This appendix describes the findings from interviews with practitioners on the topic of freeway and interchange safety. The findings were used to identify design and operational elements that have a significant effect on safety and knowledge gaps. This information was used to develop a methodological framework for a freeway and interchange safety prediction methodology and analysis tool. The framework is described in Chapter 3.

OVERVIEW

The primary objectives of the interviews were to: (1) obtain a sense of the type of issues encountered in the design and operation of freeways and interchanges and (2) identify the safety-related information needed by practitioners during the project planning and development processes.

Three different groups were included in the interviews. One group included planners and engineers that were interviewed using a common set of questions. A second group included engineers at FHWA responsible for the review of interchange justification reports. A third group included engineers that have used ISAT to conduct an engineering analysis of interchange safety. The information obtained from each group is described in the next three subsections.

The interviews revealed that a key motivation for the development of ISAT was the request for an interchange safety evaluation tool by several FHWA division offices. These offices (notably the Illinois office) indicated that tools were needed to support the safety evaluation for interchange and access justification reports. These reports are required for all proposed changes in access to the Interstate Highway System and must be approved by FHWA.

INTERVIEWS WITH PLANNERS AND ENGINEERS

A primary source of safety information was the interviews with engineering and planning professionals. Both in-person and telephone interviews were conducted. In-person interviews were held with state DOT engineers in Alabama, Illinois, Maryland, and Washington. Telephone interviews were conducted with eighteen agencies representing FHWA field offices, state DOTs, and metropolitan planning organizations (MPO). The demographics of the agencies contacted for telephone interviews are listed in Table A-1. Collectively, 40 persons were interviewed in person and 22 persons were interviewed by telephone.

The in-person interviews typically took place over several hours and included engineers involved in freeway concept planning, preliminary design, final design, traffic operation, and safety programs. The telephone interviews were intentionally kept to about 30 minutes and typically included only one or two individuals. To adhere to this time limit, only a subset of the questions used in the in-person interviews were used for the telephone interviews. In a few instances, the interviewees opted to conduct the interview by e-mail.
TABLE A-1. Demographics of telephone interview groups

<table>
<thead>
<tr>
<th>Expertise</th>
<th>Agency Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FHWA Field Offices</td>
</tr>
<tr>
<td>Engineering</td>
<td>4</td>
</tr>
<tr>
<td>Planning</td>
<td>1</td>
</tr>
</tbody>
</table>

Each interview typically consisted of three parts. The duration of each part was adjusted depending on whether the interview was in-person or via telephone. Initially, a presentation was made by the researchers to provide background information. An overview of the project was provided and ISAT was described. Then, the questions in Figure A-1 were posed in sequence and the responses recorded. Most of these questions were intentionally broad to encourage discussion and a free flow of ideas. A subset of the questions was used for the telephone interviews. The specific questions asked during each telephone interview was varied in a predetermined manner to ensure an equal number of responses were received for each question.

Operational Issues
1. a. What are some common design problems or operational issues encountered in freeway projects?
   b. What are the safety concerns related to these problems or issues?
2. a. What are some common design problems or operational issues encountered in interchange projects?
   b. What are the safety concerns related to these problems or issues?
3. Are HOV or HOT lanes used? If yes, what are some common problems or issues encountered?

Decision-Making Process
4. Is there some official guidance that...
   a. Describes how to evaluate safety? or,
   b. How to determine when there is a safety problem?
5. How does crash severity influence decisions?

Level of Analysis Detail
6. For the planning stage of the project development process...
   a. Is it important to quantify the performance of the entire project? or
   b. Is it sufficient to evaluate a few select segments, ramps, or ramp terminals that are suspected of having issues?
7. For the design stage of the project development process...
   a. Is it important to quantify the performance of the entire project? or
   b. Is it sufficient to evaluate a few select segments, ramps, or ramp terminals that are suspected of having issues?

Evaluation Tools or Techniques
8. What simulation models are used to evaluate traffic operation?
9. Were you aware of ISAT before today?
   a. If yes, are you having it used on your projects?
   b. What is the best thing about it?
   c. What could make it more useful?

Figure A-1. Questions posed during the interviews.
A final element of the interview was an interactive session where specific design or operational elements were posed and the interviewees were asked to provide a number indicating the importance of each element. The responses to the questions in Figure A-1 are summarized in the following sections.

**Interview Questions**

*Operational Issues*

The most commonly mentioned operational issue was freeway congestion. Its impact on crash frequency, manner of collision, and crash severity are of concern to many of the interviewees. The long-standing belief that capacity improvements lead to safety improvements was cited by some. However, a more quantitative understanding of this relationship appears to be desired. Another issue that was frequently cited was bringing an alignment into compliance with the latest design criteria through reconstruction. By implication, this process should improve safety; however, a few interviewees indicated a desire for information that can be used to quantify this improvement.

Topics that were mentioned often enough to be noteworthy include weaving section design and periodic maintenance pull-outs on urban freeways. Both elements are believed to have an influence on safety, but the relationship is undocumented.

About one-half of the interviewed agencies indicate that high-occupancy-vehicle (HOV) lanes are used in their state. Most of these agencies also have some high-occupancy-toll (HOT) mileage. A range of issues was cited but with little commonality among them. This trend appears to reflect the wide range of HOV lane designs that are being used in the various states. A couple of interviewees noted that the speed differential between the HOV and adjacent lanes was a safety concern, especially when trucks were allowed in the HOV lane. Another issue cited by more than one interviewee was the lack of a shoulder of sufficient width to protect a stalled vehicle or facilitate enforcement in many barrier-separated HOV lanes.

*Decision-Making Process*

This question was answered by the state DOT interviewees. The tools for safety evaluation and safety problem identification vary among the states. Some use a site’s crash rate for evaluation and compare it to statewide averages for similar facilities to determine problem locations. Other states use an index value for safety evaluation, where the index represents a mathematical combination of crash frequency, severity, and rate. A couple of states noted that they were using (or planning to use) safety performance functions instead of statewide crash rates or indices as a basis for identifying problem locations.

The severity of crashes is recognized as an important factor in evaluating the safety of a project or highway facility. Examples illustrating the consideration of severity typically focused on fatal crashes, or fatal crash rates. A couple of states indicated the use of a weighting system to compute a site’s severity index, where the weight given to each of the severity classes (K, A, B, C,
PDO) decreases in an exponential manner, with fatality (K) weighted highest and property-damage-only (PDO) given negligible or no weight.

**Level of Analysis Detail**

The planners and the engineers involved in concept planning described a need to evaluate the entirety of the project, regardless of whether the focus is cost, operations, or safety. Some interviewees indicated that the evaluation should reflect performance of the project over its design life. A similar sentiment was expressed by some engineers involved in preliminary design and final design; however, other engineers tended to have interest only in evaluating specific intersections, segments, or ramps.

**Evaluation Tools or Techniques**

Three simulation models were identified as being used to evaluate freeway segments or interchanges; they include: CORSIM, VISSIM, and SimTraffic. No one of these tools was mentioned notably more often than the other.

Fourteen of the 18 telephone interviewees were not aware of ISAT prior to the interview. Similarly, three of the four state DOTs participating in the in-person interviews were not aware of ISAT. Of those that were aware of ISAT, only one interviewee was aware of it having been used for an engineering project.

Given the limited prior awareness of ISAT, comments about its strengths and weaknesses were limited primarily to the participants of the in-person interviews (who had the benefit of a 30-minute ISAT presentation and demonstration). In this regard, it was offered that ISAT looked easy to use. There was some concern about the need for local calibration of the many safety performance functions in ISAT. Also, its ability to model only four ramp configurations (i.e., diamond, parclo, free-flow loop, and directional) was seen as a limitation. A lack of sensitivity to many geometric and operational design elements on the freeway, crossroad, and ramp (e.g., curve radius, weave section) was also seen as a limitation.

**Interactive Session Results**

During the interactive session, specific freeway and interchange elements were posed and the interviewees were asked to provide a number indicating the importance of each element. Specifically, they were asked to indicate: (1) the frequency with which an element was discussed during the planning or project development processes and (2) the perceived influence of the element on safety. The response to each question was one of three numbers based on the following scale: 0 - never/none; 1 - sometimes/some; 2 - often/high. Thus, two “scores” were recorded for each element, one score for frequency and one score for influence.

The results of this session are shown in Tables A-2, A-3, and A-4 for freeway segments, interchange ramps, and interchange ramp terminals, respectively. The last column of each table indicates how the element ranked, relative to the other elements in the same table. The ranking is
based on the product of the two scores. An element that ranks with a “1” is considered most frequently and is believed to have the most influence on safety, relative to the other elements listed.

**TABLE A-2. Safety information needs for freeway segments**

<table>
<thead>
<tr>
<th>Category</th>
<th>Element 1</th>
<th>Rank 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadway</td>
<td>Lane width</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td><strong>Inside or outside shoulder width</strong></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Median width</td>
<td>9</td>
</tr>
<tr>
<td>Roadside</td>
<td>Clear recovery distance</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td><strong>Side slope</strong></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td><strong>Barrier length along embankments</strong></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Barrier type (say, to less rigid)</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Median barrier</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td><strong>Crash cushions at roadside features</strong></td>
<td>5</td>
</tr>
<tr>
<td>Roadside</td>
<td><strong>Horizontal curve radius</strong></td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Superelevation of horizontal curve</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Vertical grade</td>
<td>15</td>
</tr>
<tr>
<td>Other elements</td>
<td>Continuous shoulder rumble strips</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Highway illumination between interchanges</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td><strong>Distance between two ramps (e.g., weaving section)</strong></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>HOV lane(s)</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Use buffer-separation or barrier-separation for HOV lane</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>HOV lane entrance or exit frequency or location</td>
<td>17</td>
</tr>
<tr>
<td>Any</td>
<td>Other:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interchange spacing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lane drop (lane drop in curve)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Congestion extent or duration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Truck-only facilities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lane continuity along segment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ramp meter operation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tangent length between curves</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crest vertical curvature</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lane add</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median crossover</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lane balance at ramp ent. and exit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Signing consistency</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Barrier on curve (block sight lines)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shoulder use by bicyclists</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1- Top ranking elements are identified by bold font.
2- 1 = most frequently considered and believed to have most influence on safety.
TABLE A-3. Safety information needs for interchange ramps

<table>
<thead>
<tr>
<th>Category</th>
<th>Element</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadway</td>
<td>Ramp configuration (diamond, loop; direct, semidirect)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Lane width</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Inside or outside shoulder width</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Number of lanes</td>
<td>9</td>
</tr>
<tr>
<td>Roadside</td>
<td>Clear recovery distance</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Side slopes</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td><strong>Crash cushions at roadside features</strong></td>
<td>1</td>
</tr>
<tr>
<td>Alignment</td>
<td><strong>Horizontal curve radius</strong></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td><strong>Superelevation of horizontal curve</strong></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td><strong>Vertical grade</strong></td>
<td>4</td>
</tr>
<tr>
<td>Other elements</td>
<td>Ramp illumination</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Use of collector-distributor road</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Weaving length on collector-distributor road</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Ramp meter</td>
<td>14</td>
</tr>
<tr>
<td>Any</td>
<td>Other:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HOV bypass lane on entrance ramps</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1- Top ranking elements are identified by bold font.
2- 1 = most frequently considered and believed to have most influence on safety.

The number of responses that underlie a rank ranges from seven to ten, with nine being the most common. There was some variability in the responses for each element that reflects differences in opinion among the interviewees. Nevertheless, those elements in the top one-third of the rankings are consistently in the “more important” category for almost all interviewees. These elements have been identified in the table by bold font. Similarly, those elements in the bottom one-third of the rankings are consistently in the “less important” category for almost all interviewees.

The last row in each of the three tables lists other elements that were identified during the interviews. In each instance, one or more interviewees felt that safety information about the element listed would be helpful in their work.
### TABLE A-4. Safety information needs for interchange ramp terminal

<table>
<thead>
<tr>
<th>Category</th>
<th>Element 1</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway speed-change lane</td>
<td>Left-hand or right-hand ramp</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Lane length (sensitivity to truck percent, grade, no. of ramp lanes)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Ramp illumination</td>
<td>12</td>
</tr>
<tr>
<td>Crossroad speed-change lane</td>
<td>Provide (or not)</td>
<td>16</td>
</tr>
<tr>
<td>Crossroad ramp terminal</td>
<td>Interchange type (SPUI, diamond, parclo)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Intersection skew angle</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Left-turn lane or bay</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Right-turn lane or bay</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Left-turn lane length</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Right-turn lane length</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Outside shoulder width</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Intersection median width</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Sight distance restrictions</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Driveway presence on crossroad approaches to intersection</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Lane width</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Channelized (free) right-turn lane</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Illumination at terminal</td>
<td>7</td>
</tr>
<tr>
<td>Any</td>
<td>Other:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ramp entrance or exit on freeway curve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design or signing treatments to reduce wrong-way maneuvers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roundabout crossroad ramp terminal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Taper versus parallel entrance ramp</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Various (unnamed) pedestrian accommodations at terminals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ramp storage size to minimize queue spillback onto freeway</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grade of terminal approach</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
1- Top ranking elements are identified by bold font.
2- 1 = most frequently considered and believed to have most influence on safety.

### MEETING WITH FHWA ENGINEERS

The researchers met with engineers in FHWA’s Office of Infrastructure. This office has the responsibility of approving interchange justification reports and access justification reports. These reports have been required by FHWA since about the mid-1980s. In the early 1990s, FHWA’s policy for modifications to access to the Interstate Highway System was updated to require adherence to eight specific elements. The third element states that the proposed access point should “...not have a significant adverse impact on the safety and operation of the Interstate facility based on an analysis of current and future traffic.” This element provides the motivation for documenting the findings from a formal safety evaluation in the preparation of these reports.

Experience in reviewing justification reports indicates that the safety impacts of a proposed access point are often addressed through an assessment of its compliance with approved design
criteria. In many instances, capacity improvements made in conjunction with the new access are cited as having an indirect safety benefit through the alleviation of queue spillback or bottleneck. It was noted that some interchange or access justification reports are prepared at a time in the project development process where some design details have not been determined. This situation can limit the level of analysis detail.

Specific evaluation tools (e.g., ISAT or CORSIM) are not required for the safety or operations evaluation. The operations evaluation is only required when the freeway facility will experience congested flow conditions. The FHWA engineers estimated that these conditions are encountered in about one-half of the reports that they review. VISSIM is the most commonly used simulation tool used for operational evaluation. However, CORSIM is also often used and the Highway Capacity Manual methods are used in some situations.

There are three ingredients that FHWA desires in the safety evaluation for an interchange or access justification report. First, the evaluation should address the entire project, as opposed to just selected locations or components. Second, the evaluation should reflect consideration of the crash history in the most recent three-year period for which crash data are available. These data would be used to identify locations in the project area at which crashes are relatively frequent. Third, the report should describe the proposed changes such that the project will not have a significant adverse effect on safety.

The presence of HOV lanes on the freeway in the project vicinity is rarely a point of concern in the interchange or access justification report. Issues that have come up when reviewing these reports include: (1) the distance between the HOV entrance (or exit) and the nearest ramp terminal and (2) the speed differential between the HOV lane and adjacent through lane during peak traffic periods.

The FHWA engineers have not found many reports where ISAT has been used in the safety evaluation. They believe that this trend may be a result of its limited ability to model complicated ramps and interchanges. They suggested that its capability should be broadened so that it could be used to evaluate ramp-to-ramp junctions, combined system and service interchanges, and complicated ramp alignments (e.g., braided ramps).

INTERVIEWS WITH ISAT USERS

The purpose of the interviews with ISAT users was to determine the types of applications for which ISAT is being used and to identify any useful improvements that could be made to it. Eleven professionals were identified as potential ISAT users. They were identified in a variety of ways, including information provided by FHWA’s Office of Safety R&D and leads provided during the interviews with planners and engineers. Each potential user was contacted by e-mail and asked to provide some feedback on their ISAT experience. Only three persons indicated that they had experience using ISAT (a few did not reply and a few others indicated that they had ISAT but have not had an occasion to use it).
One of the respondents used ISAT in preparation of an interchange justification report. The other respondents used it for environmental evaluations and planning studies. The stated benefits of using ISAT were:

- it can be used to evaluate a range of alternative interchange types, and
- it can predict crash frequency by severity.

Identified areas of potential technical improvement for ISAT include the ability to evaluate the following design elements and components:

- weaving section design,
- left-hand versus right-hand ramps,
- the length of the marked gore area,
- auxiliary lane addition, and
- sensitivity to level of service or volume-to-capacity ratio.

Identified areas of potential user-interface improvement for ISAT include:

- improved guidelines for model calibration, and
- ability to generate a user-friendly report of computed safety measures.
APPENDIX B

DATABASE ENHANCEMENT

As described in Chapter 4, the data maintained by three state DOTs provide the foundation for the database used for model calibration. These data describe road inventory information for the state highway system in each state. The highways are represented as a series of consecutive road segments with a homogenous cross section and a length ranging from 0.05 to 1.0 mi. The state data were acquired from the Highway Safety Information System (HSIS).

This appendix describes the process used to enhance the state data. Data enhancement consisted of using supplemental data sources to acquire additional data for each segment in the database.

This appendix consists of two parts. The first part describes the procedural steps of the enhancement process. The second part summarizes the findings from a data verification activity that was undertaken to assess the consistency between data in a state database and that acquired from aerial photographs.

DATA ENHANCEMENT ACTIVITIES

The data enhancement activities focused on two tasks. One task was the development of data to describe for each segment the proportion of hours per day that are congested. Supplemental data were collected and used to derive this proportion for freeway segments. Automatic traffic recorder (ATR) data for the station nearest to each freeway segment were used for this purpose. These ATR data were acquired from the appropriate state agencies.

The second task of the data enhancement activity was the use of aerial photography to collect additional data for each segment or ramp terminal. These photographs were obtained from Google Earth. The data collected include the width of key cross section elements, barrier presence and location, horizontal curvature, ramp configuration, turn bay presence, and median type.

Data Extraction Process

A process was developed to partially automate the extraction of data from aerial photographs. The process is based on the digitization of roadway design elements using aerial photographs that are keyed to a geodetic coordinate system. Using this process, the road alignments, the road cross sections, the barrier pieces, and the speed-change lanes are all manually digitized. Software is used to process the digitized locations and compute the desired quantities.

Using this process, a technician digitizes the photograph of each segment, saves the measurement locations in a file, and submits the file to a computer program for error checking. At a later time, an engineer reviews the technician’s measurement locations by viewing them on the
digitized photo. He or she then submits the file to a second computer program that computes the desired variable values. This process is described in more detail in the following sections.

This process is used to digitize cross sections and alignments. When applied to alignments, the engineer digitizes the horizontal alignment of a length of roadway and saves the file of digitized locations. He or she then submits the file to a computer program that computes (1) the coordinates of each segment begin milepost and (2) the geometry of each horizontal curve.

Digitized locations along an alignment are saved in an “alignment file.” Digitized locations along a cross section are saved in a “segment file.” Details of these two files and the process by which they are assembled are provided in the next two sections.

Digitized Alignment File

Google Earth is used to develop the digitized alignment file. The start and end of an alignment is predetermined to include one or more target road segments, as well as the nearest interchange. Figure B-1 illustrates a digitized alignment for a 2.2-mile section of Interstate 5 in California.

The alignment shown in Figure B-1 consists of 29 “placemarks” located along the alignment. A placemark represents a point of known latitude and longitude. Each placemark is shown using a push-pin symbol. For this reason, placemarks are hereafter referred to as “pins.”

The digitizing process consists of three steps. During the first step, pins are located along the roadway reference line in the direction of increasing milepost. For freeway segments, this line is defined by the inside edge of traveled way for the increasing milepost direction. The pins are placed at the start of the alignment, the end of the alignment, and at a short spacing along each horizontal curve located between the start and end points. The maximum distance between pins along a curve is intentionally short such that errors in length measurement are negligible.

When the alignment file is complete, it is saved in keyhole markup language (kml) format (Wikipedia, 2010b). This format is an xml-based, standardized file structure for describing geographic annotation in Internet-based Earth browsers. A more complete description of this language is provided at the Google Earth website (KML, 2010).

During the second step, additional pins are placed along the alignment and saved in a second kml file. These pins correspond to known interchange gore points or intersections that are defined in the state database by milepost. Multiple gore points and intersections are located in this manner and then used to determine the milepost that corresponds to the start of the alignment file.

During the third step, additional pins are placed along the alignment and saved in the kml file established in the second step. These pins correspond to the begin milepost of each road segment in the roadlog database provided by HSIS. The location of a segment begin milepost is determined by computing the difference between it and that determined to correspond to the start of the alignment.
Each begin milepost pin is located at the computed distance, as measured along the alignment reference line.

**Figure B-1. Example digitized alignment.**

Steps two and three are automated using Earth Tools software developed for this project and described in a subsequent section.

The geodetic coordinates (i.e., latitude and longitude) of each segment begin (and end) milepost are determined through this process. In terms of defining a feature’s relative location on a common photograph, the standard error of these coordinates is about ±0.1 ft. Thus, the standard error for a lane width or curve length measurement is about ±0.14 ft. In terms of defining a feature’s true earth location, the standard error is about ±30 ft.

**Digitized Segment File**

Google Earth is used to develop the digitized segment file. The segment file is used to describe the cross section, barrier, and speed-change lanes on a given segment. One file is created for each segment. Figure B-2 illustrates a digitized 0.273-mile segment on Interstate 5 in California.
Figure B-2. Example digitized segment.

The segment shown in Figure B-2 consists of 59 pins located at key points along the alignment. One pin is used to define the begin milepost (i.e., 29.226) and one pin is used to define the end milepost (i.e., 29.499). One set of 14 pins are used to define the cross section elements (i.e., clear zone, outside shoulder, lane, inside shoulder, median, and median barrier widths) near the middle of the segment and another set of 14 pins are used to define the cross section at the end of the segment. A third set of pins are used to define the roadside barrier near the start of the segment (right roadbed) and that near the end of the segment (left roadbed). A fourth set of pins are used to define the gore points associated with the weaving section (left roadbed). A fifth set of pins are used to define the speed-change lane near the start of the segment (right roadbed).

The digitizing process consists of locating the pins for each design element present on the segment. In practice, one technician is tasked with locating the cross section pins. Another technician is tasked with locating the barrier pins. An engineer is tasked with locating the pins for speed-change lanes (and weaving sections) due to their greater complication.

All pins for a segment are saved in one kml file. The geodetic coordinates of each design feature are determined through this process. In terms of defining a feature’s relative location or length, the standard error of these coordinates is about ±0.1 ft.
Processing Software

Computer software was developed to process both the alignment and segment files. This processing included reading the kml file, diagnosing the pin placements, and computing the desired database variables. The software was written as a Visual Basic for Applications (VBA) macro in an Excel® spreadsheet. It was called Earth Tools. The welcome screen for Earth Tools is shown in Figure B-3.

![Figure B-3. Google Earth Calculation Tools welcome screen.](image)

The software includes a variety of tools useful to the researchers in developing or evaluating kml files. Each tool is provided its own spreadsheet, as accessed by the corresponding tab identified along the bottom of Figure B-3. Of particular note are the following tools:

- Curve Analysis
- Alignment
- Segment

The purpose of each of these tools is described in the following subsections.
Curve Analysis Tool

The Curve Analysis tool is used to compute the geometry of each horizontal curve represented in an alignment file. The tool computes the radius, deflection angle, chord, length of curve on a specified segment, curve begin milepost, and curve end milepost.

The tool converts the geodetic coordinates associated with each pin into earth-centered-earth-fixed (ECEF) Cartesian coordinates, and then into east-north-up (ENU) Cartesian coordinates (Wikipedia, 2010a). The ENU coordinates are desirable because they place the roadway in an $x$-$y$ plane where $x$ is east, $y$ is north, and $z$ represents elevation. The distance between any two pins is then computed using their $x$-$y$ coordinates (the error caused by ignoring the elevation change is negligible for the distances being measured). The relationship between the ECEF and ENU coordinate systems is shown in Figure B-4.

Curve radius is computed using an algorithm developed by Imram et al. (2006). This algorithm incorporates a non-linear regression procedure derived by Manthey (2010). The algorithm was adapted to use the pins in an alignment file (see Figure B-1). It can be used to compute the geometry of simple curves, two-centered compound curves, and three-centered compound curves. Geometric data are provided for each curve in a compound curve. A circular curve with spiral transitions is approximated as a compound curve and an average radius is computed for the spiral transition.

Figure B-4. Earth-Centered-Earth-Fixed and East-North-Up coordinate systems.
The accuracy of the computed curve geometry was evaluated using data from one state database. The computed radii were found to be within 4 percent of the reported radii. The computed deflection angles were found to be within 5 percent of the reported deflection angles. Further inspection of the data indicates that the larger deviations in either range occurs when the photograph quality is poor or when the curve can be characterized as having a short length and small deflection angle. Additional information about this evaluation is provided in the second part of this appendix.

Alignment Tool

The Alignment tool is used to compute the coordinates of user-specified mileposts. Typically, the mileposts of interest are those representing the begin milepost of a segment. The computations require an alignment file (as described previously) that includes the segment of interest. They also require the user to input the milepost of the starting point of the alignment. The Alignment tool then reads the file and defines the coordinates of the user-specified mileposts based on their distance along the reference line.

Once computed, the coordinates for each user-specified milepost are exported to a new kml file. This file can be loaded into Google Earth and the computed points displayed on an aerial photograph of the roadway. This type of display is shown in Figure B-5 for a section of road comprised of five segments.

Figure B-5. Display of computed begin mileposts for five segments.
Segment Tool

The Segment tool is used to diagnose the segment file and compute the desired database variables. It includes an extensive set of routines that check the completeness and logic of the pins placed in the segment file. If a file is determined to have missing pins or illogical pin placements, then an error message is displayed indicating the nature of the error and a suggested means of correction. If a file is determined to be error-free, then the computed values for specified variables are displayed in a manner suitable for inclusion in the safety database.

Table B-1 lists the variables computed from the segment files. The speed-change lane variables listed in the table are provided for up to four speed-change lanes per segment.

VERIFICATION OF SELECTED VARIABLES

Some of the data collected during the enhancement process were redundant to the data in the state databases. These data were used to verify the accuracy of the extracted data. The findings from this activity are described in this section. The objective of the verification process was to provide justification for using the enhancement process. It is not intended to suggest that state highway databases are inaccurate for their intended purposes.

The verification process is based on the graphical and statistical comparison of selected variables. For each variable, data were extracted from aerial photographs and checked following the process described in the previous part of this appendix. These variables are referred to as “measured” variables. They are then compared to identically defined data provided in the state database. These variables are referred to as “reported” variables.

Separate verification activities were undertaken for the cross section measurements and the alignment measurements. The findings from these two activities are described separately in the following two sections.
### TABLE B-1. Variables computed from segment file

<table>
<thead>
<tr>
<th>Category</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadway</td>
<td>inc_drop-add_lanes</td>
<td>Number of lane drops or adds on seg. for travel in increasing milepost</td>
</tr>
<tr>
<td></td>
<td>dec_drop-add_lanes</td>
<td>Number of lane drops or adds on seg. for travel in decreasing milepost</td>
</tr>
<tr>
<td></td>
<td>out_shld_meas</td>
<td>Outside shoulder width (average of both directions)</td>
</tr>
<tr>
<td></td>
<td>lane_meas</td>
<td>Lane width (average for all lanes in both directions)</td>
</tr>
<tr>
<td></td>
<td>in_meas</td>
<td>Width of both shoulders and median</td>
</tr>
<tr>
<td></td>
<td>in_shld_meas</td>
<td>Inside shoulder width (average of both directions)</td>
</tr>
<tr>
<td></td>
<td>med_width_meas</td>
<td>Width of median</td>
</tr>
<tr>
<td></td>
<td>med_nontrav_meas</td>
<td>Width of median barrier, if present</td>
</tr>
<tr>
<td>Roadside</td>
<td>med_type_meas</td>
<td>Median type (1 = raised curb, 2 = barrier, 3 = depressed or unsurfaced)</td>
</tr>
<tr>
<td></td>
<td>in_lane_barrier_len</td>
<td>Total length of barrier adjacent to the lane in median</td>
</tr>
<tr>
<td></td>
<td>in_shld_barrier_len</td>
<td>Total length of barrier adjacent to the shoulder in median</td>
</tr>
<tr>
<td></td>
<td>in_off_barrier_len</td>
<td>Total length of barrier offset from the shoulder in median</td>
</tr>
<tr>
<td></td>
<td>out_lane_barrier_len</td>
<td>Total length of barrier adjacent to the lane on roadside</td>
</tr>
<tr>
<td></td>
<td>out_shld_barrier_len</td>
<td>Total length of barrier adjacent to the shoulder on roadside</td>
</tr>
<tr>
<td></td>
<td>out_off_barrier_len</td>
<td>Total length of barrier offset from the shoulder on roadside</td>
</tr>
<tr>
<td></td>
<td>inc_clear_zone</td>
<td>Average clear zone width for travel in increasing milepost</td>
</tr>
<tr>
<td></td>
<td>dec_clear_zone</td>
<td>Average clear zone width for travel in decreasing milepost</td>
</tr>
<tr>
<td>Speed-Change Lane</td>
<td>sc_design</td>
<td>Design for speed-change lane (e.g., P=parallel, T=taper, etc.)</td>
</tr>
<tr>
<td></td>
<td>sc_type</td>
<td>Orientation of speed-change lane (e.g., entrance/exit, left/right side)</td>
</tr>
<tr>
<td></td>
<td>sc_lgt_on_seg</td>
<td>Length of speed-change lane on subject segment</td>
</tr>
<tr>
<td></td>
<td>sc_ramp_lanes</td>
<td>Number of lanes in the speed-change lane</td>
</tr>
<tr>
<td>Weaving Section</td>
<td>inc_A_lanes⁺</td>
<td>Number of lanes on freeway and ramps before weaving section</td>
</tr>
<tr>
<td></td>
<td>inc_C_lanes⁺</td>
<td>Number of lanes on freeway and ramps after weaving section</td>
</tr>
<tr>
<td></td>
<td>inc_D_lanes⁺</td>
<td>Number of lanes on right-side entrance ramp before weaving section</td>
</tr>
<tr>
<td></td>
<td>inc_E_lanes⁺</td>
<td>Number of lanes on right-side exit ramp after weaving section</td>
</tr>
<tr>
<td></td>
<td>inc_Lw⁺</td>
<td>Length of weaving section (gore to gore)</td>
</tr>
<tr>
<td></td>
<td>inc_wev_lgt_on_seg⁺</td>
<td>Length of weaving section on segment</td>
</tr>
<tr>
<td></td>
<td>dec_A_lanes⁻</td>
<td>Number of lanes on freeway and ramps before weaving section</td>
</tr>
<tr>
<td></td>
<td>dec_C_lanes⁻</td>
<td>Number of lanes on freeway and ramps after weaving section</td>
</tr>
<tr>
<td></td>
<td>dec_D_lanes⁻</td>
<td>Number of lanes on right-side entrance ramp before weaving section</td>
</tr>
<tr>
<td></td>
<td>dec_E_lanes⁻</td>
<td>Number of lanes on right-side exit ramp after weaving section</td>
</tr>
<tr>
<td></td>
<td>dec_Lw⁻</td>
<td>Length of weaving section (gore to gore)</td>
</tr>
<tr>
<td></td>
<td>dec_wev_lgt_on_seg⁻</td>
<td>Length of weaving section on segment</td>
</tr>
<tr>
<td>Other</td>
<td>ramp_exit_cnt</td>
<td>Count of ramp exit gore points adjacent to segment</td>
</tr>
<tr>
<td></td>
<td>ramp_ent_cnt</td>
<td>Count of ramp entrance gore points adjacent to segment</td>
</tr>
</tbody>
</table>

**Cross Section Elements**

The findings for selected ramp cross section variables are described first. Then, the findings for selected freeway segment cross section variables are described. Data associated with ramp lane count and lane width are shown in Figure B-6. Figure B-6a indicates that ramps with one lane were
correctly identified in the database as having one lane for 96 percent of the segments (4 percent of these segments were reported as having two lanes). Similarly, ramps with two lanes were correctly identified in the database as having two lanes for 86 percent of the segments (14 percent of these segments were reported as having one lane).

![Bar Chart](image1)

**Percent of Segments**

**Measured Number of Lanes**

**Reported Number of Lanes**

**Figure B-6. Ramp lane data comparison.**

- **Number of lanes.**

- **Lane width.**

Figure B-6b indicates a weak correlation between the measured ramp lane width and the lane width reported in the database. The figure indicates that there is considerable random variation in the error and the “best fit” trend line suggest that there is some bias (e.g., ramps measured to have 10-ft lane width, tend to be reported as having a 14-ft lane width). This type of bias is particularly problematic because it translates into biased regression coefficients.

From a statistical standpoint, random error in a variable can be overcome by increasing the sample size. Thus, it could be argued that using the entire state database (instead of just those segments that can be manually verified using data from aerial photographs or similar) would overcome the random variation shown in Figure B-6b. However, random variation in the independent variable of a regression model will bias the regression coefficients. Through simulation experiments, Weed and Barros (1987) found that significant variability in the independent variable causes bias in the regression model coefficients. This variability also increases the model’s residual error and makes the t-tests of model coefficients less efficient.

The findings from a comparison of ramp shoulder width are shown in Figure B-7. The random error is notable, as is the bias in the data.

The findings from a comparison of freeway median width and left (inside) shoulder width are shown in Figure B-8. Again, the random error and bias in the shoulder width data is notable. The median width does not appear to exhibit significant bias but the random error is large.
Horizontal Curve Geometry

Curve data for ramp and freeway segments in one state database were computed using the Curve Analysis tool and alignment files. The findings from the evaluation of the ramp curve data are shown in Figure B-9. Each data point shown represents one curve. The 28 curves included in this evaluation were randomly selected and rationalized to be representative.

The graphs shown (and statistics cited) in Figure B-9 indicate that there is good agreement between the measured and reported curve radius and deflection angle on ramps. The trend line shown in each graph is a line of “best fit” based on a linear regression analysis. The t-statistic for the slope of the regression line in Figure B-9a indicates that the slope is not significantly different from 1.0.
Also, the intercept for this line is not significantly different from 0.0. Similar results were found for the regression line coefficients shown in Figure B-9b.

**Figure B-9. Ramp curve geometry data comparison.**

A small number of data points in Figure B-9a indicate a notable difference of several hundred feet between the measured and reported radius values. A closer inspection of these points indicated that the difference may be due to the inclusion of short spiral transitions (or compound transition curvature with a short, large-radius curve) prior to a sharp curve on the ramp. Transition curves are difficult to visually detect from photographs, especially if they have a short length and small deflection angle. If they were not detected, the measured radius would represent an average value for the combined circular curve and transition curve.

A couple of the deflection angles shown in Figure B-9b indicate a notable difference of several degrees between the measured and reported values. An examination of the data indicated that the measured values from Curve Analysis Tool were in agreement with manually measured deflections taken directly from the aerial photograph with a protractor. It is recognized that photograph quality could explain a few degrees of deviation in extreme cases, but not the several degrees found for a couple of curves. It is believed that these curves have spiral transitions and that the deflection angle reported in the state database is for the circular portion of the curve, rather than the total deflection in the alignment.

The findings from the evaluation of the freeway curve data are shown in Figure B-10. Each data point shown represents one curve. The 26 curves included in this evaluation were randomly selected and rationalized to be representative.

The graphs shown (and statistics cited) in Figure B-10 indicate that there is good agreement between the measured and reported curve radius and deflection angle on freeway segments. The trend line shown in each graph is a line of “best fit” based on a linear regression analysis. The t-statistic for the slope of the regression line in Figure B-10a indicates that the slope is not
significantly different from 1.0. Also, the intercept for this line is not significantly different from 0.0. Similar results were found for the regression line coefficients shown in Figure B-10b.

\[ y = 0.925x + 0.7028 \]
\[ R^2 = 0.9486 \]

\[ y = 1.01x - 35.261 \]
\[ R^2 = 0.9965 \]

A few of the deflection angles shown in Figure B-10b indicate a difference of several degrees between the measured and reported values. The reasons for these deviations are the same as offered in the discussion of Figure B-9b.

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DRAFT HSM FREEWAYS CHAPTER
# CHAPTER 13—PREDICTIVE METHOD FOR FREEWAYS

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Chapter 13—Predictive Method for Freeways

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

The predictive method for freeways provides a structured methodology to estimate the expected average crash frequency (in total, or by crash type or severity) for a freeway with known characteristics. Crashes involving vehicles of all types are included in the estimate. The predictive method can be applied to an existing freeway, a design alternative for an existing freeway, a new freeway, or for alternative traffic volume projections. An estimate can be made of expected average crash frequency for a prior time period (i.e., what did or would have occurred) or a future time period (i.e., what is expected to occur). The development of the predictive method in Chapter 13 is documented by Bonneson et al. (1).

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

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

13.2. OVERVIEW OF THE PREDICTIVE METHOD
The predictive method provides an 18-step procedure to estimate the expected average crash frequency (in total, or by crash type or severity) for a roadway network, facility, or site. A site is a freeway segment or a freeway speed-change lane. A freeway speed-change lane is an uncontrolled terminal between a ramp and a freeway. It has a length along the freeway that is measured between the marked gore point and the taper point of the speed-change lane. The freeway lanes adjacent to the speed-change lane are considered part of the terminal area because of challenges in identifying (a) crashes in the lane associated with the ramp entrance or exit and (b) crashes specifically related to speed-change lane operation.
A facility consists of a contiguous set of individual sites. Different facilities are determined by the surrounding land use, roadway cross section, and degree of access. A roadway network consists of a number of contiguous facilities.

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

The predictive models used within the Chapter 13 predictive method are described in detail in Section 13.3. The predicted average crash frequency from a predictive model can be used as an estimate of the expected average crash frequency, or it can be combined with observed crash data (using the empirical Bayes [EB] Method) to obtain a more reliable estimate of the expected average crash frequency.

The predictive models used in Chapter 13 to determine the predicted average crash frequency are of the general form shown in Equation 13-1.

\[
N_{p, w, x, y, z} = N_{spf, w, x, y, z} \times (CMF_{1, w, x, y, z} \times CMF_{2, w, x, y, z} \times \ldots \times CMF_{m, w, x, y, z}) \times C_{w, x, y, z}
\]

Equation 13-1

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 features \( m \); 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, or by crash type or 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 ten 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.

### 13.3. Freeways—Definitions and Predictive Models

This section provides the definitions of the facility and site types included in Chapter 13. It also provides the predictive models for each of the site types.

#### 13.3.1. Definition of Freeway Facility and Site Types

The predictive method in Chapter 13 applies to the following freeway facilities: rural freeway segment with four to eight lanes, urban freeway segment with four to ten lanes, and freeway speed-change lanes associated with entrance ramps and exit ramps. Freeways have fully-restricted access control and grade separation with all intersecting roadways. Freeways are accessed only through grade-separated interchanges. Roads having at-grade access should be analyzed as rural highways or urban or suburban arterials. These facility types are addressed in Chapters 10, 11, and 12.
The terms “freeway,” “roadway,” and “road” are used interchangeably in this chapter and apply to all freeways independent of official state designation or local highway designation.

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

Table 13-1 identifies the freeway segment site types for which SPFs have been developed. These SPFs are used to estimate the predicted average crash frequency by crash type (i.e., multiple-vehicle, single-vehicle) and crash severity (i.e., fatal-and-injury, property-damage-only). These estimates are added to yield the total predicted average crash frequency for an individual site. The freeway segment SPFs are used to evaluate both freeway travel directions combined.

### Table 13-1. Freeway Segment SPFs

<table>
<thead>
<tr>
<th>Site Type (w)</th>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>SPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway segments (fs)</td>
<td>Four-lane divided (4)</td>
<td>Multiple vehicle (mv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, fs, 4, mv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, fs, 4, mv, pdo}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single vehicle (sv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, fs, 4, sv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, fs, 4, sv, pdo}$</td>
</tr>
<tr>
<td></td>
<td>Six-lane divided (6)</td>
<td>Multiple vehicle (mv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, fs, 6, mv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, fs, 6, mv, pdo}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single vehicle (sv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, fs, 6, sv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, fs, 6, sv, pdo}$</td>
</tr>
<tr>
<td></td>
<td>Eight-lane divided (8)</td>
<td>Multiple vehicle (mv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, fs, 8, mv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, fs, 8, mv, pdo}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single vehicle (sv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, fs, 8, sv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, fs, 8, sv, pdo}$</td>
</tr>
<tr>
<td></td>
<td>Ten-lane divided (10) (urban areas only)</td>
<td>Multiple vehicle (mv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, fs, 10, mv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, fs, 10, mv, pdo}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single vehicle (sv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, fs, 10, sv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, fs, 10, sv, pdo}$</td>
</tr>
</tbody>
</table>

The freeway segment is defined as follows:

- **Four-lane freeway segment (4)**—a length of roadway consisting of four lanes with a continuous cross section providing two directions of travel in which the opposing travel lanes are physically separated by either distance or a barrier.
- **Six-lane freeway segment (6)** — a length of roadway consisting of six lanes with a continuous cross section providing two directions of travel in which the opposing travel lanes are physically separated by either distance or a barrier.

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

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

Table 13-2 identifies the speed-change lane site types for which SPFs have been developed. These SPFs are used to estimate the predicted average crash frequency by crash severity (i.e., fatal-and-injury, property-damage-only). These estimates are added to yield the total predicted average crash frequency for an individual site. The speed-change lane SPFs are used to evaluate the speed-change lane with the adjacent freeway lanes (i.e., those lanes on the same side of the freeway as the speed-change lane).

### Table 13-2. Freeway Speed-Change Lane SPFs

<table>
<thead>
<tr>
<th>Site Type (w)</th>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>SPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed-change lanes (sc)</td>
<td>Ramp entrance to four-lane divided (4EN)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, sc, 4EN, at, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, sc, 4EN, at, pdo}$</td>
</tr>
<tr>
<td></td>
<td>Ramp entrance to six-lane divided (6EN)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, sc, 6EN, at, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, sc, 6EN, at, pdo}$</td>
</tr>
<tr>
<td></td>
<td>Ramp entrance to eight-lane divided (8EN)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, sc, 8EN, at, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, sc, 8EN, at, pdo}$</td>
</tr>
<tr>
<td></td>
<td>Ramp entrance to eight-lane divided (10EN) (urban areas only)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, sc, 10EN, at, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, sc, 10EN, at, pdo}$</td>
</tr>
<tr>
<td></td>
<td>Ramp exit from four-lane divided (4EX)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, sc, 4EX, at, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, sc, 4EX, at, pdo}$</td>
</tr>
<tr>
<td></td>
<td>Ramp exit from six-lane divided (6EX)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, sc, 6EX, at, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, sc, 6EX, at, pdo}$</td>
</tr>
<tr>
<td></td>
<td>Ramp exit from eight-lane divided (8EX)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, sc, 8EX, at, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, sc, 8EX, at, pdo}$</td>
</tr>
<tr>
<td></td>
<td>Ramp exit from eight-lane divided (10EX) (urban areas only)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, sc, 10EX, at, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, sc, 10EX, at, pdo}$</td>
</tr>
</tbody>
</table>
The speed-change lane is defined as a ramp entrance (EN) or ramp exit (EX). Its cross section is defined by the number of lanes in the freeway segment cross section adjacent to the speed-change lane (as defined previously for freeway segments).

### 13.3.2. Predictive Model for Freeway Segments

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

The predictive model for freeway segments is used to estimate the predicted average frequency of segment crashes (i.e., the estimate does not include speed-change-lane-related crashes). Speed-change-related crashes are defined in Section 13.3.3 and estimated using the predictive method described in that section.

The predictive model for freeway segments is presented in Equation 13-2 through Equation 13-6.

\[
N_{p, fs, n, at, as} = N_{p, fs, n, mv, fi} + N_{p, fs, n, sv, fi} + N_{p, fs, n, sv, pdo} + N_{p, fs, n, sv, pdo} \\
N_{p, fs, n, mv, fi} = C_{fs, ac, mv, fi} \times N_{spf, fs, n, mv, fi} \times \left( \text{CMF}_{1, fs, ac, mv, fi} \times \ldots \times \text{CMF}_{m, fs, ac, mv, fi} \right) \\
N_{p, fs, n, sv, fi} = C_{fs, ac, sv, fi} \times N_{spf, fs, n, sv, fi} \times \left( \text{CMF}_{1, fs, ac, sv, fi} \times \ldots \times \text{CMF}_{m, fs, ac, sv, fi} \right) \\
N_{p, fs, n, mv, pdo} = C_{fs, ac, mv, pdo} \times N_{spf, fs, n, mv, pdo} \times \left( \text{CMF}_{1, fs, ac, mv, pdo} \times \ldots \times \text{CMF}_{m, fs, ac, mv, pdo} \right) \\
N_{p, fs, n, sv, pdo} = C_{fs, ac, sv, pdo} \times N_{spf, fs, n, sv, pdo} \times \left( \text{CMF}_{1, fs, ac, sv, pdo} \times \ldots \times \text{CMF}_{m, fs, ac, sv, pdo} \right)
\]

Where:

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

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

- \( \text{CMF}_{m, fs, ac, y, z} \) = crash modification factor for a freeway segment with any number of lanes \( ac \), features \( m \), crash type \( y \) (\( y = sv \): single vehicle, \( mv \): multiple vehicle, \( at \): all types), and severity \( z \) (\( z = fi \): fatal and injury, \( pdo \): property damage only); and

- \( C_{fs, ac, y, z} \) = calibration factor for freeway segments with crash type \( y \) (\( y = sv \): single vehicle, \( mv \): multiple vehicle, \( at \): all types), and severity \( z \) (\( z = fi \): fatal and injury, \( pdo \): property damage only).
Equation 13-2 shows that freeway segment crash frequency is estimated as the sum of four components: fatal-and-injury multiple-vehicle crash frequency, fatal-and-injury single-vehicle crash frequency, property-damage-only multiple-vehicle crash frequency, and property-damage-only single-vehicle crash frequency.

Different CMFs are used in Equation 13-3 to Equation 13-6. The first term in parentheses in each equation recognizes that the influence of some geometric features is unique to each crash type. In contrast, the second term in parentheses in these equations recognizes that some geometric features have a similar influence on all crash types. All CMFs are unique to crash severity.

Equation 13-3 and Equation 13-4 are used to estimate the fatal-and-injury crash frequency. Equation 13-5 and Equation 13-6 are used to estimate the property-damage-only crash frequency.

The SPFs for freeway segments are presented in Section 13.6.1. The associated CMFs are presented in Section 13.7.1. Similarly, the associated SDFs are presented in Section 13.8. A procedure for establishing the value of the calibration factor is described in Part C, Appendix A.1.

13.3.3. Predictive Model for Freeway Speed-Change Lanes

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

The predictive model for ramp entrance speed-change lanes is presented in Equation 13-7 to Equation 13-9.

\[
N_{p, sc, nEN, at, z} = N_{p, sc, nEN, at, fi} + N_{p, sc, nEN, at, pdo} 
\]

\[
N_{p, sc, nEN, at, fi} = C_{sc, EN, at, fi} \times N_{pf, sc, nEN, at, fi} \times \left( CMF_{1, sc, nEN, at, fi} \times \ldots \times CMF_{m, sc, nEN, at, fi} \right) 
\]

\[
N_{p, sc, nEN, at, pdo} = C_{sc, EN, at, pdo} \times N_{pf, sc, nEN, at, pdo} \times \left( CMF_{1, sc, nEN, at, pdo} \times \ldots \times CMF_{m, sc, nEN, at, pdo} \right) 
\]

Where:

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

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

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

\(C_{sc, EN, at, z}\) = calibration factor for a ramp entrance speed-change lane with all crash types \(at\) and severity \(z\) (\(z = fi\): fatal and injury, \(pdo\): property damage only).
The predictive model for ramp exit speed-change lanes is presented in Equation 13-10 and Equation 13-12.

\[ N_{p, sc, nEX, at, z} = N_{p, sc, nEX, at, fi} + N_{p, sc, nEX, at, pdo} \]  
\[ N_{p, sc, nEX, at, fi} = C_{sc, EX, at, fi} \times N_{spf, sc, nEX, at, fi} \times (CMF_{1, sc, nEX, at, fi} \times \ldots \times CMF_{m, sc, nEX, at, fi}) \]  
\[ N_{p, sc, nEX, at, pdo} = C_{sc, EX, at, pdo} \times N_{spf, sc, nEX, at, pdo} \times (CMF_{1, sc, nEX, at, pdo} \times \ldots \times CMF_{m, sc, nEX, at, pdo}) \]

Where:

- \( N_{p, sc, nEX, at, z} \) is the predicted average crash frequency of ramp exit speed-change lane on a freeway with \( n \) lanes, all crash types \( at \), and severity \( z \) (\( z = fi: \) fatal and injury, \( pdo: \) property damage only, \( as: \) all severities) (crashes/yr);
- \( N_{spf, sc, nEX, at, z} \) is the predicted average crash frequency of a ramp exit speed-change lane on a freeway with base conditions, \( n \) lanes, all crash types \( at \), and severity \( z \) (\( z = fi: \) fatal and injury, \( pdo: \) property damage only) (crashes/yr); and
- \( C_{sc, EX, at, z} \) is the calibration factor for a ramp exit speed-change lane with all crash types \( at \) and severity \( z \) (\( z = fi: \) fatal and injury, \( pdo: \) property damage only).

Equation 13-7 and Equation 13-10 show that speed-change lane crash frequency is estimated as the sum of two components: predicted average fatal-and-injury crash frequency and predicted average property-damage-only crash frequency.

Different CMFs are used in Equation 13-8, Equation 13-9, Equation 13-11, and Equation 13-12. The first term in parentheses in each equation recognizes that the influence of some geometric features is unique to each speed-change lane type. In contrast, the second and third terms in parentheses in these equations recognizes that some geometric features have a similar influence on freeway segments as on speed-change lanes. All CMFs are unique to crash severity.

The SPFs for speed-change lanes are presented in Section 13.6.2. The associated CMFs are presented in Section 13.7.2. Similarly, the associated SDFs are presented in Section 13.8. A procedure for establishing the value of the calibration factor is described in Part C, Appendix A.1.

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

13.4.1. Step-by-Step Description of the Predictive Method
The predictive method for freeways is shown in Figure 13-1. Applying the predictive method yields an estimate of the expected average crash frequency (in total, or by crash type or severity) for a freeway facility or network. The components of the predictive models in Chapter 13 are determined and applied in Steps 9, 10, and 11 of the predictive method. The information to apply each step is provided in the following sections and in Appendix A of Part C.
Define roadway limits and facility type.

Define the period of study.

Determine AADT and availability of crash data for every year in the period of interest.

Determine geometric conditions.

Divide roadway into individual roadway segments and speed-change lanes.

Assign observed crashes to individual sites (if applicable).

Select a roadway segment or speed-change lane.

Select first or next year of the evaluation period.

Select and apply SPF.

Apply CMFs.

Apply a calibration factor.

