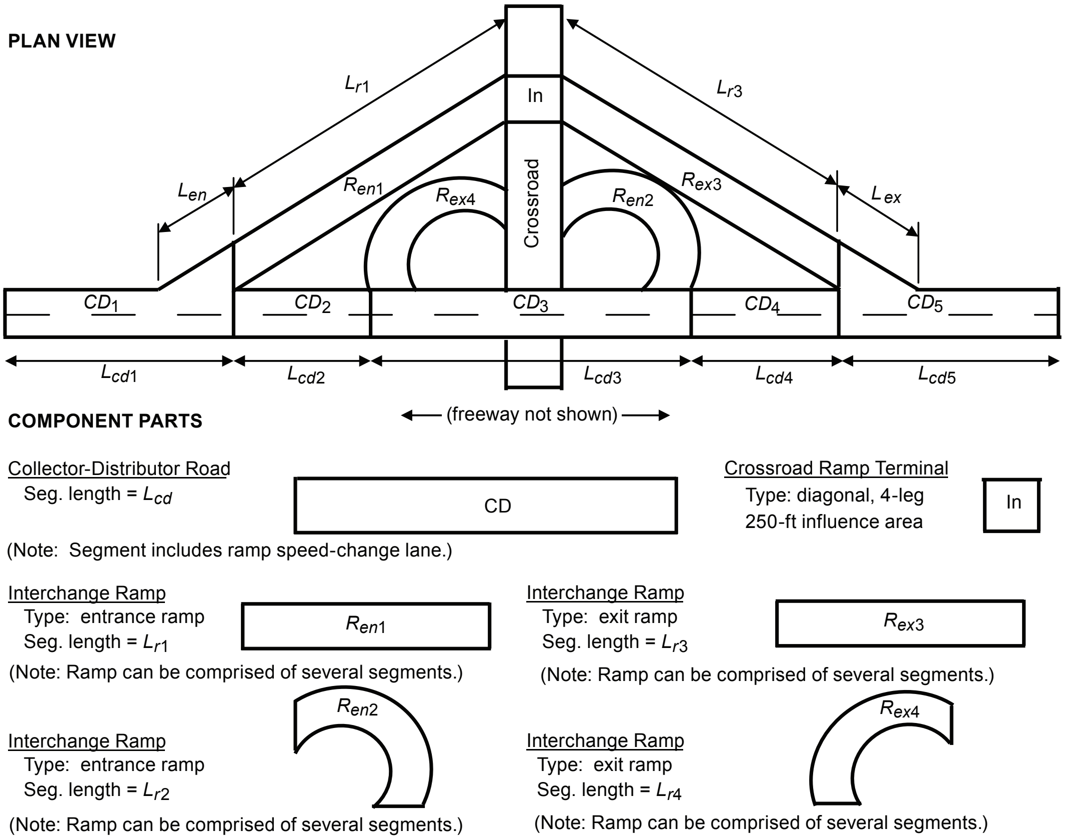


Figure 19-10. Illustrative Ramp Segments and Ramp Terminals

19.5.2 Segmentation Process

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

- *Number of through lanes*—Begin segment at the gore point if the lane is added or dropped at a ramp or C-D road. Begin segment at the upstream start of taper if the lane is added or dropped by taper. Guidance in this regard is described in the text accompanying Figure 19-3.
- *Lane width*—Measure the lane width at successive points along the roadway. Compute an average lane width for each point and round this average to the nearest 0.5 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 12.5 to 13.0 ft).

- *Right shoulder width*—Measure the right shoulder width at successive points along the roadway. Round the measured shoulder width at each point to the nearest 1.0 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 4 to 5 ft).
- *Left shoulder width*—Measure the left shoulder width at successive points along the roadway. Round the measured shoulder width at each point to the nearest 1.0 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 4 to 3 ft).
- *Merging ramp or C-D road presence*—Begin segment at the gore point.
- *Diverging ramp or C-D road presence*—Begin segment at the gore point.

The presence of a horizontal curve does not necessarily define ramp or C-D road segment boundaries. This approach represents a difference with the process described in Chaper 10, where a curve does define segment boundaries.

When a segment begins or ends at a crossroad ramp terminal, the length of the segment is measured from the near edge of the crossroad traveled way (shown as ramp-mile 0.0 in the lower half of Figure 19-4). When a segment begins or ends at a terminal formed by a merging or diverging ramp or C-D road, then the length of the segment is measured from the gore point, as shown in Figure 19-4. A ramp or C-D road segment can include no more than one ramp entrance (i.e., merge with a second ramp) and one ramp exit (i.e., diverge with a second ramp).

