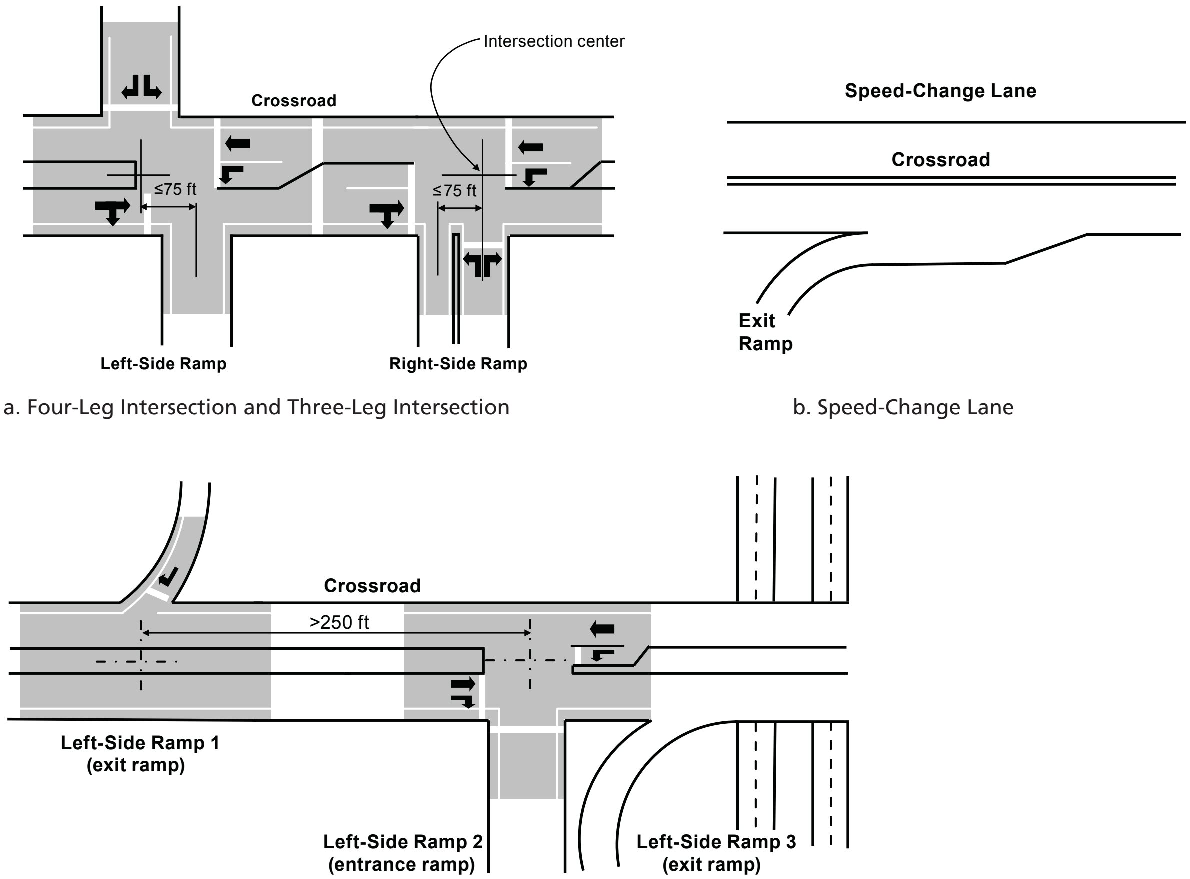
- *Length of weaving section located in the segment, between the segment's beginning and ending points*—This length cannot exceed the length of the segment. This length cannot exceed the length of the weaving section.

- 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).