Is there another year?

Apply site-specific EB method (if applicable) and apply SDF.

Is there another site?

Apply project-level EB method (if applicable).

Sum all sites and years.

Is there an alternative design, treatment, or forecast AADT to be evaluated?

Yes

Compare and evaluate results.

Figure 13-1. The HSM Predictive Method
There are 18 steps in the predictive method. In some situations, certain steps will not be needed because data are not available or the step is not applicable to the situation at hand. In other situations, steps may be repeated if an estimate is desired for several sites or for a period of several years. In addition, the predictive method can be repeated as necessary to undertake crash estimation for each alternative design, traffic volume scenario, or proposed treatment option (within the same time period to allow for comparison).

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

Step 1—Define the limits of the project for which the expected average crash frequency, severity, and crash types are to be estimated.
A project can be a freeway network, a freeway facility, or a site. A site is either a speed-change lane or a homogeneous freeway segment. A site is further categorized by its cross section. A description of the specific site types is provided in Section 13.3.

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

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 (based on observed AADT volumes) for:
  - An existing freeway network, facility, or site. If observed crash data are available, the study period is the period of time for which the observed crash data are available and for which (during that period) the site geometric design features, traffic control features, and traffic volumes are known.
  - An existing freeway network, facility, or site for which alternative geometric design features or traffic control features are proposed (for near-term conditions).

- A future period (based on forecast AADT volumes) for:
  - An existing freeway network, facility, or site for a future period where forecast traffic volumes are available.
An existing freeway network, facility, or site for which alternative geometric design or traffic control features are proposed for implementation in the future.

A new freeway network, facility, or site that does not currently exist but is proposed for construction during some future period.

**Step 3—For the study period, determine the availability of annual average daily traffic volumes and, for an existing 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 reported crash data are also acquired in this step.

**Determining Traffic Volumes**

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

For each freeway segment, five AADT values are required. They include the AADT volume of the freeway segment, AADT volume of the nearest entrance ramp upstream of (or in) the segment for both travel directions, and AADT volume of the nearest exit ramp downstream of (or in) the segment for both travel directions.

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

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

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

In many cases, it is expected that AADT data will not be available for all years of the evaluation period. In that case, an estimate of AADT volume for each 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 in which no data are available.

- 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 alternative conditions 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 A.2.1 in Appendix A to Part C.

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 A.2.2 in Appendix A to Part C.

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 13.4.2.

Step 5—Divide the roadway network or facility into individual homogeneous freeway segments and speed-change lanes, which are referred to as sites.

Using the information from Step 1 and Step 4, the freeway is divided into individual sites, consisting of individual homogeneous freeway segments and speed-change lanes. The procedure for dividing the freeway into individual segments is provided in Section 13.5.

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 using the criteria outlined in the next paragraph. Specific criteria for assigning crashes to individual freeway segments or speed-change lanes are presented in Section A.2.3 in Appendix A to Part C.

Speed-change-related crashes include all crashes that are located between the gore point and the taper point of a speed-change lane and that involve vehicles (a) in the speed-change lane or (b) in the freeway lanes on the same side of the freeway as the speed-change lane. Crashes that satisfy this definition are assigned to the speed-change lane. Crashes that do not satisfy this definition are assigned to the freeway segment on which they occur.

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

Steps 7 through 14 are repeated for each site within the project limits identified in Step 1.

Any site can be selected for evaluation because each site is considered to be independent of the other sites. However, good practice is to select the sites in an orderly manner, such as in the order of their physical occurrence in the direction of increasing milepost.
Step 8—For the selected site, select the first or next year in the period of interest. If there are no more years to be evaluated for that site, proceed to Step 13.
Steps 8 through 12 are repeated for each year in the evaluation period for the selected site.

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

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site type and features.
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 13.6.

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 to adjust base conditions to site-specific geometric design and traffic control features.
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 13.7.

All CMFs in Chapter 13 have the same base conditions as the SPFs used in Chapter 13. Only the CMFs presented in Section 13.7 may be used as part of the Chapter 13 predictive method.

For the selected site, determine the appropriate CMFs for the site type, 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 Chapter 13 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 Part C, Appendix A.1.1.

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 Part C, Appendix A.2.4.
The decision to apply the site-specific EB Method was determined in Step 3. If the EB Method is not used, then the 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 A.2.6 in Appendix A to Part C 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 13.8. 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 Part C, Appendix A.1.4.

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 13.6. 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 freeway segment or speed-change lane within the facility.

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

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

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 SPF s and some CMFs are dependent on AADT volume, which may change from year to year.

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

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

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

Step 16—Sum all sites and years in the study to estimate the expected average 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 13-13:

\[
N^*_e, aS, at, as = \sum_{j=1}^{ns} \left( \sum_{i=1}^{\text{all sites}} N_e, fr(i), n, at, as, j + \sum_{i=1}^{\text{all sites}} N_e, sc(i), nEN, at, as, j + \sum_{i=1}^{\text{all sites}} N_e, sc(i), nEX, at, as, j \right)
\]

Equation 13-13

Where:

\(N^*_e, aS, at, as\) = total expected number of crashes for all sites \(aS\) and all years in the study period (includes all crash types \(at\) and all severities \(as\)) (crashes);

\(N_e, fr(i), n, at, as, j\) = total expected average crash frequency of freeway segment \(i\) with \(n\) lanes for year \(j\) (includes all crash types \(at\) and all severities \(as\)) (crashes/yr);

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

\(N_e, sc(i), nEX, at, as, j\) = total expected average crash frequency of ramp exit speed-change lane \(i\) on a freeway with \(n\) lanes for year \(j\) (includes all crash types \(at\) and all severities \(as\)) (crashes/yr); and

\(ns\) = number of years in the study period (yr).

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

Equation 13-14 is used to estimate the total expected average crash frequency within the project limits during the study period.

\[
N^*_e, aS, at, as = \frac{N^*_e, aS, at, as}{ns}
\]

Equation 13-14

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

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

13.4.2. 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. The data are needed for each site selected for evaluation. They are described in the following list in terms of the values or descriptors needed by the model variables.

- Number of through lanes. The total number of through lanes at the beginning of the segment (in the direction of travel). Rural freeway segments are limited to eight lanes. Urban freeway segments are limited to ten lanes. A segment with a lane add (or lane drop) by taper is considered to have the same number of through lanes as the segment just downstream of the lane add (or lane drop) taper.

- Do not include in this number any high-occupancy vehicle (HOV) lanes.

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

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

- Length of freeway segment and speed-change lane (if present). Speed-change lane length is measured from the gore point to the taper point. Figure 13-2 illustrates these measurement points for a ramp entrance and a ramp exit speed-change lane with the parallel and taper design, respectively.
Presence of a horizontal curve on one or both roadbeds. If a curve is present, then the following data are needed:

- **Length of curve.** This length is measured along the inside edge of traveled way.
  - Curve length is measured from the point where the tangent ends and the curve begins (i.e., the PC) to the point where the curve ends and the tangent begins (PT).
  - If the curve 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 mileposts, 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.

- **Radius of curve.** If the curve has spiral transitions, then enter the radius of the central circular portion of the curve. The reference line used to measure curve radius is dependent on whether one or both roadbeds have curves, as follows:
  - One Direction. Measure to the inside edge of the traveled way of the roadbed associated with the curved roadbed.
  - Both Directions. Measure radius on the inside edge of the traveled way of the roadbed serving travel in the increasing milepost direction. In this case, the curves are assumed to be concentric.

- **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.

- **Widths of lanes, outside shoulders, inside shoulders, and median.** The first three elements represent an average for both roadbeds. These widths should be measured where the cross section is constant, such as along line A or B shown in Figure 13-3. They should not be measured where one or more edges are discontinuous or tapered. If a width varies continuously along the segment, then enter a length-weighted average width. Shoulder width represents the paved width. Median width is measured from the near edge of traveled way on one roadbed to the near edge of traveled way on the other roadbed.
Avoid measuring widths where one or more edges are discontinuous or tapered.

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

**Figure 13-3.** Measurement of Cross Section Data Elements

- Length of rumble strips on the inside (or median) shoulder and on the outside (or roadside) shoulder. Measured separately for each shoulder type and travel direction.

- Length of (and offset to) the barrier in the median and the barrier on the roadside. Measured for each short piece of barrier. Offset is also measured for barrier that continues for the length of the segment (and beyond). Each piece is represented once for a site. It is referenced to the nearest edge of traveled way.

- Figure 13-4 illustrates these measurements for two barrier elements protecting a sign support in a median with width $W_m$ and adjacent to shoulders with width $W_{is}$. Each barrier element has a portion of its length that is parallel to the roadway and a portion of its length that is tapered from the roadway. One way to evaluate these elements is to separate them into four pieces, as shown in Figure 13-4. Each piece is represented by its average offset $W_{off,in,i}$ and length $L_{ib,i}$. Alternatively, the analyst may recognize that the offset is the same for pieces 1 and 4 and for pieces 2 and 3. In this case, each pair can be combined by adding the two lengths (e.g., $L_{ib,1} + L_{ib,4}$) and using the common offset value.

- A barrier is associated with the freeway if the offset from the near edge of traveled way is 30 ft or less. Barrier adjacent to a ramp but also within 30 ft of the freeway traveled way should also be associated with the freeway. The determination of whether a barrier is adjacent to a speed-change lane or a ramp is based on the gore and taper points, as shown in Figure 13-3.

**Figure 13-4.** Barrier Variables

- Width of continuous median barrier, if present.
Presence and length of a Type B weaving section.

A Type B weaving section has the following characteristics: (a) one of the two weaving movements can be made without making any lane changes, (b) the other weaving movement requires at most one lane change, and (c) both the ramp entrance and ramp exit associated with the weaving section are located on the right side of the freeway. Typical Type B weaving sections are shown in Figure 13-5.

Weaving section length is measured along the edge of the freeway traveled way from the gore point of the ramp entrance to the gore point of the next ramp exit, as shown in Figure 13-5. The gore point is located where the pair of solid white pavement edge markings that separate the ramp from the freeway main lanes are 2.0 ft apart. If the markings do not extend to a point where they are 2.0 ft apart, then the gore point is found by extrapolating both markings until the extrapolated portion is 2.0 ft apart. If the measured gore-to-gore distance exceeds 0.85 mi (4,500 ft), then a weaving section is not considered to exist. Rather, the entrance ramp is a “lane add” and the exit ramp is a “lane drop.”

**Figure 13-5.** Type B Weaving Section and Length

Distance to nearest upstream entrance ramp in each travel direction.

Measure this distance from the segment boundary to the ramp gore point, along the freeway’s solid white pavement edge marking that intersects the gore point. The distance to the nearest upstream entrance ramp in each travel direction is shown in Figure 13-6 using the two variables \( X_{b, ent} \) and \( X_{e, ent} \). If the ramp entrance is located in the segment, then the corresponding distance is equal to 0.0 mi. If the ramp does not exist or is located more than 0.5 mi from the segment, then this distance can be set to a large value (i.e., 999) in the predictive method to obtain the correct results.

The gore point is located where the pair of solid white pavement edge markings that separate the ramp from the freeway main lanes are 2.0 ft apart. If the markings do not extend to a point where they are 2.0 ft apart, then the gore point is found by extrapolating both markings until the extrapolated portion is 2.0 ft apart.
Upstream exit ramps are not of direct interest, and data are not needed for them if they exist in the vicinity of the segment. Figure 13-6a shows an upstream exit ramp serving travel in the decreasing milepost direction. This ramp is not of interest to the evaluation of the subject segment.

Distance to nearest downstream exit ramp in each travel direction. The measurement technique is the same as for upstream entrance ramps. This distance is shown in Figure 13-6 using the two variables $X_{b, \text{ext}}$ and $X_{e, \text{ext}}$. Downstream entrance ramps are not of direct interest, and their data are not needed.

All measurements are to the marked gore point.

**Figure 13-6. Distance to Nearest Ramp**

- **Clear zone width.** This width is measured from the edge of traveled way to typical limits of vertical obstruction (e.g., ditch, fence line, utility poles) along the roadway. It includes the width of the outside shoulder. It is measured for both travel directions. If this width varies along the segment, then enter the estimated length-weighted average clear zone width. Do not measure to (or consider) roadside barrier when determining the clear zone width for the predictive method. Barrier location and influence is addressed in other CMFs. If the segment has roadside barrier on both sides for its entire length, then clear zone width will not influence the model prediction and any value can be used as a model input (e.g., 30 ft).

This guidance is illustrated in Figure 13-7 where the clear zone is shown to be established by a fence line that varies in offset from the edge of traveled way. A length-weighted width is appropriate for this situation. The lone tree and the guardrail are not considered in the determination of clear zone width.
Figure 13-7. Clear Zone Width Considerations

- Proportion of freeway AADT volume that occurs during hours where the lane volume exceeds 1,000 vehicles per hour per lane (veh/h/ln). The lane volume for hour $i$ $L_V^i$ is computed as $L_V^i = H_V^i / n$ where $H_V^i$ is the volume during hour $i$ ($i = 1, 2, 3, ..., 24$) and $n$ is the number of through lanes. The desired proportion $P_{hv}$ is computed as $P_{hv} = (\Sigma H_V^i) / AADT$ where $\Sigma H_V^i$ is the sum of the volume during each hour where the lane volume exceeds 1,000 veh/h/ln. The $AADT$, $HV$, and $n$ variables include both freeway travel directions. A default value can be computed as $P_{hv} = 1.0 - \exp(1.45 - 0.000124 \times AADT/n)$. If the value computed is less than 0.0, then it is set to 0.0.

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

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

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

A speed-change lane site is defined as the section of roadway area located (a) between the marked gore and taper points of a ramp merge or diverge area, and (b) on the same side of the freeway as the merge or diverge area. The location of the gore and taper points is identified in Figure 13-2.

Three freeway segments are shown schematically in Figure 13-8. They are labeled $Fr$ in the figure. The presence of a speed-change lane on a freeway segment requires a reduction in the effective length of the freeway segment. This reduction is used to account for the crashes assigned to the speed-change lane. The equation for computing the “effective” segment length is shown in the bottom of Figure 13-8 for a freeway segment with one ramp entrance and one ramp exit.

Two speed-change lanes are shown schematically in Figure 13-8. The speed-change lane associated with an entrance ramp is labeled $SCen$ and that associated with an exit ramp exit is labeled $SCex$. 
13.5.2 Segmentation Process

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

- Number of through lanes. Begin segment at the gore point if the lane is added or dropped at a ramp or C-D road; begin segment at the upstream taper point if the lane is added or dropped by taper.

- Lane width. Begin segment if change in lane width exceeds ±0.5 ft.

- Outside shoulder width. Begin segment if change in outside shoulder width exceeds ±1.0 ft.

- Inside shoulder width. Begin segment if change in inside shoulder width exceeds ±1.0 ft.

- Median width. When the median width is less than 90 ft, begin segment where the median starts a notable change in width and where the median ends a notable change in width (a notable change occurs if the
width changes ±10 percent or more). Also, begin segment where the median width increases above 90 ft and where the median width decreases below 90 ft.

- Ramp presence. Begin segment at the ramp gore point.
- Clear zone width. Begin segment if change in clear zone exceeds 5.0 ft.

A speed-change lane site begins at the gore (or taper) point and ends at the associated taper (or gore) point. These points are shown in Figure 13-2. The presence of a horizontal curve does not necessarily define segment boundaries.

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

Application of the “median width” segmentation criterion is shown in Figure 13-9. The freeway section in this figure is shown to consist of five segments. Segment 1 has a constant median width of 30 ft. Segment 2 starts where the median first starts changing. Segment 3 begins at the point where the median width first exceeds 90 ft. Segment 4 begins where the median width first drops below 90 ft. Segment 5 begins where the median width stops changing. Also shown in the figure is the median width value used in the Median Width CMF described in Section 13-7.

![Figure 13-9. Segmentation for Varying Median Width](image)

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

13.6. SAFETY PERFORMANCE FUNCTIONS
When using the predictive method, the appropriate safety performance functions (SPFs) are used to estimate the predicted average crash frequency of a site with base conditions. Each SPF was developed as a regression model using observed crash data for a set of similar sites as the dependent variable. The SPFs, like all regression models, estimate the value of the dependent variable as a function of a set of independent variables. The independent variables for the freeway segment SPFs include the segment AADT volume, segment length, and area type (i.e., rural or urban). The independent variables for the speed-change lane
SPFs include the AADT volume of the freeway, speed-change lane length, and area type. The SPFs in Chapter 13 are summarized in Table 13-3.

<table>
<thead>
<tr>
<th>Site Type (w)</th>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>SPF Equations</th>
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<td>Single vehicle (sv)</td>
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<tr>
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<td></td>
<td>Ramp exit (EX)</td>
<td>All types (at)</td>
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</tbody>
</table>

A detailed discussion of SPFs and their use in the HSM is presented in Chapter 3, Section 3.5.2 of Part C—Introduction and Applications Guidance, Section C.6.3.

Some highway 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 A.1.2 in Appendix A to Part C.

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 A.2 in Appendix A to Part C.

13.6.1. Safety Performance Functions for Roadway Segments

The SPFs for freeway segments are presented in this section. Specifically, SPFs are provided for freeway segments with 4, 6, 8, or 10 through lanes (total of both travel directions). The range of AADT volume for which these SPFs are applicable is shown in Table 13-4. Application of the SPFs to sites with AADT volumes substantially outside these ranges may not provide reliable results.

<table>
<thead>
<tr>
<th>Area Type</th>
<th>Cross Section (Through Lanes) (x)</th>
<th>Applicable AADT Volume Range (veh/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>4</td>
<td>0 to 73,000</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0 to 130,000</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0 to 190,000</td>
</tr>
<tr>
<td>Urban</td>
<td>4</td>
<td>0 to 110,000</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0 to 180,000</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0 to 270,000</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0 to 310,000</td>
</tr>
</tbody>
</table>

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

Other types of freeway segments may be found on freeways but are not addressed by the predictive model in Chapter 13.

**Multiple-Vehicle Crashes**

The base conditions for the SPFs for multiple-vehicle crashes on freeway segments are:

- Horizontal curve: Not present
- Lane width: 12 ft
- Inside shoulder width: 6 ft
- Median width: 60 ft
- Median barrier: Not present
- Hours where volume exceeds 1000 vehicles per hour per lane: None
- Upstream ramp entrances and downstream ramp exits: More than 0.5 mi from segment
- Type B weaving section: Not present

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

$$N_{sfp, fs, n, mv, z} = L^* \times \exp(a + b \times \ln(c \times AADT_{fs}))$$

Equation 13-15

with,

$$L^* = L_{fs} - \left(0.5 \times \sum L_{en,seg,i}\right) - \left(0.5 \times \sum L_{ex,seg,i}\right)$$

Equation 13-16

Where:

- $N_{sfp, fs, n, mv, z}$ = predicted average multiple-vehicle crash frequency of a freeway segment with base conditions, $n$ lanes, and severity $z$ ($z = fi$: fatal and injury, $pdo$: property damage only) (crashes/yr);
- $L^*$ = effective length of freeway segment (mi);
- $L_{fs}$ = length of freeway segment (mi);
- $L_{en,seg,i}$ = length of ramp entrance $i$ on segment (mi);
- $L_{ex,seg,i}$ = length of ramp exit $i$ on segment (mi);
\( AADT_{fs} \) = annual average daily traffic volume of freeway segment (veh/day); and

\( a, b, c \) = regression coefficients.

The calculation of the “effective length of freeway segment” was discussed in the text associated with Figure 13-8. The “length of ramp entrance on the segment” represents the length of the speed-change lane located between the start and end points of the freeway segment. This length cannot exceed the length of the segment or the length of the ramp entrance speed-change lane. Similarly, the “length of exit ramp on the segment” represents the length of the speed-change lane located between the start and end points of the freeway segment.

The SPF regression coefficients and the inverse dispersion parameter are provided in Table 13-5. The SPFs are illustrated in Figure 13-10.

**Table 13-5. SPF Coefficients for Multiple-Vehicle Crashes on Freeway Segments**

<table>
<thead>
<tr>
<th>Crash Severity ((z))</th>
<th>Area Type</th>
<th>Number of Through Lanes ((n))</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter (K_{fs, n, mv, z} (\text{mi}^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal and injury ((fi))</td>
<td>Rural</td>
<td>4</td>
<td>(-5.975)</td>
<td>1.492</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>(-6.092)</td>
<td>1.492</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>(-6.140)</td>
<td>1.492</td>
</tr>
<tr>
<td>Urban</td>
<td></td>
<td>4</td>
<td>(-5.470)</td>
<td>1.492</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>(-5.587)</td>
<td>1.492</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>(-5.635)</td>
<td>1.492</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>(-5.842)</td>
<td>1.492</td>
</tr>
<tr>
<td>Property damage only ((pdo))</td>
<td>Rural</td>
<td>4</td>
<td>(-6.880)</td>
<td>1.936</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>(-7.141)</td>
<td>1.936</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>(-7.329)</td>
<td>1.936</td>
</tr>
<tr>
<td>Urban</td>
<td></td>
<td>4</td>
<td>(-6.548)</td>
<td>1.936</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>(-6.809)</td>
<td>1.936</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>(-6.997)</td>
<td>1.936</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>(-7.260)</td>
<td>1.936</td>
</tr>
</tbody>
</table>
The value of the overdispersion parameter associated with the SPFs for freeway segments is determined as a function of the segment length. This value is computed using Equation 13-17.

\[ k_{fs, n, mv, z} = \frac{1}{K_{fs, n, mv, z} \times L^z} \]  

Equation 13-17

Where:

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

The inverse dispersion parameter for segments with even numbers of lanes is provided in Table 13-5. A procedure is described in Section A.2.7 in Appendix A to Part C for using these parameters to estimate the overdispersion parameter for segments with an odd number of lanes.

The crash frequency obtained from Equation 13-15 can be multiplied by the proportions in Table 13-6 to estimate the predicted average multiple-vehicle crash frequency by crash type category.
Table 13-6. Default Distribution of Multiple-Vehicle Crashes by Crash Type for Freeway Segments

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

Single-Vehicle Crashes
The base conditions for the SPFs for single-vehicle crashes on freeway segments are:

- Horizontal curve: Not present
- Lane width: 12 ft
- Inside shoulder width: 6 ft
- Median width: 60 ft
- Median barrier: Not present
- Hours where volume exceeds 1000 vehicles per hour per lane: None
- Outside shoulder width: 10 ft
- Shoulder rumble strip: Not present
- Outside clearance: 30-ft clear zone
- Outside barrier: Not present

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

\[ N_{spf, sv, n, z} = L' \times \exp(a + b \times \ln(c \times AADT_{fs})) \]

Equation 13-18

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

The SPF regression coefficients and the inverse dispersion parameter are provided in Table 13-7. The SPFs are illustrated in Figure 13-11.

**Table 13-7. SPF Coefficients for Single-Vehicle Crashes on Freeway Segments**

<table>
<thead>
<tr>
<th>Crash Severity (z)</th>
<th>Area Type</th>
<th>Number of Through Lanes (n)</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter ( K_{fs, n, sv, z} ) (mi(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>4</td>
<td>-2.126 0.646 0.001</td>
<td>4</td>
<td>30.1</td>
</tr>
<tr>
<td>Urban</td>
<td>4</td>
<td>-2.126 0.646 0.001</td>
<td>4</td>
<td>30.1</td>
</tr>
<tr>
<td>Urban</td>
<td>6</td>
<td>-2.055 0.646 0.001</td>
<td>6</td>
<td>30.1</td>
</tr>
<tr>
<td>Rural</td>
<td>8</td>
<td>-1.985 0.646 0.001</td>
<td>8</td>
<td>30.1</td>
</tr>
<tr>
<td>Rural</td>
<td>10</td>
<td>-1.915 0.646 0.001</td>
<td>10</td>
<td>30.1</td>
</tr>
<tr>
<td>Urban</td>
<td>4</td>
<td>-2.235 0.876 0.001</td>
<td>4</td>
<td>20.7</td>
</tr>
<tr>
<td>Urban</td>
<td>6</td>
<td>-2.274 0.876 0.001</td>
<td>6</td>
<td>20.7</td>
</tr>
<tr>
<td>Rural</td>
<td>8</td>
<td>-2.312 0.876 0.001</td>
<td>8</td>
<td>20.7</td>
</tr>
<tr>
<td>Urban</td>
<td>10</td>
<td>-2.351 0.876 0.001</td>
<td>10</td>
<td>20.7</td>
</tr>
</tbody>
</table>

Figure 13-11. Graphical Form of the SPFs for Single-Vehicle Crashes on Freeway Segments
The value of the overdispersion parameter associated with the SPFs for freeway segments is determined as a function of the segment length. This value is computed using Equation 13-19.

$$k_{fs,n,sv,z} = \frac{1}{K_{fs,n,sv,z} \times L}$$  \hspace{1cm} \text{Equation 13-19}

Where:

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

The inverse dispersion parameter for segments with even numbers of lanes is provided in Table 13-7. A procedure is described in Section A.2.7 in Appendix A to Part C for using these parameters to estimate the overdispersion parameter for segments with odd numbers of lanes.

The crash frequency obtained from Equation 13-18 can be multiplied by the proportions in Table 13-8 to estimate the predicted average single-vehicle crash frequency by crash type category.

**Table 13-8. Default Distribution of Single-Vehicle Crashes by Crash Type for Freeway Segments**

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

**13.6.2. Safety Performance Functions for Speed-Change Lanes**

The SPFs for freeway speed-change lanes are presented in this section. SPFs are provided for ramp entrances and ramp exits adjacent to freeway segments with 4, 6, 8, or 10 through lanes. The SPFs for speed-change lanes are applicable to the same freeway segment AADT volume ranges that are listed in Table 13-4. Application to sites with AADT volumes substantially outside these ranges may not provide reliable results.
The SPFs described in this section are directly applicable to speed-change lanes adjacent to freeway segments with an even number of through lanes. They can be extended to the evaluation of segments with 5, 7, and 9 lanes using the procedure described in Section 13.6.1.

**Ramp Entrance Speed-Change Lanes**
The base conditions for the SPFs for ramp-entrance speed-change lanes are:

- Horizontal curve: Not present
- Lane width: 12 ft
- Inside shoulder width: 6 ft
- Median width: 60 ft
- Median barrier: Not present
- Hours where volume exceeds 1,000 vehicles per hour per lane: None

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

\[
N_{\text{spf, sc, nEN, at, z}} = L_{en} \times \exp(a + b \times \ln(c \times AADT_{fi}))
\]

Equation 13-20

Where:

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

The SPF regression coefficients and the inverse dispersion parameter are provided in Table 13-9. The SPFs are illustrated in Figure 13-12.

The Ramp entrance CMF is combined with this SPF to create the trend lines shown in the figure. This CMF is a function of entrance ramp volume and the speed-change lane length. These variables in combination do not readily lend themselves to the specification of a representative base condition. For this reason, the CMF is combined with the SPF for the graphical presentation. The Ramp entrance CMF is described in Section 13.7.2.
### Table 13-9. SPF Coefficients for Ramp-Entrance-Related Crashes in Speed-Change Lanes

<table>
<thead>
<tr>
<th>Crash Severity (z)</th>
<th>Area Type</th>
<th>Number of Through Lanes (n)</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter Ksc, nEN, at, z (mi⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Fatal and injury (fi) Rural</td>
<td>4</td>
<td>-3.894</td>
<td>1.173</td>
<td>0.0005</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>-4.154</td>
<td>1.173</td>
<td>0.0005</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-4.414</td>
<td>1.173</td>
<td>0.0005</td>
</tr>
<tr>
<td>Urban</td>
<td>4</td>
<td>-3.714</td>
<td>1.173</td>
<td>0.0005</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>-3.974</td>
<td>1.173</td>
<td>0.0005</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-4.234</td>
<td>1.173</td>
<td>0.0005</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>-4.494</td>
<td>1.173</td>
<td>0.0005</td>
</tr>
<tr>
<td>Property damage only (pdo) Rural</td>
<td>4</td>
<td>-2.895</td>
<td>1.215</td>
<td>0.0005</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>-3.097</td>
<td>1.215</td>
<td>0.0005</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-3.299</td>
<td>1.215</td>
<td>0.0005</td>
</tr>
<tr>
<td>Urban</td>
<td>4</td>
<td>-2.796</td>
<td>1.215</td>
<td>0.0005</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>-2.998</td>
<td>1.215</td>
<td>0.0005</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-3.200</td>
<td>1.215</td>
<td>0.0005</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>-3.402</td>
<td>1.215</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

### Figure 13-12. Graphical Form of the SPFs for Ramp Entrance Speed-Change Lanes

a. Fatal-and-Injury Crash Frequency  

b. Property-Damage-Only Crash Frequency
The value of the overdispersion parameter associated with the SPF s for ramp-entrance speed-change lanes is determined as a function of the speed-change lane length. This value is computed as:

\[ k_{sc,nEN,at,z} = \frac{1}{K_{sc,nEN,at,c} \times L_{en}} \]  

Equation 13-21

Where:

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

The inverse dispersion parameter for speed-change lanes adjacent to freeway segments with 4, 6, 8, or 10 through lanes is provided in Table 13-9. A procedure is described in Section A.2.7 in Appendix A to Part C for using these parameters to estimate the overdispersion parameter for speed-change lanes adjacent to freeway segments with 5, 7, or 9 lanes.

The crash frequency obtained from Equation 13-20 can be multiplied by the proportions in Table 13-10 to estimate the predicted average ramp-entrance-related crash frequency by crash type or crash type category. These proportions are based on ramp-entrance speed-change lane crashes. They do not include crashes associated with a ramp entrance that adds a lane to the cross section.
### Table 13-10. Default Distribution of Ramp-Entrance-Related Crashes by Crash Type

<table>
<thead>
<tr>
<th>Area Type</th>
<th>Crash Type</th>
<th>Crash Type Category</th>
<th>Proportion of Crashes by Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>Multiple vehicle</td>
<td>Head-on</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right-angle</td>
<td>0.032</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rear-end</td>
<td>0.351</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sideswipe</td>
<td>0.128</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other multiple-vehicle</td>
<td>0.011</td>
</tr>
<tr>
<td>Single</td>
<td>Crash with animal</td>
<td>0</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>Crash with fixed object</td>
<td>0</td>
<td>0.245</td>
</tr>
<tr>
<td></td>
<td>Crash with other object</td>
<td>0</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td>Crash with parked vehicle</td>
<td>0</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td>Other single-vehicle crashes</td>
<td>0</td>
<td>0.170</td>
</tr>
<tr>
<td>Urban</td>
<td>Multiple vehicle</td>
<td>Head-on</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right-angle</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rear-end</td>
<td>0.543</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sideswipe</td>
<td>0.133</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other multiple-vehicle</td>
<td>0.017</td>
</tr>
<tr>
<td>Single</td>
<td>Crash with animal</td>
<td>0</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>Crash with fixed object</td>
<td>0</td>
<td>0.194</td>
</tr>
<tr>
<td></td>
<td>Crash with other object</td>
<td>0</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>Crash with parked vehicle</td>
<td>0</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>Other single-vehicle crashes</td>
<td>0</td>
<td>0.067</td>
</tr>
</tbody>
</table>

**Ramp Exit Speed-Change Lanes**

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

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

\[
N_{sfe, sc, nEX, at, z} = L_{ex} \times \exp(a + b \times \ln(c \times AADT_{fs}))
\]

**Equation 13-22**

Where:

\( N_{sfe, sc, nEX, at, z} \) = predicted average crash frequency of a ramp exit speed-change lane on a freeway with base conditions, \( n \) lanes, all crash types \( at \), and severity \( z \) (\( z = fi \): fatal and injury, \( pdo \): property damage only) (crashes/yr); and
\[ L_{ex} = \text{length of ramp exit (mi)}. \]

The SPF regression coefficients and the inverse dispersion parameter are provided in Table 13-11. The SPFs are illustrated in Figure 13-13.

**Table 13-11.** SPF Coefficients for Ramp-Exit-Related Crashes in Speed-Change Lanes

<table>
<thead>
<tr>
<th>Crash Severity ((z))</th>
<th>Area Type</th>
<th>Number of Through Lanes ((n))</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter (K_{sc, nEX, at, z})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal and injury ((fi))</td>
<td>Rural</td>
<td>4, 6, 8</td>
<td>-2.679</td>
<td>0.903</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>4, 6, 8, 10</td>
<td>-2.679</td>
<td>0.903</td>
</tr>
<tr>
<td>Property damage only ((pdo))</td>
<td>Rural</td>
<td>4, 6, 8</td>
<td>-1.798</td>
<td>0.932</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>4, 6, 8, 10</td>
<td>-1.798</td>
<td>0.932</td>
</tr>
</tbody>
</table>

\[ a. \text{Fatal-}\text{and-}\text{Injury Crash Frequency} \]
\[ b. \text{Property-}\text{Damage-}\text{Only Crash Frequency} \]

**Figure 13-13.** Graphical Form of the SPFs for Ramp Exit Speed-Change Lanes

The Ramp exit CMF is combined with the fatal-and-injury SPF to create the trend lines shown in the figure for fatal-and-injury crashes. This CMF is a function of the speed-change lane length. This variable (in combination with the SPF length variable) does not readily lend itself to the specification of a representative base condition. For this reason, the CMF is combined with the SPF for the graphical presentation. The Ramp exit CMF is described in Section 13.7.2.

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

\[ k_{sc, nEX, at, z} = \frac{1}{K_{sc, nEX, at, z}} \quad \text{Equation 13-23} \]

Where:

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

The inverse dispersion parameter for speed-change lanes adjacent to freeway segments with 4, 6, 8, or 10 through lanes is provided in Table 13-11. A procedure is described in Section A.2.7 in Appendix A to Part C for using these parameters to estimate the overdispersion parameter for speed-change lanes adjacent to freeway segments with 5, 7, or 9 lanes.

The crash frequency obtained from Equation 13-22 can be multiplied by the proportions in Table 13-12 to estimate the predicted average ramp-exit-related crash frequency by crash type or crash type category. These proportions are based on ramp-exit speed-change lane crashes. They do not include crashes associated with a ramp exit that drops a lane from the cross section.

<table>
<thead>
<tr>
<th>Area Type</th>
<th>Crash Type</th>
<th>Crash Type Category</th>
<th>Proportion of Crashes by Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>Multiple</td>
<td>Head-on</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>vehicle</td>
<td>Right-angle</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rear-end</td>
<td>0.463</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sideswipe</td>
<td>0.104</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other multiple-vehicle crash</td>
<td>0.000</td>
</tr>
<tr>
<td>Single</td>
<td></td>
<td>Crash with animal</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>vehicle</td>
<td>Crash with fixed object</td>
<td>0.224</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with other object</td>
<td>0.030</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with parked vehicle</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other single-vehicle crashes</td>
<td>0.164</td>
</tr>
<tr>
<td>Urban</td>
<td>Multiple</td>
<td>Head-on</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>vehicle</td>
<td>Right-angle</td>
<td>0.011</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rear-end</td>
<td>0.549</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sideswipe</td>
<td>0.158</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other multiple-vehicle crash</td>
<td>0.016</td>
</tr>
<tr>
<td>Single</td>
<td></td>
<td>Crash with animal</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>vehicle</td>
<td>Crash with fixed object</td>
<td>0.196</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with other object</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with parked vehicle</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other single-vehicle crashes</td>
<td>0.049</td>
</tr>
</tbody>
</table>

Table 13-12. Default Distribution of Ramp-Exit-Related Crashes by Crash Type
13.7. CRASH MODIFICATION FACTORS

This section describes the CMFs applicable to the SPFs presented in Section 13.6. These CMFs were calibrated along with the SPFs. They are summarized in Table 13-13.

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

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

Note: Subscripts to the CMF variables use the following notation:

- Site type $w$ ($w = fs$: freeway segment, $sc$: speed-change lane),
- Cross section $x$ ($x = n$: $n$-lane freeway, $nEN$: ramp entrance speed-change lane adjacent to a freeway with $n$ lanes, $nEX$: ramp exit speed-change lane adjacent to a freeway with $n$ lanes, $ac$: all cross sections),
- 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).

Many of the CMFs in Table 13-13 are developed for specific site types, cross sections, crash types, or crash severities. This approach was undertaken to make the predictive model sensitive to the geometric design and traffic control features of specific sites with specific cross sections, in terms of their influence on specific crash types and severities. The subscripts for each CMF variable indicate the sites, cross sections, crash types, and severities to which each CMF is applicable. The subscript definitions are provided in the table footnote. In some cases, a CMF is applicable to several site types, cross sections, crash types, or severities. In these cases, the subscript retains the generic letter $w$, $x$, $y$, or $z$, as appropriate. The discussion of these CMFs in Section 13.7.1 or 13.7.2 identifies the specific site types, cross sections, crash types, or severities to which they apply.

As indicated in Table 13-13, some of the CMFs apply to both freeway segments and speed-change lanes. These CMFs are presented in Section 13.7.1 and referenced in Section 13.7.2. For some of the CMFs, supplemental calculations must be performed before the CMF value can be computed. For example, to apply the Median width CMF, the proportion of the segment length having inside barrier and the length-weighted
average barrier offset (as measured from the edge of the inside shoulder) must be computed. Procedures for supplemental calculations are described in Section 13.7.3.

**13.7.1. Crash Modification Factors for Roadway Segments**
The CMFs for geometric design and traffic control features of freeway segments are presented in this section.

**CMF_{1,w,x,y,z}—Horizontal Curve**
Four CMFs are used to describe the relationship between horizontal curve geometry and predicted crash frequency. The SPFs to which they apply are identified in the following list:

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

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

\[
CMF_{1, f_s, ac, y, z} = 1.0 + a \times \left( \sum_{i=1}^{m} \left( \frac{5.730}{R_i} \right)^2 \times P_{c, i} \times f_{c, i} \right)
\]

**Equation 13-24**

Where:

- \(CMF_{1, f_s, ac, y, z}\) = crash modification factor for horizontal curvature on a freeway segment with crash type \(y\), and severity \(z\);
- \(R_i\) = radius of curve \(i\) (ft);
- \(P_{c, i}\) = proportion of segment length with curve \(i\);
- \(f_{c, i}\) = roadbed adjustment factor for curve \(i\) (= 1.0 if both roadbeds are curved, 0.5 if only one roadbed is curved); and
- \(m\) = number of horizontal curves on the segment.

The regression coefficient for Equation 13-24 is provided in Table 13-14. Equation 13-24 is derived to recognize that more than one curve may exist on a segment and that a curve may be located only partially on the segment (and partially on an adjacent segment). The variable \(P_{c, i}\) is computed as the ratio of the length of curve \(i\) on the segment to the length of the freeway segment \(L_p\). For example, consider a segment that is 0.5 mi long and a curve that is 0.2 mi long. If one-half of the curve is on the segment, then \(P_{c, i} = 0.20 (= 0.1/0.5)\). In fact, this proportion is the same regardless of the curve’s length (provided that it is 0.1 mi or longer and 0.1 mi of this curve is located on the segment).

The roadbed adjustment factor \(f_{c, i}\) is used to modify the CMF so that it can be applied to freeway segments where only one roadbed is curved (and the other roadbed is tangent). This situation occurs on some freeway segments in rural areas (although, it can also occur in urban areas).
Table 13-14. Coefficients for Horizontal Curve CMF–Freeway Segments

<table>
<thead>
<tr>
<th>Cross Section ((x))</th>
<th>Crash Type ((y))</th>
<th>Crash Severity ((z))</th>
<th>CMF Variable</th>
<th>Regression Coefficient ((a))</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections ((ac))</td>
<td>Multiple vehicle ((mv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_1, fs, ac, mv, fi)</td>
<td>0.0172</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_1, fs, ac, mv, pdo)</td>
<td>0.0340</td>
</tr>
<tr>
<td>Single vehicle ((sv))</td>
<td>Multiple vehicle ((mv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_1, fs, ac, sv, fi)</td>
<td>0.0719</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_1, fs, ac, sv, pdo)</td>
<td>0.0626</td>
</tr>
</tbody>
</table>

Details regarding the measurement of radius and curve length are provided in Section 13.4. The CMF is applicable to curves with a radius of 1,000 ft or larger.

CMF\(_2, w, x, y, n\)—Lane Width

Two CMFs are used to describe the relationship between average lane width and predicted crash frequency. The SPFs to which they apply are identified in the following list:
- SPF for fatal-and-injury multiple-vehicle crashes, specified number of lanes \((fs, n, mv, fi)\); and
- SPF for fatal-and-injury single-vehicle crashes, specified number of lanes \((fs, n, sv, fi)\).

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

\[
CMF_2, fs, ac, y, fi = \begin{cases} \exp(a\times[W_l - 12]) & : If \ W_l < 13 \text{ ft} \\ b & : If \ W_l \geq 13 \text{ ft} \end{cases}
\]  
Equation 13-25

Where:
- \(CMF_2, fs, ac, y, fi\) = crash modification factor for lane width on a freeway segment with crash type \(y\), and fatal-and-injury crashes \(fi\); and
- \(W_l\) = lane width (ft).

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

Table 13-15. Coefficients for Lane Width CMF–Freeway Segments

<table>
<thead>
<tr>
<th>Cross Section ((x))</th>
<th>Crash Type ((y))</th>
<th>Crash Severity ((z))</th>
<th>CMF Variable</th>
<th>Regression Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections ((ac))</td>
<td>Multiple vehicle ((mv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_2, fs, ac, mv, fi)</td>
<td>-0.0376 0.963</td>
</tr>
<tr>
<td>Single vehicle ((sv))</td>
<td>Multiple vehicle ((mv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_2, fs, ac, sv, fi)</td>
<td>-0.0376 0.963</td>
</tr>
</tbody>
</table>
The lane width used in Equation 13-25 is an average for all through lanes on the segment (excluding managed lanes and auxiliary lanes associated with a weaving section). The CMF is applicable to lane widths in the range of 10.5 to 14 ft.

**CMF\textsubscript{3, w, x, y, z}—Inside Shoulder Width**

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

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

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

\[
CMF_{3, fs, ac, y, z} = \exp(a \times (W_{is} - 6))
\]

Equation 13-26

Where:

\[
CMF_{3, fs, ac, y, z} = \text{crash modification factor for inside shoulder width on a freeway segment with crash type } y \text{, and severity } z; \text{ and}
\]

\[
W_{is} = \text{inside shoulder width (ft)}.
\]

The regression coefficient for Equation 13-26 is provided in Table 13-16. For a given severity, the coefficient values are the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs.

<table>
<thead>
<tr>
<th>Cross Section ((x))</th>
<th>Crash Type ((y))</th>
<th>Crash Severity ((z))</th>
<th>CMF Variable</th>
<th>Regression Coefficient ((a))</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections ((ac))</td>
<td>Multiple vehicle ((mv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{3, fs, ac, mv, fi})</td>
<td>-0.0172</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{3, fs, ac, mv, pdo})</td>
<td>-0.0153</td>
</tr>
<tr>
<td>Single vehicle ((sv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{3, fs, ac, sv, fi})</td>
<td>-0.0172</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{3, fs, ac, sv, pdo})</td>
<td>-0.0153</td>
<td></td>
</tr>
</tbody>
</table>

The inside shoulder width used in Equation 13-26 is an average for both directions of travel. The CMF is applicable to shoulder widths in the range of 2 to 12 ft.

**CMF\textsubscript{4, w, x, y, z}—Median Width**

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

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

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

\[
CMF_{4, fs, ac, y, z} = (1 - P_{ib}) \times \exp(a \times [W_m - 2 \times W_{icb} - 48]) + P_{ib} \times \exp(a \times [2 \times W_{icb} - 48])
\]

Equation 13-27

Where:
- \(CMF_{4, fs, ac, y, z}\) = crash modification factor for median width on a freeway segment with crash type \(y\), and severity \(z\);
- \(P_{ib}\) = proportion of segment length with a barrier present in the median (i.e., inside);
- \(W_m\) = median width (measured from near edges of traveled way in both directions) (ft); and
- \(W_{icb}\) = distance from edge of inside shoulder to barrier face (ft).

The regression coefficient for Equation 13-27 is provided in Table 13-17. These CMFs are derived to be applicable to a segment that has median barrier present along some portion of the segment. Guidance for computing the variables \(P_{ib}\) and \(W_{icb}\) is provided in Section 13.7.3.

### Table 13-17. Coefficients for Median Width CMF–Freeway Segments

<table>
<thead>
<tr>
<th>Cross Section ((x))</th>
<th>Crash Type ((y))</th>
<th>Crash Severity ((z))</th>
<th>CMF Variable</th>
<th>Regression Coefficient ((a))</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections ((ac))</td>
<td>Multiple vehicle ((mv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{4, fs, ac, mv, fi})</td>
<td>-0.00302</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{4, fs, ac, mv, pdo})</td>
<td>-0.00291</td>
</tr>
<tr>
<td>Single vehicle ((sv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{4, fs, ac, rv, fi})</td>
<td>0.00102</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{4, fs, ac, rv, pdo})</td>
<td>-0.00289</td>
<td></td>
</tr>
</tbody>
</table>

The median width used in Equation 13-27 is an average for the segment. Similarly, the value used for \(W_{icb}\) is an average for the median. Median width is measured from the near edge of the traveled way on one roadbed to the near edge of the traveled way on the other roadbed (i.e., it includes the inside shoulders). The CMF is applicable to median widths of 9 ft or more. If the median width exceeds 90 ft, then 90 ft should be used for \(W_m\) in Equation 13-27. This guidance is illustrated in Figure 13-9.

### CMF\(_{5, w, x, y, z}\) — Median Barrier

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

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

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

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

Equation 13-28

Where:

\[CMF_{5, fs, ac, y, z}\] = crash modification factor for median barrier on a freeway segment with crash type \(y\), and severity \(z\).

The regression coefficient for Equation 13-28 is provided in Table 13-18. For a given severity, the coefficient values are the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs. Guidance for computing the variables \(P_{ib}\) and \(W_{icb}\) is provided in Section 13.7.3.

**Table 13-18.** Coefficients for Median Barrier CMF–Freeway Segments

<table>
<thead>
<tr>
<th>Cross Section ((x))</th>
<th>Crash Type ((y))</th>
<th>Crash Severity ((z))</th>
<th>CMF Variable</th>
<th>Regression Coefficient ((a))</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections ((ac))</td>
<td>Multiple vehicle ((mv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{5, fs, ac, mv, fi})</td>
<td>0.131</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{5, fs, ac, mv, pdo})</td>
<td>0.169</td>
</tr>
<tr>
<td>Single vehicle ((sv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{5, fs, ac, rv, fi})</td>
<td>0.131</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{5, fs, ac, rv, pdo})</td>
<td>0.169</td>
<td></td>
</tr>
</tbody>
</table>

The variable \(W_{icb}\) represents the distance from the edge of inside shoulder to median barrier face. The value used for this variable in Equation 13-28 is an average for the segment. The CMF is applicable to \(W_{icb}\) values in the range of 0.25 to 17 ft. This CMF is applicable to cable barrier, concrete barrier, guardrail, and bridge rail.

**CMF\(_{6, w, x, y, z}\) — High Volume**

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

A statistic was developed to describe the degree of volume concentration during peak hours of the average day. It represents the proportion of the AADT that occurs during hours where the volume exceeds 1,000 vehicles per hour per lane (veh/h/ln). It has a value of zero if the volume on the associated segment does not exceed the threshold value for any hour of the day. It has a value of one if the volume during each hour of the average day exceeds the threshold value. In general, its value is large when hourly volumes are continuously high or when there is a peak few hours with an exceptionally large volume.
Typical freeway speed-volume relationships show that the average speed tends to drop as flow rates increase beyond 1,000 veh/h/ln. This trend suggests that drivers reduce their speed to improve their comfort and safety as their headway gets shorter than 3.6 s/veh (= 3,600/1,000).

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

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

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

\[
CMF_{6, fs, ac, y, z} = \exp(a \times P_{hv})
\]

Equation 13-29

Where:

- \(CMF_{6, fs, ac, y, z}\) = crash modification factor for high volume on a freeway segment with \(y\) and severity \(z\); and
- \(P_{hv}\) = proportion of AADT during hours where volume exceeds 1,000 veh/h/ln.

The regression coefficient for Equation 13-29 is provided in Table 13-19.

**Table 13-19. Coefficients for High Volume CMF–Freeway Segments**

<table>
<thead>
<tr>
<th>Cross Section ((x))</th>
<th>Crash Type ((y))</th>
<th>Crash Severity ((z))</th>
<th>CMF Variable</th>
<th>Regression Coefficient ((a))</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections ((ac))</td>
<td>Multiple vehicle ((mv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{6, fs, ac, mv, fi})</td>
<td>0.350</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{6, fs, ac, mv, pdo})</td>
<td>0.283</td>
</tr>
<tr>
<td></td>
<td>Single vehicle ((sv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{6, fs, ac, sv, fi})</td>
<td>-0.0675</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{6, fs, ac, sv, pdo})</td>
<td>-0.611</td>
</tr>
</tbody>
</table>

The proportion of AADT during hours where the volume exceeds 1,000 veh/h/ln is computed using the average hourly volume distribution associated with the subject segment. This distribution will typically be computed using the data obtained from the nearest continuous traffic counting station (on a freeway of similar character).

**CMF\(_{7, fs, ac, mv, z}\) —Lane Change**

Two CMFs are used to describe the relationship between lane change activity and predicted crash frequency. The SPFs to which they apply are identified in the following list:
SPF for fatal-and-injury multiple-vehicle crashes, specified number of lanes \((fs, n, mv, fi)\); and

SPF for property-damage-only multiple-vehicle crashes, specified number of lanes \((fs, n, mv, pdo)\).

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

\[
CMF_{x, fs, ac, mv, z} = (0.5 \times f_{wev, inc} \times f_{lc, inc}) + (0.5 \times f_{wev, dec} \times f_{lc, dec})
\]

Equation 13-30

with,

\[
f_{wev, inc} = (1.0 - P_{wevB, inc}) \times 1.0 + P_{wevB, inc} \times \exp \left( \frac{a}{L_{wev, inc}} \right)
\]

Equation 13-31

\[
f_{wev, dec} = (1.0 - P_{wevB, dec}) \times 1.0 + P_{wevB, dec} \times \exp \left( \frac{a}{L_{wev, dec}} \right)
\]

Equation 13-32

\[
f_{lc, inc} = \left(1.0 + \frac{\exp(-b \times X_{b, ent} + d \times \ln[c \times AADT_{b, ent}])}{b \times L_{fs}} \right) \times \left[1.0 - \exp(-b \times L_{fs})\right]
\]

\[
\times \left(1.0 + \frac{\exp(-b \times X_{e, ext} + d \times \ln[c \times AADT_{e, ext}])}{b \times L_{fs}} \right) \times \left[1.0 - \exp(-b \times L_{fs})\right]
\]

Equation 13-33

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

\[
\times \left(1.0 + \frac{\exp(-b \times X_{e, ext} + d \times \ln[c \times AADT_{e, ext}])}{b \times L_{fs}} \right) \times \left[1.0 - \exp(-b \times L_{fs})\right]
\]

Equation 13-34

Where:

\(CMF_{x, fs, ac, mv, z}\) = crash modification factor for lane changes on a freeway segment with multiple-vehicle crashes \(mv\) and severity \(z\);

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The regression coefficients for Equation 13-31 to Equation 13-34 are provided in Table 13-20.