Guidance regarding the location of the lane and shoulder width measurement points is provided in Figure 19-4. Each width represents an average for the segment. The rounded lane and shoulder width values are used solely to determine segment boundaries. Once these boundaries are determined, the unrounded values for the segment are then used for all subsequent calculations in the predictive method.

19.5.3. Crash Assignment to Sites

Observed crash counts are assigned to the individual sites to apply the site-specific EB Method. Any crashes that occur on a ramp or C-D road are classified as either intersection-related or segment-related crashes. The intersection-related crashes are assigned to the corresponding crossroad ramp terminal. The predictive model for crossroad ramp terminals estimates the frequency of these crashes. The segment-related crashes are assigned to the corresponding ramp or C-D road segment. The ramp segment predictive model estimates the frequency of these crashes. The procedure for assignment of crashes to individual sites is presented in Section B.2.3 in Appendix B.

Speed-change lanes can occur at locations where ramp segments and C-D road segments connect, or where two ramp segments connect. For the predictive method, these speed-change lanes are considered to be part of the ramp or C-D road segment. Crashes occurring in these speed-change lanes are assigned to the segment.

19.6. SAFETY PERFORMANCE FUNCTIONS

When using the predictive method, the appropriate safety performance functions (SPFs) are used to estimate the predicted average crash frequency of a site with base conditions. Each SPF was developed as a regression model using observed crash data for a set of similar sites as the dependent variable. The SPFs, like all regression models, estimate the value of the dependent variable as a function of a set of independent variables. The independent variables for the ramp and C-D road segment SPFs include the segment AADT volume, segment length, and area type (i.e., rural or urban). The independent variables for the crossroad ramp terminal SPFs include the AADT volume of the intersection legs and area type. The SPFs in this chapter are summarized in Table 19-3.

Table 19-3. Ramp Safety Performance Functions

Site Type (*w*)	Cross Section and Control Type (*x*)	Crash Type (*y*)	SPF Equations
Ramp segments (*rps*)	Ramp entrance, *n* lanes (*nEN*)	Multiple vehicle (*mv*)	Equation 19-20
		Single vehicle (*sv*)	Equation 19-24
	Ramp exit, *n* lanes (*nEX*)	Multiple vehicle (*mv*)	Equation 19-20
		Single vehicle (*sv*)	Equation 19-24
C-D road segments (*cds*)	*n* lanes (*n*)	Multiple vehicle (*mv*)	Equation 19-22
		Single vehicle (*sv*)	Equation 19-26
Three-leg terminals with diagonal exit ramp (*D3ex*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28
Three-leg terminals with diagonal entrance ramp (*D3en*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28
Four-leg terminals with diagonal ramps (*D4*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28
Four-leg terminals at four-quadrant partial cloverleaf A (*A4*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28
Four-leg terminals at four-quadrant partial cloverleaf B (*B4*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28
Three-leg terminals at two-quadrant partial cloverleaf A (*A2*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28
Three-leg terminals at two-quadrant partial cloverleaf B (*B2*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28

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

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

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

19.6.1. Safety Performance Functions for Ramp Segments

The SPFs for ramp and C-D road segments are presented in this section. Specifically, SPFs are provided for ramp and C-D road segments with 1 or 2 through lanes. The range of AADT volume for which these SPFs are applicable is shown in Table 19-4. Application of the SPFs to sites with AADT volumes substantially outside these ranges may not provide reliable results.

Table 19-4. Applicable AADT Volume Ranges for Ramp SPFs

Area Type	Cross Section (Through Lanes) (x)	Applicable AADT Volume Range (veh/day)
Rural	1	0 to 7,000
Urban	1	0 to 18,000
	2	0 to 32,000

Other types of ramp and C-D road segments may be found at interchanges, but they are not addressed by the predictive model described in this chapter.