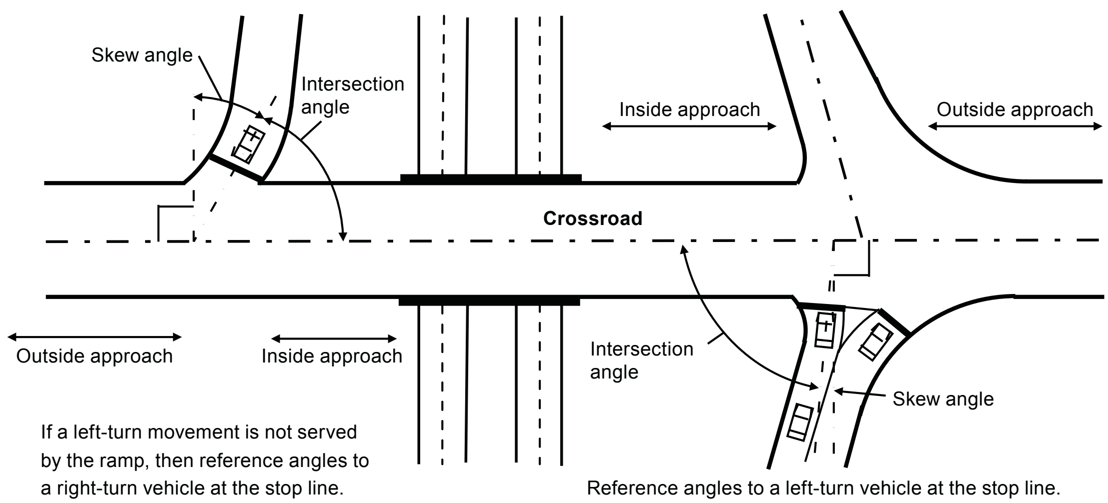


Figure 19-9. Exit Ramp Skew Angle

- *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.