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections (ac)</td>
<td>Multiple vehicle (mv)</td>
<td>Fatal and injury (fi)</td>
<td>( CMF_{7, fi, ac, mv, fi} )</td>
<td>0.175 12.56 0.001 -0.272</td>
</tr>
<tr>
<td>Property damage only (pdo)</td>
<td></td>
<td></td>
<td>( CMF_{7, fi, ac, mv, pdo} )</td>
<td>0.123 13.46 0.001 -0.283</td>
</tr>
</tbody>
</table>

If the segment is in a Type B weaving section, then the length of the weaving section is an input to the CMF. The variables for weaving section length (i.e., \( L_{\text{wev, inc}}, L_{\text{wev, dec}} \)) in Equation 13-31 and Equation 13-32 are intended to reflect the degree to which the weaving activity is concentrated along the freeway. The sign of the regression coefficient in these two equations indicates that the lane change CMF value will increase if the segment is in a Type B weaving section. The amount of this increase is inversely related to the length of the weaving section. Guidance for determining if a weaving section is Type B is provided in Section 13.4.

The variables \( P_{\text{wevB, inc}} \) and \( P_{\text{wevB, dec}} \) in Equation 13-31 and Equation 13-32, respectively, are computed as the ratio of the length of the weaving section on the segment to the length of the freeway segment \( L_{fs} \). If the segment is wholly located in the weaving section, then this variable is equal to 1.0.
The $X$ and $AADT$ variables describe the distance to (and volume of) the four nearest ramps to the subject segment. Two of the ramps of interest are on the side of the freeway with travel in the increasing milepost direction. One ramp on this side of the freeway is upstream of the segment, and one ramp is downstream of the segment. Similarly, one ramp on the other side of the freeway is upstream of the segment and one ramp is downstream. Only those entrance ramps that contribute volume to the subject segment are of interest. Hence, a downstream entrance ramp is not of interest. For similar reasons, an upstream exit ramp is not of interest.

The Lane change CMF is applicable to any segment in the vicinity of one or more ramps. It is equally applicable to segments in a weaving section (regardless of the weaving section type) and segments in a non-weaving section (i.e., segments between an entrance ramp and an exit ramp where both ramps have a speed-change lane). If the weaving section is Type B, then an additional adjustment is made using Equation 13-31 and Equation 13-32. These equations are applicable to weaving section lengths between 0.10 and 0.85 mi.

The two SPFs for predicting speed-change-related crash frequency (i.e., Equation 13-20 and Equation 13-22) are not used when evaluating a weaving section because the ramps that form the weaving section do not have a speed-change lane. As a result, the predicted crash frequency for the set of segments that comprise a weaving section will tend to be smaller than that predicted for a similar set of segments located in a non-weaving section but having entrance and exit ramps. This generalization will always be true for weaving sections that are not Type B. It may or may not hold for the Type B weaving section, depending on the length of the weaving section.

**CMF F, fs, ac, sv, z—Outside Shoulder Width**

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

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

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

$$CMF_{fs, ac, sv, z} = 1.0 - \sum_{i=1}^{m} P_{c,i} \times \exp(a \times [W_s - 10]) + \sum_{i=1}^{m} P_{c,i} \times \exp(b \times [W_s - 10])$$

Equation 13-35

Where:

- $CMF_{fs, ac, sv, z}$ = crash modification factor for outside shoulder width on a freeway segment with single-vehicle crashes $sv$ and severity $z$; and
- $W_s$ = outside shoulder width (ft).

The regression coefficients for Equation 13-35 are provided in Table 13-21. The variable $P_{c,i}$ is computed as the ratio of the length of curve $i$ on the segment to the length of the freeway segment $L_{fs}$.

The outside shoulder width used in this CMF is an average for both directions of travel. The CMF is applicable to shoulder widths in the range of 4 to 14 ft.
Table 13-21. Coefficients for Outside Shoulder Width CMF–Freeway Segments

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections (ac)</td>
<td>Single vehicle (sv)</td>
<td>Fatal and injury (fi)</td>
<td>$CMF_{8, fi, ac, sv, fi}$</td>
<td>-0.0647 -0.0897</td>
</tr>
<tr>
<td></td>
<td>Property damage only (pdo)</td>
<td></td>
<td>$CMF_{8, fi, ac, sv, pdo}$</td>
<td>0.00 -0.0840</td>
</tr>
</tbody>
</table>

**CMF$_{9, fs, ac, sv, fi}$—Shoulder Rumble Strips**

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

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

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

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

Equation 13-36

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

Equation 13-37

Where:

- $CMF_{9, fi, ac, sv, fi}$ = crash modification factor for shoulder rumble strips on a freeway segment for fatal-and-injury $fi$ single-vehicle crashes $sv$;
- $f_{tan}$ = factor for rumble strip presence on tangent portions of the segment;
- $P_{ir}$ = proportion of segment length with rumble strips present on the inside shoulders; and
- $P_{or}$ = proportion of segment length with rumble strips present on the outside shoulders.

The proportion $P_{ir}$ represents the proportion of the segment length with rumble strips present on the inside shoulders. It is computed by summing the length of roadway with rumble strips on the inside shoulder in both travel directions and dividing by twice the freeway segment length $L_{fs}$. The proportion $P_{or}$ represents the proportion of the segment length with rumble strips present on the outside shoulders. It is computed by summing the length of roadway with rumble strips on the outside shoulder in both travel directions and dividing by twice the freeway segment length $L_{fs}$.

This CMF addresses shoulder rumble strip placement on uncurved (i.e., tangent) segments. It has a value less than 1.0 on tangent segments with shoulder rumble strips suggesting that crash frequency is lowered by the presence of rumble strips. The opposite trend was found in the calibration data for curved segments. Specifically, these data indicated that crashes on curved segments with shoulder rumble strips were more frequent than on curved segments without shoulder rumble strips. This finding is partially supported by research that found total crash frequency increased on curved two-lane highway segments after centerline rumble strips were added (2). It is also supported by research that found night-time crashes on curved two-lane highway segments (with radius of 1,600 ft or less) increased after permanent raised pavement markers...
were added to the centerline (3). Nevertheless, these findings are counterintuitive and are not included in the CMF until the relationship is fully understood and established by additional research.

**CMF**$_{10, fs, ac, sv, fi}$—Outside Clearance

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

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

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

$$CMF_{10, fs, ac, sv, fi} = (1.0 - P_{ob}) \times \exp(-0.00451 \times (W_{hc} - W_z - 20)) + P_{ob} \times \exp(-0.00451 \times (W_{ocb} - 20))$$

Where:

- $CMF_{10, fs, ac, sv, fi}$ = crash modification factor for outside clearance on a freeway segment with single-vehicle $sv$ fatal-and-injury $fi$ crashes;
- $P_{ob}$ = proportion of segment length with a barrier present on the roadside (i.e., outside);
- $W_{hc}$ = clear zone width (ft); and
- $W_{ocb}$ = distance from edge of outside shoulder to barrier face (ft).

This CMF is derived to be applicable to a segment that has roadside barrier present along some portion of the segment. Guidance for computing the variables $P_{ob}$ and $W_{ocb}$ is provided in Section 13.7.3.

The clear zone width used in this CMF is an average for both directions of travel. Similarly, the value used for $W_{ocb}$ is an average for the segment. The clear zone width is measured from the near edge of the traveled way (i.e., it includes the outside shoulders). Details regarding the determination of this width are provided in Section 13.4. The CMF is applicable to clear zone widths in the range of 0 to 30 ft.

**CMF**$_{11, fs, ac, sv, z}$—Outside Barrier

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

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

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

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

Where:
The variable \( W_{ocb} \) represents the distance from the edge of outside shoulder to roadside barrier face. The value used for this variable in Equation 13-39 is an average for the segment. The CMF is applicable to \( W_{ocb} \) values in the range of 0.25 to 17 ft. This CMF is applicable to cable barrier, concrete barrier, guardrail, and bridge rail.

### 13.7.2. Crash Modification Factors for Speed-Change Lanes

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

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

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

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

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

\[
CMF_{1, sc, ac, at, z} = 1.0 + a \times \left[ \sum_{i=1}^{m} \left( \frac{5,730}{R_i} \right)^2 \times P_{c,i} \right] \tag{Equation 13-40}
\]

Where:

- \( CMF_{1, sc, ac, at, z} \) = crash modification factor for horizontal curvature at a speed-change lane with any cross section \( ac \), all crash types \( at \), and severity \( z \);
- \( R_i \) = radius of curve \( i \) (ft);
- \( P_{c,i} \) = proportion of segment length with curve \( i \); and
The regression coefficient for Equation 13-40 is provided in Table 13-23. Additional discussion of this CMF is provided in Section 13.7.1.

### Table 13-23. Coefficients for Horizontal Curve CMF–Speed-Change Lanes

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficient (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections (ac)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$CMF_{1, sc, ac, at, fi}$</td>
<td>0.0172</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$CMF_{1, sc, ac, at, pdo}$</td>
<td>0.0340</td>
</tr>
</tbody>
</table>

**CMF$_{2, w, x, y, n}$—Lane Width**

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

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

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

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

Equation 13-41

Where:

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

The lane width used in Equation 13-41 is an average for all through lanes adjacent to the speed-change lane (excluding managed lanes and auxiliary lanes associated with a weaving section). The CMF is applicable to lane widths in the range of 10.5 to 14 ft.

**CMF$_{3, w, x, y, z}$—Inside Shoulder Width**

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

- SPF for fatal-and-injury crashes, ramp entrance, freeway lanes $n (sc, nEN, at, fi)$;
- SPF for property-damage-only crashes, ramp entrance, freeway lanes $n (sc, nEN, at, pdo)$;
- SPF for fatal-and-injury crashes, ramp exit, freeway lanes $n (sc, nEX, at, fi)$; and
- SPF for property-damage-only crashes, ramp exit, freeway lanes $n (sc, nEX, at, pdo)$.
The base condition is a 6-ft inside shoulder width. The CMFs are described using the following equation.

\[ CMF_{3, sc, ac, at, z} = \exp(a \times [W_{is} - 6]) \]  

Equation 13-42

Where:

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

\[ W_{is} \] = inside shoulder width (ft).

The regression coefficient for Equation 13-42 is provided in Table 13-24.

**Table 13-24. Coefficients for Inside Shoulder Width CMF–Speed-Change Lanes**

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficient (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections (ac)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>( CMF_{3, sc, ac, at, fi} )</td>
<td>-0.0172</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>( CMF_{3, sc, ac, at, pdo} )</td>
<td>-0.0153</td>
</tr>
</tbody>
</table>

The inside shoulder width used in Equation 13-42 is an average for the subject direction of travel. The CMF is applicable to shoulder widths in the range of 2 to 12 ft.

**CMF\(_{4, w, x, y, z}\)–Median Width**

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

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

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

\[ CMF_{4, sc, ac, at, z} = (1.0 - P_{ib}) \times \exp(a \times [W_{m} - 2 \times W_{is} - 48]) + P_{ib} \times \exp(a \times [2 \times W_{icb} - 48]) \]  

Equation 13-43

Where:

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

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

\[ W_{m} \] = median width (measured from near edges of traveled way in both directions) (ft); and
The regression coefficient for Equation 13-43 is provided in Table 13-25. These CMFs are derived to be applicable to a segment that has median barrier present along some portion of the segment. Guidance for computing the variables \( P_{ib} \) and \( W_{icb} \) is provided in Section 13.7.3.

**Table 13-25. Coefficients for Median Width CMF–Speed-Change Lanes**

<table>
<thead>
<tr>
<th>Cross Section ((x))</th>
<th>Crash Type ((y))</th>
<th>Crash Severity ((z))</th>
<th>CMF Variable</th>
<th>Regression Coefficient (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections ((ac))</td>
<td>All types ((at))</td>
<td>Fatal and injury ((fi))</td>
<td>CMF4, sc, ac, at, fi</td>
<td>-0.00302</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>CMF4, sc, ac, at, pdo</td>
<td>-0.00291</td>
</tr>
</tbody>
</table>

The median width used in Equation 13-43 is an average for the segment. The value used for \( W_{icb} \) is an average for the subject direction of travel. Median width is measured from the near edge of the traveled way on one roadbed to the near edge of the traveled way on the other roadbed (i.e., it includes the inside shoulders). The CMF is applicable to median widths 9 ft or more. If the median width exceeds 90 ft, then 90 ft should be used for \( W_m \) in Equation 13-43. This guidance is illustrated in Figure 13-9.

**CMF5, w, x, y, z—Median Barrier**

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

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

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

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

Equation 13-44

Where:

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

The regression coefficient for Equation 13-44 is provided in Table 13-26. Guidance for computing the variables \( P_{ib} \) and \( W_{icb} \) is provided in Section 13.7.3.
Table 13-26. Coefficients for Median Barrier CMF–Speed-Change Lanes

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficient (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections (ac)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$CMF_{5, sc, ac, at, fi}$</td>
<td>0.131</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$CMF_{5, sc, ac, at, pdo}$</td>
<td>0.169</td>
</tr>
</tbody>
</table>

The variable $W_{icb}$ represents the distance from the edge of inside shoulder to median barrier face. The value used for this variable in Equation 13-44 is an average for the subject direction of travel. The CMF is applicable to $W_{icb}$ values in the range of 0.25 to 17 ft. This CMF is applicable to cable barrier, concrete barrier, guardrail, and bridge rail.

**CMF$_{6, w, x, y, z}$—High Volume**

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

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

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

$$CMF_{6, sc, ac, at, z} = \exp(a \times P_{hv})$$  \hspace{1cm} \text{Equation 13-45}

Where:

- $CMF_{6, sc, ac, at, z}$ = crash modification factor for high volume at a speed-change lane with any cross section ac, all crash types at, and severity z; and
- $P_{hv}$ = proportion of AADT during hours where volume exceeds 1,000 veh/h/ln.

The regression coefficient for Equation 13-45 is provided in Table 13-27. Additional discussion of this CMF is provided in Section 13.7.1.

Table 13-27. Coefficients for High Volume CMF–Speed-Change Lanes

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficient (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections (ac)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$CMF_{6, sc, ac, at, fi}$</td>
<td>0.350</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$CMF_{6, sc, ac, at, pdo}$</td>
<td>0.283</td>
</tr>
</tbody>
</table>
The proportion of AADT during hours where the volume exceeds 1,000 veh/h/ln is computed using the average hourly volume distribution associated with the subject segment. This distribution will typically be computed using the data obtained from the nearest continuous traffic counting station (on a freeway of similar character).

**CMF\_12, sc, nEN, at, z—Ramp Entrance**

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

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

The CMFs are described using the following equation.

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

Equation 13-46

Where:

- \( CMF_{12, sc, nEN, at, z} \) = crash modification factor for ramp entrance geometry on a freeway with \( n \) lanes with all crash types \( at \) and severity \( z \);
- \( L_{en} \) = length of ramp entrance (mi);
- \( I_{left} \) = ramp side indicator variable (= 1.0 if entrance or exit is on left side of through lanes, 0.0 if it is on right side); and
- \( AADT_r \) = annual average daily traffic volume of ramp (veh/day).

The regression coefficients for Equation 13-46 are provided in Table 13-28.

**Table 13-28. Coefficients for Ramp Entrance CMF—Speed-Change Lanes**

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp entrance ( nEN )</td>
<td>All types ( at )</td>
<td>Fatal and injury ( fi )</td>
<td>( CMF_{12, sc, nEN, at, fi} )</td>
<td>0.594 0.0318 0.001 0.198</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ( pdo )</td>
<td>( CMF_{12, sc, nEN, at, pdo} )</td>
<td>0.824 0.0252 0.001 0.00</td>
</tr>
</tbody>
</table>

This CMF is applicable to a ramp entrance speed-change lane, as shown in Figure 13-8. The ramp entrance length is measured using the reference points identified in Figure 13-2. This CMF applies only to the side of the freeway with the subject speed-change lane.

The variable for ramp entrance length \( L_{en} \) in Equation 13-46 is intended to reflect the degree to which the lane-changing activity is concentrated along the ramp entrance. The CMF is applicable to ramp entrance lengths in the range of 0.04 to 0.30 mi (210 to 1,600 ft).
The indicator variable for ramp side \( I_{left} \) is associated with a positive regression coefficient. This sign indicates that a ramp entrance on the left side of the through lanes is associated with an increase in crash frequency, relative to one on the right side.

**CMF\(_{13, \text{sc, nEX, at, z}}\)—Ramp Exit**

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

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

The CMFs are described using the following equation.

\[
CMF_{13, \text{sc, nEX, at, z}} = \exp \left( a \times I_{left} + \frac{b}{L_{ex}} \right)
\]

Equation 13-47

Where:

- \( CMF_{13, \text{sc, nEX, at, z}} \) = crash modification factor for ramp exit geometry on a freeway with \( n \) lanes with all crash types \( at \) and severity \( z \);
- \( L_{ex} \) = length of ramp exit (mi); and
- \( I_{left} \) = ramp side indicator variable (= 1.0 if entrance or exit is on left side of through lanes, 0.0 if it is on right side).

The regression coefficients for Equation 13-47 are provided in Table 13-29.

**Table 13-29.** Coefficients for Ramp Exit CMF–Speed-Change Lanes

<table>
<thead>
<tr>
<th>Cross Section (( x ))</th>
<th>Crash Type (( y ))</th>
<th>Crash Severity (( z ))</th>
<th>CMF Variable</th>
<th>Regression Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp exit (( nEX ))</td>
<td>All types (( at ))</td>
<td>Fatal and injury (( fi ))</td>
<td>( CMF_{13, \text{sc, nEX, at, fi}} )</td>
<td>0.594 0.0116</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (( pdo ))</td>
<td>( CMF_{13, \text{sc, nEX, at, pdo}} )</td>
<td>0.824 0.00</td>
</tr>
</tbody>
</table>

This CMF is applied to a ramp exit speed-change lane, as shown in Figure 13-8. The ramp exit length is measured using the reference points identified in Figure 13-2. This CMF applies only to the side of the freeway with the subject speed-change lane.

The variable for ramp exit length \( L_{ex} \) in Equation 13-47 is intended to reflect the degree to which the lane-changing activity is concentrated along the ramp exit. The CMF is applicable to ramp exit lengths in the range of 0.02 to 0.30 mi (106 to 1600 ft).

The interpretation of the indicator variable for ramp side \( I_{left} \) is provided with the previous CMF discussion.
The indicator variable for ramp side $I_{left}$ is associated with a positive regression coefficient. This sign indicates that a ramp exit on the left side of the through lanes is associated with an increase in crash frequency, relative to one on the right side.

### 13.7.3. Supplemental Calculations to Apply Crash Modification Factors

Some of the CMFs in Section 13.7.1 and Section 13.7.2 require the completion of supplemental calculations before they can be applied to the SPFs in Section 13.6. These CMFs are:

- Median width.
- Median barrier.
- Outside clearance.
- Outside barrier.

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

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

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

Two key variables that are needed for the evaluation of barrier presence are the inside barrier offset distance $W_{icb}$ and the outside barrier offset distance $W_{ocb}$. As indicated in Equation 13-28 and Equation 13-39, this distance is included as a divisor in the exponential term. This relationship implies that the correlation between barrier distance and crash frequency is an inverse one (i.e., crash frequency decreases with increasing distance to the barrier). When multiple sections of barrier exist along the segment, a length-weighted average of the reciprocal of the individual distances is needed to properly reflect this inverse relationship. The length used to weight the average is the barrier length.

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

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

For segments or speed-change lanes with a continuous barrier centered in the median (i.e., symmetric median barrier), the following equations are used to estimate $W_{icb}$ and $P_{ib}$. 
\[ W_{icb} = \frac{2 \times L}{\sum W_{off, in, i} - W_{is} + \sum L_{ib, i}} + \frac{2 \times L - \sum L_{ib, i}}{0.5 \times (W_m - 2 \times W_{is} - W_{ib})} \]

Equation 13-48

Where:

\[ P_{ib} = 1.0 \]

Equation 13-49

Where:

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

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

\[ L = \text{length of segment (mi);} \]

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

\[ W_{ib} = \text{inside barrier width (measured from barrier face to barrier face) (ft);} \]

\[ W_{is} = \text{inside shoulder width (ft);} \]

\[ W_m = \text{median width (measured from near edges of traveled way in both directions) (ft);} \]

\[ W_{off, in, i} = \text{horizontal clearance from the edge of the traveled way to the face of inside barrier } i \text{ (ft).} \]

The first summation term “\( \sum \)” in Equation 13-48 applies to short lengths of barrier in the median. It indicates that the ratio of barrier length \( L_{ib, i} \) to clearance distance \( = W_{off, in, i} - W_{is} \) should be computed for each individual length of barrier that is found in the median along the segment (e.g., a barrier protecting a sign support). The continuous median barrier is not considered in this summation. Any clearance distance that is less than 0.25 ft should be set to 0.25 ft. Similarly, if the distance \( 0.5 \times (W_m - 2 \times W_{is} - W_{ib}) \) is less than 0.25 ft, then it should be set to 0.25 ft.

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

\[ W_{icb} = \frac{L}{W_{near} - W_{is}} + \frac{2 \times L}{\sum W_{off, in, i} - W_{is} + \sum L_{ib, i}} \quad \text{Equation 13-50} \]

\[ P_{ib} = 1.0 \quad \text{Equation 13-51} \]

Where:

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

Similar to the previous guidance, the first summation term “\( \sum \)” in Equation 13-50 applies to short lengths of barrier in the median. The ratio of barrier length \( L_{ib} \) to the clearance distance \( = W_{off, in, i} - W_{is} \) should be computed for each individual length of barrier that is found in the median along the segment. The continuous median barrier is not considered in this summation. Any clearance distance that is less than 0.25 ft should be
set to 0.25 ft. Similarly, if the distance \( W_{\text{near}} - W_{ib} \) or the distance \( W_m - 2 \times W_s - W_{ib} - W_{\text{near}} \) is less than 0.25 ft, then it should be set to 0.25 ft.

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

\[
W_{icb} = \frac{\sum L_{ib,i}}{\sum W_{\text{eff.},in,i} - W_{is}}
\]

Equation 13-52

\[
P_{ib} = \frac{\sum L_{ib,i}}{2 \times L}
\]

Equation 13-53

Any clearance distance \( = W_{\text{eff.}, in, i} - W_{is} \) that is less than 0.25 ft should be set to 0.25 ft.

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

\[
P_{ib} = 0.0
\]

Equation 13-54

As suggested by Equation 13-28, the calculation of \( W_{icb} \) is not required when \( P_{ib} = 0.0 \).

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

\[
W_{ocb} = \frac{\sum L_{ob,i}}{\sum W_{\text{eff.},o,i} - W_{i}}
\]

Equation 13-55

\[
P_{ob} = \frac{\sum L_{ob,i}}{2 \times L}
\]

Equation 13-56

Where:

- \( L_{ob,i} \) = length of lane paralleled by outside barrier \( i \) (include both travel directions) (mi);
- \( P_{ob} \) = proportion of segment length with a barrier present on the roadside (i.e., outside);
- \( W_{ocb} \) = distance from edge of outside shoulder to barrier face (ft);
- \( W_i \) = outside shoulder width (ft); and
- \( W_{\text{eff.},o,i} \) = horizontal clearance from the edge of the traveled way to the face of outside barrier \( i \) (ft).

Any clearance distance \( = W_{\text{eff.}, o, i} - W_i \) that is less than 0.25 ft should be set to 0.25 ft.

For segments or speed-change lanes without barrier on the roadside, the following equation should be used to estimate \( P_{ob} \).
As suggested by Equation 13-39, the calculation of $W_{ob}$ is not required when $P_{ob} = 0.0$.

### 13.8. SEVERITY DISTRIBUTION FUNCTIONS

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

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

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

Equation 13-58

Where:

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

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

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

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

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

$$P_{fi+sc,ac,at,K} = \frac{\exp(V_K)}{1.0 + \exp(V_K) + \exp(V_A) + \exp(V_B)}$$

Equation 13-59

$$P_{fi+sc,ac,at,A} = \frac{\exp(V_A)}{1.0 + \exp(V_K) + \exp(V_A) + \exp(V_B)}$$

Equation 13-60
\[ P_{f+s+c, \text{ac}, \text{at}, B} = \frac{\exp(V_B)}{C_{\text{sdf, f+s+c}}} + \exp(V_K) + \exp(V_A) + \exp(V_B) \]  

Equation 13-61

\[ P_{f+s+c, \text{ac}, \text{at}, C} = 1.0 - (P_K + P_A + P_B) \]  

Equation 13-62

with,

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

Equation 13-63

Where:

\[ V_j \] = systematic component of crash severity likelihood for severity level \( j \);

\[ C_{\text{sdf, f+s+c}} \] = calibration factor to adjust SDF for local conditions for freeway segments and speed-change lanes;

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

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

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

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

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

\[ P_{c,i} \] = proportion of segment length with curve \( i \);

\[ W_l \] = lane width (ft);

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

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

The SDF regression coefficients in Equation 13-63 are provided in Table 13-30. Guidance for computing the variables \( P_{ib} \) and \( P_{ob} \) is provided in Section 13.7.3.

### Table 13-30. SDF Coefficients for Freeway Segments and Speed-Change Lanes

<table>
<thead>
<tr>
<th>Severity Level (( j ))</th>
<th>Variable</th>
<th>Regression Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( a )</td>
</tr>
<tr>
<td>Fatal (K)</td>
<td>( V_K )</td>
<td>-0.171</td>
</tr>
<tr>
<td>Incapacitating injury (A)</td>
<td>( V_A )</td>
<td>-2.393</td>
</tr>
<tr>
<td>Non-incapacitating inj. (B)</td>
<td>( V_B )</td>
<td>0.0732</td>
</tr>
</tbody>
</table>
The proportion of AADT during hours where the volume exceeds 1,000 veh/h/ln is computed using the average hourly volume distribution associated with the subject segment. This distribution will typically be computed using the data obtained from the nearest continuous traffic counting station (on a freeway of similar character). Additional discussion of this variable is provided in Section 13.7.1 for the High Volume CMF.

The proportion $P_r$ is computed by summing the length of roadway with rumble strips on the inside shoulder in both travel directions and dividing by twice the freeway segment length $L_{fs}$. The proportion $P_o$ is computed by summing the length of roadway with rumble strips on the outside shoulder in both travel directions and dividing by twice the freeway segment length $L_{fs}$.

The variable $P_{c,i}$ is computed as the ratio of the length of curve $i$ on the segment to the length of the freeway segment $L_{fs}$. For example, consider a segment that is 0.5 mi long and a curve that is 0.2 mi long. If one-half of the curve is on the segment, then $P_{c,i} = 0.20 (= 0.1/0.5)$. In fact, this proportion is the same regardless of the curve’s length (provided that it is 0.1 mi or longer and 0.1 mi of this curve is located on the segment).

The lane width variable $W_l$ is an average for all through lanes on the segment (excluding managed lanes and auxiliary lanes associated with a weaving section).

The sign of any regression coefficient in Table 13-30 indicates the change in the proportion of crashes associated with a change in the corresponding variable. For example, the negative coefficient associated with barrier presence indicates that the proportion of fatal K crashes decreases with an increase in the proportion of barrier present on the segment. A similar trend is indicated for barrier presence on incapacitating injury A crashes and non-incapacitating injury B crashes. By inference, the proportion of possible injury C crashes increases with an increase in the proportion of barrier present.

13.9. CALIBRATION OF THE SPFS AND SDFS TO LOCAL CONDITIONS

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

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

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

Calibration factors provide one method of using local crash data to improve the estimated crash frequency for individual agencies or locations. Several other default values used in the methodology, such as crash type distribution, can also be replaced with locally derived values. The derivation of values for these parameters is addressed in the calibration procedure in Section A.1.3 of Appendix A to Part C.
13.10. LIMITATIONS OF PREDICTIVE METHOD IN CHAPTER 13
The limitations of the predictive method which apply generally across all of the Part C chapters are discussed in Section C.14 of Part C—Introduction and Applications Guidance chapter. This section discusses limitations of the predictive models described in this chapter.

The predictive method in Chapter 13 can be applied to the combinations of area type (rural or urban) and number of lanes that are listed in Section 13.6. The method can be extended to freeway segments with unequal number of lanes in opposing directions, but only if the number of lanes is within the ranges listed in Section 13.6.1 and varies by no more than one lane between the two travel directions.

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

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

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

13.11. APPLICATION OF PREDICTIVE METHOD IN CHAPTER 13
The predictive method presented in Chapter 13 is applied to a freeway facility by following the 18 steps presented in Section 13.4. Worksheets are provided in Appendix 13A for applying calculations in the predictive method steps specific to Chapter 13. All computations of crash frequencies within these worksheets are conducted with values expressed to three decimal places. This level of precision is needed only for consistency in computations. In the last stage of computations, rounding the final estimates of expected average crash frequency to one decimal place is appropriate.

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

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

13.12. SUMMARY
The predictive method for freeways is applied by following the 18 steps of the predictive method presented in Section 13.4. It is used to estimate the expected average crash frequency for a series of contiguous sites, or a single individual site. If a freeway facility is being evaluated, then it is divided into a series of sites in
Step 5 of the predictive method. Predictive models are applied in Steps 9, 10, and 11 of the method to estimate the expected average crash frequency of each site.

Each predictive model consists of a safety performance function (SPF), crash modification factors (CMFs), a severity distribution function (SDF), and calibration factors. The SPF is selected in Step 9. It is used to estimate the predicted average crash frequency for a site with base conditions. CMFs are selected in Step 10. They are combined with the estimate from the SPF to produce the expected average crash frequency for the subject site. Optionally, the SDFs are selected in Step 13. They can be used to estimate the expected average crash frequency for one or more crash severity levels (i.e., fatal, incapacitating injury, non-incapacitating injury, or possible injury crash). Optionally, the crash type distribution can be used in Step 13 to estimate the expected crash frequency for one or more crash types (e.g., head-on, fixed object).

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

The SPF is calibrated to the specific state or geographic region in which the project is located. Calibration accounts for differences in state or regional crash frequencies, relative to the states and regions represented in the regression coefficients documented in Chapter 13. The process for determining calibration factors for the predictive models is described in Part C, Appendix A.1.

Section 13.13 presents several sample problems that detail the application of the predictive method. A series of worksheets are used to guide the method application and document the calculations. The use of these worksheets is illustrated in the sample problems. Appendix 13A contains blank worksheets that can be copied to document future method applications.
13.13. SAMPLE PROBLEMS
In this section, six sample problems are presented using the predictive method steps for freeway facilities. Sample Problems 1 and 2 illustrate how to calculate the predicted average crash frequency for freeway segments. Sample Problem 3 illustrates how to calculate the predicted average crash frequency for an entrance-ramp speed-change lane. Sample Problem 4 illustrates a similar calculation for an exit-ramp speed-change lane. Sample Problem 5 illustrates how to combine the results from Sample Problems 1 and 2 in a case where site-specific observed crash data are available (i.e., using the site-specific EB Method). Sample Problem 6 illustrates how to combine the results from Sample Problems 1 and 2 in a case where crash data are available but cannot be assigned to specific segments (i.e., using the project-level EB Method).

Table 13-31. List of Sample Problems in Chapter 13

<table>
<thead>
<tr>
<th>Problem No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Predicted average crash frequency for a tangent six-lane urban freeway segment</td>
</tr>
<tr>
<td>2</td>
<td>Predicted average crash frequency for a six-lane urban freeway segment with a curve</td>
</tr>
<tr>
<td>3</td>
<td>Predicted average crash frequency for a urban freeway entrance-ramp speed-change lane</td>
</tr>
<tr>
<td>4</td>
<td>Predicted average crash frequency for a urban freeway exit-ramp speed-change lane</td>
</tr>
<tr>
<td>5</td>
<td>Expected average crash frequency for a facility when site-specific observed crash data are available</td>
</tr>
<tr>
<td>6</td>
<td>Expected average crash frequency for a facility when site-specific observed crash data are not available</td>
</tr>
</tbody>
</table>

13.13.1. Sample Problem 1

The Site/Facility
A tangent six-lane urban freeway segment.

The Question
What is the predicted average crash frequency of the freeway segment for a one-year period?

The Facts
The study year is 2011. The conditions present during this year are provided in the following list.

- 0.75-mi length
- 120,000 veh/day
- 10 percent of AADT volume occurs during high-volume hours
- No horizontal curvature
- 12-ft lane width
- 10-ft outside shoulder width
- 6-ft inside shoulder width
- 40-ft median width
- No rumble strips on inside or outside shoulders
- No median or roadside barrier
- 30-ft clear zone width
- No Type B weaving sections
- Data to describe four ramps in the vicinity of the segment

<table>
<thead>
<tr>
<th>Variable Subscript (a,b)</th>
<th>Distance from Segment, X_{a,b} (mi)</th>
<th>Ramp Volume, AADT_{a,b} (veh/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>b, ent</td>
<td>0.5</td>
<td>8,000</td>
</tr>
<tr>
<td>e, ext</td>
<td>0.85</td>
<td>7,150</td>
</tr>
<tr>
<td>e, ent</td>
<td>0.85</td>
<td>6,750</td>
</tr>
<tr>
<td>b, ext</td>
<td>0.5</td>
<td>7,675</td>
</tr>
</tbody>
</table>

**Assumptions**
- Crash type distributions used are the default values presented in Table 13-6 and Table 13-8.
- The calibration factor is 1.00.

**Results**
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the roadway segment in Sample Problem 1 is determined to be 6.0 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 14.7 crashes per year (rounded to one decimal place).
Steps

Step 1 through 8
To determine the predicted average crash frequency of the freeway segment in Sample Problem 1, only Steps 9 through 13 are conducted. No other steps are necessary because only one freeway segment is analyzed for one year, and the EB Method is not applied.

Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site’s facility type and traffic control features.
For a six-lane urban freeway segment, SPF values for multiple-vehicle and single-vehicle crashes are determined.

Multiple-Vehicle Crashes
The SPF for multiple-vehicle fatal-and-injury crashes is calculated from Equation 13-15 and Table 13-5 as follows:

\[ N_{pf, fs, 6, mv, fi} = L \times \exp\left(a + b \times \ln\left[c \times AADT_{fs}\right]\right) \]

\[ = 0.75 \times \exp(-5.587 + 1.492 \times \ln[0.001 \times 120,000]) \]

\[ = 3.555 \text{ crashes/year} \]

Similarly, the SPF for multiple-vehicle property-damage-only crashes is calculated from Equation 13-15 and Table 13-5 to yield the following result:

\[ N_{pf, fs, 6, mv, pdo} = 8.775 \text{ crashes/year} \]

Single-Vehicle Crashes
The SPF for single-vehicle fatal-and-injury crashes is calculated from Equation 13-18 and Table 13-7 as follows:

\[ N_{pf, fs, 6, sv, fi} = L \times \exp\left(a + b \times \ln\left[c \times AADT_{fs}\right]\right) \]

\[ = 0.75 \times \exp(-2.055 + 0.646 \times \ln[0.001 \times 120,000]) \]

\[ = 2.117 \text{ crashes/year} \]

Similarly, the SPF for single-vehicle property-damage-only crashes is calculated from Equation 13-18 and Table 13-7 to yield the following result:

\[ N_{pf, fs, 6, sv, pdo} = 5.115 \text{ crashes/year} \]

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

Horizontal Curve (CMF\textsubscript{1,fs,6,y,z})
The segment does not have horizontal curvature. Hence, CMF\textsubscript{1,fs,6,y,fi} and CMF\textsubscript{1,fs,6,y,pdo} are equal to 1.000.
**Lane Width (CMF\textsubscript{2,fs,6,y,z})**
The segment has 12-ft lanes, which is the base condition for the lane width CMF. Hence, $CMF_{2,fs,6,y,fi}$ and $CMF_{2,fs,6,y,pdo}$ are equal to 1.000.

**Inside Shoulder Width (CMF\textsubscript{3,fs,6,y,z})**
The segment has 6-ft inside shoulders, which is the base condition for the inside shoulder width CMF. Hence, $CMF_{3,fs,6,y,fi}$ and $CMF_{3,fs,6,y,pdo}$ are equal to 1.000.

**Median Width (CMF\textsubscript{4,fs,6,y,z})**
$CMF_{4,fs,6,y,fi}$ is calculated from Equation 13-27 as follows:

\[
CMF_{4,fs,6,y,fi} = (1.0 - P_{ib}) \times \exp(a \times [W_m - 2 \times W_{is} - 48]) + P_{ib} \times \exp(a \times [2 \times W_{icb} - 48])
\]

The segment does not have inside barrier, so $P_{ib} = 0.0$ and the calculation of $W_{icb}$ does not apply. From Table 13-17, $a = -0.00302$ for multiple-vehicle fatal-and-injury crashes. $CMF_{4,fs,6,mv,fi}$ is calculated as follows:

\[
CMF_{4,fs,6,mv,fi} = (1.0 - 0.0) \times \exp(-0.00302 \times [40 - 2 \times 6 - 48]) + 0.0 \times \exp(-0.00302 \times [2 \times W_{icb} - 48]) = 1.062
\]

Calculations using the other coefficients from Table 13-17 yield the following results:

\[
CMF_{4,fs,6,sv,fi} = 0.980
\]
\[
CMF_{4,fs,6,mv,pdo} = 1.060
\]
\[
CMF_{4,fs,6,sv,pdo} = 1.060
\]

**Median Barrier (CMF\textsubscript{5,fs,6,y,z})**
The segment does not have inside barrier. Hence, $CMF_{5,fs,6,y,fi}$ and $CMF_{5,fs,6,y,pdo}$ are equal to 1.000.

**High Volume (CMF\textsubscript{6,fs,6,y,z})**
$CMF_{6,fs,6,mv,fi}$ is calculated from Equation 13-29 and the coefficient $a = 0.350$ from Table 13-19 as follows:

\[
CMF_{6,fs,6,mv,fi} = \exp(a \times P_{hv})
\]
\[
= \exp(0.350 \times 0.1)
\]
\[
= 1.036
\]

Calculations using the other coefficients from Table 13-19 yield the following results:

\[
CMF_{6,fs,6,sv,fi} = 0.993
\]
\[
CMF_{6,fs,6,mv,pdo} = 1.029
\]
\[
CMF_{6,fs,6,sv,pdo} = 0.941
\]
**Lane Change (CMF7, fs, 6, mv, z)**
The segment does not have a ramp entrance or a ramp exit within 0.5 mi, which is the base condition for the lane change CMF. Hence, \( CMF7, fs, 6, mv, fi \) and \( CMF7, fs, 6, mv, pdo \) are equal to 1.000.

**Outside Shoulder Width (CMF8, fs, 6, sv, z)**
The segment has 10-ft outside shoulders, which is the base condition for the outside shoulder width CMF. Hence, \( CMF8, fs, 6, sv, fi \) and \( CMF8, fs, 6, sv, pdo \) are equal to 1.000.

**Shoulder Rumble Strip (CMF9, fs, 6, sv, z)**
The segment does not have shoulder rumble strips. Hence, \( CMF9, fs, 6, sv, fi \) and \( CMF9, fs, 6, sv, pdo \) are equal to 1.000.

**Outside Clearance (CMF10, fs, 6, sv, z)**
The segment has 30-ft clear zones and no outside barrier, which are the base conditions for the outside clearance CMF. Hence, \( CMF10, fs, 6, sv, fi \) and \( CMF10, fs, 6, sv, pdo \) are equal to 1.000.

**Outside Barrier (CMF11, fs, 6, sv, z)**
The segment does not have outside barrier. Hence, \( CMF11, fs, 6, sv, fi \) and \( CMF11, fs, 6, sv, pdo \) are equal to 1.000.

**Multiple-Vehicle Crashes**
The CMFs are applied to the multiple-vehicle fatal-and-injury SPF as follows:

\[
N_{p^*, fs, 6, mv, fi} = N_{spf, fs, 6, mv, fi} \times \left( CMF1, fs, 6, mv, fi \times \ldots \times CMF7, fs, 6, mv, fi \right) \\
= 3.555 \times \left( 1.000 \times 1.000 \times 1.000 \times 1.062 \times 1.000 \times 1.036 \times 1.000 \right) \\
= 3.555 \times 1.100 \\
= 3.911 \text{ crashes/year}
\]

The CMFs are applied to the multiple-vehicle property-damage-only SPF as follows:

\[
N_{p^*, fs, 6, mv, pdo} = N_{spf, fs, 6, mv, pdo} \times \left( CMF1, fs, 6, mv, pdo \times \ldots \times CMF7, fs, 6, mv, pdo \right) \\
= 8.775 \times \left( 1.000 \times 1.000 \times 1.000 \times 1.060 \times 1.000 \times 1.029 \times 1.000 \right) \\
= 8.775 \times 1.091 \\
= 9.569 \text{ crashes/year}
\]

**Single-Vehicle Crashes**
The CMFs are applied to the single-vehicle fatal-and-injury SPF as follows:

\[
N_{p^*, fs, 6, sv, fi} = N_{spf, fs, 6, sv, fi} \times \left( CMF1, fs, 6, sv, fi \times \ldots \times CMF6, fs, 6, sv, fi \times CMF7, fs, 6, sv, fi \times \ldots \times CMF11, fs, 6, sv, fi \right) \\
= 2.117 \times \left( 1.000 \times 1.000 \times 1.000 \times 0.980 \times 1.000 \times 0.993 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \right) \\
= 2.117 \times 0.973 \\
= 2.060 \text{ crashes/year}
\]

The CMFs are applied to the single-vehicle property-damage-only SPF as follows:
Step 11 – Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor of 1.00 has been determined for local conditions. As a result, 

\[ N_{p*, fs, 6, sv, pdo} = N_{np, fs, 6, sv, pdo} \times CMF_{1, fs, 6, sv, pdo} \times \ldots \times CMF_{6, fs, 6, sv, pdo} \times \ldots \times CMF_{11, fs, 6, sv, pdo} \]

\[ = 5.115 \times (1.000 \times 1.000 \times 1.000 \times 1.060 \times 1.000 \times 0.941 \times 1.000 \times 1.000 \times 1.000) \]

\[ = 5.115 \times 0.997 \]

\[ = 5.099 \text{ crashes/year} \]

**Calculation of Predicted Average Crash Frequency**
The predicted average crash frequency is calculated using Equation 13-2 based on the results obtained in Steps 9 through 11 as follows.

**Fatal-and-injury crashes:**

\[ N_{p, fs, 6, at, fi} = N_{p, fs, 6, mv, fi} + N_{p, fs, 6, sv, fi} \]

\[ = 3.911 + 2.060 \]

\[ = 5.971 \text{ crashes/year} \]

**Property-damage-only crashes:**

\[ N_{p, fs, 6, at, pdo} = N_{p, fs, 6, mv, pdo} + N_{p, fs, 6, sv, pdo} \]

\[ = 9.569 + 5.099 \]

\[ = 14.668 \text{ crashes/year} \]

**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.**
The study period is one year (2011), so steps 8 through 11 need not be repeated.

**Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.**
This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

**Apply the site-specific EB Method to a future time period, if appropriate.**
The site-specific EB Method is not applied in this sample problem because crash data are not available.

**Apply the severity distribution functions (SDFs), if desired.**
To apply the SDFs, the systematic component of crash severity likelihood \( V_j \) is computed for each severity level \( j \) using Equation 13-63 as follows:

\[ V_j = a + \left( b \times \frac{P_{ib} + P_{ob}}{2} \right) + \left( c \times P_{hv} \right) + \left( d \times \frac{P_{pv} + P_{ov}}{2} \right) + \left( e \times \sum P_{ci} \right) + \left( f \times W_j \right) + \left( g \times I_{rural} \right) \]
The coefficients $a, b, c, d, e, f$, and $g$ are obtained from Table 13-30 for each severity level $j$. The segment does not have barrier, rumble strips, or horizontal curvature, so $P_{ab}, P_{ob}, P_{sr}, P_{or}$, and $P_{cr}$ are equal to 0.0. $V_j$ is computed for fatal crashes as follows:

$$V_K = -0.171 + \left( -0.388 \times \frac{0.0 + 0.0}{2} \right) + (-0.924 \times 0.1) + \left( 0.387 \times \frac{0.0 + 0.0}{2} \right) + (0.208 \times 0.0) + (-0.261 \times 12) + (0.492 \times 0.0)$$
$$= -3.392$$

Calculations using the coefficients for incapacitating injury crashes and non-incapacitating injury crashes from Table 13-30 yield the following results:

$$V_A = -2.478$$
$$V_B = -0.571$$

Using these computed $V_K, V_A,$ and $V_B$ values, and assuming a calibration factor $C_{sdf, fs+sc}$ of 1.0, the probability of occurrence of a fatal crash is computed using Equation 13-59 as follows:

$$P_{fs+sc, ac, at, K} = \frac{\exp(V_K)}{1.0 + \exp(V_K) + \exp(V_A) + \exp(V_B)}$$
$$= \frac{\exp(-3.392)}{1.0 + \exp(-3.392) + \exp(-2.478) + \exp(-0.571)}$$
$$= 0.020$$

Similar calculations using Equation 13-60 and Equation 13-61 yield the following results:

$$P_{fs+sc, ac, at, A} = 0.050$$
$$P_{fs+sc, ac, at, B} = 0.336$$

The probability of occurrence of a possible-injury crash is computed using Equation 13-62 as follows:

$$P_{fs+sc, ac, at, C} = 1.0 - (P_{fs+sc, ac, at, K} + P_{fs+sc, ac, at, A} + P_{fs+sc, ac, at, B})$$
$$= 1.0 - (0.020 + 0.050 + 0.336)$$
$$= 0.594$$

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 13-58 as follows:

$$N_{e, fs, 6, at, K} = N_{e, fs, 6, at, f} \times P_{fs+sc, ac, at, K}$$
$$= 5.971 \times 0.020$$
$$= 0.119 \text{ crashes/year}$$
Similar calculations using Equation 13-58 and the probabilities of occurrences of the other crash severities yield the following results:

\[ N_{e,fr,6,at,A} = 0.298 \text{ crashes/year} \]

\[ N_{e,fr,6,at,B} = 2.005 \text{ crashes/year} \]

\[ N_{e,fr,6,at,C} = 3.548 \text{ crashes/year} \]

*Apply the crash type distribution, if desired.*

The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 13-6 and Table 13-8 by the predicted average crash frequencies obtained in Step 11.

**Worksheets**

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

- Table 13-32. Freeway Segment Worksheet (1 of 4)—Sample Problem 1
- Table 13-33. Freeway Segment Worksheet (2 of 4)—Sample Problem 1
- Table 13-34. Freeway Segment Worksheet (3 of 4)—Sample Problem 1
- Table 13-35. Freeway Segment Worksheet (4 of 4)—Sample Problem 1

Filled versions of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 13 Appendix A.

Table 13-32 is a summary of general information about the freeway segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 1. The input data include area type, crash data, basic roadway data, alignment data, and cross section data.

Table 13-33 is a summary of general information about the freeway segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 1. The input data include roadside data, ramp access data, and traffic data.

Table 13-34 is a tabulation of the CMF and SPF computations for Sample Problem 1.

Table 13-35 is a tabulation of the crash severity and crash type distributions for Sample Problem 1.
### Table 13-32. Freeway Segment Worksheet (1 of 4)—Sample Problem 1

<table>
<thead>
<tr>
<th>General Information</th>
<th>Location Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Roadway</td>
</tr>
<tr>
<td>Agency or company</td>
<td>Roadway section</td>
</tr>
<tr>
<td>Date performed</td>
<td>Study year</td>
</tr>
<tr>
<td>Area type</td>
<td>X Urban Rural</td>
</tr>
</tbody>
</table>

#### Input Data

**Crash Data**

<table>
<thead>
<tr>
<th>Crash Data</th>
<th>Crash Period</th>
<th>Study Year</th>
<th>Complete the study year column. Complete the crash period column if the EB Method is used.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash data time period</td>
<td></td>
<td>First year</td>
<td>-- Last year</td>
</tr>
<tr>
<td>Count of multiple-vehicle FI crashes $N_{o, fs, n, mv, fi}$</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count of single-vehicle FI crashes $N_{o, fs, n, sv, fi}$</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count of multiple-vehicle PDO crashes $N_{o, fs, n, mv, pdo}$</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count of single-vehicle PDO crashes $N_{o, fs, n, sv, pdo}$</td>
<td>--</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Basic Roadway Data**

<table>
<thead>
<tr>
<th>Basic Roadway Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of through lanes $n$</td>
<td>6</td>
</tr>
<tr>
<td>Segment length $L$ (mi)</td>
<td>0.75</td>
</tr>
</tbody>
</table>

**Alignment Data**

**Horizontal Curve Data**

| 1 | Presence of horizontal curve 1 | -- | Y/N | N | Y/N | If Yes, then enter data in the next three rows. |
|   | Curve radius $R_1$ (ft) | -- | -- | -- | |
|   | Length of curve $L_{c1}$ (mi) | -- | -- | |
|   | Length of curve in segment $L_{c1, seg}$ (mi) | -- | -- | |
| 2 | Presence of horizontal curve 2 | -- | Y/N | N | Y/N | If Yes, then enter data in the next three rows. |
|   | Curve radius $R_2$ (ft) | -- | -- | |
|   | Length of curve $L_{c2}$ (mi) | -- | -- | |
|   | Length of curve in segment $L_{c2, seg}$ (mi) | -- | -- | |

**Cross Section Data**

<table>
<thead>
<tr>
<th>Cross Section Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane width $W_l$ (ft)</td>
<td>12</td>
</tr>
<tr>
<td>Outside shoulder width $W_s$ (ft)</td>
<td>10</td>
</tr>
<tr>
<td>Inside shoulder width $W_i$ (ft)</td>
<td>6</td>
</tr>
<tr>
<td>Median width $W_m$ (ft)</td>
<td>40</td>
</tr>
<tr>
<td>Presence of rumble strips on outside shoulder</td>
<td>--</td>
</tr>
<tr>
<td>Length of rumble strip in increasing milepost dir. (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Length of rumble strip in decreasing milepost dir. (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Presence of rumble strips on inside shoulder</td>
<td>--</td>
</tr>
<tr>
<td>Length of rumble strip in increasing milepost dir. (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Length of rumble strip in decreasing milepost dir. (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Presence of barrier in median</td>
<td>--</td>
</tr>
</tbody>
</table>
Table 13-33. Freeway Segment Worksheet (2 of 4)—Sample Problem 1

<table>
<thead>
<tr>
<th>Input Data</th>
<th></th>
<th></th>
<th>Complete the study year column. Complete the crash period column if the EB Method is used.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roadside Data</strong></td>
<td><strong>Crash Period</strong></td>
<td><strong>Study Year</strong></td>
<td></td>
</tr>
<tr>
<td>Clear zone width $W_{Rc}$ (ft)</td>
<td>--</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Presence of barrier on roadside</td>
<td>--</td>
<td>Y/N</td>
<td>N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ramp Access Data</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Travel in Increasing Milepost Direction</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ent. ramp</td>
<td>Distance from begin milepost to upstream entrance ramp gore $X_{b,ent}$ (mi)</td>
<td>--</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Presence of speed-change lane in segment</td>
<td>--</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>Length of s-c lane in segment $L_{s-c, inc}$ (mi)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Exit ramp</td>
<td>Distance from end milepost to upstream exit ramp gore $X_{e, ext}$ (mi)</td>
<td>--</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Presence of speed-change lane in segment</td>
<td>--</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>Length of s-c lane in segment $L_{s-c, dec}$ (mi)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Weave</strong></td>
<td>Presence of a Type B weave in segment</td>
<td>--</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>Length of weaving section $L_{wev, inc}$ (mi)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Length of weaving section in seg. $L_{wev, seg, inc}$ (mi)</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

| Travel in Decreasing Milepost Direction |  |  |  |
| Ent. ramp | Distance from end milepost to upstream entrance ramp gore $X_{b, ent}$ (mi) | -- | 0.85 | If ramp entrance is in the segment, enter 0.0. |
| | Presence of speed-change lane in segment | -- | Y/N | N | Y/N | If Yes, then enter data in the next row. |
| | Length of s-c lane in segment $L_{s-c, dec}$ (mi) | -- | -- |  |
| Exit ramp | Distance from begin milepost to downstream exit ramp gore $X_{e, ext}$ (mi) | -- | 0.5 | If ramp exit is in the segment, enter 0.0. |
| | Presence of speed-change lane in segment | -- | Y/N | N | Y/N | If Yes, then enter data in the next row. |
| | Length of s-c lane in segment $L_{s-c, dec}$ (mi) | -- | -- |  |
| **Weave** | Presence of a Type B weave in segment | -- | Y/N | N | Y/N | If Yes, then enter data in the next two rows. |
| | Length of weaving section $L_{wev, dec}$ (mi) | -- | -- |  |
| | Length of weaving section in seg. $L_{wev, seg, dec}$ (mi) | -- | -- |  |

| Traffic Data |  |  |
| Proportion of AADT during high-volume hours $P_{hv}$ | -- | 0.1 |  |
| Freeway segment AADT $AADT_{fs}$ (veh/day) | -- | 120,000 |  |
| AADT of entrance ramp for travel in increasing milepost direction $AADT_{b,ent}$ (veh/day) | -- | 8,000 |  |
| AADT of exit ramp for travel in increasing milepost direction $AADT_{e,ext}$ (veh/day) | -- | 7,150 |  |
| AADT of entrance ramp for travel in decreasing milepost direction $AADT_{e,ent}$ (veh/day) | -- | 6,750 |  |
| AADT of exit ramp for travel in decreasing milepost direction $AADT_{b,ext}$ (veh/day) | -- | 7,675 |  |
Table 13-34. Freeway Segment Worksheet (3 of 4)—Sample Problem 1

### Crash Modification Factors

Complete the study year column. Complete the crash period column if the EB Method is used.