Multiple-Vehicle Crashes on Ramp Segments

The base conditions for the SPFs for multiple-vehicle crashes on ramp segments are presented in the following list (the variables are defined in Section 19.4.2):

- Length of horizontal curve 0.0 mi (i.e., not present)
- Lane width 14 ft
- Right shoulder width (paved) 8 ft
- Left shoulder width (paved) 4 ft
- Length of right-side barrier 0.0 mi (i.e., not present)
- Length of left-side barrier 0.0 mi (i.e., not present)
- Length of lane add or drop 0.0 mi (i.e., not present)
- Length of ramp speed-change lane 0.0 mi (i.e., not present)

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

$$N_{spf,\,rps,x,mv,z} = L_r \times \exp\left(a + b \times \ln[c \times AADT_r] + d[c \times AADT_r]\right) \quad (19\text{-}20)$$

Where:

$N_{spf,\,rps,\,x,\,mv,\,z}$ = predicted average multiple-vehicle crash frequency of a ramp segment with base conditions, cross section x ($x = nEN$: n-lane entrance ramp, nEX: n-lane exit ramp), and severity z ($z = fi$: fatal and injury, pdo: property damage only) (crashes/yr);

L_r = length of ramp segment (mi);

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

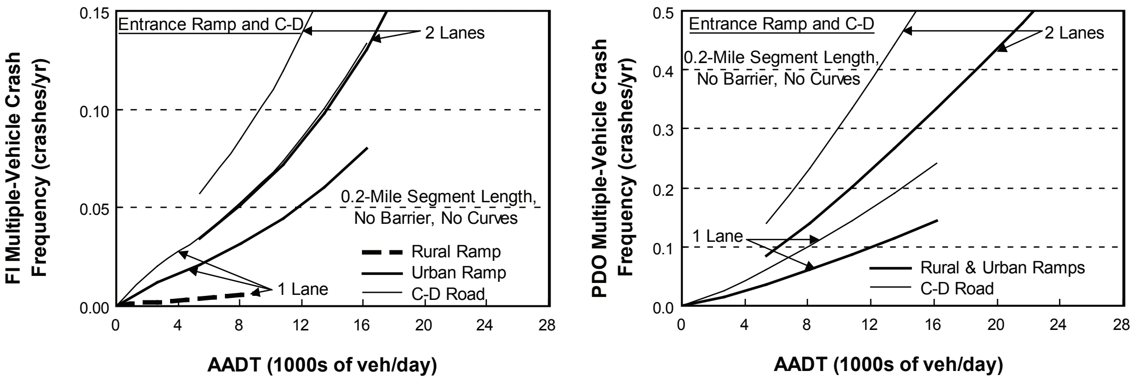
a, b, d = regression coefficients; and

c = AADT scale coefficient.

The SPF coefficients and inverse dispersion parameter are provided in Table 19-5. The SPFs are illustrated in Figure 19-11 and Figure 19-12.

Table 19-5. SPF Coefficients for Multiple-Vehicle Crashes on Ramp Segments

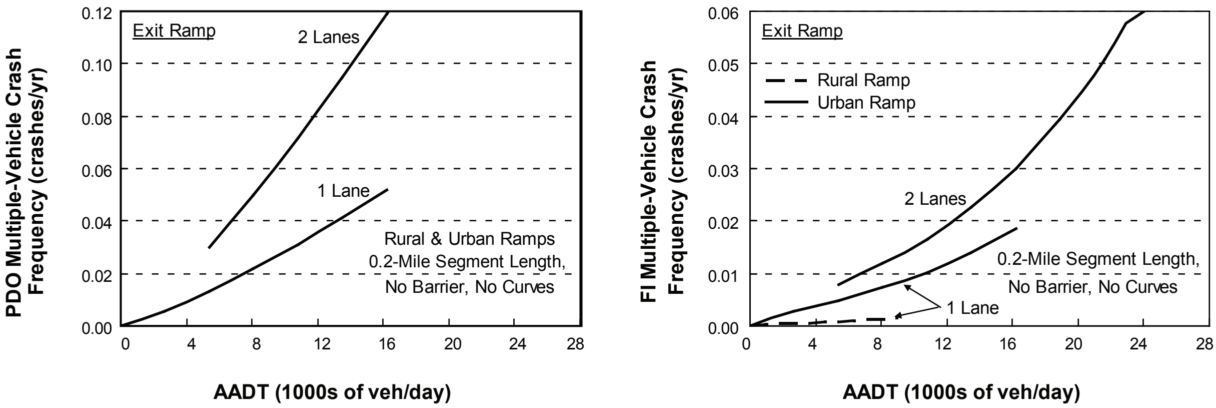
Crash Severity (z)	Area Type	Cross Section (x)	SPF Coefficient a	b	c	d	Inverse Dispersion Parameter $K_{rps, x, mv, z}$ (mi^{-1})
Fatal and injury (*fi*)	Rural	One-lane entrance (*1EN*)	–5.226	0.524	0.001	0.0699	14.6
		One-lane exit (*1EX*)	–6.692	0.524	0.001	0.0699	14.6
	Urban	One-lane entrance (*1EN*)	–3.505	0.524	0.001	0.0699	14.6
		One-lane exit (*1EX*)	–4.971	0.524	0.001	0.0699	14.6
		Two-lane entrance (*2EN*)	–3.023	0.524	0.001	0.0699	14.6
		Two-lane exit (*2EX*)	–4.489	0.524	0.001	0.0699	14.6
Property damage only (*pdo*)	Rural	One-lane entrance (*1EN*)	–3.819	1.256	0.001	0.00	12.7
		One-lane exit (*1EX*)	–4.851	1.256	0.001	0.00	12.7
	Urban	One-lane entrance (*1EN*)	–3.819	1.256	0.001	0.00	12.7
		One-lane exit (*1EX*)	–4.851	1.256	0.001	0.00	12.7
		Two-lane entrance (*2EN*)	–2.983	1.256	0.001	0.00	12.7
		Two-lane exit (*2EX*)	–4.015	1.256	0.001	0.00	12.7