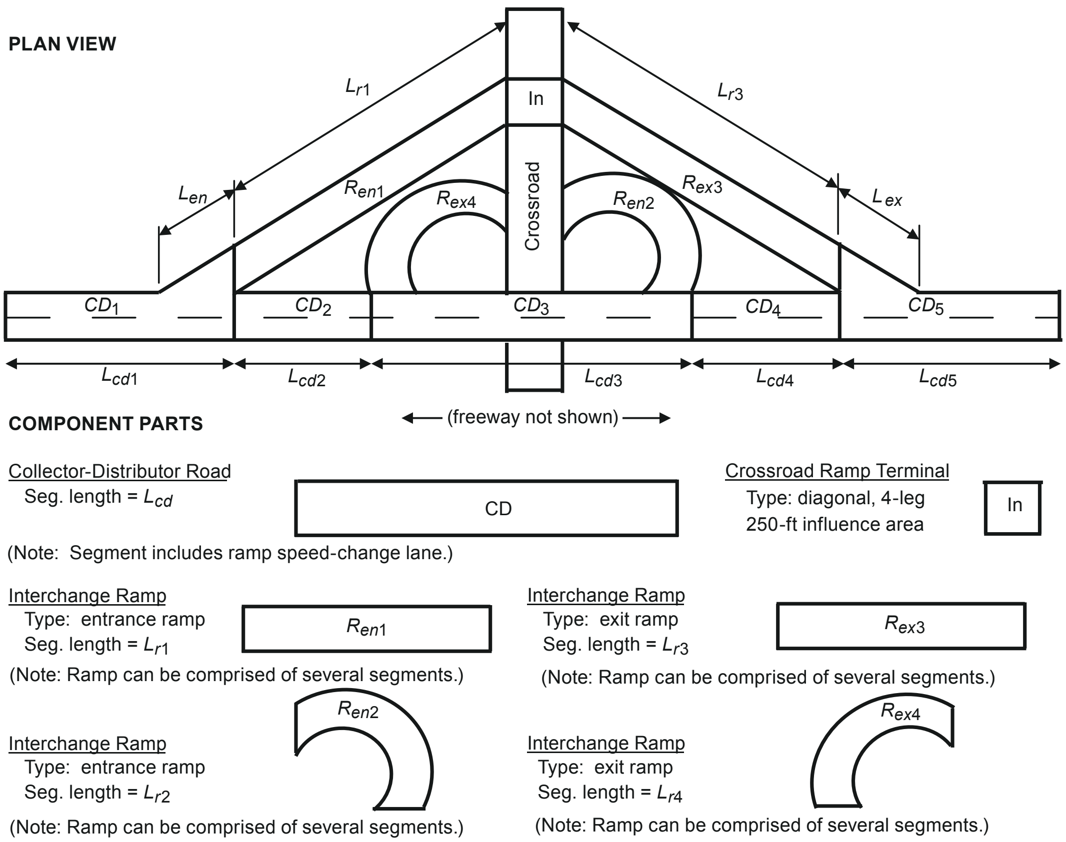


Figure 19-10. Illustrative Ramp Segments and Ramp Terminals

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:

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

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);

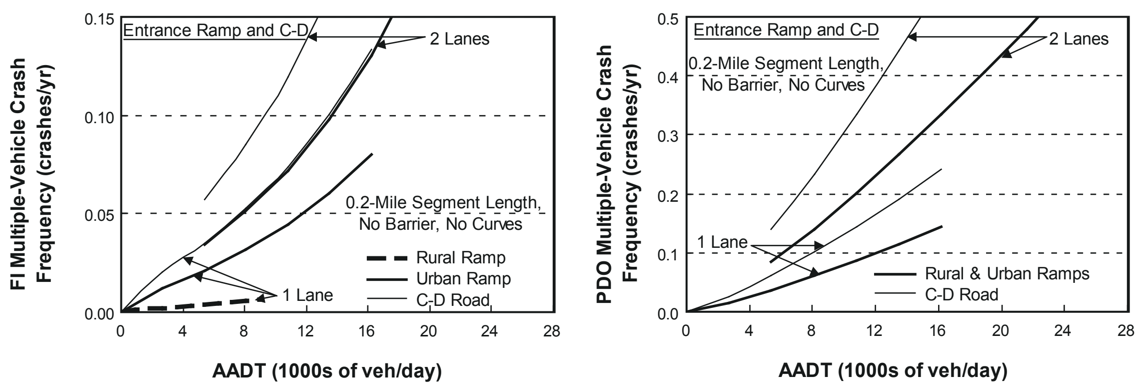
a, b, d = regression coefficients; and

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.

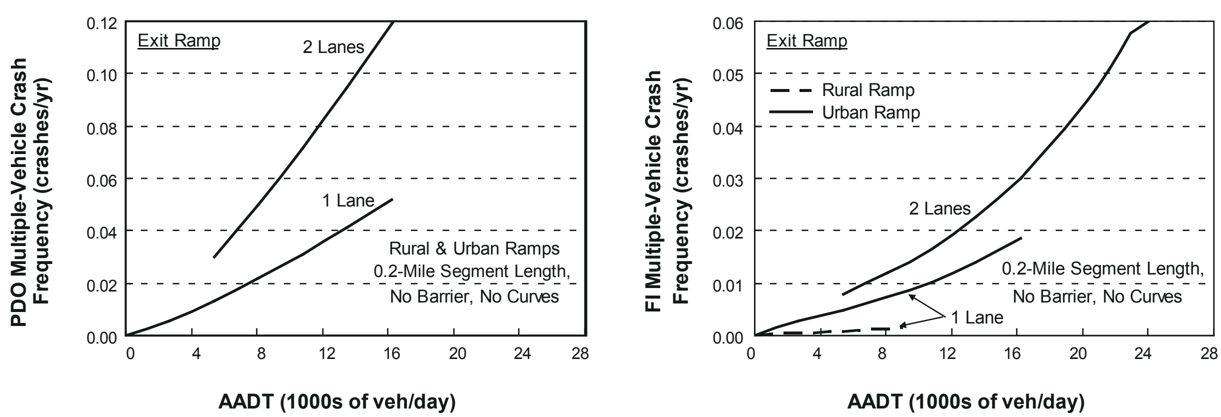
Table 19-5. SPF Coefficients for Multiple-Vehicle Crashes on Ramp Segments

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.