<table>
<thead>
<tr>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Multiple Vehicle</td>
<td>Single Vehicle</td>
</tr>
<tr>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Horizontal curve \(CMF_{i,fs,ac,y,z}\) 13-24 -- 1.000 -- 1.000 -- 1.000 -- 1.000
- Lane width \(CMF_{2,fs,ac,y,fl}\) 13-25 -- 1.000 -- 1.000
- Inside shoulder width \(CMF_{3,fs,ac,y,z}\) 13-26 -- 1.000 -- 1.000 -- 1.000 -- 1.000
- Median width \(CMF_{4,fs,ac,y,z}\) 13-27 -- 1.062 -- 0.980 -- 1.060 -- 1.060
- Median barrier \(CMF_{5,fs,ac,y,z}\) 13-28 -- 1.000 -- 1.000 -- 1.000 -- 1.000
- High volume \(CMF_{6,fs,ac,y,z}\) 13-29 -- 1.036 -- 0.993 -- 1.029 -- 0.941
- Lane change \(CMF_{7,fs,ac,sv,sv}\) 13-30 -- 1.000
- Outside shoulder width \(CMF_{8,fs,ac,sv,sv}\) 13-35 -- 1.000
- Shoulder rumble strip \(CMF_{9,fs,ac,sv,sv}\) 13-36 -- 1.000
- Outside clearance \(CMF_{10,fs,ac,sv,sv}\) 13-38 -- 1.000
- Outside barrier \(CMF_{11,fs,ac,sv,sv}\) 13-39 -- 1.000
- Combined CMF (multiply all CMFs evaluated) -- 1.100 -- 0.973 -- 1.091 -- 0.997

### Expected Average Crash Frequency

Complete the study year column. Complete the crash period column if the site-specific EB Method is used.

<table>
<thead>
<tr>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Multiple Vehicle</td>
<td>Single Vehicle</td>
</tr>
<tr>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Calibration factor \(C_{fs,ac,y,z}\) 1.00 1.00 1.00 1.00
- Overdispersion parameter \(k_{fs,ac,y,z}\) -- -- -- --
- Observed crash count \(N_{o,fs,ac,y,z}\) (cr) -- -- -- --
- Reference year \(r\) -- -- -- --
- Predicted average crash freq. for reference year \(N_{p,fs,ac,y,z,cr/yr}\) (cr/yr) -- -- -- --
- Predicted number of crashes for crash period (sum all years) \(N_{p,fs,ac,y,z}\) (cr) -- -- -- --
- Equivalent years associated with crash count \(C_{fs,ac,y,z,cr/yr}\) (yr) -- -- -- --
- Adjusted average crash freq. for ref. year given \(N_{p,cr},N_{o,cr}\) (cr/yr) -- -- -- --
- Study year \(s\) 2011 2011 2011 2011
- Predicted average crash freq. for study year \(N_{p,fs,ac,y,z,cr/yr}\) (cr/yr) 3.911 2.060 9.568 5.099
- Expected average crash freq. for study year \(N_{p,fs,ac,y,z,cr/yr}\) (cr/yr) 3.911 2.060 9.568 5.099
- Expected average crash freq. for study year (all crash types) \(N_{e,fs,ac,y,z,cr/yr}\) (cr/yr) 5.971 14.668

**Note:**

- If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e.”
Table 13-35. Freeway Segment Worksheet (4 of 4)—Sample Problem 1

**Expected Average Crash Frequency**

<table>
<thead>
<tr>
<th>Crash Severity Distribution</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Total FI</th>
<th>PDO</th>
<th>Total FI + PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion by injury level</td>
<td>0.020</td>
<td>0.050</td>
<td>0.336</td>
<td>0.594</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected average crash freq. for study year (all crash types) ( N_e, f_0, n, a, t, c, s ) (cr/yr)</td>
<td>0.119</td>
<td>0.298</td>
<td>2.005</td>
<td>3.548</td>
<td>5.971</td>
<td>14.668</td>
<td>20.638</td>
</tr>
</tbody>
</table>

**Crash Type Distribution**

<table>
<thead>
<tr>
<th>Crash Type Category</th>
<th>Table 13-6</th>
<th>Fatal and Injury</th>
<th>Proportion</th>
<th>Expected Average Crash Frequency for Study Year ( N_e, f_0, n, a, t, c, s ) (cr/yr)</th>
<th>Property Damage Only</th>
<th>Proportion</th>
<th>Expected Average Crash Frequency for Study Year ( N_e, f_0, n, a, t, c, s ) (cr/yr)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple-Vehicle Crashes</td>
<td>13-6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head-on</td>
<td>0.008</td>
<td>0.031</td>
<td>0.002</td>
<td>0.019</td>
<td>0.050</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right-angle</td>
<td>0.031</td>
<td>0.121</td>
<td>0.018</td>
<td>0.172</td>
<td>0.293</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rear-end</td>
<td>0.750</td>
<td>2.933</td>
<td>0.690</td>
<td>6.602</td>
<td>9.535</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sideswipe</td>
<td>0.180</td>
<td>0.704</td>
<td>0.266</td>
<td>2.545</td>
<td>3.249</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other multiple-vehicle crashes</td>
<td>0.031</td>
<td>0.121</td>
<td>0.024</td>
<td>0.230</td>
<td>0.351</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>3.911</td>
<td>1.000</td>
<td>9.568</td>
<td>13.479</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Single-Vehicle Crashes | 13-8       |                |            |                                               |                      |            |                                               |       |
| Crash with animal    | 0.004       | 0.008           | 0.022      | 0.112                                         | 0.120                |            |                                               |       |
| Crash with fixed object | 0.722     | 1.487           | 0.716      | 3.651                                         | 5.138                |            |                                               |       |
| Crash with other object | 0.051     | 0.105           | 0.139      | 0.709                                         | 0.814                |            |                                               |       |
| Crash with parked vehicle | 0.015    | 0.031           | 0.016      | 0.082                                         | 0.112                |            |                                               |       |
| Other single-vehicle crashes | 0.208 | 0.428 | 0.107 | 0.546 | 0.974 |
| Total                | 1.000       | 2.060           | 1.000      | 5.099                                         | 7.159                |            |                                               |       |

Note:

- If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.

**13.13.2. Sample Problem 2**

**The Site/Facility**

A six-lane urban freeway segment with a horizontal curve.

**The Question**

What is the predicted average crash frequency of the freeway segment for a one-year period?

**The Facts**

The study year is 2011. The conditions present during this year are provided in the following list.

- 0.75-mi length
- 120,000 veh/day
10 percent of AADT volume occurs during high-volume hours

- One horizontal curve
  - 2,100-ft radius
  - 0.25-mi length, entirely on the segment
  - Curve exists on both roadbeds

- 12-ft lane width
- 7-ft outside shoulder width
- 6-ft inside shoulder width
- 40-ft median width
- 0.25 mi of rumble strips on outside shoulders in both travel directions
- 0.25 mi of rumble strips on inside shoulders in both travel directions
- No median or roadside barrier
- 30-ft clear zone width
- No Type B weaving sections
- Data to describe four ramps in the vicinity of the segment

<table>
<thead>
<tr>
<th>Variable Subscript (a,b)</th>
<th>Distance from Segment, $X_{a,b}$ (mi)</th>
<th>Ramp Volume, AADT${}_{a,b}$ (veh/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>b, ent</td>
<td>1.25</td>
<td>8,000</td>
</tr>
<tr>
<td>e, ext</td>
<td>0.1</td>
<td>7,150</td>
</tr>
<tr>
<td>e, ent</td>
<td>0.1</td>
<td>6,750</td>
</tr>
<tr>
<td>b, ext</td>
<td>1.25</td>
<td>7,675</td>
</tr>
</tbody>
</table>
Assumptions
- Crash type distributions used are the default values presented in Table 13-6 and Table 13-8.
- The calibration factor is 1.00.

Results
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the freeway segment in Sample Problem 2 is determined to be 7.8 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 17.0 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the freeway segment in Sample Problem 2, only Steps 9 through 13 are conducted. No other steps are necessary because only one freeway segment is analyzed for one year, and the EB Method is not applied.

Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site’s facility type and traffic control features.
For a six-lane urban freeway segment, SPF values for multiple-vehicle and single-vehicle crashes are determined.

Multiple-Vehicle Crashes
The SPF for multiple-vehicle fatal-and-injury crashes is calculated from Equation 13-15 and Table 13-5 as follows:

\[
N_{spf, fs, 6, mv, fi} = L \times \exp\left( a + b \times \ln\left( c \times AADT_{fs} \right) \right)
\]

\[
= 0.75 \times \exp\left( -5.587 + 1.492 \times \ln\left( 0.001 \times 120,000 \right) \right)
= 3.555 \text{ crashes/year}
\]

Similarly, the SPF for multiple-vehicle property-damage-only crashes is calculated from Equation 13-15 and Table 13-5 to yield the following result:

\[
N_{spf, fs, 6, mv, pdo} = 8.775 \text{ crashes/year}
\]

Single-Vehicle Crashes
The SPF for single-vehicle fatal-and-injury crashes is calculated from Equation 13-18 and Table 13-7 as follows:

\[
N_{spf, fs, 6, sv, fi} = L \times \exp\left( a + b \times \ln\left( c \times AADT_{fs} \right) \right)
\]

\[
= 0.75 \times \exp\left( -2.055 + 0.646 \times \ln\left( 0.001 \times 120,000 \right) \right)
= 2.117 \text{ crashes/year}
\]

Similarly, the SPF for single-vehicle property-damage-only crashes is calculated from Equation 13-18 and Table 13-7 to yield the following result:
Step 10 – Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site-specific geometric design and traffic control features.

Each CMF used in the calculation of the predicted average crash frequency of the freeway segment is calculated in this step.

**Horizontal Curve (CMF$_{1,fs,6, y, z}$)**

$CMF_{1, fs, 6, y, fi}$ is calculated from Equation 13-24 as follows:

$$CMF_{1, fs, 6, y, fi} = 1.0 + a \times \left[ \sum_{i=1}^{m} \left( \frac{5.730}{R_i} \right)^2 \times P_{e, i} \times f_{c, i} \right]$$

The segment is 0.75 mi long, the curve is 0.25 mi long, and its entire length is on the segment. Hence, $P_{e, i} = 0.33$. The curve exists on both roadbeds, so $f_{c, i} = 1.0$. From Table 13-14, $a = 0.0172$ for multiple-vehicle fatal-and-injury crashes. $CMF_{1, fs, 6, mv, fi}$ is calculated as follows:

$$CMF_{1, fs, 6, mv, fi} = 1.0 + 0.0172 \times \left[ \sum_{i=1}^{m} \left( \frac{5.730}{2.100} \right)^2 \times 0.33 \times 1.0 \right]$$

$$= 1.043$$

Calculations using the other coefficients from Table 13-14 yield the following results:

$CMF_{1, fs, 6, sv, fi} = 1.178$

$CMF_{1, fs, 6, mv, pdo} = 1.084$

$CMF_{1, fs, 6, sv, pdo} = 1.155$

**Lane Width (CMF$_{2,fs,6, y, z}$)**

The segment has 12-ft lanes, which is the base condition for the lane width CMF. Hence, $CMF_{2, fs, 6, y, fi}$ and $CMF_{2, fs, 6, y, pdo}$ are equal to 1.000.

**Inside Shoulder Width (CMF$_{3,fs,6, y, z}$)**

The segment has 6-ft inside shoulders, which is the base condition for the inside shoulder width CMF. Hence, $CMF_{3, fs, 6, y, fi}$ and $CMF_{3, fs, 6, y, pdo}$ are equal to 1.000.

**Median Width (CMF$_{4,fs,6, y, z}$)**

$CMF_{4, fs, 6, y, fi}$ is calculated from Equation 13-27 as follows:

$$CMF_{4, fs, 6, y, z} = (1.0 - P_{ib}) \times \exp(a \times [W_m - 2 \times W_{ss} - 48]) + P_{ib} \times \exp(a \times [2 \times W_{ib} - 48])$$

The segment does not have inside barrier, so $P_{ib} = 0.0$ and the calculation of $W_{ib}$ does not apply. From Table 13-17, $a = -0.00302$ for multiple-vehicle fatal-and-injury crashes. $CMF_{4, fs, 6, mv, fi}$ is calculated as follows:
Calculations using the other coefficients from Table 13-17 yield the following results:

\[
CMF_{4, fs, 6, mv, fi} = (1.0 - 0.0) \times \exp(-0.00302 \times [40 - 2 \times 6 - 48]) + 0.0 \times \exp(-0.00302 \times [2 \times W_{icb} - 48]) = 1.062
\]

Median Barrier (CMF5, fs, 6, y, z)
The segment does not have inside barrier. Hence, CMF5, fs, 6, y, fi and CMF5, fs, 6, y, pdo are equal to 1.000.

High Volume (CMF6, fs, 6, y, z)
CMF6, fs, 6, mv, fi is calculated from Equation 13-29 and the coefficient \( a = 0.350 \) from Table 13-19 as follows:

\[
CMF_{6, fs, 6, mv, fi} = \exp(a \times P_{nv}) = \exp(0.350 \times 0.1) = 1.036
\]

Calculations using the other coefficients from Table 13-19 yield the following results:

\[
CMF_{b, 6, 6, sv, fi} = 0.993
\]

\[
CMF_{6, fs, 6, mv, pdo} = 1.029
\]

\[
CMF_{6, fs, 6, sv, pdo} = 0.941
\]

Lane Change (CMF7, fs, 6, mv, z)
CMF7, fs, 6, mv, fi is calculated from Equation 13-30 as follows:

\[
CMF_{7, fs, 6, mv, fi} = \left(0.5 \times f_{inc, wev} \times f_{inc, lc}\right) + \left(0.5 \times f_{dec, wev} \times f_{dec, lc}\right)
\]

The segment does not have Type B weaving sections, so the weaving section adjustment factors \( f_{inc, wev} \) and \( f_{dec, wev} \) are equal to 1.00. The lane change adjustment factors \( f_{inc, lc} \) and \( f_{dec, lc} \) are calculated from Equation 13-33 and Equation 13-34 as follows:

\[
f_{inc, lc} = \left(1.0 + \frac{\exp(-b \times X_{b, ent} + d \times \ln\left[\frac{c \times AADT_{b, ent}}{b \times L_{fi}}\right])}{b \times L_{fi}}\right) \times \left(1.0 - \exp(-b \times L_{fi})\right)
\]

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

From Table 13-20, the coefficients \(b\), \(c\), and \(d\) for fatal-and-injury crashes are 12.56, 0.001, and -0.272, respectively. The lane change adjustment factors are calculated as follows:

\[
f_{inc, le} = \left(1.0 + \frac{\exp(-12.56 \times 1.25 - 0.272 \times \ln(0.001 \times 8,000)}{12.56 \times 0.75}\right) \times \left[1.0 - \exp(-12.56 \times 0.75)\right]
\]
\[
\times \left(1.0 + \frac{\exp(-12.56 \times 0.1 - 0.272 \times \ln(0.001 \times 7,150})}{12.56 \times 0.75} \right) \times \left[1.0 - \exp(-12.56 \times 0.75)\right]
\]
\[= 1.018\]

\[
f_{dec, le} = \left(1.0 + \frac{\exp(-12.56 \times 0.1 - 0.272 \times \ln(0.001 \times 6,750})}{12.56 \times 0.75} \right) \times \left[1.0 - \exp(-12.56 \times 0.75)\right]
\]
\[
\times \left(1.0 + \frac{\exp(-12.56 \times 1.25 - 0.272 \times \ln(0.001 \times 7,675})}{12.56 \times 0.75} \right) \times \left[1.0 - \exp(-12.56 \times 0.75)\right]
\]
\[= 1.018\]

\(CMF_{7, fs, 6, mv, fi}\) is calculated using the weaving section and lane change adjustment factors as follows:

\[CMF_{7, fs, 6, mv, fi} = (0.5 \times 1.00 \times 1.018) + (0.5 \times 1.00 \times 1.018)\]
\[= 1.018\]

Similar calculations using the property-damage-only coefficients from Table 13-20 yield the following results:

\[CMF_{7, fs, 6, mv, pdo}= 1.015\]

**Outside Shoulder Width (CMF_{8, fs, 6, sv, z})**

\(CMF_{8, fs, 6, sv, fi}\) is calculated from Equation 13-35 as follows:

\[CMF_{8, fs, ac, sv, z} = (1.0 - \sum P_{c,i}) \times \exp(a \times [W - 10]) + (\sum P_{c,i}) \times \exp(b \times [W - 10])\]

The segment is 0.75 mi long, the curve is 0.25 mi long, and its entire length is on the segment. Hence, \(P_{c,i} = 0.33\). From Table 13-21, \(a = -0.0647\) and \(b = -0.0897\). \(CMF_{8, fs, 6, sv, fi}\) is calculated as follows:

\[CMF_{8, fs, 6, sv, fi} = (1.0 - 0.33) \times \exp(-0.0647 \times [7 - 10]) + (0.33) \times \exp(-0.0897 \times [7 - 10])\]
\[= 1.246\]

Similar calculations using the property-damage-only coefficients from Table 13-21 yield the following results:

\[CMF_{8, fs, 6, sv, pdo} = 1.096\]
Shoulder Rumble Strip \( (CMF_{9,fs,6,sv,fi}) \)

\( CMF_{9,fs,6,sv,fi} \) is calculated from Equation 13-36 as follows:

\[
CMF_{9,fs,6,sv,fi} = (1.0 - \sum P_{c,i}) \times f_{tan} + \left( \sum P_{c,i} \right) \times 1.0
\]

The factor \( f_{tan} \) is calculated from Equation 13-37 as follows:

\[
f_{tan} = 0.5 \times \left[ (1.0 - P_{i}) \times 1.0 + P_{or} \times 0.811 \right] + 0.5 \times \left[ (1.0 - P_{or}) \times 1.0 + P_{ar} \times 0.811 \right]
\]

\[
= 0.5 \times [ (1.0 - 0.33) \times 1.0 + 0.33 \times 0.811 ] + 0.5 \times [ (1.0 - 0.33) \times 1.0 + 0.33 \times 0.811 ]
\]

\[
= 0.906
\]

\( CMF_{9,fs,6,sv,fi} \) is calculated as follows:

\[
CMF_{9,fs,6,sv,fi} = (1.0 - 0.33) \times 0.906 + (0.33) \times 1.0
\]

\[
= 0.958
\]

Outside Clearance \( (CMF_{10,fs,6,sv,fi}) \)

The segment has 30-ft clear zones and no outside barrier, which are the base conditions for the outside clearance CMF. Hence, \( CMF_{10,fs,6,sv,fi} \) and \( CMF_{10,fs,6,sv,pdo} \) are equal to 1.000.

Outside Barrier \( (CMF_{11,fs,6,sv,fi}) \)

The segment does not have outside barrier. Hence, \( CMF_{11,fs,6,sv,fi} \) and \( CMF_{11,fs,6,sv,pdo} \) are equal to 1.000.

Multiple-Vehicle Crashes

The CMFs are applied to the multiple-vehicle fatal-and-injury SPF as follows:

\[
N_{p*,fs,6,mv,fi} = N_{spf,fs,6,mv,fi} \times \left( CMF_{1,fs,6,mv,fi} \times \ldots \times CMF_{7,fs,6,mv,fi} \right)
\]

\[
= 3.555 \times (1.043 \times 1.000 \times 1.000 \times 1.062 \times 1.000 \times 1.036 \times 1.018)
\]

\[
= 3.555 \times 1.168
\]

\[
= 4.150 \text{ crashes/year}
\]

The CMFs are applied to the multiple-vehicle property-damage-only SPF as follows:

\[
N_{p*,fs,6,mv,pdo} = N_{spf,fs,6,mv,pdo} \times \left( CMF_{1,fs,6,mv,pdo} \times \ldots \times CMF_{7,fs,6,mv,pdo} \right)
\]

\[
= 8.775 \times (1.084 \times 1.000 \times 1.000 \times 1.060 \times 1.000 \times 1.029 \times 1.015)
\]

\[
= 8.775 \times 1.200
\]

\[
= 10.530 \text{ crashes/year}
\]

Single-Vehicle Crashes

The CMFs are applied to the single-vehicle fatal-and-injury SPF as follows:

\[
N_{p*,fs,6,sv,fi} = N_{spf,fs,6,sv,fi} \times \left( CMF_{1,fs,6,sv,fi} \times \ldots \times CMF_{5,fs,6,sv,fi} \times CMF_{8,fs,6,sv,fi} \times \ldots \times CMF_{11,fs,6,sv,fi} \right)
\]

\[
= 2.117 \times (1.178 \times 1.000 \times 1.000 \times 0.980 \times 1.000 \times 0.993 \times 1.246 \times 0.958 \times 0.987 \times 1.000)
\]

\[
= 2.117 \times 1.351
\]

\[
= 2.858 \text{ crashes/year}
\]
The CMFs are applied to the single-vehicle property-damage-only SPF as follows:

\[
N_{p, fs, 6, sv, pdo}^* = N_{p, fs, 6, sv, pdo}^* \times \left( \frac{CMF_{1, fs, 6, sv, pdo} \times \ldots \times CMF_{6, fs, 6, sv, pdo} \times \ldots \times CMF_{11, fs, 6, sv, pdo}}{} \right)
\]

\[
= 5.115 \times (1.155 \times 1.000 \times 1.000 \times 1.060 \times 1.000 \times 0.941 \times 1.096 \times 1.000 \times 1.000 \times 1.000)
\]

\[
= 5.115 \times 1.263
\]

\[
= 6.454 \text{ crashes/year}
\]

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

It is assumed that a calibration factor of 1.00 has been determined for local conditions. As a result, 

\[
N_{p, fs, 6, y, z} = N_{p, fs, 6, y, z}^*
\]

for both crash types \(y \) (\(y = \text{mv}\): multiple-vehicle, \(sv\): single-vehicle) and both crash severities \(z \) (\(z = \text{fi}\): fatal-and-injury, \(pdo\): property-damage-only). See Part C Appendix A.1 for further discussion on calibration of the predicted models.

**Calculation of Predicted Average Crash Frequency**

The predicted average crash frequency is calculated using Equation 13-2 based on the results obtained in Steps 9 through 11 as follows.

**Fatal-and-injury crashes:**

\[
N_{p, fs, 6, at, fi} = N_{p, fs, 6, mv, fi} + N_{p, fs, 6, sv, fi}
\]

\[
= 4.150 + 2.858
\]

\[
= 7.008 \text{ crashes/year}
\]

**Property-damage-only crashes:**

\[
N_{p, fs, 6, at, pdo} = N_{p, fs, 6, mv, pdo} + N_{p, fs, 6, sv, pdo}
\]

\[
= 10.530 + 6.454
\]

\[
= 16.984 \text{ crashes/year}
\]

**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.**

The study period is one year (2011), so steps 8 through 11 need not be repeated.

**Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.**

This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

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

The site-specific EB Method is not applied in this sample problem because crash data are not available.

**Apply the severity distribution functions (SDFs), if desired.**

To apply the SDFs, the systematic component of crash severity likelihood \(V_j\) is computed for each severity level \(j\) using Equation 13-63 as follows:

\[
V_j = a + \left(b \times \frac{P_{ib} + P_{db}}{2}\right) + \left(c \times P_{iw}\right) + \left(d \times \frac{P_{ie} + P_{ae}}{2}\right) + \left(e \times \sum P_{c, i}\right) + \left(f \times W_j\right) + \left(g \times I_{rural}\right)
\]
The coefficients $a$, $b$, $c$, $d$, $e$, $f$, and $g$ are obtained from Table 13-30 for each severity level $j$. The segment does not have barrier, so $P_{ib}$ and $P_{ob}$ are equal to 0.0. $V_j$ is computed for fatal crashes as follows:

$$V_K = -0.171 + (-0.388 \times 0.0 + 0.0) + (-0.924 \times 0.1) + (0.387 \times \frac{0.33 + 0.33}{2})$$
$$+ (0.208 \times 0.33) + (-0.261 \times 12) + (0.492 \times 0.0)$$
$$= -3.194$$

Calculations using the coefficients for incapacitating injury crashes and non-incapacitating injury crashes from Table 13-30 yield the following results:

$$V_A = -2.267$$
$$V_B = -0.482$$

Using these computed $V_K$, $V_A$, and $V_B$ values, and assuming a calibration factor $C_{sdff,fs+sc}$ of 1.0, the probability of occurrence of a fatal crash is computed using Equation 13-59 as follows:

$$P_{fs+sc,at,K} = \frac{\exp(V_K)}{1.0 + \exp(V_K) + \exp(V_A) + \exp(V_B)}$$
$$= \frac{\exp(-3.194)}{1.0 + \exp(-3.194) + \exp(-2.267) + \exp(-0.482)}$$
$$= 0.023$$

Similar calculations using Equation 13-60 and Equation 13-61 yield the following results:

$$P_{fs+sc,at,A} = 0.059$$
$$P_{fs+sc,at,B} = 0.350$$

The probability of occurrence of a possible-injury crash is computed using Equation 13-62 as follows:

$$P_{fs+sc,at,C} = 1.0 - (P_{fs+sc,at,K} + P_{fs+sc,at,A} + P_{fs+sc,at,B})$$
$$= 1.0 - (0.020 + 0.050 + 0.336)$$
$$= 0.567$$

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 13-58 as follows:

$$N_{e,fs,at,K} = N_{e,fs,at,fi} \times P_{fs+sc,at,K}$$
$$= 7.008 \times 0.023$$
$$= 0.163 \text{ crashes/year}$$

Similar calculations using Equation 13-58 and the probabilities of occurrences of the other crash severities yield the following results:
Apply the crash type distribution, if desired.
The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 13-6 and Table 13-8 by the predicted average crash frequencies obtained in Step 11.

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

- Table 13-36. Freeway Segment Worksheet (1 of 4)—Sample Problem 2
- Table 13-37. Freeway Segment Worksheet (2 of 4)—Sample Problem 2
- Table 13-38. Freeway Segment Worksheet (3 of 4)—Sample Problem 2
- Table 13-39. Freeway Segment Worksheet (4 of 4)—Sample Problem 2

Filled versions of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 13 Appendix A.

Table 13-36 is a summary of general information about the freeway segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 2. The input data include area type, crash data, basic roadway data, alignment data, and cross section data.

Table 13-37 is a summary of general information about the freeway segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 2. The input data include roadside data, ramp access data, and traffic data.

Table 13-38 is a tabulation of the CMF and SPF computations for Sample Problem 2.

Table 13-39 is a tabulation of the crash severity and crash type distributions for Sample Problem 2.
### Table 13-36. Freeway Segment Worksheet (1 of 4)—Sample Problem 2

<table>
<thead>
<tr>
<th>General Information</th>
<th>Location Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Roadway</td>
</tr>
<tr>
<td>Agency or company</td>
<td>Roadway section</td>
</tr>
<tr>
<td>Date performed</td>
<td>Study year</td>
</tr>
<tr>
<td>Area type</td>
<td>X Urban Rural</td>
</tr>
</tbody>
</table>

#### Input Data

<table>
<thead>
<tr>
<th>Crash Data</th>
<th>Crash Period</th>
<th>Study Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash data time period</td>
<td>--</td>
<td>First year</td>
</tr>
<tr>
<td>Count of multiple-vehicle FI crashes $N_{o, f_t, m, f_t}$</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Count of single-vehicle FI crashes $N_{o, f_t, m, f_t}$</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Count of multiple-vehicle PDO crashes $N_{o, f_t, m, p_d}$</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Count of single-vehicle PDO crashes $N_{o, f_t, m, p_d}$</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

#### Basic Roadway Data

| Number of through lanes $n$ | 6 | Same value for crash period and study year. |
| Segment length $L$ (mi) | -- | 0.75 |

#### Alignment Data

<table>
<thead>
<tr>
<th>Horizontal Curve Data</th>
<th>Crash Period</th>
<th>Study Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence of horizontal curve 1</td>
<td>--</td>
<td>Y/N</td>
</tr>
<tr>
<td>Curve radius $R_1$ (ft)</td>
<td>--</td>
<td>2,100</td>
</tr>
<tr>
<td>Length of curve $L_{c1}$ (mi)</td>
<td>--</td>
<td>0.25</td>
</tr>
<tr>
<td>Length of curve in segment $L_{c1, seg}$ (mi)</td>
<td>--</td>
<td>0.25</td>
</tr>
<tr>
<td>Presence of horizontal curve 2</td>
<td>--</td>
<td>Y/N</td>
</tr>
<tr>
<td>Curve radius $R_2$ (ft)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Length of curve $L_{c2}$ (mi)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Length of curve in segment $L_{c2, seg}$ (mi)</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

#### Cross Section Data

| Lane width $W_l$ (ft) | -- | 12 |
| Outside shoulder width $W_s$ (ft) | -- | 7 |
| Inside shoulder width $W_i$ (ft) | -- | 6 |
| Median width $W_m$ (ft) | -- | 40 |
| Presence of rumble strips on outside shoulder | -- | Y/N | Y |
| Length of rumble strip in increasing milepost dir. (mi) | -- | 0.25 |
| Length of rumble strip in decreasing milepost dir. (mi) | -- | 0.25 |
| Presence of rumble strips on inside shoulder | -- | Y/N | Y |
| Length of rumble strip in increasing milepost dir. (mi) | -- | 0.25 |
| Length of rumble strip in decreasing milepost dir. (mi) | -- | 0.25 |
| Presence of barrier in median | -- | Y/N | N | Y/N | If Yes, then use the freeway barrier worksheet. |
### Table 13-37. Freeway Segment Worksheet (2 of 4)—Sample Problem 2

#### Input Data

<table>
<thead>
<tr>
<th>Roadside Data</th>
<th>Crash Period</th>
<th>Study Year</th>
<th>Complete the study year column. Complete the crash period column if the EB Method is used.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear zone width $W_{zc}$ (ft)</td>
<td>--</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Presence of barrier on roadside</td>
<td>--</td>
<td>Y/N</td>
<td>N</td>
</tr>
</tbody>
</table>

#### Ramp Access Data

**Travel in Increasing Milepost Direction**

| Ent. ramp | Distance from begin milepost to upstream entrance ramp gore $X_{b, ent}$ (mi) | -- | 1.25 | If ramp entrance is in the segment, enter 0.0. |
| Presence of speed-change lane in segment | -- | Y/N | N | Y/N | If Yes, then enter data in the next row. |
| Length of s-c lane in segment $L_{en, seg, inc}$ (mi) | -- | -- |

| Exit ramp | Distance from end milepost to upstream exit ramp gore $X_{e, ent}$ (mi) | -- | 0.1 | If ramp exit is in the segment, enter 0.0. |
| Presence of speed-change lane in segment | -- | Y/N | N | Y/N | If Yes, then enter data in the next row. |
| Length of s-c lane in segment $L_{es, seg, inc}$ (mi) | -- | -- |

| Weave | Presence of a Type B weave in segment | -- | Y/N | N | Y/N | If Yes, then enter data in the next two rows. |
| Length of weaving section $L_{wvc, inc}$ (mi) | -- | -- |
| Length of weaving section in seg. $L_{wv, seg, inc}$ (mi) | -- | -- |

**Travel in Decreasing Milepost Direction**

| Ent. ramp | Distance from end milepost to upstream entrance ramp gore $X_{b, ent}$ (mi) | -- | 0.1 | If ramp entrance is in the segment, enter 0.0. |
| Presence of speed-change lane in segment | -- | Y/N | N | Y/N | If Yes, then enter data in the next row. |
| Length of s-c lane in segment $L_{en, seg, dec}$ (mi) | -- | -- |

| Exit ramp | Distance from begin milepost to downstream exit ramp gore $X_{e, ext}$ (mi) | -- | 1.25 | If ramp exit is in the segment, enter 0.0. |
| Presence of speed-change lane in segment | -- | Y/N | N | Y/N | If Yes, then enter data in the next row. |
| Length of s-c lane in segment $L_{es, seg, dec}$ (mi) | -- | -- |

| Weave | Presence of a Type B weave in segment | -- | Y/N | N | Y/N | If Yes, then enter data in the next two rows. |
| Length of weaving section $L_{wvc, dec}$ (mi) | -- | -- |
| Length of weaving section in seg. $L_{wv, seg, dec}$ (mi) | -- | -- |

#### Traffic Data

<table>
<thead>
<tr>
<th>Traffic Data</th>
<th>Crash Period</th>
<th>Study Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of AADT during high-volume hours $P_{hv}$</td>
<td>--</td>
<td>0.1</td>
</tr>
<tr>
<td>Freeway segment AADT $AADT_{fs}$ (veh/day)</td>
<td>--</td>
<td>120,000</td>
</tr>
<tr>
<td>AADT of entrance ramp for travel in increasing milepost direction $AADT_{b, inc}$ (veh/day)</td>
<td>--</td>
<td>8,000</td>
</tr>
<tr>
<td>AADT of exit ramp for travel in increasing milepost direction $AADT_{e, inc}$ (veh/day)</td>
<td>--</td>
<td>7,150</td>
</tr>
<tr>
<td>AADT of entrance ramp for travel in decreasing milepost direction $AADT_{b, dec}$ (veh/day)</td>
<td>--</td>
<td>6,750</td>
</tr>
<tr>
<td>AADT of exit ramp for travel in decreasing milepost direction $AADT_{e, dec}$ (veh/day)</td>
<td>--</td>
<td>7,675</td>
</tr>
</tbody>
</table>
Table 13-38. Freeway Segment Worksheet (3 of 4)—Sample Problem 2

Crash Modification Factors

<table>
<thead>
<tr>
<th>Component</th>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Multiple Vehicle</td>
<td>Single Vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td>Horizontal curve CMF&lt;sub&gt;1&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;c&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>13-24</td>
<td>--</td>
<td>1.043</td>
</tr>
<tr>
<td>Lane width CMF&lt;sub&gt;2&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>13-25</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Inside shoulder width CMF&lt;sub&gt;3&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>13-26</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Median width CMF&lt;sub&gt;4&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>13-27</td>
<td>--</td>
<td>1.062</td>
</tr>
<tr>
<td>Median barrier CMF&lt;sub&gt;5&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>13-28</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>High volume CMF&lt;sub&gt;6&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>13-29</td>
<td>--</td>
<td>1.036</td>
</tr>
<tr>
<td>Lane change CMF&lt;sub&gt;7&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>13-30</td>
<td>--</td>
<td>1.018</td>
</tr>
<tr>
<td>Outside shoulder width CMF&lt;sub&gt;8&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>13-35</td>
<td>--</td>
<td>1.246</td>
</tr>
<tr>
<td>Shoulder rumble strip CMF&lt;sub&gt;9&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>13-36</td>
<td>--</td>
<td>0.958</td>
</tr>
<tr>
<td>Outside clearance CMF&lt;sub&gt;10&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>13-38</td>
<td>--</td>
<td>0.987</td>
</tr>
<tr>
<td>Outside barrier CMF&lt;sub&gt;11&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>13-39</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Combined CMF (multiply all CMFs evaluated)</td>
<td>--</td>
<td>1.168</td>
<td>--</td>
</tr>
</tbody>
</table>

Expected Average Crash Frequency<sup>a</sup>

<table>
<thead>
<tr>
<th>Component</th>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Multiple Vehicle</td>
<td>Single Vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td>Calibration factor C&lt;sub&gt;f&lt;/sub&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Overdispersion parameter k&lt;sub&gt;f&lt;/sub&gt;,&lt;i&gt;n&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Observed crash count N&lt;sub&gt;c&lt;/sub&gt;,&lt;i&gt;n&lt;/i&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Reference year r</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Predicted average crash freq. for reference year N&lt;sub&gt;p&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;n&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;,&lt;i&gt;r&lt;/i&gt;,&lt;i&gt;c&lt;/i&gt; (cr/yr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Predicted number of crashes for crash period (sum all years) N&lt;sub&gt;p&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;n&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;,&lt;i&gt;r&lt;/i&gt; (cr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Equivalent years associated with crash count C&lt;sub&gt;n&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;n&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;,&lt;i&gt;r&lt;/i&gt;,&lt;i&gt;c&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt; (yr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Adjusted average crash freq. for ref. year given N&lt;sub&gt;e&lt;/sub&gt; = N&lt;sub&gt;p&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;n&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;,&lt;i&gt;r&lt;/i&gt;,&lt;i&gt;c&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;r&lt;/i&gt; (cr/yr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Study year s</td>
<td>2011</td>
<td>2011</td>
<td>2011</td>
</tr>
<tr>
<td>Predicted average crash freq. for study year N&lt;sub&gt;p&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;n&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;,&lt;i&gt;r&lt;/i&gt;,&lt;i&gt;c&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt; (cr/yr)</td>
<td>4.150</td>
<td>2.858</td>
<td>10.530</td>
</tr>
<tr>
<td>Expected average crash freq. for study year N&lt;sub&gt;e&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;s&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;n&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;z&lt;/i&gt;,&lt;i&gt;r&lt;/i&gt;,&lt;i&gt;c&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt; (cr/yr)</td>
<td>4.150</td>
<td>2.858</td>
<td>10.530</td>
</tr>
<tr>
<td>Expected average crash freq. for study year (all crash types) N&lt;sub&gt;e&lt;/sub&gt;,&lt;i&gt;f&lt;/i&gt;,&lt;i&gt;n&lt;/i&gt;,&lt;i&gt;a&lt;/i&gt;,&lt;i&gt;c&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt;,&lt;i&gt;r&lt;/i&gt;,&lt;i&gt;c&lt;/i&gt;,&lt;i&gt;y&lt;/i&gt; (cr/yr)</td>
<td>7.008</td>
<td>16.984</td>
<td></td>
</tr>
</tbody>
</table>

Note:
<sup>a</sup> If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.
Table 13-39. Freeway Segment Worksheet (4 of 4)—Sample Problem 2

**Expected Average Crash Frequency**

<table>
<thead>
<tr>
<th>Crash Severity Distribution</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Total FI</th>
<th>PDO</th>
<th>Total FI + PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion by injury level</td>
<td>0.023</td>
<td>0.059</td>
<td>0.350</td>
<td>0.567</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected average crash freq. for study year (all crash types) $N_{e,fs,n,at,s} (cr/yr)$</td>
<td>0.163</td>
<td>0.412</td>
<td>2.456</td>
<td>3.977</td>
<td>7.008</td>
<td>16.984</td>
<td>23.992</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crash Type Distribution</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash Type Category</td>
<td>Proportion</td>
<td>Expected Average Crash Frequency for Study Year $N_{e,fs,n,y,pdo,s} (cr/yr)$</td>
<td>Proportion</td>
</tr>
<tr>
<td>Multiple-Vehicle Crashes</td>
<td>13-6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head-on</td>
<td>0.008</td>
<td>0.033</td>
<td>0.002</td>
</tr>
<tr>
<td>Right-angle</td>
<td>0.031</td>
<td>0.129</td>
<td>0.018</td>
</tr>
<tr>
<td>Rear-end</td>
<td>0.750</td>
<td>3.113</td>
<td>0.690</td>
</tr>
<tr>
<td>Sideswipe</td>
<td>0.180</td>
<td>0.747</td>
<td>0.266</td>
</tr>
<tr>
<td>Other multiple-vehicle crashes</td>
<td>0.031</td>
<td>0.129</td>
<td>0.024</td>
</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>4.150</td>
<td>1.000</td>
</tr>
</tbody>
</table>

| Single-Vehicle Crashes  | 13-8             |                      |       |
| Crash with animal       | 0.004            | 0.011                | 0.022 | 0.142 | 0.153 |
| Crash with fixed object | 0.722            | 2.063                | 0.716 | 4.621 | 6.685 |
| Crash with other object | 0.051            | 0.146                | 0.139 | 0.897 | 1.043 |
| Crash with parked vehicle | 0.015 | 0.043 | 0.016 | 0.103 | 0.146 |
| Other single-vehicle crashes | 0.208 | 0.594 | 0.107 | 0.691 | 1.285 |
| Total                   | 1.000            | 2.858                | 1.000 | 6.454 | 9.312 |

**Note:**

- If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e.”

### 13.13.3. Sample Problem 3

**The Site/Facility**

A ramp-entrance speed-change lane on a six-lane urban freeway.

**The Question**

What is the predicted average crash frequency of the speed-change lane for a one-year period?

**The Facts**

The study year is 2011. The conditions present during this year are provided in the following list.

- 0.1-mi length
Freeway mainline data
- 120,000 veh/day
- 10 percent of AADT volume occurs during high-volume hours
- No horizontal curvature
- 12-ft lane width
- 6-ft inside shoulder width
- 40-ft median width
- No median barrier

Ramp entrance data
- 6,750 veh/day
- On right side of mainline

Assumptions
- Crash type distributions used are the default values presented in Table 13-10.
- The calibration factor is 1.00.

Results
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the speed-change lane in Sample Problem 3 is determined to be 0.5 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 1.0 crashes per year (rounded to one decimal place).

Steps
Step 1 through 8
To determine the predicted average crash frequency of the speed-change lane in Sample Problem 3, only Steps 9 through 11 are conducted. No other steps are necessary because only one speed-change lane is analyzed for one year, and the EB Method is not applied.

Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site’s facility type and traffic control features.
For a ramp-entrance speed-change lane on a six-lane urban freeway, an SPF value for ramp entrance crashes is determined.

Ramp Entrance Crashes
The SPF for fatal-and-injury ramp entrance crashes is calculated from Equation 13-20 and Table 13-9 as follows:
Similarly, the SPF for property-damage-only ramp entrance crashes is calculated from Equation 13-20 and Table 13-9 to yield the following result:

\[ N_{spf,sc,6EN,at,fi} = 0.722 \text{ crashes/year} \]

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

Each CMF used in the calculation of the predicted average crash frequency of the speed-change lane is calculated below:

**Horizontal Curve (CMF_1, sc, 6EN, at, z)**

The speed-change lane does not have horizontal curvature. Hence, \( CMF_{1, sc, 6EN, at, fi} \) and \( CMF_{1, sc, 6EN, at, pdo} \) are equal to 1.000.

**Lane Width (CMF_2, sc, 6EN, at, z)**

The segment has 12-ft lanes, which is the base condition for the lane width CMF. Hence, \( CMF_{2, sc, 6EN, at, fi} \) and \( CMF_{2, sc, 6EN, at, pdo} \) are equal to 1.000.

**Inside Shoulder Width (CMF_3, sc, 6EN, at, z)**

The segment has 6-ft inside shoulders, which is the base condition for the inside shoulder width CMF. Hence, \( CMF_{3, sc, 6EN, at, fi} \) and \( CMF_{3, sc, 6EN, at, pdo} \) are equal to 1.000.

**Median Width (CMF_4, sc, 6EN, at, z)**

\( CMF_{4, sc, 6EN, at, fi} \) is calculated from Equation 13-43 as follows:

\[
CMF_{4, sc, 6EN, at, fi} = (1.0 - P_{ib}) \times \exp(a \times [W_m - 2 \times W_{is} - 48]) + P_{ib} \times \exp(2 \times W_{icb} - 48)
\]

The segment does not have inside barrier, so \( P_{ib} = 0.0 \) and the calculation of \( W_{icb} \) does not apply. From Table 13-25, \( a = -0.00302 \). \( CMF_{4, sc, 6EN, at, fi} \) is calculated as follows:

\[
CMF_{4, sc, 6EN, at, fi} = (1.0 - 0.0) \times \exp(-0.00302 \times [40 - 2 \times 6 - 48]) + 0.0 \times \exp(-0.00302 \times [2 \times W_{icb} - 48]) = 1.062
\]

Similar calculations using the property-damage-only coefficient from Table 13-25 yield the following results:

\[ CMF_{4, sc, 6EN, at, pdo} = 1.060 \]

**Median Barrier (CMF_5, sc, 6EN, at, z)**

The segment does not have inside barrier. Hence, \( CMF_{5, sc, 6EN, at, fi} \) and \( CMF_{5, sc, 6EN, at, pdo} \) are equal to 1.000.

**High Volume (CMF_6, sc, 6EN, at, z)**

\( CMF_{6, sc, 6EN, at, fi} \) is calculated from Equation 13-45 and the coefficient \( a = 0.350 \) from Table 13-27 as follows:
Similar calculations using the property-damage-only coefficients from Table 13-27 yield the following results:

\[ CMF_{6, sc, 6EN, at, pdo} = 1.029 \]

**Ramp Entrance (CMF_{12, sc, 6EN, at, fi})**

\[ CMF_{12, sc, 6EN, at, fi} \text{ is calculated from Equation 13-46 as follows:} \]

\[
CMF_{12, sc, 6EN, at, fi} = \exp\left( a \times I_{left} + \frac{b}{L_{en}} + d \times \ln[c \times AADT,] \right)
\]

The ramp entrance connects to the right side of the freeway mainline. Hence, \( I_{left} = 0.0 \). From Table 13-28, the coefficients \( a, b, c, \) and \( d \) for fatal-and-injury crashes are 0.594, 0.0318, 0.001, and 0.198, respectively. \( CMF_{12, sc, 6EN, at, fi} \) is calculated as follows:

\[
CMF_{12, sc, 6EN, at, fi} = \exp\left( 0.594 \times 0.0 + \frac{0.0318}{0.1} + 0.198 \times \ln[0.001 \times 6,750] \right) = 2.006
\]

Similar calculations using the property-damage-only coefficients from Table 13-28 yield the following results:

\[ CMF_{12, sc, 6EN, at, pdo} = 1.287 \]

**Ramp Entrance Crashes**

The CMFs are applied to the ramp entrance fatal-and-injury SPF as follows:

\[
N_{p, sc, 6EN, at, fi} = N_{spf, sc, 6EN, at, fi} \times CMF_{1, sc, 6EN, at, fi} \times \ldots \times CMF_{6, sc, 6EN, at, fi} \times CMF_{12, sc, 6EN, at, fi} \\
= 0.229 \times (1.000 \times 1.000 \times 1.062 \times 1.000 \times 1.036 \times 2.006) \\
= 0.229 \times 2.207 \\
= 0.505 \text{ crashes/year}
\]

The CMFs are applied to the ramp entrance property-damage-only SPF as follows:

\[
N_{p, sc, 6EN, at, pdo} = N_{spf, sc, 6EN, at, pdo} \times CMF_{1, sc, 6EN, at, pdo} \times \ldots \times CMF_{6, sc, 6EN, at, pdo} \times CMF_{12, sc, 6EN, at, pdo} \\
= 0.722 \times (1.000 \times 1.000 \times 1.060 \times 1.000 \times 1.029 \times 1.287) \\
= 0.722 \times 1.403 \\
= 1.013 \text{ crashes/year}
\]

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

It is assumed that a calibration factor of 1.00 has been determined for local conditions. See Part C Appendix A.1 for further discussion on calibration of the predicted models.
CHAPTER 13—PREDICTIVE METHOD FOR FREEWAYS

Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated using Equation 13-2 based on the results obtained in Steps 9 through 11 as follows.

Fatal-and-injury crashes:

\[ N_{p, sc, 6EN, at, fi} = N_{spf*, sc, 6EN, at, fi} \times C_{fs, sc, 6EN, at, fi} \]

\[ = 0.505 \times 1.00 \]

\[ = 0.505 \text{ crashes/year} \]

Property-damage-only crashes:

\[ N_{p, sc, 6EN, at, pdo} = N_{spf*, sc, 6EN, at, pdo} \times C_{fs, sc, 6EN, at, pdo} \]

\[ = 1.013 \times 1.00 \]

\[ = 1.013 \text{ crashes/year} \]

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.

The study period is one year (2011), so steps 8 through 11 need not be repeated.

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

This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

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

The site-specific EB Method is not applied in this sample problem because crash data are not available.

Apply the severity distribution functions (SDFs), if desired.