a. Fatal-and-Injury Crash Frequency

b. Property-Damage-Only Crash Frequency

Figure 19-11. Graphical Form of the SPFs for Multiple-Vehicle Crashes on Entrance Ramp Segments



a. Fatal-and-Injury Crash Frequency

b. Property-Damage-Only Crash Frequency

Figure 19-12. Graphical Form of the SPFs for Multiple-Vehicle Crashes on Exit Ramp Segments

The value of the overdispersion parameter associated with the SPFs for ramp segments is determined as a function of the segment length. This value is computed using Equation 19-21.

$$k_{rps,x,mv,z} = \frac{1.0}{K_{rps,x,mv,z} \times L_r} \tag{19-21}$$

Where:

$k_{rps,\,x,\,mv,\,z}$ = overdispersion parameter for ramp segments with cross section x, multiple-vehicle crashes mv, and severity z; and

$K_{rps,\,x,\,mv,\,z}$ = inverse dispersion parameter for ramp segments with cross section x, multiple-vehicle crashes mv, and severity z (mi^{-1}).

The crash frequency obtained from Equation 19-20 can be multiplied by the proportions in Table 19-6 to estimate the predicted average multiple-vehicle crash frequency by crash type category.

Table 19-6. Default Distribution of Multiple-Vehicle Crashes by Crash Type for Ramp and C-D Road Segments

		Proportion of Crashes by Severity	
Area Type	**Crash Type Category**	**Fatal and Injury**	**Property Damage Only**
Rural or urban	Head-on	0.015	0.009
	Right-angle	0.010	0.005
	Rear-end	0.707	0.550
	Sideswipe	0.129	0.335
	Other multiple-vehicle crashes	0.139	0.101

Multiple-Vehicle Crashes on C-D Road Segments

The base conditions for the SPFs for multiple-vehicle crashes on C-D road segments are the same as those for multiple-vehicle crashes on ramp segments, as described in the preceding subsection. One additional base condition for this SPF is that there is no weaving section present.

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

$$N_{spf,\,cds,n,mv,z} = L_{cd} \times \exp\left(a + b \times \ln[c \times AADT_c] + d[c \times AADT_c]\right) \tag{19-22}$$

Where:

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

L_{cd} = length of C-D road segment (mi); and

$AADT_c$ = AADT volume of C-D road segment (veh/day).

The SPF coefficients and inverse dispersion parameter are provided in Table 19-7. The SPFs are illustrated in Figure 19-11.

Table 19-7. SPF Coefficients for Multiple-Vehicle Crashes on C-D Road Segments

Crash Severity (z)	Area Type	Number of Through Lanes (n)	SPF Coefficient a	b	c	d	Inverse Dispersion Parameter $K_{cds, x, mv, z}$ (mi^{-1})
Fatal and injury (*fi*)	Rural	1	–4.718	0.524	0.001	0.0699	14.6
	Urban	1	–2.997	0.524	0.001	0.0699	14.6
		2	–2.515	0.524	0.001	0.0699	14.6
Property damage only (*pdo*)	Rural	1	–3.311	1.256	0.001	0.00	12.7
	Urban	1	–3.311	1.256	0.001	0.00	12.7
		2	–2.475	1.256	0.001	0.00	12.7

The value of the overdispersion parameter associated with the SPFs for C-D road segments is determined as a function of the segment length. This value is computed using Equation 19-23.

$$k_{cds,x,mv,z} = \frac{1.0}{K_{cds,x,mv,z} \times L_{cd}} \tag{19-23}$$

Where:

$k_{cds, x, mv, z}$ = overdispersion parameter for C-D road segments with cross section x, multiple-vehicle crashes mv, and severity z; and

$K_{cds, x, mv, z}$ = inverse dispersion parameter for C-D road segments with cross section x, multiple-vehicle crashes mv, and severity z (mi^{-1}).

The crash frequency obtained from Equation 19-22 can be multiplied by the proportions in Table 19-6 to estimate the predicted average multiple-vehicle crash frequency by crash type category.

Single-Vehicle Crashes on Ramp Segments

With one exception, the base conditions for the SPFs for single-vehicle crashes on ramp segments are the same as those for multiple-vehicle crashes on ramp segments, as described in a preceding subsection. The "ramp speed-change lane presence" condition does not apply to the single-vehicle SPFs.

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

$$N_{spf,rps,x,sv,z} = L_r \times \exp\left(a + b \times \ln[c \times AADT_r]\right) \tag{19-24}$$

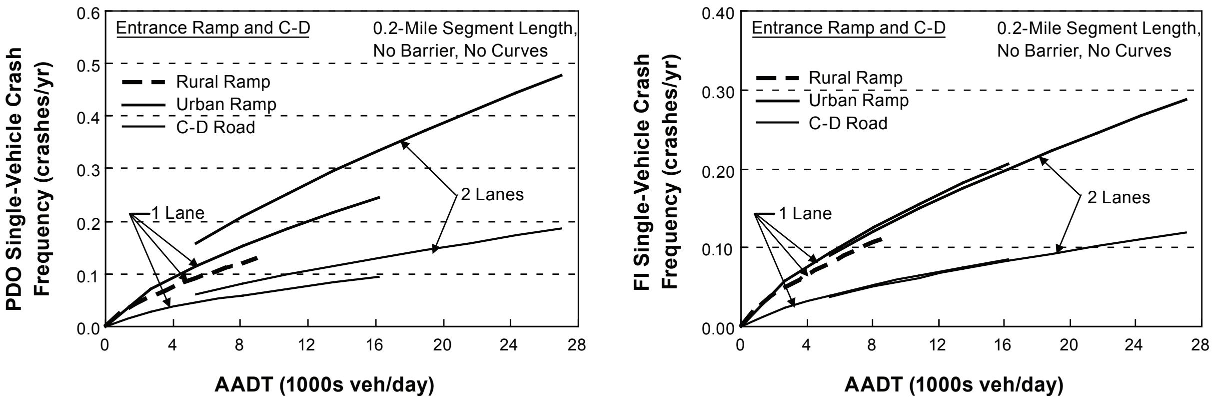
Where:

$N_{spf, rps, x, sv, z}$ = predicted average single-vehicle crash frequency of a ramp segment with base conditions, cross section x (x = nEN: n-lane entrance ramp, nEX: n-lane exit ramp), and severity z (z = fi: fatal and injury, pdo: property damage only) (crashes/yr).

The SPF coefficients and inverse dispersion parameter are provided in Table 19-8. The SPFs are illustrated in Figure 19-13 and Figure 19-14.

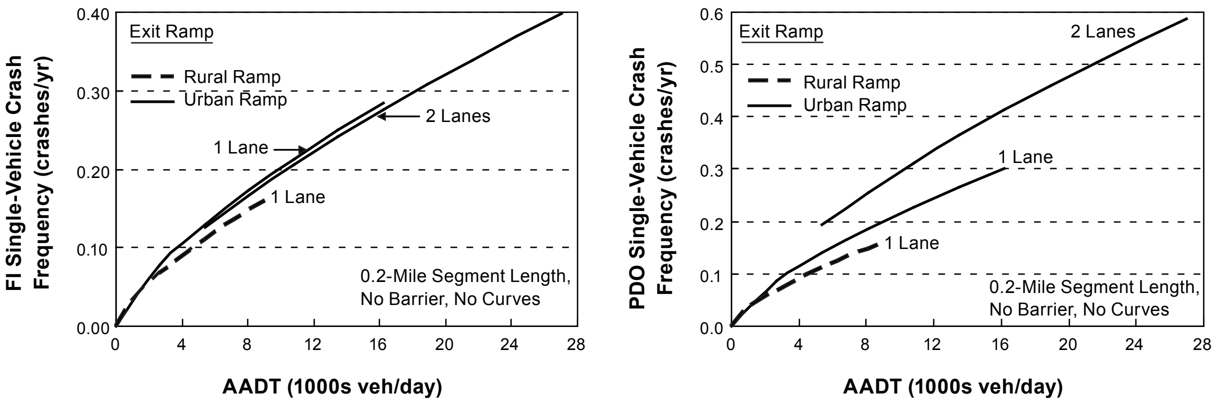
Table 19-8. SPF Coefficients for Single-Vehicle Crashes on Ramp Segments