To apply the SDFs, the systematic component of crash severity likelihood \( V_j \) is computed for each severity level \( j \) using Equation 13-63 as follows:

\[ V_j = a + b \times \left( \frac{P_{ib} + P_{ob}}{2} \right) + c \times P_{ir} + d \times \left( \frac{P_{ir} + P_{or}}{2} \right) + e \times \sum P_{ci} + f \times W_j + g \times I_{rural} \]

The coefficients \( a, b, c, d, e, f, \) and \( g \) are obtained from Table 13-30 for each severity level \( j \). The segment does not have barrier, rumble strips, or horizontal curvature, so \( P_{ib}, P_{ob}, P_{ir}, P_{or}, \) and \( P_{ci} \) are equal to 0.0. \( V_j \) is computed for fatal crashes as follows:

\[ V_k = -0.171 + (-0.388 \times \frac{0.0 + 0.0}{2}) + (-0.924 \times 0.1) + (0.387 \times \frac{0.0 + 0.0}{2}) \]

\[ + (0.208 \times 0.0) + (-0.261 \times 12) + (0.492 \times 0.0) \]

\[ = -3.392 \]

Calculations using the coefficients for incapacitating injury crashes and non-incapacitating injury crashes from Table 13-30 yield the following results:

\[ V_A = -2.478 \]
Using these computed \( V_K, V_A, \) and \( V_B \) values, and assuming a calibration factor \( C_{sd, fs+sc} \) of 1.0, the probability of occurrence of a fatal crash is computed using Equation 13-59 as follows:

\[
P_{fs+sc, ac, at, K} = \frac{\exp(V_K)}{1.0 + \exp(V_K) + \exp(V_A) + \exp(V_B)}
\]

\[
= \frac{\exp(-3.392)}{1.0 + \exp(-3.392) + \exp(-2.478) + \exp(-0.571)}
\]

\[
= 0.020
\]

Similar calculations using Equation 13-60 and Equation 13-61 yield the following results:

\[
P_{fs+sc, ac, at, A} = 0.050
\]

\[
P_{fs+sc, ac, at, B} = 0.336
\]

The probability of occurrence of a possible-injury crash is computed using Equation 13-62 as follows:

\[
P_{fs+sc, ac, at, C} = 1.0 - (P_{fs+sc, ac, at, K} + P_{fs+sc, ac, at, A} + P_{fs+sc, ac, at, B})
\]

\[
= 1.0 - (0.020 + 0.050 + 0.336)
\]

\[
= 0.594
\]

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 13-58 as follows:

\[
N_{e, sc, 6EN, at, K} = N_{e, sc, 6EN, at, fi} \times P_{fs+sc, ac, at, K}
\]

\[
= 0.505 \times 0.020
\]

\[
= 0.010 \text{ crashes/year}
\]

Similar calculations using Equation 13-58 and the probabilities of occurrences of the other crash severities yield the following results:

\[
N_{e, sc, 6EN, at, A} = 0.025 \text{ crashes/year}
\]

\[
N_{e, sc, 6EN, at, B} = 0.170 \text{ crashes/year}
\]

\[
N_{e, sc, 6EN, at, C} = 0.300 \text{ crashes/year}
\]

**Apply the crash type distribution, if desired.**

The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 13-10 by the predicted average crash frequencies obtained in Step 11.
Worksheets
The step-by-step instructions are provided to illustrate the predictive method for calculating the predicted average crash frequency for a freeway segment. To apply the predictive method steps to multiple segments, a series of worksheets are provided for determining the predicted average crash frequency. The worksheets include:

- Table 13-40. Freeway Speed-Change Lane Worksheet (1 of 3)—Sample Problem 3
- Table 13-41. Freeway Speed-Change Lane Worksheet (2 of 3)—Sample Problem 3
- Table 13-42. Freeway Speed-Change Lane Worksheet (3 of 3)—Sample Problem 3

Filled versions of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 13 Appendix A.

Table 13-40 is a summary of general information about the freeway speed-change lane, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 3. The input data include area type, crash data, basic roadway data, alignment data, cross section data, and traffic data.

Table 13-41 is a tabulation of the CMF and SPF computations for Sample Problem 3.

Table 13-42 is a tabulation of the crash severity and crash type distributions for Sample Problem 3.
Table 13-40. Freeway Speed-Change Lane Worksheet (1 of 3)—Sample Problem 3

<table>
<thead>
<tr>
<th>General Information</th>
<th>Location Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Roadway</td>
</tr>
<tr>
<td>Agency or company</td>
<td>Roadway section</td>
</tr>
<tr>
<td>Date performed</td>
<td>Study year</td>
</tr>
<tr>
<td>Area type</td>
<td>X Urban Rural</td>
</tr>
</tbody>
</table>

**Input Data**

<table>
<thead>
<tr>
<th>Crash Data</th>
<th>Crash Period</th>
<th>Study Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First year</td>
<td>Last year</td>
</tr>
</tbody>
</table>

- **Crash data time period**:
- **Count of speed-change-related FI crashes** $N_{n,sc,x,at,fi}$ --
- **Count of speed-change-related PDO crashes** $N_{n,sc,x,at,pdo}$ --

**Basic Roadway Data**

- **Number of through lanes $n$**: 6
- **Segment length $L$ (mi)**: 0.1

**Alignment Data**

<table>
<thead>
<tr>
<th>Horizontal Curve Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence of horizontal curve 1</td>
</tr>
<tr>
<td>Curve radius $R_1$ (ft)</td>
</tr>
<tr>
<td>Length of curve $L_{c1}$ (mi)</td>
</tr>
<tr>
<td>Length of curve in segment $L_{c1,seg}$ (mi)</td>
</tr>
</tbody>
</table>

| Presence of horizontal curve 2 | Y/N | N | Y/N | If Yes, then enter data in the next three rows. |
| Curve radius $R_2$ (ft) | -- | -- |
| Length of curve $L_{c2}$ (mi) | -- | -- |
| Length of curve in segment $L_{c2,seg}$ (mi) | -- | -- |

**Cross Section Data**

- **Lane width $W_l$ (ft)**: 12
- **Inside shoulder width $W_s$ (ft)**: 6
- **Median width $W_m$ (ft)**: 40
- **Presence of barrier in median**: Y/N | N | Y/N | If Yes, then use the freeway barrier worksheet. |
- **Entrance or exit side (left- or right-hand side)**: L/R | R | L/R |

**Traffic Data**

- **Proportion of AADT during high-volume hours $P_{hv}$**: 0.1
- **Freeway segment AADT $AADT_{fs}$ (veh/day)**: 120,000
- **AADT of ramp $AADT_r$ (veh/day)**: 6,750 | Only needed for entrance ramp. |
Table 13-41. Freeway Speed-Change Lane Worksheet (2 of 3)—Sample Problem 3

<table>
<thead>
<tr>
<th>Crash Modification Factors</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crash Period</td>
<td>Study Year 1</td>
</tr>
<tr>
<td>Vertical curve (CMF_{1,vc,ac,at,z})</td>
<td>13-40</td>
<td>--</td>
</tr>
<tr>
<td>Lane width (CMF_{2,sc,ac,at,fi})</td>
<td>13-41</td>
<td>--</td>
</tr>
<tr>
<td>Inside shoulder width (CMF_{3,sc,ac,at,z})</td>
<td>13-42</td>
<td>--</td>
</tr>
<tr>
<td>Median width (CMF_{4,sc,ac,at,z})</td>
<td>13-43</td>
<td>--</td>
</tr>
<tr>
<td>Median barrier (CMF_{5,sc,ac,at,z})</td>
<td>13-44</td>
<td>--</td>
</tr>
<tr>
<td>High volume (CMF_{6,sc,ac,at,z})</td>
<td>13-45</td>
<td>--</td>
</tr>
<tr>
<td>Ramp entrance (CMF_{12,sc,nEN,at,z})</td>
<td>13-46</td>
<td>--</td>
</tr>
<tr>
<td>Ramp exit (CMF_{13,sc,nEX,at,z})</td>
<td>13-47</td>
<td>--</td>
</tr>
<tr>
<td>Combined CMF (multiply all CMFs evaluated)</td>
<td>--</td>
<td>2.207</td>
</tr>
</tbody>
</table>

**Expected Average Crash Frequency**

<table>
<thead>
<tr>
<th></th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crash Period</td>
<td>Study Year 1</td>
</tr>
<tr>
<td>Calibration factor (C_{sc,ac,at,z})</td>
<td>1.00</td>
<td>--</td>
</tr>
<tr>
<td>Overdispersion parameter (k_{sc,ac,at,z})</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Observed crash count (N_{o,sc,ac,at,z}(cr))</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Reference year (r)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Predicted average crash freq. for reference year (N_{p,sc,ac,at,z,r}(cr/yr))</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Predicted number of crashes for crash period (sum all years) (N_{p,sc,ac,at,z}(cr))</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Equivalent years associated with crash count (C_{sc,ac,at,z,r}(yr))</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Adjusted average crash freq. for ref. year given (N_{o,sc,ac,at,z,r}(cr/yr))</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Study year (s)</td>
<td>2011</td>
<td>2011</td>
</tr>
<tr>
<td>Predicted average crash freq. for study year (N_{p,sc,ac,at,z,r}(cr/yr))</td>
<td>0.505</td>
<td>--</td>
</tr>
<tr>
<td>Expected average crash freq. for study year (N_{e,sc,ac,at,z}(cr/yr))</td>
<td>0.505</td>
<td>--</td>
</tr>
</tbody>
</table>

*Note:* If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e.”
Table 13-42. Freeway Speed-Change Lane Worksheet (3 of 3)—Sample Problem 3

### Expected Average Crash Frequency a

| Crash Severity Distribution | K | A | B | C | Total FI | PDO | Total FI + PDO |
|-----------------------------|--|--|--|--|--|----|--|-----------|
| Proportion by injury level  | 0.020 | 0.050 | 0.336 | 0.594 | 1.000 |    |            |
| Expected average crash freq. for study year $N_{e, s, x, a, t, f, i, o}$ (cr/yr) | 0.010 | 0.025 | 0.170 | 0.300 | 0.505 | 1.013 | 1.518 |

<table>
<thead>
<tr>
<th>Crash Type Distribution</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crash Type Category</strong></td>
<td><strong>Table 13-10 or 13-12</strong></td>
<td><strong>Proportion</strong></td>
<td><strong>Expected Average Crash Frequency for Study Year $N_{e, s, x, a, t, f, i, o}$ (cr/yr)</strong></td>
</tr>
<tr>
<td>Multiple-Vehicle Crashes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head-on</td>
<td>0.004</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td>Right-angle</td>
<td>0.019</td>
<td>0.010</td>
<td>0.016</td>
</tr>
<tr>
<td>Rear-end</td>
<td>0.543</td>
<td>0.274</td>
<td>0.530</td>
</tr>
<tr>
<td>Sideswipe</td>
<td>0.133</td>
<td>0.067</td>
<td>0.252</td>
</tr>
<tr>
<td>Other multiple-vehicle crashes</td>
<td>0.017</td>
<td>0.009</td>
<td>0.015</td>
</tr>
<tr>
<td>Single-Vehicle Crashes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crash with animal</td>
<td>0.000</td>
<td>0.000</td>
<td>0.002</td>
</tr>
<tr>
<td>Crash with fixed object</td>
<td>0.194</td>
<td>0.098</td>
<td>0.129</td>
</tr>
<tr>
<td>Crash with other object</td>
<td>0.019</td>
<td>0.010</td>
<td>0.036</td>
</tr>
<tr>
<td>Crash with parked vehicle</td>
<td>0.004</td>
<td>0.002</td>
<td>0.003</td>
</tr>
<tr>
<td>Other single-vehicle crashes</td>
<td>0.067</td>
<td>0.034</td>
<td>0.016</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1.000</td>
<td>0.505</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Note:
a - If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.

### 13.13.4. Sample Problem 4

**The Site/Facility**
A ramp-exit speed-change lane on a six-lane urban freeway.

**The Question**
What is the predicted average crash frequency of the speed-change lane for a one-year period?

**The Facts**
The study year is 2011. The conditions present during this year are provided in the following list.

- 0.1-mi length
- Freeway mainline data
120,000 veh/day
- 10 percent of AADT volume occurs during high-volume hours
- No horizontal curvature
- 12-ft lane width
- 6-ft inside shoulder width
- 40-ft median width
- No median barrier
- Ramp exit data
- On right side of mainline

**Assumptions**
- Crash type distributions used are the default values presented in Table 13-12.
- The calibration factor is 1.00.

**Results**
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the speed-change lane in Sample Problem 4 is determined to be 0.3 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 0.8 crashes per year (rounded to one decimal place).

**Steps**

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

**Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site’s facility type and traffic control features.**
For a ramp-exit speed-change lane on a six-lane urban freeway, SPF values for ramp exit crashes are determined.

**Ramp Exit Crashes**
The SPF for fatal-and-injury ramp exit crashes is calculated from Equation 13-22 and Table 13-11 as follows:

\[
N_{spf,sc,6EX.at,fi} = L_{ex} \times \exp\left[a + b \times \ln\left(c \times AADT_{fs}\right)\right]
\]

\[
= 0.10 \times \exp(-2.679 + 0.903 \times \ln(0.0005 \times 120,000))
\]

\[
= 0.277 \text{ crashes/year}
\]
Similarly, the SPF for property-damage-only ramp exit crashes is calculated from Equation 13-22 and Table 13-11 to yield the following result:

\[ N_{spf, \text{sc}, 6\text{EX}, \text{pdo}} = 0.752 \text{ crashes/year} \]

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

Each CMF used in the calculation of the predicted average crash frequency of the speed-change lane is calculated in this step.

*Horizontal Curve (CMF\(_1\), \text{sc}, 6\text{EX}, \text{at}, z)*

The segment does not have horizontal curvature. Hence, CMF\(_1\), \text{sc}, 6\text{EX}, \text{at}, fi and CMF\(_1\), \text{sc}, 6\text{EX}, \text{at}, pdo are equal to 1.000.

*Lane Width (CMF\(_2\), \text{sc}, 6\text{EX}, \text{at}, fi)*

The segment has 12-ft lanes, which is the base condition for the lane width CMF. Hence, CMF\(_2\), \text{sc}, 6\text{EX}, \text{at}, fi is equal to 1.000.

*Inside Shoulder Width (CMF\(_3\), \text{sc}, 6\text{EX}, \text{at}, z)*

The segment has 6-ft inside shoulders, which is the base condition for the inside shoulder width CMF. Hence, CMF\(_3\), \text{sc}, 6\text{EX}, \text{at}, fi and CMF\(_3\), \text{sc}, 6\text{EX}, \text{at}, pdo are equal to 1.000.

*Median Width (CMF\(_4\), \text{sc}, 6\text{EX}, \text{at}, z)*

CMF\(_4\), \text{sc}, 6\text{EX}, \text{at}, fi is calculated from Equation 13-43 as follows:

\[ CMF_{4, \text{sc}, 6\text{EX}, \text{at}, fi} = (1.0 - P_{ib}) \times \exp(a \times [W_m - 2 \times W_{is} - 48]) + P_{ib} \times \exp(a \times [2 \times W_{icb} - 48]) \]

The segment does not have inside barrier, so \( P_{ib} = 0.0 \) and the calculation of \( W_{icb} \) does not apply. From Table 13-25, \( a = -0.00302 \) for fatal-and-injury crashes. CMF\(_4\), \text{sc}, 6\text{EX}, \text{at}, fi is calculated as follows:

\[ CMF_{4, \text{sc}, 6\text{EX}, \text{at}, fi} = (1.0 - 0.0) \times \exp(-0.00302 \times [40 - 2 \times 6 - 48]) + 0.0 \times \exp(-0.00302 \times [2 \times W_{icb} - 48]) \]

\[ = 1.062 \]

Similar calculations using the property-damage-only coefficients from Table 13-25 yield the following results:

\[ CMF_{4, \text{sc}, 6\text{EX}, \text{at}, pdo} = 1.060 \]

*Median Barrier (CMF\(_5\), \text{sc}, 6\text{EX}, \text{at}, z)*

The segment does not have inside barrier. Hence, CMF\(_5\), \text{sc}, 6\text{EX}, \text{at}, fi and CMF\(_5\), \text{sc}, 6\text{EX}, \text{at}, pdo are equal to 1.000.

*High Volume (CMF\(_6\), \text{sc}, 6\text{EX}, \text{at}, z)*

CMF\(_6\), \text{sc}, 6\text{EX}, \text{at}, fi is calculated from Equation 13-45 and the coefficient \( a = 0.350 \) from Table 13-27 as follows:

\[ CMF_{6, \text{sc}, 6\text{EX}, \text{at}, fi} = \exp(a \times P_{lv}) \]

\[ = \exp(0.350 \times 0.1) \]

\[ = 1.036 \]
Similar calculations using the property-damage-only coefficients from Table 13-27 yield the following results:

\[ CMF_{6,sc,6EX,at,pdo} = 1.029 \]

**Ramp Exit (CMF_{13,sc,6EX,at,fi})**

\[ CMF_{13,sc,6EX,at,fi} \] is calculated from Equation 13-47 as follows:

\[ CMF_{13,sc,6EX,at,fi} = \exp \left( a \times I_{exp,6,13} + \frac{b}{L_{ex}} \right) \]

The ramp entrance connects to the right side of the freeway mainline. Hence, \( I_{left} = 0.0 \). From Table 13-29, the coefficients \( a \) and \( b \) for fatal-and-injury crashes are 0.594 and 0.0116, respectively. \( CMF_{13,sc,6EX,at,fi} \) is calculated as follows:

\[ CMF_{13,sc,6EX,at,fi} = \exp \left( 0.594 \times 0.0 + \frac{0.0116}{0.1} \right) = 1.123 \]

Similar calculations using the property-damage-only coefficients from Table 13-29 yield the following results:

\[ CMF_{13,sc,6EX,at,pdo} = 1.000 \]

**Ramp Exit Crashes**

The CMFs are applied to the ramp exit fatal-and-injury SPF as follows:

\[
N_{p^*, sc, 6EX, at, fi} = N_{spf, sc, 6EX, at, fi} \times (CMF_{1,sc,6EX,at,fi} \times \ldots \times CMF_{6,sc,6EX,at,fi} \times CMF_{13,sc,6EX,at,fi})
\]

\[ = 0.277 \times (1.000 \times 1.000 \times 1.000 \times 1.062 \times 1.000 \times 1.036 \times 1.123) \]

\[ = 0.277 \times 1.235 \]

\[ = 0.342 \text{ crashes/year} \]

The CMFs are applied to the ramp exit property-damage-only SPF as follows:

\[
N_{p^*, sc, 6EX, at, pdo} = N_{spf, sc, 6EX, at, pdo} \times (CMF_{1,sc,6EX,at,pdo} \times \ldots \times CMF_{6,sc,6EX,at,pdo} \times CMF_{13,sc,6EX,at,pdo})
\]

\[ = 0.752 \times (1.000 \times 1.000 \times 1.000 \times 1.060 \times 1.000 \times 1.029 \times 1.000) \]

\[ = 0.752 \times 1.090 \]

\[ = 0.820 \text{ crashes/year} \]

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

It is assumed that a calibration factor of 1.00 has been determined for local conditions. See Part C Appendix A.1 for further discussion on calibration of the predicted models.

**Calculation of Predicted Average Crash Frequency**

The predicted average crash frequency is calculated using Equation 13-2 based on the results obtained in Steps 9 through 11 as follows.
Fatal-and-injury crashes:

\[ N_{p, \text{sc}, 6EX, at, fi} = N_{\text{spf}, \text{sc}, 6EX, at, fi} \times C_{fs, \text{sc}, 6EX, at, fi} \]
\[ = 0.342 \times 1.00 \]
\[ = 0.342 \text{ crashes/year} \]

Property-damage-only crashes:

\[ N_{p, \text{sc}, 6EX, at, pdo} = N_{\text{spf}, \text{sc}, 6EX, at, pdo} \times C_{fs, \text{sc}, 6EX, at, pdo} \]
\[ = 0.820 \times 1.00 \]
\[ = 0.820 \text{ crashes/year} \]

**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.

The study period is one year (2011), so steps 8 through 11 need not be repeated.

**Step 13**—Apply site-specific EB Method (if applicable) and apply SDFs.

This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

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

The site-specific EB Method is not applied in this sample problem because crash data are not available.

**Apply the severity distribution functions (SDFs), if desired.**

To apply the SDFs, the systematic component of crash severity likelihood \( V_j \) is computed for each severity level \( j \) using Equation 13-63 as follows:

\[ V_j = a + \left( b \times \frac{P_{ib} + P_{ob}}{2} \right) + \left( c \times P_{ir} \right) + \left( d \times \frac{P_{ir} + P_{or}}{2} \right) + \left( e \times \sum P_{c,i} \right) + \left( f \times W_i \right) + \left( g \times I_{rural} \right) \]

The coefficients \( a, b, c, d, e, f, \) and \( g \) are obtained from Table 13-30 for each severity level \( j \). The segment does not have barrier, rumble strips, or horizontal curvature, so \( P_{ib}, P_{ob}, P_{ir}, P_{or} \), and \( P_{c,i} \), are equal to 0.0. \( V_j \) is computed for fatal crashes as follows:

\[ V_K = -0.171 + \left( -0.388 \times \frac{0.0 + 0.0}{2} \right) + \left( -0.924 \times 0.1 \right) + \left( 0.387 \times \frac{0.0 + 0.0}{2} \right) + \left( 0.208 \times 0.0 \right) + \left( -0.261 \times 12 \right) + \left( 0.492 \times 0.0 \right) = -3.392 \]

Calculations using the coefficients for incapacitating injury crashes and non-incapacitating injury crashes from Table 13-30 yield the following results:

\[ V_A = -2.478 \]
\[ V_B = -0.571 \]
Using these computed $V_K$, $V_A$, and $V_B$ values, and assuming a calibration factor $C_{sdff,fs+sc}$ of 1.0, the probability of occurrence of a fatal crash is computed using Equation 13-59 as follows:

$$P_{fs+sc,ac,at,K} = \frac{\exp(V_K)}{C_{sdff,fs+sc} + \exp(V_K) + \exp(V_A) + \exp(V_B)}$$

$$= \frac{\exp(-3.392)}{1.0 + \exp(-3.392) + \exp(-2.478) + \exp(-0.571)}$$

$$= 0.020$$

Similar calculations using Equation 13-60 and Equation 13-61 yield the following results:

$$P_{fs+sc,ac,at,A} = 0.050$$

$$P_{fs+sc,ac,at,B} = 0.336$$

The probability of occurrence of a possible-injury crash is computed using Equation 13-62 as follows:

$$P_{fs+sc,ac,at,C} = 1.0 - (P_{fs+sc,ac,at,K} + P_{fs+sc,ac,at,A} + P_{fs+sc,ac,at,B})$$

$$= 1.0 - (0.020 + 0.050 + 0.336)$$

$$= 0.594$$

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 13-58 as follows:

$$N_{e,sc,6EX,at,K} = N_{e,sc,6EX,at,fi} \times P_{fs+sc,ac,at,K}$$

$$= 0.342 \times 0.020$$

$$= 0.007 \text{ crashes/year}$$

Similar calculations using Equation 13-58 and the probabilities of occurrences of the other crash severities yield the following results:

$$N_{e,sc,6EX,at,A} = 0.017 \text{ crashes/year}$$

$$N_{e,sc,6EX,at,B} = 0.115 \text{ crashes/year}$$

$$N_{e,sc,6EX,at,C} = 0.203 \text{ crashes/year}$$

*Apply the crash type distribution, if desired.*

The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 13-12 by the predicted average crash frequencies obtained in Step 11.

**Worksheets**

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

- Table 13-43. Freeway Speed-Change Lane Worksheet (1 of 3)—Sample Problem 4
- Table 13-44. Freeway Speed-Change Lane Worksheet (2 of 3)—Sample Problem 4
- Table 13-45. Freeway Speed-Change Lane Worksheet (3 of 3)—Sample Problem 4

Filled versions of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 13 Appendix A.

Table 13-43 is a summary of general information about the freeway speed-change lane, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 4. The input data include area type, crash data, basic roadway data, alignment data, cross section data, and traffic data.

Table 13-44 is a tabulation of the CMF and SPF computations for Sample Problem 4.

Table 13-45 is a tabulation of the crash severity and crash type distributions for Sample Problem 4.
Table 13-43. Freeway Speed-Change Lane Worksheet (1 of 3)—Sample Problem 4

<table>
<thead>
<tr>
<th>General Information</th>
<th>Location Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Roadway</td>
</tr>
<tr>
<td>Agency or company</td>
<td>Roadway section</td>
</tr>
<tr>
<td>Date performed</td>
<td>Study year</td>
</tr>
<tr>
<td>Area type</td>
<td>X, Urban, Rural</td>
</tr>
</tbody>
</table>

**Input Data**

**Crash Data**

<table>
<thead>
<tr>
<th>Crash Data</th>
<th>Crash Period</th>
<th>Study Year (First year</th>
<th>Last year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash data time period</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count of speed-change-related FI crashes (N_{c,sc,x,at,fi}^)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Count of speed-change-related PDO crashes (N_{c,sc,x,at,pdo}^)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

**Basic Roadway Data**

<table>
<thead>
<tr>
<th>Basic Roadway Data</th>
<th>Crash Period</th>
<th>Study Year (First year</th>
<th>Last year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of through lanes (n)</td>
<td>6</td>
<td>Same value for crash period and study year.</td>
<td></td>
</tr>
<tr>
<td>Segment length (L) (mi)</td>
<td>--</td>
<td>0.1</td>
<td>Equals the length of the speed-change lane.</td>
</tr>
</tbody>
</table>

**Alignment Data**

**Horizontal Curve Data**

1. Presence of horizontal curve 1 | -- | Y/N | N | Y/N | If Yes, then enter data in the next three rows. |
   | Curve radius \(R_1\) (ft) | -- | -- |    | |
   | Length of curve \(L_{c1}\) (mi) | -- | -- |    | |
   | Length of curve in segment \(L_{c1,seg}\) (mi) | -- | -- |    | |

2. Presence of horizontal curve 2 | -- | Y/N | N | Y/N | If Yes, then enter data in the next three rows. |
   | Curve radius \(R_2\) (ft) | -- | -- |    | |
   | Length of curve \(L_{c2}\) (mi) | -- | -- |    | |
   | Length of curve in segment \(L_{c2,seg}\) (mi) | -- | -- |    | |

**Cross Section Data**

<table>
<thead>
<tr>
<th>Cross Section Data</th>
<th>Crash Period</th>
<th>Study Year (First year</th>
<th>Last year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane width (W_1) (ft)</td>
<td>--</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Inside shoulder width (W_s) (ft)</td>
<td>--</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Median width (W_m) (ft)</td>
<td>--</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Presence of barrier in median</td>
<td>--</td>
<td>Y/N</td>
<td>N</td>
</tr>
<tr>
<td>Entrance or exit side (left- or right-hand side)</td>
<td>--</td>
<td>L/R</td>
<td>R</td>
</tr>
</tbody>
</table>

**Traffic Data**

<table>
<thead>
<tr>
<th>Traffic Data</th>
<th>Crash Period</th>
<th>Study Year (First year</th>
<th>Last year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of AADT during high-volume hours (P_{h,v})</td>
<td>--</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Freeway segment AADT (AADT_{fs}) (veh/day)</td>
<td>--</td>
<td>120,000</td>
<td></td>
</tr>
<tr>
<td>AADT of ramp (AADT_r) (veh/day)</td>
<td>--</td>
<td>--</td>
<td>Only needed for entrance ramp.</td>
</tr>
</tbody>
</table>
### Table 13-44. Freeway Speed-Change Lane Worksheet (2 of 3)—Sample Problem 4

#### Crash Modification Factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
<td>Crash Period</td>
</tr>
<tr>
<td>Horizontal curve $CMF_{1,w,ac,at,z}$</td>
<td>13-40</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Lane width $CMF_{2,w,ac,at,fi}$</td>
<td>13-41</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Inside shoulder width $CMF_{3,w,ac,at,z}$</td>
<td>13-42</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Median width $CMF_{d,w,ac,at,z}$</td>
<td>13-43</td>
<td>--</td>
<td>1.062</td>
</tr>
<tr>
<td>Median barrier $CMF_{5,w,ac,at,z}$</td>
<td>13-44</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>High volume $CMF_{6,w,ac,at,z}$</td>
<td>13-45</td>
<td>--</td>
<td>1.036</td>
</tr>
<tr>
<td>Ramp entrance $CMF_{12,w,EN,at,z}$</td>
<td>13-46</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Ramp exit $CMF_{13,w,EX,at,z}$</td>
<td>13-47</td>
<td>--</td>
<td>1.123</td>
</tr>
<tr>
<td>Combined CMF (multiply all CMFs evaluated)</td>
<td>--</td>
<td>--</td>
<td>1.235</td>
</tr>
</tbody>
</table>

#### Expected Average Crash Frequency *

<table>
<thead>
<tr>
<th>Factor</th>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
<td>Crash Period</td>
</tr>
<tr>
<td>Calibration factor $C_{sc,x,at,z}$</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Overdispersion parameter $k_{sc,x,at,z}$</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Observed crash count $N_{o,w,sc,x,at,z}$ (cr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Reference year $r$</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Predicted average crash freq. for reference year $N_{p,w,sc,x,at,z}$ (cr/yr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Predicted number of crashes for crash period (sum all years) $N_{p,w,sc,x,at,z}$ (cr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Equivalent years associated with crash count $C_{b,w,sc,x,at,z}$ (yr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Adjusted average crash freq. for ref. year given $N_{o,w,sc,x,at,z}$ (cr/yr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Study year $s$</td>
<td>2011</td>
<td>2011</td>
<td></td>
</tr>
<tr>
<td>Predicted average crash freq. for study year $N_{p,w,sc,x,at,z,cr}$ (cr/yr)</td>
<td>0.342</td>
<td>0.342</td>
<td>0.820</td>
</tr>
<tr>
<td>Expected average crash freq. for study year $N_{e,w,sc,x,at,z}$ (cr/yr)</td>
<td>0.342</td>
<td>0.342</td>
<td>0.820</td>
</tr>
</tbody>
</table>

**Note:**

- If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e.”
Table 13-45. Freeway Speed-Change Lane Worksheet (3 of 3)—Sample Problem 4

Expected Average Crash Frequency

<table>
<thead>
<tr>
<th>Crash Severity Distribution</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Total FI</th>
<th>PDO</th>
<th>Total FI + PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion by injury level</td>
<td>0.020</td>
<td>0.050</td>
<td>0.336</td>
<td>0.594</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected average crash freq. for study year (N_e, x, a, z, s) (cr/yr)</td>
<td>0.007</td>
<td>0.017</td>
<td>0.115</td>
<td>0.203</td>
<td>0.342</td>
<td>0.820</td>
<td>1.162</td>
</tr>
</tbody>
</table>

Crash Type Distribution

<table>
<thead>
<tr>
<th>Crash Type Category</th>
<th>Table 13-10 or 13-12</th>
<th>Proportion</th>
<th>Expected Average Crash Frequency for Study Year (N_e, x, a, z, s) (cr/yr)</th>
<th>Proportion</th>
<th>Expected Average Crash Frequency for Study Year (N_e, x, a, z, s) (cr/yr)</th>
<th>Expected Average Crash Frequency for Study Year (N_e, x, a, z, s) (cr/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple-Vehicle Crashes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head-on</td>
<td></td>
<td>0.004</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Right-angle</td>
<td></td>
<td>0.019</td>
<td>0.006</td>
<td>0.016</td>
<td>0.013</td>
<td>0.020</td>
</tr>
<tr>
<td>Rear-end</td>
<td></td>
<td>0.543</td>
<td>0.186</td>
<td>0.530</td>
<td>0.435</td>
<td>0.620</td>
</tr>
<tr>
<td>Sideswipe</td>
<td></td>
<td>0.133</td>
<td>0.045</td>
<td>0.252</td>
<td>0.207</td>
<td>0.252</td>
</tr>
<tr>
<td>Other multiple-vehicle crashes</td>
<td></td>
<td>0.017</td>
<td>0.006</td>
<td>0.015</td>
<td>0.012</td>
<td>0.018</td>
</tr>
<tr>
<td>Single-Vehicle Crashes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crash with animal</td>
<td></td>
<td>0.000</td>
<td>0.000</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>Crash with fixed object</td>
<td></td>
<td>0.194</td>
<td>0.066</td>
<td>0.129</td>
<td>0.106</td>
<td>0.172</td>
</tr>
<tr>
<td>Crash with other object</td>
<td></td>
<td>0.019</td>
<td>0.006</td>
<td>0.036</td>
<td>0.030</td>
<td>0.036</td>
</tr>
<tr>
<td>Crash with parked vehicle</td>
<td></td>
<td>0.004</td>
<td>0.001</td>
<td>0.003</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>Other single-vehicle crashes</td>
<td></td>
<td>0.067</td>
<td>0.023</td>
<td>0.016</td>
<td>0.013</td>
<td>0.036</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1.000</td>
<td>0.342</td>
<td>1.000</td>
<td>0.820</td>
<td>1.162</td>
</tr>
</tbody>
</table>

Note:
a - If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.

13.13.5. Sample Problem 5

The Project
A project of interest consists of two sites located on a six-lane urban freeway: a tangent segment and a segment with a horizontal curve. (This project is a compilation of the freeway segments from Sample Problems 1 and 2.)

The Question
What is the expected crash frequency of the project for a particular year incorporating both the predicted crash frequencies from Sample Problems 1 and 2 and the observed crash frequencies using the site-specific EB Method?

The Facts
The study year is 2011. The conditions present during this year are provided in the following list.
2 freeway segments—segment 1 (tangent), segment 2 (curved)

Crash period is 2009 and 2010

Use the same AADT volumes for 2009 to 2011

30 observed fatal-and-injury crashes

- Segment 1: 10 multiple-vehicle, 4 single-vehicle
- Segment 2: 8 multiple-vehicle, 8 single-vehicle

50 observed property-damage-only crashes

- Segment 1: 14 multiple-vehicle, 12 single-vehicle
- Segment 2: 10 multiple-vehicle, 14 single-vehicle

Outline of Solution
To calculate the expected crash frequency, site-specific observed crash frequencies are combined with predicted crash frequencies for the project using the site-specific EB Method (i.e., observed crashes are assigned to specific speed-change lanes or freeway segments) presented in Section A.2.4 of Part C Appendix.

Results
The expected average crash frequency for the project is 13.5 fatal-and-injury crashes per year and 27.5 property-damage-only crashes per year (rounded to one decimal place).

Steps
The expected average crash frequency for reference year $r$ at a site $i$ with type $w(i)$ and cross section or control type $x(i)$ for a specified crash type $y$ and severity $z$ is computed using Equation A-5 through Equation A-7 as follows:

\[
N_{r, w(i), x(i), y, z, r} = w_{w(i), x(i), y, z} \times N_{p, w(i), x(i), y, z, r} + \left(1 - w_{w(i), x(i), y, z}\right) \times \frac{N_{o, w(i), x(i), y, z, r}}{C_{b, w(i), y, z, r}}
\]

\[
w_{w(i), x(i), y, z} = \frac{1.0}{1.0 + \left(k_{w(i), x(i), y, z} \times \sum_{j=1}^{n} N_{p, w(i), x(i), y, z, r}\right)}
\]

\[
C_{b, w(i), x(i), y, z, r} = \frac{1.0}{N_{p, w(i), x(i), y, z, r}} \times \sum_{j=1}^{n} N_{p, w(i), x(i), y, z, j}
\]

$C_{b, w(i), x(i), y, z, r} = 2.0$ because the same AADT volumes are used for all years in the analysis period. The overdispersion parameter for segment 1 for fatal-and-injury multiple-vehicle crashes $k_{f, b, 6, mv, fi}$ is computed using Equation 13-17 with the segment length and the inverse dispersion parameter from Table 13-5.

\[
k_{f, b, 6, mv, fi} = \frac{1.0}{17.6 \times 0.75} = 0.076
\]
The predicted average fatal-and-injury multiple-vehicle crash frequency $N_{p, fs, 6, mv, fi}$ was computed as 3.911 crashes/year in Sample Problem 1. The weighted adjustment factor $w_{fs, 6, mv, fi}$ is computed as follows:

$$w_{fs, 6, mv, fi} = \frac{1.0}{1.0 + (0.076 \times [3.911 + 3.911])} = 0.627$$

Then, the expected average crash frequency $N_{e, fs, 6, mv, fi}$ is computed as follows:

$$N_{e, fs, 6, mv, fi} = 0.627 \times 3.911 + (1.0 - 0.627) \times \frac{10}{2} = 4.316 \text{ crashes/year}$$

This process is repeated for fatal-and-injury single-vehicle crashes, property-damage-only multiple-vehicle crashes, and property-damage-only single-vehicle crashes for segment 1, and for all crashes for segment 2, to obtain the following results:

- **Segment 1**
  - $N_{e, fs, 6, mv, fi, r} = 4.316 \text{ crashes/year}$
  - $N_{e, fs, 6, sv, fi, r} = 2.050 \text{ crashes/year}$
  - $N_{e, fs, 6, mv, pdo, r} = 8.090 \text{ crashes/year}$
  - $N_{e, fs, 6, sv, pdo, r} = 5.456 \text{ crashes/year}$

- **Segment 2**
  - $N_{e, fs, 6, mv, fi, r} = 4.092 \text{ crashes/year}$
  - $N_{e, fs, 6, sv, fi, r} = 3.089 \text{ crashes/year}$
  - $N_{e, fs, 6, mv, pdo, r} = 7.218 \text{ crashes/year}$
  - $N_{e, fs, 6, sv, pdo, r} = 6.702 \text{ crashes/year}$

**Worksheets**

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

- Table 13-46. Freeway Segment Worksheet (1 of 4)—Sample Problem 5
- Table 13-47. Freeway Segment Worksheet (2 of 4)—Sample Problem 5
- Table 13-48. Freeway Segment Worksheet (3 of 4)—Sample Problem 5
- Table 13-49. Freeway Segment Worksheet (4 of 4)—Sample Problem 5
Filled versions of these worksheets are provided below for segment 1. The same worksheets would be used for segment 2, but are not shown. Blank versions of worksheets used in the Sample Problems are provided in Chapter 13 Appendix A.

Table 13-46 is a summary of general information about the freeway segment, analysis, input data (i.e., “The Facts”), and assumptions for segment 1. The input data include area type, crash data, basic roadway data, alignment data, and cross section data.

Table 13-47 is a summary of general information about the freeway segment, analysis, input data (i.e., “The Facts”), and assumptions for segment 1. The input data include roadside data, ramp access data, and traffic data.

Table 13-48 is a tabulation of the CMF and SPF computations for segment 1.

Table 13-49 is a tabulation of the crash severity and crash type distributions for segment 1.
### Table 13-46. Freeway Segment Worksheet (1 of 4)—Sample Problem 5

<table>
<thead>
<tr>
<th>General Information</th>
<th>Location Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Roadway</td>
</tr>
<tr>
<td>Agency or company</td>
<td>Roadway section</td>
</tr>
<tr>
<td>Date performed</td>
<td>Study year</td>
</tr>
<tr>
<td>Area type</td>
<td>X Urban Rural</td>
</tr>
</tbody>
</table>

#### Input Data

##### Crash Data

<table>
<thead>
<tr>
<th>Crash Data</th>
<th>Crash Period</th>
<th>Study Year</th>
<th>Complete the study year column. Complete the crash period column if the EB Method is used.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash data time period</td>
<td></td>
<td>First year</td>
<td>2009</td>
</tr>
<tr>
<td>Count of multiple-vehicle FI crashes $N_{a,fr, n, mv, fi}$</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count of single-vehicle FI crashes $N_{a,fr, n, sv, fi}$</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count of multiple-vehicle PDO crashes $N_{a,fr, n, mv, pdo}$</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count of single-vehicle PDO crashes $N_{a,fr, n, sv, pdo}$</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

##### Basic Roadway Data

<table>
<thead>
<tr>
<th>Basic Roadway Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of through lanes $n$</td>
<td>6</td>
</tr>
<tr>
<td>Segment length $L (mi)$</td>
<td>0.75</td>
</tr>
</tbody>
</table>

##### Alignment Data

**Horizontal Curve Data**

1. Presence of horizontal curve 1
   - Curve radius $R_1 (ft)$: -- --
   - Length of curve $L_{c1} (mi)$: -- --
   - Length of curve in segment $L_{c1, \text{seg}} (mi)$: -- --

2. Presence of horizontal curve 2
   - Curve radius $R_2 (ft)$: -- --
   - Length of curve $L_{c2} (mi)$: -- --
   - Length of curve in segment $L_{c2, \text{seg}} (mi)$: -- --

##### Cross Section Data

<table>
<thead>
<tr>
<th>Cross Section Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane width $W_l (ft)$</td>
<td>12</td>
</tr>
<tr>
<td>Outside shoulder width $W_o (ft)$</td>
<td>10</td>
</tr>
<tr>
<td>Inside shoulder width $W_i (ft)$</td>
<td>6</td>
</tr>
<tr>
<td>Median width $W_m (ft)$</td>
<td>40</td>
</tr>
<tr>
<td>Presence of rumble strips on outside shoulder</td>
<td>N</td>
</tr>
<tr>
<td>Length of rumble strip in increasing milepost dir. (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Length of rumble strip in decreasing milepost dir. (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Presence of rumble strips on inside shoulder</td>
<td>N</td>
</tr>
<tr>
<td>Length of rumble strip in increasing milepost dir. (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Length of rumble strip in decreasing milepost dir. (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Presence of barrier in median</td>
<td>N</td>
</tr>
</tbody>
</table>

---

**Note:** The table provides a structured format for inputting data related to freeway segments, including general information, input data, and specific details about horizontal curves and cross sections. The data is designed to support predictive methods for freeway safety and planning.
Table 13-47. Freeway Segment Worksheet (2 of 4)—Sample Problem 5

### Input Data

<table>
<thead>
<tr>
<th>Roadside Data</th>
<th>Crash Period</th>
<th>Study Year</th>
<th>Complete the study year column. Complete the crash period column if the EB Method is used.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear zone width $W_{hc}$ (ft)</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Presence of barrier on roadside</td>
<td>N</td>
<td>Y/N</td>
<td>N</td>
</tr>
</tbody>
</table>

#### Ramp Access Data

**Travel in Increasing Milepost Direction**

<table>
<thead>
<tr>
<th>Ent. ramp</th>
<th>Distance from begin milepost to upstream entrance ramp gore $X_{b, en}$ (mi)</th>
<th>0.5</th>
<th>0.5</th>
<th>If ramp entrance is in the segment, enter 0.0.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Presence of speed-change lane in segment</td>
<td>N</td>
<td>Y/N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Length of s-c lane in segment $L_{en, seg, in}$ (mi)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exit ramp</th>
<th>Distance from end milepost to upstream exit ramp gore $X_{e, ex}$ (mi)</th>
<th>0.85</th>
<th>0.85</th>
<th>If ramp exit is in the segment, enter 0.0.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Presence of speed-change lane in segment</td>
<td>N</td>
<td>Y/N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Length of s-c lane in segment $L_{ex, seg, in}$ (mi)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

**Weave**

| Presence of a Type B weave in segment | N | Y/N | N | Y/N | If Yes, then enter data in the next two rows. |
| Length of weaving section $L_{wev, inc}$ (mi) | -- | -- | -- |
| Length of weaving section in seg. $L_{wev, seg, inc}$ (mi) | -- | -- | -- |

**Travel in Decreasing Milepost Direction**

<table>
<thead>
<tr>
<th>Ent. ramp</th>
<th>Distance from end milepost to upstream entrance ramp gore $X_{e, ex}$ (mi)</th>
<th>0.85</th>
<th>0.85</th>
<th>If ramp entrance is in the segment, enter 0.0.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Presence of speed-change lane in segment</td>
<td>N</td>
<td>Y/N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Length of s-c lane in segment $L_{en, seg, dec}$ (mi)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exit ramp</th>
<th>Distance from begin milepost to downstream exit ramp gore $X_{b, ext}$ (mi)</th>
<th>0.5</th>
<th>0.5</th>
<th>If ramp exit is in the segment, enter 0.0.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Presence of speed-change lane in segment</td>
<td>N</td>
<td>Y/N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Length of s-c lane in segment $L_{ex, seg, dec}$ (mi)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

**Weave**

| Presence of a Type B weave in segment | N | Y/N | N | Y/N | If Yes, then enter data in the next two rows. |
| Length of weaving section $L_{wev, dec}$ (mi) | -- | -- | -- |
| Length of weaving section in seg. $L_{wev, seg, dec}$ (mi) | -- | -- | -- |

#### Traffic Data

| Proportion of AADT during high-volume hours $P_{hv}$ | 0.1 | 0.1 | |
| Freeway segment AADT $AADT_{f}$ (veh/day) | 120,000 | 120,000 | |
| AADT of entrance ramp for travel in increasing milepost direction $AADT_{b, en}$ (veh/day) | 8,000 | 8,000 | |
| AADT of exit ramp for travel in increasing milepost direction $AADT_{e, ex}$ (veh/day) | 7,150 | 7,150 | |
| AADT of entrance ramp for travel in decreasing milepost direction $AADT_{b, ext}$ (veh/day) | 6,750 | 6,750 | |
| AADT of exit ramp for travel in decreasing milepost direction $AADT_{e, ex}$ (veh/day) | 7,675 | 7,675 | |
### Table 13-48. Freeway Segment Worksheet (3 of 4)—Sample Problem 5

**Crash Modification Factors**

<table>
<thead>
<tr>
<th></th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Multiple Vehicle</td>
<td>Single Vehicle</td>
</tr>
<tr>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td>Horizontal curve CMF₁, fs, ac, y, z</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Lane width CMF₂, fs, ac, y, f</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Inside shoulder width CMF₃, fs, ac, y, z</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Median width CMF₄, fs, ac, y, z</td>
<td>1.062</td>
<td>1.062</td>
</tr>
<tr>
<td>Median barrier CMF₅, fs, ac, y, z</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>High volume CMF₆, fs, ac, y, z</td>
<td>1.036</td>
<td>1.036</td>
</tr>
<tr>
<td>Lane change CMF₇, fs, ac, y, z</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Outside shoulder width CMF₈, fs, ac, y, z</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Shoulder rumble strip CMF₉, fs, ac, y, b</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Outside clearance CMF₁₀, fs, ac, y, z</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Outside barrier CMF₁₁, fs, ac, y, z</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Combined CMF (multiply all CMFs evaluated)</td>
<td>1.100</td>
<td>1.100</td>
</tr>
</tbody>
</table>

**Expected Average Crash Frequency**

<table>
<thead>
<tr>
<th></th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Multiple Vehicle</td>
<td>Single Vehicle</td>
</tr>
<tr>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td>Calibration factor Cₛ, ac, y, z</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Overdispersion parameter kₛ, n, y, z</td>
<td>0.076</td>
<td>0.044</td>
</tr>
<tr>
<td>Observed crash count Nₒₙ, fs, n, y, z, (cr)</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Reference year r</td>
<td>2009</td>
<td>2009</td>
</tr>
<tr>
<td>Predicted average crash freq. for reference year Nₒₙ, fs, n, y, z, (cr/yr)</td>
<td>3.911</td>
<td>2.060</td>
</tr>
<tr>
<td>Predicted number of crashes for crash period (sum all years) Nₒₙ, fs, n, y, z, (cr)</td>
<td>3.911</td>
<td>2.060</td>
</tr>
<tr>
<td>Equivalent years associated with crash count Cₛₙ, fs, n, y, z, (yr)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Adjusted average crash freq. for ref. year given Nₒₙ, Nₒₙ, n, y, z, (cr/yr)</td>
<td>4.316</td>
<td>2.050</td>
</tr>
<tr>
<td>Study year s</td>
<td>2011</td>
<td>2011</td>
</tr>
<tr>
<td>Predicted average crash freq. for study year Nₒₙ, fs, n, y, z, s, (cr/yr)</td>
<td>3.911</td>
<td>2.060</td>
</tr>
<tr>
<td>Expected average crash freq. for study year Nₑₙ, fs, n, y, z, s, (cr/yr)</td>
<td>4.316</td>
<td>2.050</td>
</tr>
<tr>
<td>Expected average crash freq. for study year (all crash types) Nₑₙ, n, at, y, z, (cr/yr)</td>
<td>6.367</td>
<td>13.546</td>
</tr>
</tbody>
</table>

Note:

a - If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e.”
Table 13-49. Freeway Segment Worksheet (4 of 4)—Sample Problem 5

Expected Average Crash Frequency *a*

<table>
<thead>
<tr>
<th>Crash Severity Distribution</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Total FI</th>
<th>PDO</th>
<th>Total FI + PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion by injury level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.020</td>
<td>0.050</td>
<td>0.336</td>
</tr>
<tr>
<td>Expected average crash freq. for study year (all crash types) (N_{e, fs, n, y, at, z, s}) (cr/yr)</td>
<td>0.127</td>
<td>0.317</td>
<td>2.138</td>
<td>3.784</td>
<td>6.367</td>
<td>13.546</td>
<td>19.912</td>
</tr>
</tbody>
</table>

Crash Type Distribution

<table>
<thead>
<tr>
<th>Crash Type Category</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proportion</td>
<td>Proportion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Expected Average Crash Frequency for Study Year (N_{e, fs, n, y, at, z, s}) (cr/yr)</td>
<td>Expected Average Crash Frequency for Study Year (N_{e, fs, n, y, pdo, s}) (cr/yr)</td>
<td>Expected Average Crash Frequency for Study Year (N_{e, fs, n, y, as, s}) (cr/yr)</td>
</tr>
<tr>
<td>Multiplevehicle Crashes</td>
<td>13-6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head-on</td>
<td>0.008</td>
<td>0.035</td>
<td>0.002</td>
</tr>
<tr>
<td>Right-angle</td>
<td>0.031</td>
<td>0.134</td>
<td>0.018</td>
</tr>
<tr>
<td>Rear-end</td>
<td>0.750</td>
<td>3.237</td>
<td>0.690</td>
</tr>
<tr>
<td>Sideswipe</td>
<td>0.180</td>
<td>0.777</td>
<td>0.266</td>
</tr>
<tr>
<td>Other multiple-vehicle crashes</td>
<td>0.031</td>
<td>0.134</td>
<td>0.024</td>
</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>4.316</td>
<td>1.000</td>
</tr>
<tr>
<td>Single-vehicle Crashes</td>
<td>13-8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crash with animal</td>
<td>0.004</td>
<td>0.008</td>
<td>0.022</td>
</tr>
<tr>
<td>Crash with fixed object</td>
<td>0.722</td>
<td>1.480</td>
<td>0.716</td>
</tr>
<tr>
<td>Crash with other object</td>
<td>0.051</td>
<td>0.105</td>
<td>0.139</td>
</tr>
<tr>
<td>Crash with parked vehicle</td>
<td>0.015</td>
<td>0.031</td>
<td>0.016</td>
</tr>
<tr>
<td>Other single-vehicle crashes</td>
<td>0.208</td>
<td>0.427</td>
<td>0.107</td>
</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>2.050</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Note:

*a* - If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.

13.13.6. Sample Problem 6

The Project

A project of interest consists of two sites located on a six-lane urban freeway: a tangent segment and a segment with a horizontal curve. (This project is a compilation of freeway segments from Sample Problems 1 and 2.)

The Question

What is the expected crash frequency of the project for a particular year incorporating both the predicted crash frequencies from Sample Problems 1 and 2 and the observed crash frequencies using the project-level EB Method?
The Facts
The study year is 2011. The conditions present during this year are provided in the following list.

- 2 freeway segments—segment 1 (tangent), segment 2 (curved)
- Crash period is 2009 and 2010
- Use the same AADT volumes for 2009 to 2011
- 30 observed fatal-and-injury crashes and 50 observed property-damage-only crashes (but no information is available to attribute specific crashes to specific sites)

Outline of Solution
Observed crash frequencies for the project as a whole are combined with predicted average crash frequencies for the project as a whole using the project-level EB Method (i.e., observed crash data for individual freeway segments and speed-change lanes are not available, but observed crashes are assigned to a facility as a whole) presented in Section A.2.5 of Part C Appendix.

Results
The expected average crash frequency for the project is 13.9 fatal-and-injury crashes per year and 27.1 property-damage-only crashes per year (rounded to one decimal place).

Steps

Step 1—Sum the predicted average crash frequency and observed crash counts.
The predicted average crash frequencies for segments 1 and 2 were computed in Sample Problems 1 and 2, respectively. For freeway segments, separate values are obtained for multiple-vehicle and single-vehicle crashes, and for fatal-and-injury and property-damage-only crashes. The following values were obtained:

- Segment 1
  - \( N_{p, fs, 6, mv, fi, r} = 3.911 \) crashes/year
  - \( N_{p, fs, 6, sv, fi, r} = 2.060 \) crashes/year
  - \( N_{p, fs, 6, mv, pdo, r} = 9.568 \) crashes/year
  - \( N_{p, fs, 6, sv, pdo, r} = 5.099 \) crashes/year

- Segment 2
  - \( N_{p, fs, 6, mv, fi, r} = 4.150 \) crashes/year
  - \( N_{p, fs, 6, sv, fi, r} = 2.858 \) crashes/year
  - \( N_{p, fs, 6, mv, pdo, r} = 10.530 \) crashes/year
  - \( N_{p, fs, 6, sv, pdo, r} = 6.454 \) crashes/year

- All fatal-and-injury crashes: \( N_{p, aS, ac, at, fi, r} = 12.979 \) crashes/year
- All property-damage-only crashes: \( N_{p, aS, ac, at, pdo, r} = 31.651 \) crashes/year
The crash period is two years, and the same AADT volumes were used for the two years. Hence, the predicted numbers of crashes in the crash period are simply double the predicted average crash frequency. That is:

- All fatal-and-injury crashes: \( N_{p, aS, ac, at, fi}^* = 25.958 \) crashes/year
- All property-damage-only crashes: \( N_{p, aS, ac, at, pdo}^* = 63.302 \) crashes/year

The observed crash counts were given as 30 fatal-and-injury crashes and 50 property-damage-only crashes in the years 2009 and 2010. That is:

- \( N_{o, aS, ac, at, fi} = 30 \) crashes/year
- \( N_{o, aS, ac, at, pdo} = 50 \) crashes/year

**Step 2—Compute the variance of the predicted average crash frequency.**

Two variance estimates are computed in this step. One estimate is based on the assumption that the sites are independent and the other estimate is based on the assumption that the sites are perfectly correlated. Equation A-11 and Equation A-12 are used for these computations. The overdispersion parameters \( k_{fs, 6, mv, fi} \) and \( k_{fs, 6, rv, fi} \) were computed in Sample Problem 5 as 0.076 and 0.044, respectively. The two variance estimates for fatal-and-injury crashes are computed as follows.

Assuming independence:

\[
V_{0, fs, ac, at, fi} = \sum_i \sum_k \left( k_{fs, 6, at, fi} \right)^2 \left( \sum_j N_{p, fs, 6, at, fi} \right) \]

\[
= 0.076 \times (2 \times 3.911)^2 + 0.044 \times (2 \times 2.060)^2 + 0.076 \times (2 \times 4.150)^2 + 0.044 \times (2 \times 2.858)^2 \\
= 12.053
\]

Assuming perfect correlation:

\[
V_{1, fs, ac, at, fi} = \left( \sum_i \sum_k \sqrt{ k_{fs, 6, at, fi} } \times \left[ \sum_j N_{p, fs, 6, at, fi} \right] \right)^2 \\
= \left( \sqrt{0.076 \times (2 \times 3.911)^2} + \sqrt{0.044 \times (2 \times 2.060)^2} + \sqrt{0.076 \times (2 \times 4.150)^2} + \sqrt{0.044 \times (2 \times 2.858)^2} \right)^2 \\
= \left( \sqrt{0.076 \times (2 \times 3.911)^2} + \sqrt{0.044 \times (2 \times 2.060)^2} + \sqrt{0.076 \times (2 \times 4.150)^2} + \sqrt{0.044 \times (2 \times 2.858)^2} \right)^2 \\
= 42.346
\]

Similar calculations using the property-damage-only crash frequencies and counts yield the following results.

Assuming independence:

\[
V_{0, fs, ac, at, pdo} = 74.858
\]
Assuming perfect correlation:

\[ V_{1, \text{fs,ac,at}, \text{pdo}} = 274.531 \]

**Step 3—Compute the weighted adjustment factor.**

Two weighted adjustment factors are computed in this step. One estimate is based on the assumption that the sites are independent and the other estimate is based on the assumption that the sites are perfectly correlated. Equation \( A-13 \) and Equation \( A-14 \) are used for these computations. The two weighted adjustment factor estimates for fatal-and-injury crashes are computed as follows.

Assuming independence:

\[
\begin{align*}
  w_{0, \text{fs,ac,at}, \text{fi}} &= \frac{1.0}{1.0 + \frac{V_{0, \text{fs,ac,at}, \text{fi}}}{N^p_{\text{fs,ac,at}, \text{fi}}}} \\
  &= \frac{1.0}{1.0 + \frac{12.053}{25.958}} \\
  &= 0.683
\end{align*}
\]

Assuming perfect correlation:

\[
\begin{align*}
  w_{1, \text{fs,ac,at}, \text{fi}} &= \frac{1.0}{1.0 + \frac{V_{1, \text{fs,ac,at}, \text{fi}}}{N^p_{\text{fs,ac,at}, \text{fi}}}} \\
  &= \frac{1.0}{1.0 + \frac{42.346}{25.958}} \\
  &= 0.380
\end{align*}
\]

Similar calculations using the property-damage-only variances yield the following results.

Assuming independence:

\[ w_{0, \text{fs,ac,at}, \text{pdo}} = 0.458 \]

Assuming perfect correlation:

\[ w_{1, \text{fs,ac,at}, \text{pdo}} = 0.187 \]

**Step 4—Compute the equivalent years in the crash period.**

The crash period is two years, and the same AADT volumes were used for the two years. Hence, the number of equivalent years in the crash period is 2.000.

**Step 5—Compute the expected average crash frequency.**

The expected average fatal-and-injury crash frequency for the reference year (2009) is computed as follows.

Assuming independence:
\[ N_{0, \text{fs, ac, at, fi, r}} = w_{0, \text{fs, ac, at, fi}} \times N_{p, \text{fs, ac, at, fi, r}} + \left(1.0 - w_{0, \text{fs, ac, at, fi}}\right) \times \frac{N^*_{0, \text{fs, ac, at, fi, r}}}{C_{b, \text{fs, ac, at, fi, r}}} \]
\[ = 0.683 \times 12.979 + \left(1.0 - 0.683\right) \times \frac{30}{2} \]
\[ = 13.619 \text{ crashes/year} \]

Assuming perfect correlation:

\[ N_{1, \text{fs, ac, at, fi, r}} = w_{1, \text{fs, ac, at, fi}} \times N_{p, \text{fs, ac, at, fi, r}} + \left(1.0 - w_{1, \text{fs, ac, at, fi}}\right) \times \frac{N^*_{0, \text{fs, ac, at, fi, r}}}{C_{b, \text{fs, ac, at, fi, r}}} \]
\[ = 0.380 \times 12.979 + \left(1.0 - 0.380\right) \times \frac{30}{2} \]
\[ = 14.232 \text{ crashes/year} \]

Expected average fatal-and-injury crash frequency:

\[ N_{e, \text{fs, ac, at, fi, r}} = \frac{N_{0, \text{fs, ac, at, fi, r}} + N_{1, \text{fs, ac, at, fi, r}}}{2} \]
\[ = \frac{13.619 + 14.232}{2} \]
\[ = 13.926 \text{ crashes/year} \]

Similar calculations yield the expected average property-damage-only crash frequency:

\[ N_{e, \text{fs, ac, at, pdo, r}} = 27.147 \text{ crashes/year} \]

Worksheets
To apply the project-level EB Method to multiple freeway segments and speed-change lanes on a freeway combined, two worksheets are provided for determining the expected average crash frequency. The two worksheets include:

- Table 13-50. Project-Level EB Method Worksheet (1 of 2)—Sample Problem 6
- Table 13-51. Project-Level EB Method Worksheet (2 of 2)—Sample Problem 6

Filled versions of these worksheets are provided below for fatal-and-injury crashes. The same worksheets would be used for property-damage-only crashes, but are not shown. Blank versions of worksheets used in the Sample Problems are provided in Chapter 13 Appendix A.

Table 13-50 is a summary of the predicted average crash frequencies for segments 1 and 2 that were obtained in Sample Problems 1 and 2. It also contains calculations of the variances of the predicted average crash frequencies.

Table 13-51 is a summary of the expected average crash frequency calculations. These calculations involve applying weights to the predicted average crash frequencies (based on their variances) and their observed crash counts to obtain a refined estimate of expected average crash frequency.
### Table 13-50. Project-Level EB Method Worksheet (1 of 2)—Sample Problem 6

<table>
<thead>
<tr>
<th>Calculations by Site</th>
<th>Crash severity category addressed (z)</th>
<th>X</th>
<th>FI</th>
<th>PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Site Summary</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Overdispersion Parameter</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Multiple-vehicle crashes ( k_{w, x, mv, z} )</td>
<td>0.076</td>
<td>0.076</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) Single-vehicle crashes ( k_{w, x, sv, z} )</td>
<td>0.044</td>
<td>0.044</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) All crash types ( k_{w, x, at, z} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Predicted Number of Crashes during the Crash Period**

| (4) Multiple-vehicle crashes \( N_{p, w, x, mv, z} (cr) \) | 7.8 | 8.3 | 16.1 |
| (5) Single-vehicle crashes \( N_{p, w, x, sv, z} (cr) \) | 4.1 | 5.7 | 9.8  |
| (6) All crash types \( N_{p, w, x, at, z} (cr) \) |                          |

Predicted number of crashes \( N_{p, aS, ac, at, z} (cr) \) = (4) + (5) + (6) = 26.0

**Predicted Average Crash Frequency for Reference Year**

| (7) Multiple-vehicle crashes \( N_{p, w, x, mv, z, r} (cr/yr) \) | 3.9 | 4.2 | 8.1  |
| (8) Single-vehicle crashes \( N_{p, w, x, sv, z, r} (cr/yr) \) | 2.1 | 2.9 | 4.9  |
| (9) All crash types \( N_{p, w, x, at, z, r} (cr/yr) \) |                          |

Predicted freq. for reference year \( N_{p, aS, ac, at, z, r} (cr/yr) \) = (7) + (8) + (9) = 13.0

**Predicted Average Crash Frequency for Study Year**

| (10) Multiple-vehicle crashes \( N_{p, w, x, mv, z, s} (cr/yr) \) | 3.9 | 4.2 | 8.1  |
| (11) Single-vehicle crashes \( N_{p, w, x, sv, z, s} (cr/yr) \) | 2.1 | 2.9 | 4.9  |
| (12) All crash types \( N_{p, w, x, at, z, s} (cr/yr) \) |                          |

Predicted freq. for study year \( N_{p, aS, ac, at, z, s} (cr/yr) \) = (10) + (11) + (12) = 13.0

**Variance of Predicted Average Crash Frequency**

| (13) Multiple-vehicle product \( = (1) \times (4)^2 \) | 4.7 | 5.2 |
| (14) Single-vehicle product \( = (2) \times (5)^2 \) | 0.7 | 1.4 |
| (15) All crash types \( = (3) \times (6)^2 \) |                          |

\[ \text{Variance if independent } V_{0, aS, ac, at, z} = (13) + (14) + (15) = 12.1 \]

| (16) Multiple-vehicle product \( = (1)^{0.5} \times (4) \) | 2.15 | 2.29 |
| (17) Single-vehicle product \( = (2)^{0.5} \times (5) \) | 0.86 | 1.20 |
| (18) All crash types \( = (3)^{0.5} \times (6) \) |                          |

\[ \text{Variance if correlated } V_{1, aS, ac, at, z} = [(16) + (17) + (18)]^2 = 42.3 \]

**Notes:**

a. Site numbering convention: \( X, y \). \( X \): site type; \( F = \) freeway segment, \( R = \) ramp segment, \( C = \) C-D road segment, \( T = \) crossroad ramp terminal. \( y \): site number; 1, 2, 3, ...
b. Use additional sheets if there are more than nine sites in the project limits.
c. Use the “multiple-vehicle” and “single-vehicle” rows for segments. Use the “all crash types” rows for speed-change lanes and crossroad ramp terminals.
Table 13-51. Project-Level EB Method Worksheet (2 of 2)—Sample Problem 6

<table>
<thead>
<tr>
<th>Calculations for Project</th>
<th>Crash Period</th>
<th>Study Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed crash count during the crash period</td>
<td>30</td>
<td>Include crashes of all types at all sites during the crash period.</td>
</tr>
<tr>
<td>Reference year r</td>
<td>2009</td>
<td>Choose the first year of the crash period.</td>
</tr>
<tr>
<td>Predicted average crash freq. for reference year</td>
<td>12.979</td>
<td></td>
</tr>
<tr>
<td>Predicted number of crashes for crash period (sum all years)</td>
<td>25.958</td>
<td></td>
</tr>
<tr>
<td>Equivalent years associated with crash count</td>
<td>2.000</td>
<td>$N^<em>_{p, aS, ac, at, z, r} = \frac{N^</em><em>{p, aS, ac, at, z}}{C</em>{b, aS, ac, at, z, r}}$</td>
</tr>
<tr>
<td>Independent Sites Crash Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variance if independent $V_{0, aS, ac, at, z}$</td>
<td>12.053</td>
<td></td>
</tr>
<tr>
<td>Weight associated with $N_{p, aS, ac, at, z}$</td>
<td>0.683</td>
<td>$w_{0, aS, ac, at, z} = 1.0 / (1.0 + \frac{V_{0, aS, ac, at, z}}{N^*_{p, aS, ac, at, z, r}})$</td>
</tr>
<tr>
<td>Adjusted average crash freq. for reference year given $N^*_{ac}$</td>
<td>13.619</td>
<td>$w_{0, aS, ac, at, z} \times N^<em><em>{p, aS, ac, at, z, r} + (1.0 - w</em>{0, aS, ac, at, z}) \times N^</em>_{ac, aS, ac, at, z, r}$</td>
</tr>
<tr>
<td>Correlated Sites Crash Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variance if correlated $V_{1, aS, ac, at, z}$</td>
<td>42.346</td>
<td></td>
</tr>
<tr>
<td>Weight associated with $N_{p, aS, ac, at, z}$</td>
<td>0.380</td>
<td>$w_{1, aS, ac, at, z} = 1.0 / (1.0 + \frac{V_{1, aS, ac, at, z}}{N^*_{p, aS, ac, at, z, r}})$</td>
</tr>
<tr>
<td>Adjusted average crash freq. for reference year given $N^*_{ac}$</td>
<td>14.232</td>
<td>$w_{1, aS, ac, at, z} \times N^<em><em>{p, aS, ac, at, z, r} + (1.0 - w</em>{1, aS, ac, at, z}) \times N^</em>_{ac, aS, ac, at, z, r}$</td>
</tr>
<tr>
<td>Expected Average Crash Frequency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted average crash freq. for reference year given $N^*_{ac}$</td>
<td>13.926</td>
<td>$(N^<em>_{0, aS, ac, at, z, r} + N^</em>_{1, aS, ac, at, z, r}) / 2.0$</td>
</tr>
<tr>
<td>Study year s</td>
<td>2011</td>
<td></td>
</tr>
<tr>
<td>Predicted average crash freq. for study year</td>
<td>12.979</td>
<td></td>
</tr>
<tr>
<td>Expected average crash freq. for study year</td>
<td>13.926</td>
<td>$N_{p, aS, ac, at, z} \times N^*_{p, aS, ac, at, z, r}$</td>
</tr>
</tbody>
</table>

13.14. REFERENCES


APPENDIX 13A—WORKSHEETS FOR PREDICTIVE METHOD FOR FREEWAYS
[Section to be completed after method is reviewed and approved.]
APPENDIX D

DRAFT HSM RAMPS CHAPTER
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Chapter 14—Predictive Method for Ramps

14.1. INTRODUCTION
This chapter presents the predictive method for ramps, as used to connect two or more highway legs at an interchange. The method is also applicable to collector-distributor (C-D) roadways that connect with ramps and one or more highway legs 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, or by crash type or 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 Chapter 14 is documented in 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.
- 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.
- Sample problems illustrating the application of the predictive method.

14.2. OVERVIEW OF THE PREDICTIVE METHOD
The predictive method provides an 18-step procedure to estimate the expected average crash frequency (in total, or by crash type or severity) for an entire ramp or C-D road. An “entire ramp” is the roadway between the freeway speed-change lane and either the crossroad ramp terminal or the crossroad speed-change lane. An “entire C-D road” is the roadway between the freeway ramp exit speed-change lane and the freeway ramp.
entrance speed-change lane. 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 can also be used to estimate the crash frequency for an individual 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 at an interchange. The interchange may connect a freeway and a crossroad (service interchanges) or two freeways (system interchanges). 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 time period of interest.

The predictive models used within the Chapter 14 predictive method are described in detail in Section 14.3. The predicted average crash frequency from a predictive model can be used as an estimate of the expected average crash frequency, or it can be combined with observed crash data (using the empirical Bayes [EB] Method) to obtain a more reliable estimate of the expected average crash frequency.

The predictive models used in Chapter 14 to determine the predicted average crash frequency are of the general form shown in Equation 14-1.

\[
N_{p,w,x,y,z} = N_{spf,w,x,y,z} \times \left( CMF_{1,w,x,y,z} \times CMF_{2,w,x,y,z} \times \ldots \times CMF_{m,w,x,y,z} \right) \times C_{w,x,y,z}
\]

Equation 14-1

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 features \(m\); 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, or by crash type or 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 ten 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.

**14.3. RAMPS—DEFINITIONS AND PREDICTIVE MODELS**

This section provides the definitions of the site types included in Chapter 14. It also provides the predictive models for each of the site types.
14.3.1. Definition of Ramp Site Types

The predictive method in Chapter 14 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 14-1.

a. Three-Leg Ramp Terminal With Diagonal Exit or Entrance Ramp ($D3_{ex}$ and $D3_{en}$)

b. Four-Leg Ramp Terminal With Diagonal Ramps ($D4$)

c. Four-Leg Ramp Terminal at Four-Quadrant Parclo A ($A4$)

Figure 14-1. Ramp Terminal Configurations
d. Four-Leg Ramp Terminal at Four-Quadrant Parclo B (B4)

Figure 14-1. Ramp Terminal Configurations continued

Differences among the terminals shown Figure 14-1 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.

The terms “highway,” “roadway,” and “road” are used interchangeably in this chapter and apply to all freeways and crossroads independent of official state or local highway designation.
Classifying an area as urban, suburban, or rural is subject to the roadway characteristics, surrounding population, and 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 14-1 identifies the ramp and C-D road segment site types for which SPFs have been developed. These SPFs are used to estimate the predicted average crash frequency by crash type (i.e., multiple-vehicle, single-vehicle) and crash severity (i.e., fatal-and-injury, property-damage-only). These estimates are added to yield the total predicted average crash frequency for an individual site.

<table>
<thead>
<tr>
<th>Site Type (w)</th>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>SPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp segments (rps)</td>
<td>One-lane entrance ramp (1EN)</td>
<td>Multiple vehicle (mv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{yfg, rps, 1EN, mv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{yfg, rps, 1EN, mv, pdo}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single vehicle (sv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{yfg, rps, 1EN, sv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{yfg, rps, 1EN, sv, pdo}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two-lane entrance ramp (2EN) (urban areas only)</td>
<td>Multiple vehicle (mv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{yfg, rps, 2EN, mv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{yfg, rps, 2EN, mv, pdo}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single vehicle (sv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{yfg, rps, 2EN, sv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{yfg, rps, 2EN, sv, pdo}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>One-lane exit ramp (1EX)</td>
<td>Multiple vehicle (mv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{yfg, rps, 1EX, mv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{yfg, rps, 1EX, mv, pdo}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single vehicle (sv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{yfg, rps, 1EX, sv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{yfg, rps, 1EX, sv, pdo}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two-lane exit ramp (2EX) (urban areas only)</td>
<td>Multiple vehicle (mv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{yfg, rps, 2EX, mv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{yfg, rps, 2EX, mv, pdo}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single vehicle (sv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{yfg, rps, 2EX, sv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{yfg, rps, 2EX, sv, pdo}$</td>
<td></td>
</tr>
<tr>
<td>C-D road segments (cds)</td>
<td>One-lane C-D road (1)</td>
<td>Multiple vehicle (mv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{yfg, cds, 1, mv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{yfg, cds, 1, mv, pdo}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single vehicle (sv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{yfg, cds, 1, sv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{yfg, cds, 1, sv, pdo}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two-lane C-D road (2) (urban areas only)</td>
<td>Multiple vehicle (mv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{yfg, cds, 2, mv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{yfg, cds, 2, mv, pdo}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single vehicle (sv)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{yfg, cds, 2, sv, fi}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{yfg, cds, 2, sv, pdo}$</td>
<td></td>
</tr>
</tbody>
</table>
The ramp segment and C-D road segment are defined as follows:

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

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

Table 14-2 identifies the crossroad ramp terminal site types for which SPFs have been developed. These SPFs are used to estimate the predicted average crash frequency by crash severity (i.e., fatal-and-injury, property-damage-only). These estimates are added to yield the total predicted average crash frequency for an individual site.

### Table 14-2. Crossroad Ramp Terminal SPFs

<table>
<thead>
<tr>
<th>Site Type (w)</th>
<th>Cross Section and Control Type (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>SPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-leg terminals with diagonal exit ramp (D3ex),</td>
<td>One-way stop control;</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, w, ST, at, fi}$</td>
</tr>
<tr>
<td>Three-leg terminals with diagonal entrance ramp (D3en),</td>
<td>2, 3, or 4 lane crossroad (ST)</td>
<td></td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, w, ST, at, pdo}$</td>
</tr>
<tr>
<td>Four-leg terminals with diagonal ramps (D4),</td>
<td>Signal control, 2-lane crossroad (SG2)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, w, SG2, at, fi}$</td>
</tr>
<tr>
<td>Four-leg terminals at four-quadrant parclo A (A4),</td>
<td>Signal control, 3-lane crossroad (SG3)</td>
<td>All types (at)</td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, w, SG3, at, pdo}$</td>
</tr>
<tr>
<td>Four-leg terminals at four-quadrant parclo B (B4),</td>
<td>Signal control, 4-lane crossroad (SG4)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, w, SG4, at, fi}$</td>
</tr>
<tr>
<td>Three-leg terminals at two-quadrant parclo A (A2),</td>
<td>Signal control, 5-lane crossroad (SG5) (urban areas only)</td>
<td>All types (at)</td>
<td>Property damage only (pdo)</td>
<td>$N_{spf, w, SG5, at, pdo}$</td>
</tr>
<tr>
<td>Three-leg terminals at two-quadrant parclo B (B2),</td>
<td>Signal control, 6-lane crossroad (SG6) (urban areas only)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>$N_{spf, w, SG6, at, pdo}$</td>
</tr>
</tbody>
</table>

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 14-1. 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.

### 14.3.2. 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, or by crash type or 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 on 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 14-2 through Equation 14-6.

\[
N_{p, rps, nEN, at, as} = \frac{N_{p, rps, nEN, mv, fi} + N_{p, rps, nEN, sv, fi}}{N_{p, rps, nEN, mv} + N_{p, rps, nEN, sv}} + \frac{N_{p, rps, nEN, sv, pdo} + N_{p, rps, nEN, sv, pdo}}{N_{p, rps, nEN, sv}}
\]

**Equation 14-2**

\[
N_{p, rps, nEN, mv, fi} = C_{rps, EN, mv, fi} \times \frac{N_{spf, rps, nEN, mv, fi}}{N_{spf, rps, nEN}} \times \left( \prod_{i=1}^{m} CMF_{1, rps, ac, mv, fi} \times \prod_{i=m+1}^{n} CMF_{m, rps, ac, mv, fi} \right)
\]

**Equation 14-3**

\[
N_{p, rps, nEN, sv, fi} = C_{rps, EN, sv, fi} \times \frac{N_{spf, rps, nEN, sv, fi}}{N_{spf, rps, nEN}} \times \left( \prod_{i=1}^{m} CMF_{1, rps, ac, sv, fi} \times \prod_{i=m+1}^{n} CMF_{m, rps, ac, sv, fi} \right)
\]

**Equation 14-4**

\[
N_{p, rps, nEN, mv, pdo} = C_{rps, EN, mv, pdo} \times \frac{N_{spf, rps, nEN, mv, pdo}}{N_{spf, rps, nEN}} \times \left( \prod_{i=1}^{m} CMF_{1, rps, ac, mv, pdo} \times \prod_{i=m+1}^{n} CMF_{m, rps, ac, mv, pdo} \right)
\]

**Equation 14-5**

\[
N_{p, rps, nEN, sv, pdo} = C_{rps, EN, sv, pdo} \times \frac{N_{spf, rps, nEN, sv, pdo}}{N_{spf, rps, nEN}} \times \left( \prod_{i=1}^{m} CMF_{1, rps, ac, sv, pdo} \times \prod_{i=m+1}^{n} CMF_{m, rps, ac, sv, pdo} \right)
\]

**Equation 14-6**

Where:

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

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

\[
CMF_{m, rps, ac, y, z} = \text{crash modification factor for a ramp segment with any number of lanes } ac, \text{ features } m, \text{ crash type } y (y = sv: \text{single vehicle}, mv: \text{multiple vehicle}, at: \text{all types}), \text{ and severity } z (z = fi: \text{fatal and injury}, pdo: \text{property damage only}); \text{ and}
\]

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

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 14-2 to Equation 14-6.

Equation 14-2 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 14-3 to Equation 14-6. The first terms in parentheses in each equation recognizes that the influence of some geometric factors is unique to each crash type. In contrast, the second term in parentheses in these equations recognizes that some geometric features have a similar influence on all crash types. All CMFs are unique to crash severity.

Equation 14-3 and Equation 14-4 are used to estimate the fatal-and-injury crash frequency. Equation 14-5 and Equation 14-6 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 14-7 through Equation 14-11.

\[
N_{p, \text{cds}, n, \text{at}, as} = N_{p, \text{cds}, n, \text{mv}, fi} + N_{p, \text{cds}, n, sv, fi} + N_{p, \text{cds}, n, mv, pdo} + N_{p, \text{cds}, n, sv, pdo}
\]

Equation 14-7

\[
N_{p, \text{cds}, n, \text{mv}, fi} = C_{\text{cds}, \text{ac}, \text{mv}, fi} \times N_{\text{spf}, \text{cds}, n, \text{mv}, fi} \times \left( CMF_{1, \text{cds}, \text{ac}, \text{mv}, fi} \times \ldots \times CMF_{m, \text{cds}, \text{ac}, \text{mv}, fi} \right)
\]

Equation 14-8

\[
N_{p, \text{cds}, n, sv, fi} = C_{\text{cds}, \text{ac}, \text{sv}, fi} \times N_{\text{spf}, \text{cds}, n, sv, fi} \times \left( CMF_{1, \text{cds}, \text{ac}, \text{sv}, fi} \times \ldots \times CMF_{m, \text{cds}, \text{ac}, \text{sv}, fi} \right)
\]

Equation 14-9

\[
N_{p, \text{cds}, n, sv, pdo} = C_{\text{cds}, \text{ac}, \text{sv}, pdo} \times N_{\text{spf}, \text{cds}, n, sv, pdo} \times \left( CMF_{1, \text{cds}, \text{ac}, \text{sv}, pdo} \times \ldots \times CMF_{m, \text{cds}, \text{ac}, \text{sv}, pdo} \right)
\]

Equation 14-10

\[
N_{p, \text{cds}, n, sv, pdo} = C_{\text{cds}, \text{ac}, \text{sv}, pdo} \times N_{\text{spf}, \text{cds}, n, sv, pdo} \times \left( CMF_{1, \text{cds}, \text{ac}, \text{sv}, pdo} \times \ldots \times CMF_{m, \text{cds}, \text{ac}, \text{sv}, pdo} \right)
\]

Equation 14-11

Where:

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

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

- \( CMF_{m, \text{cds}, \text{ac}, y, z} \) = crash modification factor for a C-D road segment with any number of lanes \( ac \), features \( m \), crash type \( y \) (\( y = \text{sv}: \) single vehicle, \( \text{mv}: \) multiple vehicle, \( \text{at}: \) all types), and severity \( z \) (\( z = \text{fi}: \) fatal and injury, \( pdo: \) property damage only); and

- \( C_{\text{cds}, \text{ac}, y, z} \) = calibration factor for C-D road segments with crash type \( y \) (\( y = \text{sv}: \) single vehicle, \( \text{mv}: \) multiple vehicle, \( \text{at}: \) all types), and severity \( z \) (\( z = \text{fi}: \) 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 14.6.1. The associated CMFs are presented in Section 14.7.1. Similarly, the associated SDFs are presented in Section 14.8.1. A procedure for establishing the value of the calibration factor is described in Appendix A of Part C.

### 14.3.3. 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 14-12 to Equation 14-14.

\[
N_{p, w, ST, at, as} = N_{p, w, ST, at, fi} + N_{p, w, ST, at, pdo}
\]  
Equation 14-12

\[
N_{p, w, ST, at, fi} = C_{aS, ST, at, fi} \times N_{spf, w, ST, at, fi} \times (CMF_{1, aS, ST, at, fi} \times \ldots \times CMF_{m, aS, ST, at, fi})
\]  
Equation 14-13

\[
N_{p, w, ST, at, pdo} = C_{aS, ST, at, pdo} \times N_{spf, w, ST, at, pdo} \times (CMF_{1, aS, ST, at, pdo} \times \ldots \times CMF_{m, aS, ST, at, pdo})
\]  
Equation 14-14

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);

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

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

\(C_{aS, ST, at, z}\) = 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).

The seven site types (i.e., \(D3ex, D3en, D4, A4, B4, A2, B2\)) are shown in Figure 14-1.

Equation 14-12 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 14-13 and Equation 14-14. The term in parentheses in each equation recognizes that the influence of some geometric features is unique to 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 14-15 to Equation 14-17.

\[
N_{p, w, SGn, at, as} = N_{p, w, SGn, at, fi} + N_{p, w, SGn, at, pdo}
\]  
Equation 14-15
Where:

\[ N_{p, w, SGn, at, z} = C_{aS, SG, at, z} \times N_{spf, w, SGn, at, z} \times (CMF_{1, aS, SGn, at, z} \times \ldots \times CMF_{m, aS, SGn, at, z}) \]  
Equation 14-16

\[ N_{p, w, SGn, at, pdo} = C_{aS, SG, at, pdo} \times N_{spf, w, SGn, at, pdo} \times (CMF_{1, aS, SGn, at, pdo} \times \ldots \times CMF_{m, aS, SGn, at, pdo}) \]  
Equation 14-17

14.4. 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.

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

The predictive method for ramps is shown in Figure 14-2. Applying the predictive method yields an estimate of the expected average crash frequency (in total, or by crash type or severity) for an entire ramp or C-D road. The components of the predictive models in Chapter 14 are determined and applied in Steps 9, 10, and 11 of the predictive method. The information to apply each step is provided in the following sections and in Part C, Appendix A.

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

The following discussion explains the details of each step of the method as applied to ramps.
Define roadway limits and facility type.

Define the period of study.

Determine AADT and availability of crash data for every year in the period of interest.

Determine geometric conditions.

Divide ramp or C-D road into individual segments and crossroad ramp terminals.

Assign observed crashes to individual sites (if applicable).

Select a segment or crossroad ramp terminal.

Select first or next year of the evaluation period.

Select and apply SPF.

Apply CMFs.

Apply a calibration factor.

Is there another year?

Apply site-specific EB method (if applicable) and apply SDF.

Is there another site?

Apply project-level EB method (if applicable).

Sum all sites and years.

Is there an alternative design, treatment, or forecast AADT to be evaluated?

Compare and evaluate results.

Figure 14-2. The HSM Predictive Method
Step 1—Define the limits of the project for which the expected average crash frequency, severity, and crash types are to be estimated.
A project can be all of the ramps and C-D roads at 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 14.3.

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 at an interchange. If comparing design alternatives, the project limits should be the same for all alternatives.

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 (based on observed AADT volumes) 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 features or traffic control features are proposed (for near-term conditions).

- A future period (based on forecast AADT volumes) 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 for implementation in the future.
  - A new ramp or C-D road that does not currently exist but is proposed for construction during some future period.
Step 3—For the study period, determine the availability of annual average daily traffic volumes and, for an existing 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 reported crash data are also acquired in this step.

Determining Traffic Volumes

The SPF values used in Step 9 (and some CMFs in Step 10) include 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 the evaluation of one or more ramp segments. The AADT volume of the C-D road is needed for the evaluation of one or more C-D road segments.

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 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 in which no data are available.

- 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 alternative conditions 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 A.2.1 in Appendix A to Part C.

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 A.2.2 in Appendix A to Part C.

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 SPF's 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 14.4.2.

Step 5—Divide the roadway into individual homogeneous ramp segments and ramp terminals, which are referred to as 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 14.5.

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 using the criteria outlined in the next paragraph. Specific criteria for assigning crashes to individual ramp segments or crossroad ramp terminals are presented in Section A.2.3 in Appendix A to Part C.

Crashes that occur near a crossroad ramp terminal, and are related to the presence of a crossroad ramp terminal, are assigned to the terminal. Crashes that occur on a ramp or between crossroad ramp terminals, and are not related to the presence of a crossroad ramp terminal, are assigned to the roadway segment on which they occur.

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 study limits identified in Step 1.

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

Step 8—For the selected site, select the first or next year in the period of interest. If there are no more years to be evaluated for that site, proceed to Step 14.
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 SPF's 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 safety performance function (SPF) for the site type and features.
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 14.6.

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 to adjust base conditions to site-specific geometric design and traffic control features.
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 14.7.

All CMFs in Chapter 14 have the same base conditions as the SPFs used in Chapter 14. Only the CMFs presented in Section 14.7 may be used as part of the Chapter 14 predictive method.

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 Chapter 14 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 Part C, Appendix A.1.1.

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 14.
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 Part C, Appendix A.2.4.

The decision to apply the site-specific EB Method was determined in Step 3. If the EB Method is not used, then the 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 SPF 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 A.2.6 in Appendix A to Part C 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 14.8. 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 Part C, Appendix A.1.4.

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 14.6. 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 ramp segment, C-D road segment, or crossroad ramp terminal 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 Part C, Appendix A.2.5.

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 SPF 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 14-18:

\[
N^*_{e,aS,ac,at,as} = \sum_{j=1}^{n_s} \left( \sum_{i=1}^{all\ sites} N_{e,rps(i),ac,at,as,j} + \sum_{i=1}^{all\ sites} N_{e,cds(i),ac,at,as,j} + \sum_{i=1}^{all\ sites} N_{e,w(i),ac,at,as,j} \right)
\]

**Equation 14-18**

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 crash types \(at\) and all severities \(as\)) (crashes);
- \(N_{e,rps(i),ac,at,as,j}\) = total 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);
- \(N_{e,cds(i),ac,at,as,j}\) = total 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);
- \(N_{e,w(i),ac,at,as,j}\) = total 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); and
- \(n_s\) = number of years in the study period (yr).

Equation 14-18 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 14-19 is used to estimate the total expected average crash frequency within the project limits during the study period.

\[
N_{e,aS,ac,at,as} = \frac{N^*_{e,aS,ac,at,as}}{n_s}
\]

**Equation 14-19**

Where:

- \(N_{e,aS,ac,at,as}\) = total expected average crash frequency for all sites \(aS\) and all years in the study period (includes all crash types \(at\) and all severities \(as\)) (crashes/yr).
Step 17—Determine if there is an alternative design, treatment, or forecast AADT to be evaluated.
Steps 3 through 17 are repeated as appropriate for the same project limits but for alternative conditions, treatments, periods of interest, or forecast AADT volumes.

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

14.4.2. 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. The data are needed for each site selected for evaluation.

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 the following list in terms of the values or descriptors needed by the predictive model variables.

- Number of through lanes. The total number of through lanes at the beginning of the segment (in the direction of travel). 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) by taper is considered to have the same number of through lanes as the segment just downstream of the lane add (or lane drop) taper.

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

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

- Do not include in this number 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 14-3 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 14-3. Number-of-Lanes Determination 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 curve 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 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. This length is measured along the right edge of traveled way. If the curve is continued from a curve on an intersecting alignment, then consider only the curve length on the subject alignment.
    - Curve length is measured from the point where the tangent ends and the curve begins (i.e., the PC) to the point where the curve ends and the tangent begins (PT).
    - If the curve 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 mileposts, 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.
  - Radius of curve. The radius is measured to the right edge of traveled way. If the curve has spiral transitions, then enter 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.
  - Milepost of beginning of curve in direction of travel. Measure to the point where the tangent ends and the curve begins. Milepost locations are measured along the right edge of the ramp through lane 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 mileposts are established for this application, and may or may not coincide with the mileposts (or stations) established for the ramp’s design.
    - If the 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 mileposts, 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.
For exit ramps, C-D roads, and entrance ramps that diverge from the crossroad using a speed-change lane, milepost 0.0 is referenced to the gore point. The gore point is defined as the point in the gore area where the distance between the near edge of the freeway (or crossroad) traveled way and the ramp traveled way is 2.0 ft. This point is shown in Figure 14-4.

For entrance ramps that intersect the crossroad, milepost 0.0 is located at the point where the ramp reference line intersects with the near edge of traveled way of the crossroad. The ramp reference line is defined as the right edge of the ramp traveled way. This point is shown in Figure 14-4.

If there is a choice of two or more points at which milepost 0.0 could be established for a ramp and it is not clearly established by the guidance in the two previous bullets, then choose the one point that is associated with the highest entering ramp volume.

**Exit Ramp, C-D Road, Entrance Ramp with Speed-Change Lane**

**Entrance Ramp with Intersection**

**Figure 14-4.** Starting Milepost 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 14-4. They should not be measured where one or more edges are discontinuous or tapered. If a width varies continuously along the segment, then enter a length-weighted average width. Shoulder width represents 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, and it is referenced to the nearest edge of traveled way.

- Figure 14-5 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 14-5. 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 14-4.

![Figure 14-5. Barrier Variables](image)

- 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 begin and end 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 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. It is shown in Figure 14-6.

  - 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.

  - 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). It is shown in Figure 14-6.
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:

- This length is measured between the segment’s begin and end points. This length cannot exceed the length of the segment. This length cannot exceed the taper length.

- Taper 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 14-7. 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.

- Length of weaving section located *in the segment*, between the segment’s begin and end points. This length cannot exceed the length of the segment. This length cannot exceed the length of the weaving section.

Segment AADT volume.
$L_{wev} = $ weaving section length

**Figure 14-7.** C-D Road Weaving Section Length

**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. Figure 14-8a and Figure 14-8b 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 14-8.** 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 14-8a 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 14-8c for the left-side ramps at a four-quadrant parclo 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 14-1), 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 14-1.
- Ramp terminal control mode (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 14.10 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 14-9. 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).
<table>
<thead>
<tr>
<th><strong>Skew angle</strong></th>
<th><strong>Intersection angle</strong></th>
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<tbody>
<tr>
<td>Reference angles to a left-turn vehicle at the stop line.</td>
<td></td>
</tr>
<tr>
<td>Reference angles to a right-turn vehicle at the stop line.</td>
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**Figure 14-9. 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 mode.** 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 mode than the left-turn movement. Modes considered include: free flow, merge, yield, stop, and signal (where free-flow and merge operation are recognized to represent “no control”). The free-flow mode is associated with an accepting (or auxiliary) lane on the crossroad for the right-turn movement. The merge mode 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). 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). 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.

- 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.

- 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.

14.5. RAMP SEGMENTS AND RAMP TERMINALS

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

14.5.1. 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 14-10. 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 $R_{en1}$, $R_{en2}$, $R_{ex1}$, and $R_{ex4}$. The C-D road segments are labeled $CD_1$ to $CD_3$. 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 14-10. 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.
14.5.2 Segmentation Process
The segmentation process produces a set of segments of varying length, each of which is homogeneous with respect to characteristics such as traffic volumes, 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 taper point if the lane is added or dropped by taper.
- Lane width. Begin segment if change in lane width exceeds ±0.5 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.
- Right shoulder width. Begin segment if change in right shoulder width exceeds ±1.0 ft.
- Left shoulder width. Begin segment if change in left shoulder width exceeds ±1.0 ft.

The presence of a horizontal curve does not necessarily define ramp or C-D road segment boundaries. Application of the “number of through lanes” criterion is shown in Figure 14-3.
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 milepost 0.0 in the lower half of Figure 14-4). 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 14-4.

There is no minimum segment length for application of the predictive models for ramps and C-D roads. When dividing entire ramps or C-D roads into smaller homogeneous segments, limiting the segment length to a minimum of 0.10 mi will minimize calculation efforts and not affect results.

14.5.3. 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 A.2.3 in Appendix A to Part C.

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.

14.6. 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 Chapter 14 are summarized in Table 14-3.

A detailed discussion of SPFs and their use in the HSM is presented in Chapter 3, Section 3.5.2 of Part C—Introduction and Applications Guidance, Section C.6.3.

Some highway 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 A.1.2 in Appendix A to Part C.

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 A.2 in Appendix A to Part C.
<table>
<thead>
<tr>
<th>Site Type ( (w) )</th>
<th>Cross Section and Control Type ( (x) )</th>
<th>Crash Type ( (y) )</th>
<th>SPF Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp segments ( (rps) )</td>
<td>All cross sections ( (ac) )</td>
<td>Multiple vehicle ( (mv) )</td>
<td>Equation 14-20</td>
</tr>
<tr>
<td>C-D road segments ( (cds) )</td>
<td>All cross sections ( (ac) )</td>
<td>Multiple vehicle ( (mv) )</td>
<td>Equation 14-22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single vehicle ( (sv) )</td>
<td>Equation 14-24</td>
</tr>
<tr>
<td>Three-leg terminals with diagonal exit ramp ( (D3ex) )</td>
<td>One-way stop control ( (ST) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-31</td>
</tr>
<tr>
<td></td>
<td>Signal control, ( n ) lanes ( (SGn) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-28</td>
</tr>
<tr>
<td>Three-leg terminals with diagonal entrance ramp ( (D3en) )</td>
<td>One-way stop control ( (ST) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-31</td>
</tr>
<tr>
<td></td>
<td>Signal control, ( n ) lanes ( (SGn) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-28</td>
</tr>
<tr>
<td>Four-leg terminals with diagonal ramps ( (D4) )</td>
<td>One-way stop control ( (ST) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-31</td>
</tr>
<tr>
<td></td>
<td>Signal control, ( n ) lanes ( (SGn) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-28</td>
</tr>
<tr>
<td>Four-leg terminals at four-quadrant parclo A ( (A4) )</td>
<td>One-way stop control ( (ST) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-31</td>
</tr>
<tr>
<td></td>
<td>Signal control, ( n ) lanes ( (SGn) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-28</td>
</tr>
<tr>
<td>Four-leg terminals at four-quadrant parclo B ( (B4) )</td>
<td>One-way stop control ( (ST) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-31</td>
</tr>
<tr>
<td></td>
<td>Signal control, ( n ) lanes ( (SGn) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-28</td>
</tr>
<tr>
<td>Four-leg terminals at two-quadrant parclo A ( (A2) )</td>
<td>One-way stop control ( (ST) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-31</td>
</tr>
<tr>
<td></td>
<td>Signal control, ( n ) lanes ( (SGn) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-28</td>
</tr>
<tr>
<td>Four-leg terminals at two-quadrant parclo B ( (B2) )</td>
<td>One-way stop control ( (ST) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-31</td>
</tr>
<tr>
<td></td>
<td>Signal control, ( n ) lanes ( (SGn) )</td>
<td>All types ( (at) )</td>
<td>Equation 14-28</td>
</tr>
</tbody>
</table>

### 14.6.1. 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 14-4. Application of the SPFs to sites with AADT volumes substantially outside these ranges may not provide reliable results.

<table>
<thead>
<tr>
<th>Area Type</th>
<th>Cross Section (Through Lanes) ( (x) )</th>
<th>Applicable AADT Volume Range (veh/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>1</td>
<td>0 to 7,000</td>
</tr>
<tr>
<td>Urban</td>
<td>1</td>
<td>0 to 18,000</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0 to 32,000</td>
</tr>
</tbody>
</table>

Other types of ramp and C-D road segments may be found at interchanges but are not addressed by the predictive model in Chapter 14.
Multiple-Vehicle Crashes on Ramp Segments
The base conditions for the SPFs for multiple-vehicle crashes on ramp segments are:

- Horizontal curve: Not present
- Lane width: 14 ft
- Right shoulder width: 8 ft
- Left shoulder width: 4 ft
- Right side barrier: Not present
- Left side barrier: Not present
- Lane add or drop: Not present
- Ramp speed-change lane: Not present

The SPFs for multiple-vehicle crashes on ramp segments is represented using the following equation.

\[
N_{\text{spf}, \text{rps}, x, \text{mv}, z} = L_r \times \exp(a + b \times \ln(c \times AADT_r) + d \times \ln(AADT_r))
\]

Equation 14-20

Where:

- \( N_{\text{spf}, \text{rps}, x, \text{mv}, z} \) = predicted average multiple-vehicle crash frequency of a ramp segment with base conditions, cross section \( x \) (\( x = \text{nEN} \): \( n \)-lane entrance ramp, \( nEX \): \( n \)-lane exit ramp), and severity \( z \) (\( z = \text{fi} \): fatal and injury, \( pdo \): property damage only) (crashes/yr);
- \( L_r \) = length of ramp segment (mi);
- \( AADT_r \) = annual average daily traffic volume of ramp segment (veh/day); and
- \( a, b, c, d \) = regression coefficients.

The SPF regression coefficients and inverse dispersion parameter are provided in Table 14-5. The SPFs are illustrated in Figure 14-11 and Figure 14-12.
### Table 14-5. SPF Coefficients for Multiple-Vehicle Crashes on Ramp Segments

<table>
<thead>
<tr>
<th>Crash Severity (z)</th>
<th>Area Type</th>
<th>Cross Section (x)</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter $K_{ps, x, mv, z}$ (mi⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Fatal and injury (fi)</td>
<td>Rural</td>
<td>One-lane entrance (1EN)</td>
<td>-5.226</td>
<td>0.524</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>One-lane exit (1EX)</td>
<td>-6.692</td>
<td>0.524</td>
</tr>
<tr>
<td>Urban</td>
<td>Rural</td>
<td>One-lane entrance (1EN)</td>
<td>-3.505</td>
<td>0.524</td>
</tr>
<tr>
<td>Urban</td>
<td>Rural</td>
<td>One-lane exit (1EX)</td>
<td>-4.971</td>
<td>0.524</td>
</tr>
<tr>
<td>Urban</td>
<td>Urban</td>
<td>One-lane entrance (1EN)</td>
<td>-3.819</td>
<td>1.256</td>
</tr>
<tr>
<td>Urban</td>
<td>Urban</td>
<td>One-lane exit (1EX)</td>
<td>-4.851</td>
<td>1.256</td>
</tr>
<tr>
<td>Urban</td>
<td>Urban</td>
<td>Two-lane entrance (2EN)</td>
<td>-3.023</td>
<td>0.524</td>
</tr>
<tr>
<td>Urban</td>
<td>Urban</td>
<td>Two-lane exit (2EX)</td>
<td>-4.489</td>
<td>0.524</td>
</tr>
</tbody>
</table>

#### Figures

**Figure 14-11.** Graphical Form of the SPFs for Multiple-Vehicle Crashes on Entrance Ramp Segments

- b. Property-Damage-Only Crash Frequency.
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 14-21.

\[
k_{\text{rps, } x, \text{mv, } z} = \frac{1}{K_{\text{rps, } x, \text{mv, } z} \times L_r}
\]

Equation 14-21

Where:

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

The crash frequency obtained from Equation 14-20 can be multiplied by the proportions in Table 14-6 to estimate the predicted average multiple-vehicle crash frequency by crash type category.

**Table 14-6.** Default Distribution of Multiple-Vehicle Crashes by Crash Type for Ramp and C-D Road Segments

<table>
<thead>
<tr>
<th>Area Type</th>
<th>Crash Type Category</th>
<th>Proportion of Crashes by Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fatal and Injury</td>
</tr>
<tr>
<td>Rural or urban</td>
<td>Head-on</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>Right-angle</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td>Rear-end</td>
<td>0.707</td>
</tr>
<tr>
<td></td>
<td>Sideswipe</td>
<td>0.129</td>
</tr>
<tr>
<td></td>
<td>Other multiple-vehicle</td>
<td>0.139</td>
</tr>
</tbody>
</table>
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 is represented using the following equation.

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

Where:

- \( N_{spf, c-d, n, mv, z} \) = 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
- \( AADT_c \) = annual average daily traffic volume of C-D road segment (veh/day).

The SPF regression coefficients and inverse dispersion parameter are provided in Table 14-7. The SPFs are illustrated in Figure 14-11.

**Table 14-7. SPF Coefficients for Multiple-Vehicle Crashes on C-D Road Segments**

<table>
<thead>
<tr>
<th>Crash Severity (z)</th>
<th>Area Type</th>
<th>Number of Through Lanes (n)</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter ( K_{c-d, x, mv, z} ) (mi⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal and injury (fi)</td>
<td>Rural</td>
<td>1</td>
<td>-4.718</td>
<td>0.524</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>1</td>
<td>-2.997</td>
<td>0.524</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>2</td>
<td>-2.515</td>
<td>0.524</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>1</td>
<td>-3.311</td>
<td>1.256</td>
</tr>
<tr>
<td>Property damage only (pdo)</td>
<td>Rural</td>
<td>1</td>
<td>-3.311</td>
<td>1.256</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>2</td>
<td>-2.475</td>
<td>1.256</td>
</tr>
</tbody>
</table>

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 14-23.

\[ k_{c-d, x, mv, z} = \frac{1}{K_{c-d, x, mv, z} \times L_{cd}} \]  

Where:

- \( k_{c-d, x, mv, z} \) = overdispersion parameter for C-D road segments with cross section \( x \), multiple-vehicle crashes \( mv \), and severity \( z \); and
- \( K_{c-d, x, mv, z} \) = 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 14-22 can be multiplied by the proportions in Table 14-6 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.