Crash Severity (z)	Area Type	Cross Section (x)	SPF Coefficient a	SPF Coefficient b	SPF Coefficient c	Inverse Dispersion Parameter $K_{rps,x,sv,z}$ (mi^{-1})
Fatal and injury (*fi*)	Rural	One-lane entrance (*1EN*)	–2.120	0.718	0.001	7.91
		One-lane exit (*1EX*)	–1.799	0.718	0.001	7.91
	Urban	One-lane entrance (*1EN*)	–1.966	0.718	0.001	7.91
		One-lane exit (*1EX*)	–1.645	0.718	0.001	7.91
		Two-lane entrance (*2EN*)	–1.999	0.718	0.001	7.91
		Two-lane exit (*2EX*)	–1.678	0.718	0.001	7.91
Property damage only (*pdo*)	Rural	One-lane entrance (*1EN*)	–1.946	0.689	0.001	9.77
		One-lane exit (*1EX*)	–1.739	0.689	0.001	9.77
	Urban	One-lane entrance (*1EN*)	–1.715	0.689	0.001	9.77
		One-lane exit (*1EX*)	–1.508	0.689	0.001	9.77
		Two-lane entrance (*2EN*)	–1.400	0.689	0.001	9.77
		Two-lane exit (*2EX*)	–1.193	0.689	0.001	9.77



a. Fatal-and-Injury Crash Frequency
b. Property-Damage-Only Crash Frequency

Figure 19-13. Graphical Form of the SPFs for Single-Vehicle Crashes on Entrance Ramp Segments



a. Fatal-and-Injury Crash Frequency
b. Property-Damage-Only Crash Frequency

Figure 19-14. Graphical Form of the SPFs for Single-Vehicle Crashes on Exit Ramp Segments

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The value of the overdispersion parameter associated with the SPFs for ramp segments is determined as a function of the segment length. This value is computed using Equation 19-25.

$$k_{rps,x,sv,z} = \frac{1.0}{K_{rps,x,sv,z} \times L_r} \qquad (19\text{-}25)$$

Where:

$k_{rps,\,x,\,sv,\,z}$ = overdispersion parameter for ramp segments with cross section x, single-vehicle crashes mv, and severity z; and

$K_{rps,\,x,\,sv,\,z}$ = inverse dispersion parameter for ramp segments with cross section x, single-vehicle crashes mv, and severity z (mi^{-1}).

The crash frequency obtained from Equation 19-24 can be multiplied by the proportions in Table 19-9 to estimate the predicted average single-vehicle crash frequency by crash type category.

Table 19-9. Default Distribution of Single-Vehicle Crashes by Crash Type for Ramp and C-D Road Segments

		Proportion of Crashes by Severity	
Area Type	**Crash Type Category**	**Fatal and Injury**	**Property Damage Only**
Rural	Crash with animal	0.012	0.022
	Crash with fixed object	0.422	0.538
	Crash with other object	0.000	0.011
	Crash with parked vehicle	0.024	0.055
	Other single-vehicle crashes	0.542	0.374
Urban	Crash with animal	0.003	0.005
	Crash with fixed object	0.718	0.834
	Crash with other object	0.015	0.023
	Crash with parked vehicle	0.012	0.012
	Other single-vehicle crashes	0.252	0.126

Single-Vehicle Crashes on C-D Road Segments

With one exception, the base conditions for the SPFs for single-vehicle crashes on C-D road segments are the same as those for multiple-vehicle crashes on ramp segments, as described in a preceding subsection. The "ramp speed-change lane presence" condition does not apply to the single-vehicle SPFs. One additional base condition for this SPF is that there is no weaving section present.

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

$$N_{spf,\,cds,n,sv,z} = L_{cd} \times \exp\left(a + b \times \ln[c \times AADT_c]\right) \qquad (19\text{-}26)$$

Where:

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

The SPF coefficients and inverse dispersion parameter are provided in Table 19-10. The SPFs are illustrated in Figure 19-13.