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

Equation 14-24

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

**Table 14-8. SPF Coefficients for Single-Vehicle Crashes on Ramp Segments**

<table>
<thead>
<tr>
<th>Crash Severity (z)</th>
<th>Area Type</th>
<th>Cross Section (x)</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter (K_{spf, x, n, z}) (mi(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal and injury (fi)</td>
<td>Rural</td>
<td>One-lane entrance (1EN)</td>
<td>-2.120 0.718 0.001</td>
<td>7.91</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>One-lane exit (1EX)</td>
<td>-1.799 0.718 0.001</td>
<td>7.91</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>One-lane entrance (1EN)</td>
<td>-1.966 0.718 0.001</td>
<td>7.91</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>One-lane exit (1EX)</td>
<td>-1.645 0.718 0.001</td>
<td>7.91</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>Two-lane entrance (2EN)</td>
<td>-1.999 0.718 0.001</td>
<td>7.91</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>Two-lane exit (2EX)</td>
<td>-1.678 0.718 0.001</td>
<td>7.91</td>
</tr>
<tr>
<td>Property damage only (pdo)</td>
<td>Rural</td>
<td>One-lane entrance (1EN)</td>
<td>-1.946 0.689 0.001</td>
<td>9.77</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>One-lane exit (1EX)</td>
<td>-1.739 0.689 0.001</td>
<td>9.77</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>One-lane entrance (1EN)</td>
<td>-1.715 0.689 0.001</td>
<td>9.77</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>One-lane exit (1EX)</td>
<td>-1.508 0.689 0.001</td>
<td>9.77</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>Two-lane entrance (2EN)</td>
<td>-1.400 0.689 0.001</td>
<td>9.77</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>Two-lane exit (2EX)</td>
<td>-1.193 0.689 0.001</td>
<td>9.77</td>
</tr>
</tbody>
</table>
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 14-25.

\[
k^{p_{ps,x,sv,z}} = \frac{1}{K^{p_{ps,x,sv,z}} \times L_r}
\]

Equation 14-25

Where:

- \( k^{p_{ps,x,sv,z}} \) = overdispersion parameter for ramp segments with cross section \( x \), single-vehicle crashes \( mv \), and severity \( z \); and
- \( K^{p_{ps,x,sv,z}} \) = 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 14-24 can be multiplied by the proportions in Table 14-9 to estimate the predicted average single-vehicle crash frequency by crash type category.
Table 14-9. Default Distribution of Single-Vehicle Crashes by Crash Type for Ramp and C-D Road Segments

<table>
<thead>
<tr>
<th>Area Type</th>
<th>Crash Type Category</th>
<th>Proportion of Crashes by Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fatal and Injury</td>
</tr>
<tr>
<td>Rural</td>
<td>Crash with animal</td>
<td>0.012</td>
</tr>
<tr>
<td>Rural</td>
<td>Crash with fixed object</td>
<td>0.422</td>
</tr>
<tr>
<td>Rural</td>
<td>Crash with other object</td>
<td>0.000</td>
</tr>
<tr>
<td>Rural</td>
<td>Crash with parked vehicle</td>
<td>0.024</td>
</tr>
<tr>
<td>Rural</td>
<td>Other single-vehicle crashes</td>
<td>0.542</td>
</tr>
<tr>
<td>Urban</td>
<td>Crash with animal</td>
<td>0.003</td>
</tr>
<tr>
<td>Urban</td>
<td>Crash with fixed object</td>
<td>0.718</td>
</tr>
<tr>
<td>Urban</td>
<td>Crash with other object</td>
<td>0.015</td>
</tr>
<tr>
<td>Urban</td>
<td>Crash with parked vehicle</td>
<td>0.012</td>
</tr>
<tr>
<td>Urban</td>
<td>Other single-vehicle crashes</td>
<td>0.252</td>
</tr>
</tbody>
</table>

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 SPF regression coefficients and inverse dispersion parameter are provided in Table 14-10. The SPFs are illustrated in Figure 14-13.

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

\[
N_{spf, cde, n, sv, z} = L_{cde} \times \exp(a + b \times \ln[c \times AADT_c])
\]

Equation 14-26

Where:

\(N_{spf, cde, n, sv, z}\) = 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 regression coefficients and inverse dispersion parameter are provided in Table 14-10. The SPFs are illustrated in Figure 14-13.
### Table 14-10. SPF Coefficients for Single-Vehicle Crashes on C-D Road Segments

<table>
<thead>
<tr>
<th>Crash Severity (z)</th>
<th>Area Type</th>
<th>Number of Through Lanes (n)</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter $K_{cdn, n, sv, z}$ (mi$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal and injury ($fi$)</td>
<td>Rural</td>
<td>1</td>
<td>$a$ $b$ $c$</td>
<td>Rural 1 -3.002 0.718 0.001 7.91</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>1</td>
<td>$a$ $b$ $c$</td>
<td>Urban 1 -2.848 0.718 0.001 7.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>$a$ $b$ $c$</td>
<td>Urban 2 -2.881 0.718 0.001 7.91</td>
</tr>
<tr>
<td>Property damage only ($pdo$)</td>
<td>Rural</td>
<td>1</td>
<td>$a$ $b$ $c$</td>
<td>Rural 1 -2.890 0.689 0.001 9.77</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>1</td>
<td>$a$ $b$ $c$</td>
<td>Urban 1 -2.659 0.689 0.001 9.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>$a$ $b$ $c$</td>
<td>Urban 2 -2.344 0.689 0.001 9.77</td>
</tr>
</tbody>
</table>

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 14-27.

$$k_{cdn, n, sv, z} = \frac{1}{K_{cdn, n, sv, z} \times L_{cd}}$$

Equation 14-27

Where:

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

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

The crash frequency obtained from Equation 14-26 can be multiplied by the proportions in Table 14-9 to estimate the predicted average single-vehicle crash frequency by crash type category.

### 14.6.2. Safety Performance Functions for Ramp Terminals

The SPFs for crossroad ramp terminals are presented in this section. Specifically, SPFs are provided for crossroad ramp terminals with 2 to 6 crossroad through lanes (total of both travel directions). The range of AADT volume for which these SPFs are applicable is shown in Table 14-11. Application of the SPFs to sites with AADT volumes substantially outside these ranges may not provide reliable results.

Other types of crossroad ramp terminal configurations may be found at interchanges but are not addressed by the predictive model in Chapter 14.
Table 14-11. Applicable AADT Volume Ranges for Crossroad Ramp Terminal SPFs

<table>
<thead>
<tr>
<th>Site Type (w)</th>
<th>Control Type (x)</th>
<th>Applicable AADT Volume Range (veh/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-leg terminals with diagonal exit ramp (D3ex)</td>
<td>Stop control ((ST))</td>
<td>0 to 22,000</td>
</tr>
<tr>
<td></td>
<td>Signal control ((SG))</td>
<td>0 to 8,000</td>
</tr>
<tr>
<td>Three-leg terminals with diagonal entrance ramp (D3en)</td>
<td>Stop control ((ST))</td>
<td>0 to 22,000</td>
</tr>
<tr>
<td></td>
<td>Signal control ((SG))</td>
<td>0 to 15,000</td>
</tr>
<tr>
<td>Four-leg terminals with diagonal ramps (D4)</td>
<td>Stop control ((ST))</td>
<td>0 to 21,000</td>
</tr>
<tr>
<td></td>
<td>Signal control ((SG))</td>
<td>0 to 10,000</td>
</tr>
<tr>
<td>Four-leg terminals at four-quadrant parclo A (A4)</td>
<td>Stop control ((ST))</td>
<td>0 to 21,000</td>
</tr>
<tr>
<td></td>
<td>Signal control ((SG))</td>
<td>0 to 12,000</td>
</tr>
<tr>
<td>Four-leg terminals at four-quadrant parclo B (B4)</td>
<td>Stop control ((ST))</td>
<td>0 to 29,000</td>
</tr>
<tr>
<td></td>
<td>Signal control ((SG))</td>
<td>0 to 29,000</td>
</tr>
<tr>
<td>Three-leg terminals at two-quadrant parclo A (A2)</td>
<td>Stop control ((ST))</td>
<td>0 to 25,000</td>
</tr>
<tr>
<td></td>
<td>Signal control ((SG))</td>
<td>0 to 12,000</td>
</tr>
<tr>
<td>Three-leg terminals at two-quadrant parclo B (B2)</td>
<td>Stop control ((ST))</td>
<td>0 to 14,000</td>
</tr>
<tr>
<td></td>
<td>Signal control ((SG))</td>
<td>0 to 22,000</td>
</tr>
</tbody>
</table>

Signal-Controlled Crossroad Ramp Terminals
The base conditions for the signalized crossroad ramp terminal SPFs are:

- Crossroad left-turn lane (or bay) Not present
- Crossroad right-turn lane (or bay) Not present
- Public street approach presence No public street approaches present
- Driveway presence No driveways present
- Distance to adjacent intersection No adjacent ramp or public street intersection within 6 mi
- Median width (on crossroad) 12 ft
- Protected left-turn phase Not present on either crossroad approach leg
- Channelized right turn on crossroad Not present
- Channelized right turn on exit ramp Not present
- Non-ramp public street leg Not present
The SPFs for crashes at signalized crossroad ramp terminals are presented using the following equation.

\[
N_{spf, w, SGn, at, z} = \exp\left( a + b \times \ln[c \times AADT_{xrd}] + d \times \ln[c \times AADT_{ex} + c \times AADT_{en}] \right)
\]

Equation 14-28

with

\[
AADT_{xrd} = 0.5 \times (AADT_{in} + AADT_{out})
\]

Equation 14-29

Where:

\(N_{spf, w, SG n, at, z}\) = 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 \(z\) \((z = fi: \text{fatal and injury}, pdo: \text{property damage only})\) (crashes/yr);

\(AADT_{xrd}\) = annual average daily traffic volume for the crossroad (veh/day);

\(AADT_{in}\) = annual average daily traffic volume for the crossroad leg between ramps (veh/day);

\(AADT_{out}\) = annual average daily traffic volume for the crossroad leg outside of interchange (veh/day);

\(AADT_{ex}\) = annual average daily traffic volume for the exit ramp (veh/day); and

\(AADT_{en}\) = annual average daily traffic volume for the entrance ramp (veh/day).

The SPF regression coefficients and inverse dispersion parameter are provided in Table 14-12 to Table 14-15. The SPFs are illustrated in Figure 14-15 to Figure 14-18. The AADT volume of the loop exit ramp at a \(B4\) terminal configuration is not included in \(AADT_{ex}\). Similarly, the AADT volume of the loop entrance ramp at an \(A4\) configuration is not included in \(AADT_{en}\).

The Exit ramp capacity CMF is combined with the SPF for fatal-and-injury crashes to create the trend lines shown in the figures for fatal-and-injury crashes. This CMF is a function of exit ramp volume, number of exit ramp lanes, and the traffic control for the exit ramp right turn. These variables in combination do not readily lend themselves to the specification of a representative base condition. For this reason, the CMF is combined with the SPF for the graphical presentation. The Exit ramp capacity CMF is described in Section 14.7.2.
Table 14-12. SPF Coefficients for Crashes at Signalized Ramp Terminals–Three-Leg Terminal at Two-Quadrant Parclo A or B (A2, B2)

<table>
<thead>
<tr>
<th>Crash Severity (z)</th>
<th>Area Type</th>
<th>Number of Crossroad Through Lanes (n)</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter Kw, SGn, at, z</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rural or urban</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatal and injury (fi)</td>
<td></td>
<td>2</td>
<td>-0.458</td>
<td>0.325 0.001 0.212 2.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>-0.298</td>
<td>0.325 0.001 0.212 2.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>-0.138</td>
<td>0.325 0.001 0.212 2.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 (urban only)</td>
<td>0.022</td>
<td>0.325 0.001 0.212 2.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 (urban only)</td>
<td>0.182</td>
<td>0.325 0.001 0.212 2.17</td>
</tr>
<tr>
<td>Property damage only (pdo)</td>
<td>Rural or urban</td>
<td>2</td>
<td>-1.537</td>
<td>0.592 0.001 0.516 4.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>-1.449</td>
<td>0.592 0.001 0.516 4.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>-1.361</td>
<td>0.592 0.001 0.516 4.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 (urban only)</td>
<td>-1.274</td>
<td>0.592 0.001 0.516 4.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 (urban only)</td>
<td>-1.186</td>
<td>0.592 0.001 0.516 4.27</td>
</tr>
</tbody>
</table>

Table 14-13. SPF Coefficients for Crashes at Signalized Ramp Terminals–Three-Leg Terminal with Diagonal Exit Ramp or Four-Leg Terminal at Four-Quadrant Parclo A (D3ex, A4)

<table>
<thead>
<tr>
<th>Crash Severity (z)</th>
<th>Area Type</th>
<th>Number of Crossroad Through Lanes (n)</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter Kw, SGn, at, z</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rural or urban</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatal and injury (fi)</td>
<td></td>
<td>2</td>
<td>-1.352</td>
<td>0.379 0.001 0.394 8.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>-1.192</td>
<td>0.379 0.001 0.394 8.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>-1.032</td>
<td>0.379 0.001 0.394 8.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 (urban only)</td>
<td>-0.872</td>
<td>0.379 0.001 0.394 8.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 (urban only)</td>
<td>-0.712</td>
<td>0.379 0.001 0.394 8.72</td>
</tr>
<tr>
<td>Property damage only (pdo)</td>
<td>Rural or urban</td>
<td>2</td>
<td>-2.247</td>
<td>0.797 0.001 0.384 4.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>-2.159</td>
<td>0.797 0.001 0.384 4.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>-2.071</td>
<td>0.797 0.001 0.384 4.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 (urban only)</td>
<td>-1.984</td>
<td>0.797 0.001 0.384 4.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 (urban only)</td>
<td>-1.896</td>
<td>0.797 0.001 0.384 4.05</td>
</tr>
</tbody>
</table>
### Table 14-14. SPF Coefficients for Crashes at Signalized Ramp Terminals–Three-Leg Terminal with Diagonal Entrance Ramp or Four-Leg Terminal at Four-Quadrant Parclo B (D3en, B4)

<table>
<thead>
<tr>
<th>Crash Severity (z)</th>
<th>Area Type</th>
<th>Number of Crossroad Through Lanes (n)</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter K_{Sw, SGn, at, z}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Fatal and injury (fi)</td>
<td>Rural or urban</td>
<td>2</td>
<td>-2.068</td>
<td>0.265</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>-1.908</td>
<td>0.265</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>-1.748</td>
<td>0.265</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 (urban only)</td>
<td>-1.588</td>
<td>0.265</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 (urban only)</td>
<td>-1.428</td>
<td>0.265</td>
</tr>
<tr>
<td>Property damage only (pdo)</td>
<td>Rural or urban</td>
<td>2</td>
<td>-2.931</td>
<td>0.741</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>-2.843</td>
<td>0.741</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>-2.755</td>
<td>0.741</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 (urban only)</td>
<td>-2.668</td>
<td>0.741</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 (urban only)</td>
<td>-2.580</td>
<td>0.741</td>
</tr>
</tbody>
</table>

### Table 14-15. SPF Coefficients for Crashes at Signalized Ramp Terminals–Four-Leg Terminal with Diagonal Ramps (D4)

<table>
<thead>
<tr>
<th>Crash Severity (z)</th>
<th>Area Type</th>
<th>Number of Crossroad Through Lanes (n)</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter K_{Sw, SGn, at, z}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Fatal and injury (fi)</td>
<td>Rural or urban</td>
<td>2</td>
<td>-2.655</td>
<td>1.191</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>-2.495</td>
<td>1.191</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>-2.335</td>
<td>1.191</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 (urban only)</td>
<td>-2.175</td>
<td>1.191</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 (urban only)</td>
<td>-2.015</td>
<td>1.191</td>
</tr>
<tr>
<td>Property damage only (pdo)</td>
<td>Rural or urban</td>
<td>2</td>
<td>-2.248</td>
<td>0.879</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>-2.160</td>
<td>0.879</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>-2.072</td>
<td>0.879</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 (urban only)</td>
<td>-1.985</td>
<td>0.879</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 (urban only)</td>
<td>-1.897</td>
<td>0.879</td>
</tr>
</tbody>
</table>
a. Fatal-and-Injury Crash Frequency

b. Property-Damage-Only Crash Frequency

**Figure 14-15.** Graphical Form of the SPF for Crashes at Signalized Ramp Terminals—Three-Leg Terminal at Two-Quadrant Parclo A or B (A2, B2)

a. Fatal-and-Injury Crash Frequency

b. Property-Damage-Only Crash Frequency

**Figure 14-16.** Graphical Form of the SPF for Crashes at Signalized Ramp Terminals—Three-Leg Terminal with Diagonal Exit Ramp or Four-Leg Terminal at Four-Quadrant Parclo A (D3ex, A4)
a. Fatal-and-Injury Crash Frequency

Figure 14-17. Graphical Form of the SPF for Crashes at Signalized Ramp Terminals—Three-Leg Terminal with Diagonal Entrance Ramp or Four-Leg Terminal at Four-Quadrant Parclo B (D3en, B4)

b. Property-Damage-Only Crash Frequency

Figure 14-18. Graphical Form of the SPF for Crashes at Signalized Ramp Terminals—Four-Leg Terminal with Diagonal Ramps (D4)

The value of the overdispersion parameter associated with the SPFs for signalized crossroad ramp terminals is computed using Equation 14-30.

\[ k_{w, SGn, at, z} = \frac{1}{K_{w, SGn, at, z}} \]  

Equation 14-30

Where:

\( k_{w, SGn, at, z} \) = overdispersion parameter for signal-controlled site of type \( w \), when \( n \) crossroad lanes, all crash types \( at \), and severity \( z \); and

\( K_{w, SGn, at, z} \) = inverse dispersion parameter for signal-controlled site of type \( w \), when \( n \) crossroad lanes, all crash types \( at \), and severity \( z \).
The crash frequency obtained from Equation 14-28 can be multiplied by the proportions in Table 14-16 to estimate the predicted average signalized crossroad ramp terminal crash frequency by crash type or crash type category.

<table>
<thead>
<tr>
<th>Area Type</th>
<th>Crash Type</th>
<th>Crash Type Category</th>
<th>Proportion of Crashes by Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>Multiple vehicle</td>
<td>Head-on</td>
<td>0.000 0.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right-angle</td>
<td>0.333 0.187</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rear-end</td>
<td>0.552 0.466</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sideswipe</td>
<td>0.000 0.219</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other multiple-vehicle crash</td>
<td>0.014 0.013</td>
</tr>
<tr>
<td>Single vehicle</td>
<td>Crash with animal</td>
<td></td>
<td>0.000 0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with fixed object</td>
<td>0.043 0.077</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with other object</td>
<td>0.000 0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with parked vehicle</td>
<td>0.000 0.013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other single-vehicle crashes</td>
<td>0.058 0.019</td>
</tr>
<tr>
<td>Urban</td>
<td>Multiple vehicle</td>
<td>Head-on</td>
<td>0.011 0.007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right-angle</td>
<td>0.260 0.220</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rear-end</td>
<td>0.625 0.543</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sideswipe</td>
<td>0.042 0.149</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other multiple-vehicle crash</td>
<td>0.009 0.020</td>
</tr>
<tr>
<td>Single vehicle</td>
<td>Crash with animal</td>
<td></td>
<td>0.000 0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with fixed object</td>
<td>0.033 0.050</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with other object</td>
<td>0.001 0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with parked vehicle</td>
<td>0.001 0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other single-vehicle crashes</td>
<td>0.018 0.007</td>
</tr>
</tbody>
</table>

One-Way Stop-Controlled Crossroad Ramp Terminals
The predictive models described in this section are calibrated to address one-way stop control, where the ramp is stop controlled. An interim predictive model is provided in Section 14.10 for all-way stop control.

The base conditions for the one-way stop-controlled crossroad ramp terminal SPFs are:

- Crossroad left-turn lane (or bay) Not present
- Crossroad right-turn lane (or bay) Not present
- Public street approach presence: No public street approaches present
- Distance to adjacent intersection: No adjacent ramp or public street intersection within 6 mi
- Median width (on crossroad): 12 ft
- Skew angle: 0.0 degrees (no skew)

The SPF for crashes at one-way stop-controlled ramp terminals is applied as follows:

\[ N_{spf, w, ST, at, z} = \exp(a + b \times \ln(c \times AADT_{xrd}) + d \times \ln(c \times AADT_{ex} + c \times AADT_{en})) \]  

Equation 14-31

Where:

\[ N_{spf, w, ST, at, z} \] = 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).

The SPF regression coefficients and inverse dispersion parameter are provided in Table 14-17 to Table 14-20. The SPFs are illustrated in Figure 14-19 to Figure 14-22.

The Exit ramp capacity CMF is combined with the SPF for fatal-and-injury crashes to create the trend lines shown in the figures for fatal-and-injury crashes. This CMF is a function of exit ramp volume, number of exit ramp lanes, and the traffic control for the exit ramp right turn. These variables in combination do not readily lend themselves to the specification of a representative base condition. For this reason, the CMF is combined with the SPF for the graphical presentation. The Exit ramp capacity CMF is described in Section 14.7.2.

**Table 14-17. SPF Coefficients for Crashes at One-Way Stop-Controlled Ramp Terminals–Three-Leg Terminal at Two-Quadrant Parclo A or B (A2, B2)**

<table>
<thead>
<tr>
<th>Crash Severity (z)</th>
<th>Area Type</th>
<th>Number of Crossroad Through Lanes (n)</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter ( K_{w, ST, at, z} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal and injury ( (fi) )</td>
<td>Rural</td>
<td>All lanes</td>
<td>(-2.363)</td>
<td>0.260</td>
</tr>
<tr>
<td>Urban</td>
<td>All lanes</td>
<td>(-2.687)</td>
<td>0.260</td>
<td>0.001</td>
</tr>
<tr>
<td>Property damage only ( (pdo) )</td>
<td>Rural</td>
<td>All lanes</td>
<td>(-3.055)</td>
<td>0.773</td>
</tr>
<tr>
<td>Urban</td>
<td>All lanes</td>
<td>(-3.055)</td>
<td>0.773</td>
<td>0.001</td>
</tr>
</tbody>
</table>
### Table 14-18. SPF Coefficients for Crashes at One-Way Stop-Controlled Ramp Terminals–Three-Leg Terminal with Diagonal Exit Ramp or Four-Leg Terminal at Four-Quadrant Parclo A ($D3ex$, $A4$)

<table>
<thead>
<tr>
<th>Crash Severity $(z)$</th>
<th>Area Type</th>
<th>Number of Crossroad Through Lanes $(n)$</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter $K_w, ST, at, z$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rural</td>
<td>All lanes</td>
<td>$-2.899$</td>
<td>$0.582$ $0.001$ $0.899$ $2.16$</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>All lanes</td>
<td>$-3.223$</td>
<td>$0.582$ $0.001$ $0.899$ $2.16$</td>
</tr>
<tr>
<td>Property damage only $(pdo)$</td>
<td>Rural</td>
<td>All lanes</td>
<td>$-2.670$</td>
<td>$0.595$ $0.001$ $0.937$ $6.57$</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>All lanes</td>
<td>$-2.670$</td>
<td>$0.595$ $0.001$ $0.937$ $6.57$</td>
</tr>
</tbody>
</table>

### Table 14-19. SPF Coefficients for Crashes at One-Way Stop-Controlled Ramp Terminals–Three-Leg Terminal with Diagonal Entrance Ramp or Four-Leg Terminal at Four-Quadrant Parclo B ($D3en$, $B4$)

<table>
<thead>
<tr>
<th>Crash Severity $(z)$</th>
<th>Area Type</th>
<th>Number of Crossroad Through Lanes $(n)$</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter $K_w, ST, at, z$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rural</td>
<td>All lanes</td>
<td>$-2.817$</td>
<td>$0.709$ $0.001$ $0.730$ $0.92$</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>All lanes</td>
<td>$-3.141$</td>
<td>$0.709$ $0.001$ $0.730$ $0.92$</td>
</tr>
<tr>
<td>Property damage only $(pdo)$</td>
<td>Rural</td>
<td>All lanes</td>
<td>$-2.358$</td>
<td>$0.885$ $0.001$ $0.350$ $3.90$</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>All lanes</td>
<td>$-2.358$</td>
<td>$0.885$ $0.001$ $0.350$ $3.90$</td>
</tr>
</tbody>
</table>

### Table 14-20. SPF Coefficients for Crashes at One-Way Stop-Controlled Ramp Terminals–Four-Leg Terminal with Diagonal Ramps $(D4)$

<table>
<thead>
<tr>
<th>Crash Severity $(z)$</th>
<th>Area Type</th>
<th>Number of Crossroad Through Lanes $(n)$</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter $K_w, ST, at, z$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rural</td>
<td>All lanes</td>
<td>$-2.740$</td>
<td>$1.008$ $0.001$ $0.177$ $2.58$</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>All lanes</td>
<td>$-3.064$</td>
<td>$1.008$ $0.001$ $0.177$ $2.58$</td>
</tr>
<tr>
<td>Property damage only $(pdo)$</td>
<td>Rural</td>
<td>All lanes</td>
<td>$-2.432$</td>
<td>$0.845$ $0.001$ $0.476$ $4.27$</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>All lanes</td>
<td>$-2.432$</td>
<td>$0.845$ $0.001$ $0.476$ $4.27$</td>
</tr>
</tbody>
</table>
a. Fatal-and-Injury Crash Frequency

b. Property-Damage-Only Crash Frequency

**Figure 14-19.** Graphical Form of the SPF Crashes at One-Way Stop-Controlled Ramp Terminals–Three-Leg Terminal at Two-Quadrant Parclo A or B (A2, B2)

a. Fatal-and-Injury Crash Frequency

b. Property-Damage-Only Crash Frequency

**Figure 14-20.** Graphical Form of the SPF Crashes at One-Way Stop-Controlled Ramp Terminals–Three-Leg Terminal with Diagonal Exit Ramp or Four-Leg Terminal at Four-Quadrant Parclo A (D3ex, A4)
The value of the overdispersion parameter associated with the SPFs for one-way stop-controlled crossroad ramp terminals is computed using Equation 14-32.

\[ k_{w, ST, at, z} = \frac{1}{K_{w, ST, at, z}} \]  

Equation 14-32

Where:

- \( k_{w, ST, at, z} \) = overdispersion parameter for a stop-controlled site of type \( w \), with \( n \) crossroad lanes, and all crash types \( at \) and severity \( z \); and
- \( K_{w, ST, at, z} \) = inverse dispersion parameter for a stop-controlled site of type \( w \), with \( n \) crossroad lanes, and all crash types \( at \) and severity \( z \).
The crash frequency obtained from Equation 14-31 can be multiplied by the proportions in Table 14-21 to estimate the predicted average stop-controlled crossroad ramp terminal crash frequency by crash type or crash type category.

**Table 14-21. Default Distribution of One-Way Stop-Controlled Ramp Terminal Crashes by Crash Type**

<table>
<thead>
<tr>
<th>Area Type</th>
<th>Crash Type</th>
<th>Crash Type Category</th>
<th>Proportion of Crashes by Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fatal and Injury</td>
</tr>
<tr>
<td>Rural</td>
<td>Multiple vehicle</td>
<td>Head-on</td>
<td>0.020</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right-angle</td>
<td>0.522</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rear-end</td>
<td>0.275</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sideswipe</td>
<td>0.020</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other multiple-vehicle crash</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td>Single vehicle</td>
<td>Crash with animal</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with fixed object</td>
<td>0.078</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with other object</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with parked vehicle</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other single-vehicle crashes</td>
<td>0.065</td>
</tr>
<tr>
<td>Urban</td>
<td>Multiple vehicle</td>
<td>Head-on</td>
<td>0.017</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right-angle</td>
<td>0.458</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rear-end</td>
<td>0.373</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sideswipe</td>
<td>0.025</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other multiple-vehicle crash</td>
<td>0.017</td>
</tr>
<tr>
<td></td>
<td>Single vehicle</td>
<td>Crash with animal</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with fixed object</td>
<td>0.085</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with other object</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with parked vehicle</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other single-vehicle crashes</td>
<td>0.025</td>
</tr>
</tbody>
</table>
### 14.7. CRASH MODIFICATION FACTORS

This section describes the CMFs applicable to the SPFs presented in Section 14.6. These CMFs were calibrated along with the SPFs. They are summarized in Table 14-22 and Table 14-23.

**Table 14-22. Ramp Segment Crash Modification Factors and their Corresponding SPFs**

<table>
<thead>
<tr>
<th>Applicable SPF(s)</th>
<th>CMF Variable</th>
<th>CMF Description</th>
<th>CMF Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp or C-D road segments</td>
<td>(CMF_{1, w, x, y, z})</td>
<td>Horizontal curve</td>
<td>Equation 14-33</td>
</tr>
<tr>
<td></td>
<td>(CMF_{2, w, x, y, \beta})</td>
<td>Lane width</td>
<td>Equation 14-34</td>
</tr>
<tr>
<td></td>
<td>(CMF_{3, w, x, y, z})</td>
<td>Right shoulder width</td>
<td>Equation 14-35</td>
</tr>
<tr>
<td></td>
<td>(CMF_{4, w, x, y, z})</td>
<td>Left shoulder width</td>
<td>Equation 14-36</td>
</tr>
<tr>
<td></td>
<td>(CMF_{5, w, x, y, z})</td>
<td>Right side barrier</td>
<td>Equation 14-37</td>
</tr>
<tr>
<td></td>
<td>(CMF_{6, w, x, y, z})</td>
<td>Left side barrier</td>
<td>Equation 14-38</td>
</tr>
<tr>
<td></td>
<td>(CMF_{7, w, x, y, \beta})</td>
<td>Lane add or drop</td>
<td>Equation 14-39</td>
</tr>
<tr>
<td>Multiple-vehicle crashes on ramp or C-D Road segments</td>
<td>(CMF_{8, w, x, m, \beta})</td>
<td>Ramp speed-change lane</td>
<td>Equation 14-40</td>
</tr>
<tr>
<td>C-D road segments</td>
<td>(CMF_{9, cds, ac, y, z})</td>
<td>Weaving section</td>
<td>Equation 14-41</td>
</tr>
</tbody>
</table>

Note: Subscripts to the CMF variables use the following notation:

- Site type \(w\) (\(w = rps\): ramp segment, \(cds\): C-D road segment),
- Cross section \(x\) (\(x = n\): \(n\)-lane C-D road, \(nEN\): \(n\)-lane entrance ramp, \(nEX\): \(n\)-lane exit ramp, \(ac\): all cross sections),
- 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).

Many of the CMFs in Table 14-22 and Table 14-23 are developed for specific site types, cross sections, crash types, or crash severities. This approach was undertaken to make the predictive model sensitive to the geometric design and traffic control features of specific sites with specific cross sections, in terms of their influence on specific crash types and severities. The subscripts for each CMF variable indicate the sites, cross sections, crash types, and severities to which each CMF is applicable. The subscript definitions are provided in the table footnote. In some cases, a CMF is applicable to several site types, cross sections, crash types, or severities. In these cases, the subscript retains the generic letter \(w, x, y, \) or \(z\), as appropriate. The discussion of these CMFs in Section 14.7.1 or 14.7.2 identifies the specific site types, cross sections, crash types, or severities to which they apply.

As indicated in Table 14-22, some of the CMFs apply to both ramp segments and C-D road segments. For some of the CMFs, supplemental calculations must be performed before the CMF value can be computed. For example, to apply the Right side barrier CMF, the proportion of the segment length having barrier on the right side and the length-weighted average barrier offset (as measured from the edge of the outside shoulder) must be computed. Procedures for supplemental calculations are described in Section 14.7.3.
### Table 14-23. Crossroad Ramp Terminal Crash Modification Factors and their Corresponding SPFs

<table>
<thead>
<tr>
<th>Applicable SPF(s)</th>
<th>CMF Variable</th>
<th>CMF Description</th>
<th>CMF Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal-controlled or one-way stop-controlled ramp terminals</td>
<td>CMF10, w, x, at, fi</td>
<td>Exit ramp capacity</td>
<td>Equation 14-42</td>
</tr>
<tr>
<td></td>
<td>CMF11, w, x, at, z</td>
<td>Crossroad left-turn lane</td>
<td>Equation 14-45</td>
</tr>
<tr>
<td></td>
<td>CMF12, w, x, at, z</td>
<td>Crossroad right-turn lane</td>
<td>Equation 14-48</td>
</tr>
<tr>
<td></td>
<td>CMF13, w, x, at, z</td>
<td>Access point frequency</td>
<td>Equation 14-49</td>
</tr>
<tr>
<td></td>
<td>CMF14, w, x, at, z</td>
<td>Segment length</td>
<td>Equation 14-50</td>
</tr>
<tr>
<td></td>
<td>CMF15, w, x, at, z</td>
<td>Median width</td>
<td>Equation 14-51</td>
</tr>
<tr>
<td>Signal-controlled crossroad ramp terminals</td>
<td>CMF16, w, SGn, at, z</td>
<td>Protected left-turn operation</td>
<td>Equation 14-53</td>
</tr>
<tr>
<td></td>
<td>CMF17, w, SGn, at, z</td>
<td>Channelized right turn on crossroad</td>
<td>Equation 14-55</td>
</tr>
<tr>
<td></td>
<td>CMF18, w, SGn, at, z</td>
<td>Channelized right turn on exit ramp</td>
<td>Equation 14-56</td>
</tr>
<tr>
<td></td>
<td>CMF19, w, SGn, at, z</td>
<td>Non-ramp public street leg</td>
<td>Equation 14-57</td>
</tr>
<tr>
<td>One-way stop-controlled ramp terminals</td>
<td>CMF20, w, ST, at, fi</td>
<td>Skew angle</td>
<td>Equation 14-58</td>
</tr>
</tbody>
</table>

Note: Subscripts to the CMF variables use the following notation:
- Site type $w$ ($w = D3ex, D3en, D4, A4, B4, A2, B2$),
- Cross section $x$ ($x = ST$: one-way stop control; $SGn$: signal control with $n$-lane crossroad; $ac$: all cross sections),
- 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).

### 14.7.1. Crash Modification Factors for Ramp Segments

The CMFs for geometric design and traffic control features of freeway segments are presented in this section.

#### CMF1, w, x, y, z—Horizontal Curve

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

- SPF for fatal-and-injury multiple-vehicle crashes, $n$-lane entrance ramp ($rps$, $nEN$, $mv$, $fi$);
- SPF for fatal-and-injury single-vehicle crashes, $n$-lane entrance ramp ($rps$, $nEN$, $sv$, $fi$);
- SPF for fatal-and-injury multiple-vehicle crashes, $n$-lane exit ramp ($rps$, $nEX$, $mv$, $fi$);
- SPF for fatal-and-injury single-vehicle crashes, $n$-lane exit ramp ($rps$, $nEX$, $sv$, $fi$);
- SPF for fatal-and-injury multiple-vehicle crashes, $n$-lane C-D road ($cds$, $n$, $mv$, $fi$); and
- SPF for fatal-and-injury single-vehicle crashes, $n$-lane C-D road ($cds$, $n$, $sv$, $fi$).

The six property-damage-only SPFs to which these CMFs apply are not shown in the previous list. However, the only difference is that the $fi$ subscript (shown in parentheses in the previous list) is replaced by $pdo$. 
The base condition is an uncurved (i.e., tangent) segment. The CMFs are described using the following equation.

\[
CMF_{1, w, x, y, z} = 1.0 + a \times \frac{1,000}{32.2} \left[ \sum_{i=1}^{m} \left( \frac{v_{\text{ent}, i}}{R_i} \right)^2 P_{c, i} \right]
\]

Equation 14-33

Where:

- \( CMF_{1, w, x, y, z} \) = crash modification factor for horizontal curvature on a site of type \( w \), cross section \( x \), crash type \( y \), and severity \( z \);
- \( v_{\text{ent}, i} \) = average entry speed for curve \( i \) (ft/s);
- \( R_i \) = radius of curve \( i \) (ft);
- \( P_{c, i} \) = proportion of segment length with curve \( i \); and
- \( m \) = number of horizontal curves on the segment.

The regression coefficient for Equation 14-33 is provided in Table 14-24. Equation 14-33 is derived to recognize that more than one curve may exist on a segment and that a curve may be located only partially on the segment (and partially on an adjacent segment). The variable \( P_{c, i} \) is computed as the ratio of the length of curve \( i \) on the segment to the length of the segment (i.e., \( L_r \) or \( L_{cd} \)). For example, consider a segment that is 0.5 mi long and a curve that is 0.2 mi long. If one-half of the curve is on the segment, then \( P_{c, i} = 0.20 \) (= 0.1/0.5). In fact, this proportion is the same regardless of the curve’s length (provided that it is 0.1 mi or longer and 0.1 mi of this curve is located on the segment).

**Table 14-24. Coefficients for Horizontal Curve CMF–Ramp and C-D Road Segments**

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficient (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections (ac)</td>
<td>Multiple vehicle (mv)</td>
<td>Fatal and injury (fi)</td>
<td>( CMF_{1, w, ac, mv, fi} )</td>
<td>0.779</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>( CMF_{1, w, ac, mv, pdo} )</td>
<td>0.545</td>
</tr>
<tr>
<td>Single vehicle (sv)</td>
<td></td>
<td>Fatal and injury (fi)</td>
<td>( CMF_{1, w, ac, sv, fi} )</td>
<td>2.406</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>( CMF_{1, w, ac, sv, pdo} )</td>
<td>3.136</td>
</tr>
</tbody>
</table>

Details regarding the measurement of radius and curve length are provided in Section 14.4. A procedure for estimating the average curve entry speed is provided in Section 14.7.3. The CMF is applicable to curves with a radius of 100 ft or larger.

**CMF\(_{2, w, x, y, z}\) — Lane Width**

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

- SPF for fatal-and-injury multiple-vehicle crashes, \( n \)-lane entrance ramp (\( rps, nEN, mv, fi \));
- SPF for fatal-and-injury single-vehicle crashes, \( n \)-lane entrance ramp (\( rps, nEN, sv, fi \));
SPF for fatal-and-injury multiple-vehicle crashes, $n$-lane exit ramp ($rps, nEX, mv, fi$);

SPF for fatal-and-injury single-vehicle crashes, $n$-lane exit ramp ($rps, nEX, sv, fi$);

SPF for fatal-and-injury multiple-vehicle crashes, $n$-lane C-D road ($cds, n, mv, fi$); and

SPF for fatal-and-injury single-vehicle crashes, $n$-lane C-D road ($cds, n, sv, fi$).

The base condition is a 14-ft lane width. The CMFs are described using the following equation.

$$CMF_{2, w, x, y, fi} = \exp(a \times [W_l - 14])$$

Equation 14-34

Where:

$CMF_{2, w, x, y, fi} = \text{crash modification factor for lane width on a site of type } w, \text{ cross section } x, \text{ crash type } y, \text{ and fatal-and-injury crashes } fi; \text{ and}$

$W_l = \text{lane width (ft)}.$

The regression coefficient for Equation 14-34 is provided in Table 14-25. In fact, the coefficient value is the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs.

**Table 14-25. Coefficients for Lane Width CMF–Ramp and C-D Road Segments**

<table>
<thead>
<tr>
<th>Cross Section ($x$)</th>
<th>Crash Type ($y$)</th>
<th>Crash Severity ($z$)</th>
<th>CMF Variable</th>
<th>Regression Coefficient ($a$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections ($ac$)</td>
<td>Multiple vehicle ($mv$)</td>
<td>Fatal and injury ($fi$)</td>
<td>$CMF_{2, w, ac, mv, fi}$</td>
<td>-0.0458</td>
</tr>
<tr>
<td>Single vehicle ($sv$)</td>
<td>Fatal and injury ($fi$)</td>
<td>$CMF_{2, w, ac, sv, fi}$</td>
<td>-0.0458</td>
<td></td>
</tr>
</tbody>
</table>

The lane width used in Equation 14-34 is an average for all through lanes on the segment. The CMF is applicable to lane widths in the range of 10 to 20 ft.

**CMF$_3, w, x, y, z$—Right Shoulder Width**

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

- SPF for fatal-and-injury multiple-vehicle crashes, $n$-lane entrance ramp ($rps, nEN, mv, fi$);
- SPF for fatal-and-injury single-vehicle crashes, $n$-lane entrance ramp ($rps, nEN, sv, fi$);
- SPF for fatal-and-injury multiple-vehicle crashes, $n$-lane exit ramp ($rps, nEX, mv, fi$);
- SPF for fatal-and-injury single-vehicle crashes, $n$-lane exit ramp ($rps, nEX, sv, fi$);
- SPF for fatal-and-injury multiple-vehicle crashes, $n$-lane C-D road ($cds, n, mv, fi$); and
- SPF for fatal-and-injury single-vehicle crashes, $n$-lane C-D road ($cds, n, sv, fi$).
The six property-damage-only SPFs to which these CMFs apply are not shown in the previous list. However, the only difference is that the $fi$ subscript (shown in parentheses in the previous list) is replaced by $pdo$.

The base condition is an 8-ft shoulder width. The CMFs are described using the following equation.

$$CMF_{3,w,x,y,z} = \exp(a \times [W_{rs} - 8])$$  \hspace{1cm} \text{Equation 14-35}

Where:

- $CMF_{3,w,x,y,z} = \text{crash modification factor for the right shoulder width on a site of type } w, \text{ cross section } x, \text{ crash type } y, \text{ and severity } z$; and
- $W_{rs} = \text{right shoulder width (ft)}$.

The regression coefficient for Equation 14-35 is provided in Table 14-26. For a given severity, the coefficient values are the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs.

### Table 14-26. Coefficients for Right Shoulder Width CMF–Ramp and C-D Road Segments

<table>
<thead>
<tr>
<th>Cross Section ($x$)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficient ($a$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections</td>
<td>Multiple vehicle ($mv$)</td>
<td>Fatal and injury ($fi$)</td>
<td>$CMF_{3, w, ac, mv, fi}$</td>
<td>-0.0539</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ($pdo$)</td>
<td>$CMF_{3, w, ac, mv, pdo}$</td>
<td>-0.0259</td>
</tr>
<tr>
<td>Single vehicle ($sv$)</td>
<td>Multiple vehicle ($mv$)</td>
<td>Fatal and injury ($fi$)</td>
<td>$CMF_{3, w, ac, sv, fi}$</td>
<td>-0.0539</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ($pdo$)</td>
<td>$CMF_{3, w, ac, sv, pdo}$</td>
<td>-0.0259</td>
</tr>
</tbody>
</table>

The right shoulder width used in Equation 14-35 is an average for both directions of travel. The CMF is applicable to shoulder widths in the range of 2 to 12 ft.

**CMF$_{4,w,x,y,z}$—Left Shoulder Width**

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

- SPF for fatal-and-injury multiple-vehicle crashes, $n$-lane entrance ramp ($rps$, $nEN$, $mv$, $fi$);
- SPF for fatal-and-injury single-vehicle crashes, $n$-lane entrance ramp ($rps$, $nEN$, $sv$, $fi$);
- SPF for fatal-and-injury multiple-vehicle crashes, $n$-lane exit ramp ($rps$, $nEX$, $mv$, $fi$);
- SPF for fatal-and-injury single-vehicle crashes, $n$-lane exit ramp ($rps$, $nEX$, $sv$, $fi$);
- SPF for fatal-and-injury multiple-vehicle crashes, $n$-lane C-D road ($cds$, $n$, $mv$, $fi$); and
- SPF for fatal-and-injury single-vehicle crashes, $n$-lane C-D road ($cds$, $n$, $sv$, $fi$).

The six property-damage-only SPFs to which these CMFs apply are not shown in the previous list. However, the only difference is that the $fi$ subscript (shown in parentheses in the previous list) is replaced by $pdo$. 
The base condition is a 4-ft shoulder width. The CMFs are described using the following equation.

\[ CMF_{4, w, x, y, z} = \exp(a \times (W_{ls} - 4)) \]  

Equation 14-36

Where:

- \( CMF_{4, w, x, y, z} \) = crash modification factor for the left shoulder width on a site of type \( w \), cross section \( x \), crash type \( y \), and severity \( z \); and
- \( W_{ls} \) = left shoulder width (ft).

The regression coefficient for Equation 14-36 is provided in Table 14-27. For a given severity, the coefficient values are the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs.

**Table 14-27. Coefficients for Left Shoulder Width CMF–Ramp and C-D Road Segments**

<table>
<thead>
<tr>
<th>Cross Section ((x))</th>
<th>Crash Type ((y))</th>
<th>Crash Severity ((z))</th>
<th>CMF Variable (CMF_{4, w, x, y, z})</th>
<th>Regression Coefficient ((a))</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections ((ac))</td>
<td>Multiple vehicle ((mv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{4, w, ac, mv, fi})</td>
<td>-0.0539</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{4, w, ac, mv, pdo})</td>
<td>-0.0259</td>
</tr>
<tr>
<td></td>
<td>Single vehicle ((sv))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{4, w, ac, rv, fi})</td>
<td>-0.0539</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{4, w, ac, rv, pdo})</td>
<td>-0.0259</td>
</tr>
</tbody>
</table>

The left shoulder width used in Equation 14-36 is an average for both directions of travel. The CMF is applicable to shoulder widths in the range of 2 to 10 ft.

**CMF_{5, w, x, y, z}—Right Side Barrier**

Four CMFs are used to describe the relationship between right side barrier presence and predicted crash frequency. The six fatal-and-injury SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, \(n\)-lane entrance ramp \((rps, nEN, mv, fi)\);
- SPF for fatal-and-injury single-vehicle crashes, \(n\)-lane entrance ramp \((rps, nEN, sv, fi)\);
- SPF for fatal-and-injury multiple-vehicle crashes, \(n\)-lane exit ramp \((rps, nEX, mv, fi)\);
- SPF for fatal-and-injury single-vehicle crashes, \(n\)-lane exit ramp \((rps, nEX, sv, fi)\);
- SPF for fatal-and-injury multiple-vehicle crashes, \(n\)-lane C-D road \((cds, n, mv, fi)\); and
- SPF for fatal-and-injury single-vehicle crashes, \(n\)-lane C-D road \((cds, n, sv, fi)\).

The six property-damage-only SPFs to which these CMFs apply are not shown in the previous list. However, the only difference is that the \(fi\) subscript (shown in parentheses in the previous list) is replaced by \(pdo\).

The base condition is no barrier present on the right side of the ramp. The CMFs are described using the following equation.
\[ CMF_{5, w, x, y, z} = (1.0 - P_{rb}) \times 1.0 + P_{rb} \times \exp \left( \frac{a}{W_{rcb}} \right) \]  

Equation 14-37

Where:

- \( CMF_{5, w, x, y, z} \) = crash modification factor for right side barrier on a site of type \( w \), cross section \( x \), crash type \( y \), and severity \( z \); and
- \( P_{rb} \) = proportion of segment length with a barrier present on the right side; and
- \( W_{rcb} \) = distance from edge of right shoulder to barrier face (ft).

The regression coefficient for Equation 14-37 is provided in Table 14-28. For a given severity, the coefficient values are the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs. Guidance for computing the variables \( P_{rb} \) and \( W_{rcb} \) is provided in Section 14.7.3.

<table>
<thead>
<tr>
<th>Cross Section ((x))</th>
<th>Crash Type ((y))</th>
<th>Crash Severity ((z))</th>
<th>CMF Variable</th>
<th>Regression Coefficient ((a))</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections ((ac))</td>
<td>Multiple vehicle ((mv))</td>
<td>Fatal and injury ((fi))</td>
<td>( CMF_{5, w, ac, mv, fi} )</td>
<td>0.210</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>( CMF_{5, w, ac, mv, pdo} )</td>
<td>0.193</td>
</tr>
<tr>
<td>Single vehicle ((sv))</td>
<td>Multiple vehicle ((mv))</td>
<td>Fatal and injury ((fi))</td>
<td>( CMF_{5, w, ac, mv, fi} )</td>
<td>0.210</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>( CMF_{5, w, ac, sv, pdo} )</td>
<td>0.193</td>
</tr>
</tbody>
</table>

The variable \( W_{rcb} \) represents the distance from the edge of right shoulder to right side barrier face. The value used for this variable in Equation 14-37 is an average for the segment. The CMF is applicable to \( W_{rcb} \) values in the range of 0.25 to 25 ft. This CMF is applicable to cable barrier, concrete barrier, guardrail, and bridge rail.

**CMF_{6, w, x, y, z}—Left Side Barrier**

Four CMFs are used to describe the relationship between left side barrier presence and predicted crash frequency. The six fatal-and-injury SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, \( n \)-lane entrance ramp \((rps, nEN, mv, fi)\);  
- SPF for fatal-and-injury single-vehicle crashes, \( n \)-lane entrance ramp \((rps, nEN, sv, fi)\);  
- SPF for fatal-and-injury multiple-vehicle crashes, \( n \)-lane exit ramp \((rps, nEX, mv, fi)\);  
- SPF for fatal-and-injury single-vehicle crashes, \( n \)-lane exit ramp \((rps, nEX, sv, fi)\);  
- SPF for fatal-and-injury multiple-vehicle crashes, \( n \)-lane C-D road \((cds, n, mv, fi)\); and  
- SPF for fatal-and-injury single-vehicle crashes, \( n \)-lane C-D road \((cds, n, sv, fi)\).
The six property-damage-only SPFs to which these CMFs apply are not shown in the previous list. However, the only difference is that the $fi$ subscript (shown in parentheses in the previous list) is replaced by $pdo$.

The base condition is no barrier present on the left side of the ramp. The CMFs are described using the following equation.

$$CMF_{6, w, x, y, z} = (1 - P_{lb}) \times 1.0 + P_{lb} \times \exp\left(\frac{a}{W_{lcb}}\right)$$

Equation 14-38

Where:

- $CMF_{6, w, x, y, z} = \text{crash modification factor for left side barrier on a site of type } w, \text{ cross section } x, \text{ crash type } y, \text{ and severity } z; \text{ and}$
- $P_{lb} = \text{proportion of segment length with a barrier present on the left side}; \text{ and}$
- $W_{lcb} = \text{distance from edge of left shoulder to barrier face (ft)}.$

The regression coefficient for Equation 14-38 is provided in Table 14-29. For a given severity, the coefficient values are the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs. Guidance for computing the variables $P_{lb}$ and $W_{lcb}$ is provided in Section 14.7.3.

**Table 14-29. Coefficients for Left Side Barrier CMF–Ramp and C-D Road Segments**

<table>
<thead>
<tr>
<th>Cross Section ($x$)</th>
<th>Crash Type ($y$)</th>
<th>Crash Severity ($z$)</th>
<th>CMF Variable</th>
<th>Regression Coefficient ($a$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections ($ac$)</td>
<td>Multiple vehicle ($mv$)</td>
<td>Fatal and injury ($fi$)</td>
<td>$CMF_{6, w, ac, mv, fi}$</td>
<td>0.210</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ($pdo$)</td>
<td>$CMF_{6, w, ac, mv, pdo}$</td>
<td>0.193</td>
</tr>
<tr>
<td></td>
<td>Single vehicle ($sv$)</td>
<td>Fatal and injury ($fi$)</td>
<td>$CMF_{6, w, ac, sv, fi}$</td>
<td>0.210</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ($pdo$)</td>
<td>$CMF_{6, w, ac, sv, pdo}$</td>
<td>0.193</td>
</tr>
</tbody>
</table>

The variable $W_{lcb}$ represents the distance from the edge of left shoulder to left side barrier face. The value used for this variable in Equation 14-38 is an average for the segment. The CMF is applicable to $W_{lcb}$ values in the range of 0.25 to 24 ft. This CMF is applicable to cable barrier, concrete barrier, guardrail, and bridge rail.

**CMF$_{7, w, x, y, n}$—Lane Add or Drop**

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

- SPF for fatal-and-injury multiple-vehicle crashes, $n$-lane entrance ramp ($rps, nEN, mv, fi$);
- SPF for fatal-and-injury single-vehicle crashes, $n$-lane entrance ramp ($rps, nEN, sv, fi$);
- SPF for fatal-and-injury multiple-vehicle crashes, $n$-lane exit ramp ($rps, nEX, mv, fi$);
- SPF for fatal-and-injury single-vehicle crashes, $n$-lane exit ramp ($rps, nEX, sv, fi$);
- SPF for fatal-and-injury multiple-vehicle crashes, \( n \)-lane C-D road \((cds, n, mv, fi)\); and

- SPF for fatal-and-injury single-vehicle crashes, \( n \)-lane C-D road \((cds, n, sv, fi)\).

The base condition is no lane change (i.e., no lanes added or dropped). The CMFs are described using the following equation.

\[
CMF_{7, w, x, y, fi} = \left(1.0 - P_{spr}\right) \times 1.0 + P_{spr} \times \exp\left(a \times \left[I_{add} - I_{drop}\right]\right)
\]

Equation 14-39

Where:

- \( CMF_{7, w, x, y, fi} \) = crash modification factor for lane add or drop on a site of type \( w \), cross section \( x \), crash type \( y \), and fatal-and-injury crashes \( fi \);
- \( P_{spr} \) = proportion of segment length adjacent to the taper associated with a lane add or drop;
- \( I_{add} \) = lane add indicator variable (= 1.0 if one or more lanes are added, 0.0 otherwise); and
- \( I_{drop} \) = lane drop indicator variable (= 1.0 if one or more lanes are dropped, 0.0 otherwise).

The regression coefficient for Equation 14-39 is provided in Table 14-30. In fact, the coefficient value is the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs. The variable \( P_{spr} \) is computed as the ratio of the length of the lane add (or drop) taper on the segment to the length of the segment. If the segment is wholly located in the taper, then this variable is equal to 1.0.

Table 14-30. Coefficients for Lane Add or Drop CMF–Ramp and C-D Road Segments

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficient (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cross sections (ac)</td>
<td>Multiple vehicle (mv)</td>
<td>Fatal and injury (fi)</td>
<td>( CMF_{7, w, ac, mv, fi} )</td>
<td>-0.231</td>
</tr>
<tr>
<td>Single vehicle (sv)</td>
<td>Fatal and injury (fi)</td>
<td>( CMF_{7, w, ac, sv, fi} )</td>
<td>-0.231</td>
<td></td>
</tr>
</tbody>
</table>

This CMF is not used with the Weaving section CMF. If a C-D road segment is being evaluated, either the Lane add or drop CMF is used for the subject segment or the Weaving section CMF is used.

If a lane add occurs as a result of a ramp-to-ramp merge, then a taper does not exist and this CMF is not used. Similarly, if a lane drop occurs as a result of a ramp-to-ramp diverge, then a taper does not exist and this CMF is not used.

**CMF_{8, w, x, mv, fi}—Ramp Speed-Change Lane**

One CMF is used to describe the relationship between ramp speed-change lane presence and predicted crash frequency. The SPFs to which it applies are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, \( n \)-lane entrance ramp \((rps, nEN, mv, fi)\);
- SPF for fatal-and-injury multiple-vehicle crashes, \( n \)-lane exit ramp \((rps, nEX, mv, fi)\); and
- SPF for fatal-and-injury multiple-vehicle crashes, \( n \)-lane C-D road \((cds, n, mv, fi)\).
The base condition is no ramp speed-change lane present. The CMF is described using the following equation.

\[
CMF_{8,w,x,mv,fi} = (1.0 - P_{en-ex}) \times 1.0 + P_{en-ex} \times \exp(0.310)
\]  
Equation 14-40

Where:

- \(CMF_{8,w,x,mv,fi}\) = crash modification factor for speed-change lane presence on a site of type \(w\), cross section \(x\), and with multiple-vehicle \(mv\) fatal-and-injury crashes \(fi\); and
- \(P_{en-ex}\) = proportion of segment length that is adjacent to the speed-change lane for a connecting ramp.

This CMF is used to evaluate a ramp or C-D road segment that is being joined by another ramp by way of a speed-change lane. The speed-change lane can be either an acceleration lane or a deceleration lane. This CMF is not used with the Weaving section CMF because the ramps in weaving section are joined by an auxiliary lane (i.e., they do not have a speed-change lane).

The variable \(P_{en-ex}\) in Equation 14-40 is computed as the ratio of the length of the ramp speed-change lane on the segment to the length of the segment. If the segment is wholly located in the speed-change lane, then this variable is equal to 1.0. If this CMF is used with the Lane add or drop CMF, then the variable \(P_{en-ex}\) is equal to the variable \(P_{yr}\).

**CMF\(_{9,cds,ac,y,z}\) — Weaving Section**

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

- SPF for fatal-and-injury multiple-vehicle crashes, \(n\)-lane C-D road \((cds, n, mv, fi)\);
- SPF for property-damage-only multiple-vehicle crashes, \(n\)-lane C-D road \((cds, n, mv, pdo)\);
- SPF for fatal-and-injury single-vehicle crashes, \(n\)-lane C-D road \((cds, n, sv, fi)\); and
- SPF for property-damage-only single-vehicle crashes, \(n\)-lane C-D road \((cds, n, sv, pdo)\).

The base condition is no weaving section on the C-D road segment. The CMFs are described using the following equation.

\[
CMF_{9,cds,ac,y,z} = (1.0 - P_{wev}) \times 1.0 + P_{wev} \times \exp\left(\frac{a + b \times \ln[c \times AADT_{e}]}{L_{wev}}\right)
\]  
Equation 14-41

Where:

- \(CMF_{9,cds,ac,y,z}\) = crash modification factor for weaving section presence on a C-D road segment with any cross section \(ac\), crash type \(y\), and severity \(z\);
- \(AADT_{e}\) = annual average daily traffic volume of C-D road segment (veh/day);
- \(P_{wev}\) = proportion of segment length within a weaving section; and
- \(L_{wev}\) = weaving section length (may extend beyond segment boundaries) (mi).
The regression coefficients for Equation 14-41 are provided in Table 14-31. The variable $P_{wev}$ in Equation 14-41 is computed as the ratio of the length of the weaving section on the segment to the length of the segment. If the segment is wholly located in the weaving section, then this variable is equal to 1.0.

### Table 14-31. Coefficients for Weaving Section CMF–C-D Road Segments

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>All types (mv)</td>
<td>Fatal and injury ($fi$)</td>
<td>$CMF_{9, cds, ac, mv, fi}$</td>
<td>0.191</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Property damage only (pdo)</td>
<td>$CMF_{9, cds, ac, mv, pdo}$</td>
<td>-0.0715</td>
<td></td>
</tr>
<tr>
<td>All types (sv)</td>
<td>Fatal and injury ($fi$)</td>
<td>$CMF_{9, cds, ac, sv, fi}$</td>
<td>0.191</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Property damage only (pdo)</td>
<td>$CMF_{9, cds, ac, sv, pdo}$</td>
<td>-0.0715</td>
<td></td>
</tr>
</tbody>
</table>

This CMF is used to evaluate C-D road segments that have some or all of their length in a weaving section. This CMF is not used with the Ramp speed-change lane CMF or the Lane add or drop CMF.

The variable for weaving section length $L_{wev}$ in Equation 14-41 is intended to reflect the degree to which the weaving activity is concentrated along the C-D road. The CMF is applicable to weaving section lengths in the range from 0.05 to 0.30 mi.

### 14.7.2. Crash Modification Factors for Ramp Terminals

The CMFs for geometric design and traffic control features of crossroad ramp terminals are presented in this section.

**CMF$_{10, w, x, at, ft}$—Exit Ramp Capacity**

Excessively long queues on exit ramps are recognized as sometimes creating unsafe operating conditions. Crash risk tends to increase as the length of ramp available for deceleration to the back of queue is reduced due to long queues at the downstream ramp terminal. The Exit ramp capacity CMF is derived to capture this influence.

Two CMFs are used to describe the relationship between exit ramp capacity and predicted crash frequency. The SPFs applicable to three-leg terminals with a diagonal exit ramp ($D3ex$) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, $n$ lanes ($D3ex, ST, at, fi$); and
- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, $n$ lanes ($D3ex, SGn, at, fi$).

There are two more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the $D3ex$ subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts ($D3en, D4, A4, B4, A2, B2$).
The CMFs are described using the following equation.

\[
CMF_{10, w, x, at, fi} = (1.0 - P_{ex}) \times 1.0 + P_{ex} \times \exp \left( a \times \frac{c \times AADT_{ex}}{n_{ex, eff}} \right)
\]

Equation 14-42

with,

\[
n_{ex, eff} = \begin{cases} 
0.5 \times (n_{ex} - 1.0) + 1.0 & : \text{merge or free–flow right turn} \\
0.5 \times n_{ex} & : \text{signal, stop, or yield–controlled right turn}
\end{cases}
\]

Equation 14-43

\[
P_{ex} = \frac{AADT_{ex}}{AADT_{en} + AADT_{out} + AADT_{en} + AADT_{ex}}
\]

Equation 14-44

Where:

\[
CMF_{10, w, x, at, fi} = \text{crash modification factor for exit ramp capacity at a site of type } w, \text{ cross section } x, \text{ and all types } at \text{ of fatal-and-injury crashes;}
\]

\[
P_{ex} = \text{proportion of total leg AADT on exit ramp leg;}
\]

\[
AADT_{en} = \text{annual average daily traffic volume for the entrance ramp (veh/day);}
\]

\[
AADT_{ex} = \text{annual average daily traffic volume for the exit ramp (veh/day);}
\]

\[
AADT_{in} = \text{annual average daily traffic volume for the crossroad leg between ramps (veh/day);}
\]

\[
AADT_{out} = \text{annual average daily traffic volume for the crossroad leg outside of interchange (veh/day);}
\]

\[
n_{ex, eff} = \text{effective number of lanes serving exit ramp traffic (lanes); and}
\]

\[
n_{ex} = \text{number of lanes serving exit ramp traffic (lanes).}
\]

The regression coefficients for Equation 14-42 are provided in Table 14-32. When computing \(P_{ex}\), the AADT volume of the loop exit ramp at a B4 terminal configuration is not included in \(AADT_{ex}\). Similarly, the AADT volume of the loop entrance ramp at an A4 configuration is not included in \(AADT_{en}\).

Table 14-32. Coefficients for Exit Ramp Capacity CMF–Crossroad Ramp Terminals

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficients</th>
</tr>
</thead>
</table>
| One-way stop control (ST)  | All types (at) | Fatal and injury (fi) | \(CMF_{10, w, ST, at, fi}\) | 0.151  
0.001                   |
| Signal control, all lanes (SGn) | All types (at) | Fatal and injury (fi) | \(CMF_{10, w, SGn, at, fi}\) | 0.0668  
0.001                   |

The effective number of lanes is based on the number of lanes on the exit ramp at the terminal, and the type of control used for the exit ramp right-turn movement. The constant “0.5” in Equation 14-43 approximately represents the ratio of capacity for a signal, stop, or yield controlled lane to the capacity of a free-flow lane.
Figure 14-23 illustrates the use of Equation 14-43 to calculate the effective number of lanes for various exit ramp configurations. This figure also indicates that all lanes counted need to be fully developed for 100 ft or more upstream from the point at which their respective movement intersects with the crossroad (as discussed in Section 14.4.2).

Figure 14-23. Effective Number of Lanes for Various Exit Ramp Configurations

Figure 14-23 shows eight exit ramps in plan view. The four ramps on the left side of the figure have two lanes serving exit ramp traffic. The four ramps on the right side of the figure have one lane serving exit ramp traffic (because the lane development is less than 100 ft). The two ramps at the bottom of the figure have merge or free-flow operation for the ramp right-turn movement. The other ramps have signal, stop, or yield control for the right-turn movement. The computed number of effective lanes is typically less than the actual lanes (i.e., \( n_{\text{ex, eff}} \leq n_{\text{ex}} \)) due to the control used for the ramp movement.

**CMF\(_{11, w, x, at, z}\)—Crossroad Left-Turn Lane**

Eight CMFs are used to describe the relationship between left-turn lane (or bay) presence and predicted crash frequency. The SPFs applicable to three-leg terminals with a diagonal exit ramp (\( D3ex \)) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, \( n \) lanes (\( D3ex, ST, at, fi \));
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, stop control, \( n \) lanes (\( D3ex, ST, at, pdo \));
- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, \( n \) lanes (\( D3ex, SGn, at, fi \)); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, \( n \) lanes (\( D3ex, SGn, at, pdo \)).
There are four more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the \( D3_{ex} \) subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (\( D3_{en}, D4, A4, B4, A2, B2 \)).

The base condition is no left-turn lane (or bay) present. The CMFs are described using the following equation.

\[
CMF_{11, w, x, at, z} = \left[ (1.0 - P_{in}) \times 1.0 + P_{in} \times a \right]^{I_{in, lt, k}} \times \left[ (1.0 - P_{out}) \times 1.0 + P_{out} \times a \right]^{I_{out, lt, k}}
\]  

Equation 14-45

with,

\[
P_{in} = \frac{AADT_{in}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}}
\]

Equation 14-46

\[
P_{out} = \frac{AADT_{out}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}}
\]

Equation 14-47

Where:

\( CMF_{11, w, x, at, z} = \) crash modification factor for left-turn lane (or bay) presence at a site of type \( w \), cross section \( x \), all crash types \( at \), and severity \( z \);

\( P_{in} = \) proportion of total leg AADT on crossroad leg between ramps;

\( P_{out} = \) proportion of total leg AADT on crossroad leg outside of interchange; and

\( I_{bay, lt, k} = \) left-turn lane (or bay) indicator variable for crossroad leg \( k \) (\( k = \text{in or out} \)) (= 1.0 if left-turn lane [or bay] is present, 0.0 otherwise).

The regression coefficient for Equation 14-45 is provided in Table 14-33. When computing \( P_{in} \) and \( P_{out} \), the AADT volume of the loop exit ramp at a \( B4 \) terminal configuration is not included in \( AADT_{ex} \). Similarly, the AADT volume of the loop entrance ramp at an \( A4 \) configuration is not included in \( AADT_{en} \).

**Table 14-33.** Coefficients for Crossroad Left-Turn Lane CMF–Crossroad Ramp Terminals

<table>
<thead>
<tr>
<th>Cross Section ((x))</th>
<th>Area Type</th>
<th>Crash Type ((y))</th>
<th>Crash Severity ((z))</th>
<th>CMF Variable</th>
<th>Regression Coefficient ((a))</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-way stop control ((ST))</td>
<td>Rural</td>
<td>All types ((at))</td>
<td>Fatal and injury ((fi))</td>
<td>( CMF_{11, w, ST, at, fi} )</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>( CMF_{11, w, ST, at, pdo} )</td>
<td>0.55</td>
</tr>
<tr>
<td>Urban</td>
<td></td>
<td></td>
<td>Fatal and injury ((fi))</td>
<td>( CMF_{11, w, ST, at, fi} )</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>( CMF_{11, w, ST, at, pdo} )</td>
<td>0.58</td>
</tr>
<tr>
<td>Signal control, all lanes ((SGn))</td>
<td>Rural</td>
<td>All types ((at))</td>
<td>Fatal and injury ((fi))</td>
<td>( CMF_{11, w, SGn, at, fi} )</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>( CMF_{11, w, SGn, at, pdo} )</td>
<td>0.66</td>
</tr>
<tr>
<td>Urban</td>
<td></td>
<td></td>
<td>Fatal and injury ((fi))</td>
<td>( CMF_{11, w, SGn, at, fi} )</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>( CMF_{11, w, SGn, at, pdo} )</td>
<td>0.68</td>
</tr>
</tbody>
</table>
This CMF is applicable to any crossroad approach that is either signalized or uncontrolled. It is not applicable to a stop-controlled approach. The CMF value is applicable to turn bays that have a design that is consistent with agency policy such that their length adequately provides for vehicle storage or deceleration, as appropriate.

**CMF\textsubscript{12, w, x, at, z}—Crossroad Right-Turn Lane**

Eight CMFs are used to describe the relationship between right-turn lane (or bay) presence and predicted crash frequency. The SPFs applicable to three-leg terminals with a diagonal exit ramp ($D3ex$) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, $n$ lanes ($D3ex$, $ST$, $at$, $fi$);
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, stop control, $n$ lanes ($D3ex$, $ST$, $at$, $pdo$);
- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, $n$ lanes ($D3ex$, $SGn$, $at$, $fi$); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, $n$ lanes ($D3ex$, $SGn$, $at$, $pdo$).

There are four more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the $D3ex$ subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts ($D3en$, $D4$, $A4$, $B4$, $A2$, $B2$).

The base condition is no right-turn lane (or bay) present. The CMFs are described using the following equation.

\[
CMF_{12, w, x, at, z} = \left[ (1.0 - P_{in}) \times 1.0 + P_{in} \times a \right]^{I_{bay, in}} \times \left[ (1.0 - P_{out}) \times 1.0 + P_{out} \times a \right]^{I_{bay, out}} \tag{Equation 14-48}
\]

Where:

- $CMF_{12, w, x, at, z} = \text{crash modification factor for right-turn lane (or bay) presence at a site of type } w, \text{ cross section } x, \text{ all crash types } at, \text{ and severity } z; \text{ and}$
- $I_{bay, rt, k} = \text{right-turn lane (or bay) indicator variable for crossroad leg } k (k = \text{in or out}) (= 1.0 \text{ if right-turn lane [or bay] is present, 0.0 otherwise}).$

The regression coefficient for Equation 14-48 is provided in Table 14-34. The variable $P_{in}$ is computed using Equation 14-46. The variable $P_{out}$ is computed using Equation 14-47.

This CMF is applicable to any crossroad approach that is either signalized or uncontrolled. It is not applicable to a stop-controlled approach. The CMF value is applicable to turn bays that have a design that is consistent with agency policy such that their length adequately provides for vehicle storage or deceleration, as appropriate.
Table 14-34. Coefficients for Crossroad Right-Turn Lane CMF–Crossroad Ramp Terminals

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Area Type</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficient (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-way stop control (ST)</td>
<td>Rural</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>CMF12, w, ST, at, fi</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>CMF12, w, ST, at, pdo</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>CMF12, w, ST, at, fi</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>CMF12, w, ST, at, pdo</td>
</tr>
<tr>
<td>Signal control, all lanes (SGn)</td>
<td>Rural</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>CMF12, w, SGn, at, fi</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>CMF12, w, SGn, at, pdo</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td>CMF12, w, SGn, at, fi</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td>CMF12, w, SGn, at, pdo</td>
</tr>
</tbody>
</table>

**CMF\textsubscript{13}, w, x, at, z—Access Point Frequency**

Three CMFs are used to describe the relationship between unsignalized access point presence and predicted crash frequency. The SPFs applicable to three-leg terminals with a diagonal exit ramp (D3ex) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, n lanes (D3ex, ST, at, fi);
- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, n lanes (D3ex, SGn, at, fi); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, n lanes (D3ex, SGn, at, pdo).

There are three more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the D3ex subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (D3en, D4, A4, B4, A2, B2).

The base condition is no unsignalized driveways and no unsignalized public street approaches present on the outside leg of the crossroad ramp terminal. The CMFs are described using the following equation.

\[
CMF_{13, \text{w, x, at, z}} = (1.0 - P_\text{out}) \times 1.0 + P_\text{out} \times \exp\left(a \times n_\text{ps} + b \times n_\text{dw}\right) \quad \text{Equation 14-49}
\]

Where:

- \(CMF_{13, \text{w, x, at, z}}\) = crash modification factor for access point frequency at a site of type w, cross section x, all crash types at, and severity z;
- \(n_\text{ps}\) = number of unsignalized public street approaches to the crossroad leg outside of the interchange and within 250 ft of the ramp terminal; and
- \(n_\text{dw}\) = number of unsignalized driveways on the crossroad leg outside of the interchange and within 250 ft of the ramp terminal.
The regression coefficients for Equation 14-49 are provided in Table 14-35. The variable $P_{out}$ is computed using Equation 14-47.

**Table 14-35. Coefficients for Access Point Frequency CMF–Crossroad Ramp Terminals**

<table>
<thead>
<tr>
<th>Cross Section ($x$)</th>
<th>Crash Type ($y$)</th>
<th>Crash Severity ($z$)</th>
<th>CMF Variable</th>
<th>Regression Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-way stop control ($ST$)</td>
<td>All types ($at$)</td>
<td>Fatal and injury ($fi$)</td>
<td>$CMF_{13, w, ST, at, fi}$</td>
<td>$a$</td>
</tr>
<tr>
<td>Signal control, all lanes ($SGn$)</td>
<td>All types ($at$)</td>
<td>Fatal and injury ($fi$)</td>
<td>$CMF_{13, w, SGn, at, fi}$</td>
<td>0.158</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ($pdo$)</td>
<td>$CMF_{13, w, SGn, at, pdo}$</td>
<td>0.203</td>
</tr>
</tbody>
</table>

This CMF applies to any ramp terminal with unsignalized driveways or unsignalized public street approaches on the crossroad leg that is outside of the interchange. Driveways and approaches on both sides of the leg should be counted when they are within 250 ft of the ramp terminal. The count of driveways should only include *active* driveways (i.e., those driveways with an average daily volume of 10 veh/day or more).

**CMF $_{14, w, x, at, z}$—Segment Length**

The distance between the subject ramp terminal and adjacent intersections (or terminals) along the crossroad is logically correlated with crossroad operating speed. This speed is likely to increase as distance increases, and an increase in speed may increase the risk of a crash.

Three CMFs are used to describe the relationship between intersection spacing and predicted crash frequency. The SPFs applicable to three-leg terminals with a diagonal exit ramp ($D3ex$) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, $n$ lanes ($D3ex, ST, at, fi$);
- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, $n$ lanes ($D3ex, SGn, at, fi$); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, $n$ lanes ($D3ex, SGn, at, pdo$).

There are three more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the $D3ex$ subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts ($D3en, D4, A4, B4, A2, B2$).

The base condition is no adjacent ramp or public street intersection within 6 mi. The CMFs are described using the following equation.

$$CMF_{14, w, x, at, z} = \exp\left(a \times \frac{1.0}{L_{emp}} + \frac{1.0}{L_{str}} - 0.333\right)$$

Equation 14-50

Where:

$CMF_{14, w, x, at, z}$ = crash modification factor for segment length at a site of type $w$, cross section $x$, all crash types $at$, and severity $z$;
\[ L_{\text{ramp}} = \text{distance between subject ramp terminal and adjacent ramp terminal (measured along the crossroad from terminal center to terminal center) (mi)}; \text{ and} \]
\[ L_{\text{CTR}} = \text{distance between subject ramp terminal and nearest public road intersection in a direction away from freeway (measured along the crossroad from terminal center to intersection center) (mi)}. \]

The regression coefficient for Equation 14-50 is provided in Table 14-36.

**Table 14-36. Coefficients for Segment Length CMF–Crossroad Ramp Terminals**

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficient ((a))</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-way stop control ((ST))</td>
<td>All types ((at))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{14, w, ST, at, fi})</td>
<td>-0.0141</td>
</tr>
<tr>
<td>Signal control, all lanes ((SGn))</td>
<td>All types ((at))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{14, w, SGn, at, fi})</td>
<td>-0.0185</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{14, w, SGn, at, pdo})</td>
<td>-0.0186</td>
</tr>
</tbody>
</table>

This CMF describes the relationship between ramp terminal crash frequency and the distance to the adjacent ramp or nearest public street intersection. The adjacent ramp or intersection can be signalized or unsignalized. The CMF is applicable to distances of 0.02 mi or more.

**CMF\(_{15, w, x, z, a, t}\)—Median Width**

Research indicates that median width at an intersection can influence crash frequency, provided that this width is 14 ft or more (2). At rural unsignalized intersections, an increase in median width is associated with a decrease in crash frequency. In contrast, at urban intersections (unsignalized and signalized), an increase in median width is associated with an increase in crash frequency. This latter trend is contrary to segment-based safety research that shows crash frequency decreases with an increase in median width. Conflict studies have confirmed a tendency for improper use of wide median areas within intersections that, when complicated by high traffic volume, results in an increased propensity for multiple-vehicle crashes (2).

Three CMFs are used to describe the relationship between crossroad median width and predicted crash frequency. The SPFs applicable to three-leg terminals with a diagonal exit ramp \((D3ex)\) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, \(n\) lanes \((D3ex, ST, at, fi)\);
- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, \(n\) lanes \((D3ex, SGn, at, fi)\); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, \(n\) lanes \((D3ex, SGn, at, pdo)\).

There are three more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the \(D3ex\) subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts \((D3en, D4, A4, B4, A2, B2)\).
The base condition is a 12-ft median width. The CMFs are described using the following equation.

\[
CMF_{15, w, x, at, z} = \left[ (1.0 - P_{in}) \times 1.0 + P_{in} \times \exp\left\{ a \times b \times c \times AADT_{in} \times W_{me, in} \right\} \right] \\
\times \left[ (1.0 - P_{out}) \times 1.0 + P_{out} \times \exp\left\{ a \times b \times c \times AADT_{out} \times W_{me, out} \right\} \right]
\]

Equation 14-51

with,

\[
W_{me, k} = W_m - \max(W_{h, k}, 12) \geq 0.0
\]

Equation 14-52

Where:

- \(CMF_{15, w, x, at, z}\) = crash modification factor for median width at a site of type \(w\), cross section \(x\), all crash types \(at\), and severity \(z\);
- \(W_{me, k}\) = width of median adjacent to turn lane (or bay) for crossroad leg \(k\) (\(k = in\) or \(out\)) (ft);
- \(W_{h, k}\) = left-turn lane (or bay) width for crossroad leg \(k\) (\(k = in\) or \(out\)) (= 0.0 if no lane present on leg) (ft); and
- \(W_m\) = median width (ft).

The regression coefficients for Equation 14-51 are provided in Table 14-37. The variable \(P_{in}\) is computed using Equation 14-46. The variable \(P_{out}\) is computed using Equation 14-47.

**Table 14-37. Coefficients for Median Width CMF–Crossroad Ramp Terminals**

<table>
<thead>
<tr>
<th>Cross Section ((x))</th>
<th>Crash Type ((y))</th>
<th>Crash Severity ((z))</th>
<th>CMF Variable</th>
<th>Regression Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-way stop control (ST)</td>
<td>All types ((at))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{15, w, ST, at, fi})</td>
<td>-0.0322 0.00354 0.001</td>
</tr>
<tr>
<td>Signal control, all lanes ((SGn))</td>
<td>All types ((at))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{15, w, SGn, at, fi})</td>
<td>0.0287 -0.00074 0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{15, w, SGn, at, pdo})</td>
<td>0.0610 -0.00246 0.001</td>
</tr>
</tbody>
</table>

For signalized ramp terminals, the applicable values for \(AADT_{in}\) and \(AADT_{out}\) range from 14,000 to 60,000 veh/day. AADT volumes smaller than 14,000 should be set to 14,000 in Equation 14-51.

For unsignalized ramp terminals, the applicable values for \(AADT_{in}\) and \(AADT_{out}\) range from 0 to 14,000 veh/day. AADT volumes larger than 14,000 should be set to 14,000 in Equation 14-51.

The CMF is applicable to \(W_m\) values in the range of 0 to 50 ft. Similarly, it is applicable to \(W_{h, k}\) values in the range of 0 to 26 ft.

**CMF_{16, w, SGn, at, z}—Protected Left-Turn Operation**

Two CMFs are used to describe the relationship between protected-only left-turn operation and predicted crash frequency. The SPF's applicable to three-leg terminals with a diagonal exit ramp (\(D3ex\)) are identified in the following list:
- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, \( n \) lanes (\( D3ex, SGn, at, fi \)); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, \( n \) lanes (\( D3ex, SGn, at, pdo \)).

There are two more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the \( D3ex \) subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (\( D3en, D4, A4, B4, A2, B2 \)).

The base condition is permissive or protected-permissive left-turn operation (i.e., not protected-only operation). The CMFs are described using the following equation.

\[
CMF_{16, w, SGn, at, z} = \left[ (1.0 - P_{xrd}) \times 1.0 + P_{xrd} \times \exp(a \times n_{x, in}) \right]^{I_{p, h, in}} \times \left[ (1.0 - P_{xrd}) \times 1.0 + P_{xrd} \times \exp(a \times n_{x, out}) \right]^{I_{p, h, out}}
\]

with,

\[
P_{xrd} = \frac{AADT_{in} + AADT_{out}}{AADT_{en} + AADT_{ex} + AADT_{in} + AADT_{ex}}
\]

where:

\( CMF_{16, w, SGn, at, z} \) = crash modification factor for protected left-turn operation at a signal-controlled site of type \( w \), with \( n \) crossroad lanes, all crash types \( at \), and severity \( z \);

\( n_{x, k} \) = number of through traffic lanes that oppose the left-turn movement on crossroad leg \( k \) (\( k = \text{in or out} \) (lanes));

\( P_{xrd} \) = proportion of total leg AADT on crossroad; and

\( I_{p, h, k} \) = protected left-turn operation indicator variable for crossroad leg \( k \) (\( k = \text{in or out} \) (= 1.0 if protected operation exists, 0.0 otherwise)).

The regression coefficient for Equation 14-53 is provided in Table 14-38. When computing \( P_{xrd} \), the AADT volume of the loop exit ramp at a \( B4 \) terminal configuration is not included in \( AADT_{ex} \). Similarly, the AADT volume of the loop entrance ramp at an \( A4 \) configuration is not included in \( AADT_{en} \).

<p>| Table 14-38. Coefficients for Protected Left-Turn Operation CMF–Crossroad Ramp Terminals |
|---------------------------------------------------------------|-------------------|---------------------------------|</p>
<table>
<thead>
<tr>
<th>Cross Section (( x ))</th>
<th>Crash Type (( y ))</th>
<th>Crash Severity (( z ))</th>
<th>CMF Variable</th>
<th>Regression Coefficient (( a ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal control, all lanes (( SGn ))</td>
<td>All types (( at ))</td>
<td>Fatal and injury (( fi ))</td>
<td>( CMF_{16, w, SGn, at, fi} )</td>
<td>-0.363</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (( pdo ))</td>
<td>( CMF_{16, w, SGn, at, pdo} )</td>
<td>-0.223</td>
</tr>
</tbody>
</table>

The CMF is applicable to \( n_{x, k} \) values in the range of 1 to 3 lanes.
**CMF \(17, w, SGn, at, z\)—Channelized Right Turn on Crossroad**

Two CMFs are used to describe the relationship between crossroad right-turn channelization and predicted crash frequency. The SPFs applicable to three-leg terminals with a diagonal exit ramp \(D3ex\) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, \(n\) lanes \((D3ex, SGn, at, fi)\); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, \(n\) lanes \((D3ex, SGn, at, pdo)\).

There are two more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the \(D3ex\) subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts \((D3en, D4, A4, B4, A2, B2)\).

The base condition is no crossroad right-turn channelization. The CMFs are described using the following equation.

\[
CMF_{17, w, SGn, at, z} = \left[ (1.0 - P_{in}) \times 1.0 + P_{in} \times \exp(a) \right]^{I_{ch, in}} \times \left[ (1.0 - P_{out}) \times 1.0 + P_{out} \times \exp(a) \right]^{I_{ch, out}} \tag{Equation 14-55}
\]

Where:

\(CMF_{17, w, SGn, at, z}\) = crash modification factor for crossroad right-turn channelization at a signal-controlled site of type \(w\), with \(n\) crossroad lanes, all crash types \(at\), and severity \(z\); and

\(I_{ch, k}\) = right-turn channelization indicator variable for crossroad leg \(k\) \((k = \text{in or out})\) (= 1.0 if right-turn channelization exists, 0.0 otherwise).

The regression coefficient for Equation 14-55 is provided in Table 14-39. The variable \(P_{in}\) is computed using Equation 14-46. The variable \(P_{out}\) is computed using Equation 14-47.

**Table 14-39. Coefficients for Channelized Right Turn on Crossroad CMF—Crossroad Ramp Terminals**

<table>
<thead>
<tr>
<th>Cross Section ((x))</th>
<th>Crash Type ((y))</th>
<th>Crash Severity ((z))</th>
<th>CMF Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal control, all lanes ((SGn))</td>
<td>All types ((at))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{17, w, SGn, at, fi})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{17, w, SGn, at, pdo})</td>
</tr>
</tbody>
</table>

This CMF is applicable to any ramp terminal with right-turn channelization on one or both crossroad legs, where the associated right-turn movement is turning from the crossroad. This CMF can be applied to channelization associated with the loop entrance ramp of the \(A4\) configuration.

**CMF \(18, w, SGn, at, z\)—Channelized Right Turn on Exit Ramp**

Two CMFs are used to describe the relationship between exit ramp right-turn channelization and predicted crash frequency. The SPFs applicable to three-leg terminals with a diagonal exit ramp \(D3ex\) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, \(n\) lanes \((D3ex, SGn, at, fi)\); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, \(n\) lanes \((D3ex, SGn, at, pdo)\).
There are two more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the \(D3\text{ex}\) subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (\(D3\text{en}, D4, A4, B4, A2, B2\)).

The base condition is no exit ramp right-turn channelization. The CMFs are described using the following equation.

\[
CMF_{18, w, SGn, at, z} = [(1.0 - P_{ex}) \times 1.0 + P_{ex} \times \exp(a)]^{I_{ch, ex}}
\]

Equation 14-56

Where:

\(CMF_{18, w, SGn, at, z}\) = crash modification factor for exit ramp right-turn channelization at a signal-controlled site of type \(w\), with \(n\) crossroad lanes, all crash types \(at\), and severity \(z\); and

\(I_{ch, ex}\) = right-turn channelization indicator variable for exit ramp (= 1.0 if right-turn channelization exists, 0.0 otherwise).

The regression coefficient for Equation 14-56 is provided in Table 14-40. The variable \(P_{ex}\) is computed using Equation 14-44.

<table>
<thead>
<tr>
<th>Cross Section ((x))</th>
<th>Crash Type ((y))</th>
<th>Crash Severity ((z))</th>
<th>CMF Variable</th>
<th>Regression Coefficient ((a))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal control, all lanes ((SGn))</td>
<td>All types ((at))</td>
<td>Fatal and injury ((fi))</td>
<td>(CMF_{18, w, SGn, at, fi})</td>
<td>0.992</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only ((pdo))</td>
<td>(CMF_{18, w, SGn, at, pdo})</td>
<td>1.429</td>
</tr>
</tbody>
</table>

This CMF is applicable to any ramp terminal with an exit ramp that has left-turn and right-turn movements and right-turn channelization. This CMF is not applicable to the loop exit ramp of the \(B4\) configuration.

**CMF\(_{19, w, SGn, at, z}\) — Non-Ramp Public Street Leg**

Two CMFs are used to describe the relationship between public-street leg presence and predicted crash frequency. The SPFs applicable to three-leg terminals with a diagonal exit ramp (\(D3\text{ex}\)) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, \(n\) lanes (\(D3\text{ex}, SGn, at, fi\)); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, \(n\) lanes (\(D3\text{ex}, SGn, at, pdo\)).

There are two more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the \(D3\text{ex}\) subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (\(D3\text{en}, D4, A4, B4, A2, B2\)).

The base condition is no public-street leg present. The CMFs are described using the following equation.

\[
CMF_{19, w, SGn, at, z} = \exp(a \times I_{ps})
\]

Equation 14-57

Where:
**CMF**<sub>19, w, SGn, at, z</sub> = crash modification factor for non-ramp public street leg presence at a signal-controlled site of type **w**, with **n** crossroad lanes, all crash types **at**, and severity **z**; and

**I<sub>px</sub>** = non-ramp public street leg indicator variable (= 1.0 if leg is present, 0.0 otherwise).

The regression coefficient for Equation 14-57 is provided in Table 14-41. The variable **P<sub>ex</sub>** is computed using Equation 14-44.

This CMF is applicable to any ramp terminal that has a fourth leg that (a) is a public street serving two-way traffic and (b) intersects with the crossroad at the terminal. 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.

**Table 14-41. Coefficients for Non-Ramp Public Street Leg CMF–Crossroad Ramp Terminals**

<table>
<thead>
<tr>
<th>Cross Section (x)</th>
<th>Crash Type (y)</th>
<th>Crash Severity (z)</th>
<th>CMF Variable</th>
<th>Regression Coefficient (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal control, all lanes (SGn)</td>
<td>All types (at)</td>
<td>Fatal and injury (fi)</td>
<td><strong>CMF</strong>&lt;sub&gt;19, w, SGn, at, fi&lt;/sub&gt;</td>
<td>0.592</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property damage only (pdo)</td>
<td><strong>CMF</strong>&lt;sub&gt;19, w, SGn, at, pdo&lt;/sub&gt;</td>
<td>0.520</td>
</tr>
</tbody>
</table>

**CMF**<sub>20, w, ST, at, fi</sub>—**Skew Angle**

One CMF is used to describe the relationship between the exit ramp skew angle and predicted crash frequency. The SPFs applicable to three-leg terminals with a diagonal exit ramp (**D3ex**) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, **n** lanes (**D3ex**, **ST**, **at**, **fi**).

There is one more SPF for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the **D3ex** subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (**D3en**, **D4**, **A4**, **B4**, **A2**, **B2**).

The base condition is no skew in the intersecting alignments (i.e., a skew angle of 0.0 degrees). The CMFs are described using the following equation.

\[
CMF_{20,w,ST,at,fi} = (1.0 - P_{ex}) \times 1.0 + P_{ex} \times \exp(0.341 \times \sin(I_{sk})) \times 0.001 \times AADT_{ex} \\
\]

Equation 14-58

Where:

**CMF**<sub>20, w, ST, at, fi</sub> = crash modification factor for skew angle at a stop-controlled site of type **w**, with **n** crossroad lanes, and all types **at** of fatal-and-injury crashes **fi**; and **I<sub>sk</sub>** = skew angle between exit ramp and crossroad (degrees).

The variable **P<sub>ex</sub>** is computed using Equation 14-44.

This CMF is applicable to any one-way stop-controlled ramp terminal with an exit ramp that has stop or yield control for the “reference” exit ramp movement. The reference movement is the left-turn movement for all terminal configurations except the **B4** configuration. At a **B4** ramp terminal, the reference movement is
the right-turn movement on the diagonal exit ramp (not the loop exit ramp). This CMF is applicable to skew angles in the range of 0 to 70 degrees.

14.7.3. Supplemental Calculations to Apply Crash Modification Factors
Some of the CMFs in Section 14.7.1 require the completion of supplemental calculations before they can be applied to the SPFs in Section 14.6. These CMFs are: Horizontal curve, Right side barrier, and Left side barrier.

This section consists of two subsections. The first section describes the procedure for calculating the curve entry speed needed for the Horizontal curve CMF. The second section describes the procedure for calculating the barrier-related variables for the Right side Barrier CMF and the Left side Barrier CMF.

Calculation of Curve Entry Speed
This subsection describes a procedure for predicting the average curve entry speed for each curve on a ramp or C-D road. This procedure is developed for use with the Horizontal curve CMF, as described in Section 14.7.1. It is not intended to be used with other applications, or to predict vehicle speed at other points along a ramp or C-D road.

The speed prediction procedure consists of a sequence of steps that lead to a prediction of average entry speed for each horizontal curve on the subject ramp or C-D road. Each curve is addressed by the procedure in the same sequence as they are encountered when traveling along the ramp or C-D road. In this manner, the speed for all previous curves encountered must be calculated first, before the speed on the subject curve can be calculated. The steps used will vary depending on whether the segment is part of an entrance ramp, exit ramp, connector ramp, or C-D road.

The horizontal curves are located along the ramp or C-D road using a linear referencing system. For exit ramps, the “0.0” milepost is located at the gore point. For entrance ramps that intersect the crossroad, the “0.0” milepost is located at the point where the ramp reference line intersects with the near edge of traveled way of the crossroad. The location of the “0.0” milepost is shown in Figure 14-4 for simple situations. It is shown in Figure 14-24 for more complex ramp and C-D road combinations. When a specific entrance ramp or C-D road segment serves traffic from two or more sources combined, the “0.0” milepost for this segment should be that of the one ramp that is the source of the highest daily traffic volume.

![Figure 14-24](image.png)

a. Exit Ramp

b. Entrance Ramp

Figure 14-24. Starting Milepost Location for Ramp and C-D Road Combinations
c. Entrance and Exit Ramps with C-D Road

Figure 14-24. Starting Milepost Location for Ramp and C-D Road Combinations continued

The input data needed for this procedure are identified in Table 14-42. The first three variables listed represent required input data. Default values are provided for the remaining variables.

Table 14-42. Input Data for Ramp Curve Speed Prediction

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Default Value</th>
<th>Applicable Site Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_i$</td>
<td>Milepost of the point of change from tangent to curve (PC) for curve $i$ (mi)</td>
<td>None</td>
<td>All</td>
</tr>
<tr>
<td>$R_i$</td>
<td>Radius of curve $i$ (ft)</td>
<td>None</td>
<td>All</td>
</tr>
<tr>
<td>$L_{c,i}$</td>
<td>Length of horizontal curve $i$ (mi)</td>
<td>None</td>
<td>All</td>
</tr>
<tr>
<td>$V_{fry}$</td>
<td>Average traffic speed on the freeway during off-peak periods of the typical day (mi/h)</td>
<td>Estimate as equal to the speed limit</td>
<td>All</td>
</tr>
<tr>
<td>$V_{xroad}$</td>
<td>Average speed at the point where the ramp connects to the crossroad (mi/h)</td>
<td>15 – ramps with stop-, yield-, or signal-controlled crossroad ramp terminals 30 – all other ramps at service interchanges</td>
<td>Entrance ramp, exit ramp, connector ramp at service interchange</td>
</tr>
<tr>
<td>$V_{cdroad}$</td>
<td>Average speed on C-D road or connector ramp (measured at the mid-point of the C-D road or ramp) (mi/h)</td>
<td>40</td>
<td>C-D road, connector ramp at system interchange</td>
</tr>
</tbody>
</table>

Notes:

a. If the curve is preceded by a spiral transition, then $X_i$ is computed as equal to the average of the TS and SC mileposts, where TS is the milepost of the point of change from tangent to spiral and SC is the milepost of the point of change from spiral to curve.

b. If the curve has spiral transitions, then $R_i$ is equal to the radius of the central circular portion of the curve.
**Entrance Ramp Procedure**

This procedure is applicable to entrance ramps and connector ramps at service interchanges that serve motorists traveling from the crossroad to the freeway.

**Step 1—Gather Input Data.** The input data needed for this procedure are identified in Table 14-42.

**Step 2—Compute Limiting Curve Speed.** The limiting curve speed is computed for each curve on the ramp using the following equation.

\[
v_{max,i} = 3.24 \times (32.2 \times R_i)^{0.30}
\]

where \(v_{max,i}\) is the limiting speed for curve \(i\) (ft/s).

The analysis proceeds in the direction of travel. The first curve encountered is curve 1 (\(i = 1\)). The value of \(v_{max}\) is computed for all curves prior to, and including, the curve of interest. The value obtained from Equation 14-59 represents an upper limit on the curve speed. The vehicle may reach this speed if the distance between curves is lengthy or the crossroad speed is high.

**Step 3—Calculate Curve 1 Entry Speed.** The average entry speed at curve 1 is computed using the following equation.

\[
v_{ent,1} = \left(1.47 \times V_{xroad}^3 + 495 \times 5.280 \times X_1 \right)^{1/3} \leq 1.47 \times V_{frwy}
\]

where \(v_{ent,1}\) is the average entry speed for curve 1 (ft/s).

The boundary condition on the right side of the equation indicates that the value computed cannot exceed the average freeway speed.

**Step 4—Calculate Curve 1 Exit Speed.** The average exit speed at curve 1 is equal to the value obtained from the following equation.

\[
v_{ext,1} = \left(v_{ent,1} + 495 \times 5.280 \times L_{c,1} \right)^{1/3} \leq v_{max,1} \text{ and } \leq 1.47 \times V_{frwy}
\]

where \(v_{ext,1}\) is the average exit speed for curve 1 (ft/s).

The boundary condition indicates that the value computed should not exceed the limiting curve speed or the average freeway speed.

**Step 5—Calculate Curve i Entry Speed.** The average entry speed at curve 2 (and all subsequent curves) is computed using the following equation.

\[
v_{ent,i} = \left(v_{ext,i-1} + 495 \times 5.280 \times \left[X_i - X_{i-1} - L_{c,i-1} \right] \right)^{1/3} \leq 1.47 \times V_{frwy}
\]

where, \(v_{ent,i}\) equals the average entry speed for curve \(i\) (\(i = 2, 3, \ldots\)) (ft/s) and \(v_{ext,i}\) equals the average exit speed for curve \(i\) (ft/s).

**Step 6—Calculate Curve i Exit Speed.** The average exit speed at curve 2 (and all subsequent curves) is computed using the following equation.
Step 7—Calculate Speed on Successive Curves. The entry and exit speeds for curve 3 and higher are computed by applying Steps 5 and 6 for each curve. Step 6 does not need to be applied for the last curve because only the entry speed is used in the safety evaluation.

**Exit Ramp Procedure**

This procedure is applicable to exit ramps and connector ramps at service interchanges that serve motorists traveling from the freeway to the crossroad.

Step 1—Gather Input Data. The input data needed for this procedure are identified in Table 14-42.

Step 2—Compute Limiting Curve Speed. This step is the same as Step 2 for the entrance ramp procedure. A lower curve speed than that obtained from Equation 14-59 is possible due to the deceleration that occurs as the driver transitions from the freeway speed to the crossroad speed.

Step 3—Calculate Curve 1 Entry Speed. The average entry speed at curve 1 is computed using the following equation.

\[ v_{ent,1} = 1.47 \times V_{frwy} - 0.034 \times 5,280 \times X_1 \geq 1.47 \times V_{xroad} \]

The boundary condition on the right side of the equation indicates that the value computed cannot be less than the average speed at the point where the ramp connects to the crossroad.

Step 4—Calculate Curve 1 Exit Speed. This step is the same as Step 4 for the entrance ramp procedure.

\[ v_{ext,1} = v_{ent,1} - 0.034 \times 5,280 \times L_{c,1} \leq v_{max,1} \text{ and } v_{ext,1} \geq 1.47 \times V_{xroad} \]

The boundary condition indicates that the value computed should not exceed the limiting curve speed and should not be less than the average speed at the point where the ramp connects to the crossroad.

Step 5—Calculate Curve \( i \) Entry Speed. The average entry speed at curve 2 (and all subsequent curves) is computed using the following equation.

\[ v_{ent,i} = v_{ent,i-1} - 0.034 \times 5,280 \times (X_i - X_{i-1} - L_{c,i-1}) \geq 1.47 \times V_{xroad} \]

Step 6—Calculate Curve \( i \) Exit Speed. The average exit speed at curve 2 (and all subsequent curves) is computed using the following equation.

\[ v_{ext,i} = v_{ent,i} - 0.034 \times 5,280 \times L_{c,i} \leq v_{max,i} \text{ and } v_{ext,i} \geq 1.47 \times V_{xroad} \]

Step 7—Calculate Speed on Successive Curves. This step is the same as Step 7 for the entrance ramp procedure.

**C-D Road Procedure**

This procedure is applicable to C-D roads and connector ramps at system interchanges.

Step 1—Gather Input Data. The input data needed for this procedure are identified in Table 14-42.

Step 2—Compute Limiting Curve Speed. This step is the same as Step 2 for the entrance ramp procedure.
Step 3—Calculate Curve 1 Entry Speed. The average entry speed at curve 1 is computed using Equation 14-68 or Equation 14-69, depending on the following two conditions.

If $1.47 \times V_{frwy} \leq v_{max,1}$ then:

$$v_{ent,1} = 1.47 \times V_{frwy}$$  \hspace{2cm} \text{Equation 14-68}

If $1.47 \times V_{frwy} > v_{max,1}$ then:

$$v_{ent,1} = 1.47 \times V_{frwy} - 0.034 \times 5.280 \times X_1 \geq 1.47 \times V_{cdroad}$$  \hspace{2cm} \text{Equation 14-69}

The boundary condition for Equation 14-69 indicates that the value computed cannot be less than the average speed on the C-D road.

Step 4—Calculate Curve 1 Exit Speed. The average exit speed at curve 1 is equal to the entrance speed, provided that it does not exceed the limiting curve speed. The following rule is used to make this determination.

$$v_{ext,1} = v_{ent,1} \leq v_{max,1}$$  \hspace{2cm} \text{Equation 14-70}

Step 5—Calculate Curve $i$ Entry Speed. The average entry speed at curve 2 (and all subsequent curves) is computed using Equation 14-71 or Equation 14-72, depending on the following conditions.

If $v_{ext,i-1} \leq v_{max,i}$ then:

$$v_{ent,i} = \left(\frac{3}{2} v_{ext,i-1} + 495 \times 5.280 \times (X_i - X_{i-1} - L_{c,i-1})\right)^{\frac{1}{3}} \leq 1.47 \times V_{frwy}$$  \hspace{2cm} \text{Equation 14-71}

If $v_{ext,i-1} > v_{max,i}$ then:

$$v_{ent,i} = v_{ext,i-1} - 0.034 \times 5.280 \times (X_i - X_{i-1} - L_{c,i-1}) \geq 1.47 \times V_{cdroad}$$  \hspace{2cm} \text{Equation 14-72}

Step 6—Calculate Curve $i$ Exit Speed. The average exit speed at curve 2 (and all subsequent curves) is computed using the following equation.

$$v_{ext,i} = v_{ent,i} \leq v_{max,i}$$  \hspace{2cm} \text{Equation 14-73}

Step 7—Calculate Speed on Successive Curves. This step is the same as Step 7 for the entrance ramp procedure.

**Calculation of Barrier-Related Variables**

The two barrier CMFs include variables that describe the presence of barrier on the left or right side of the ramp or C-D road. These variables include barrier offset and length.

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

Two key variables that are needed for the evaluation of barrier presence are the right side barrier offset distance $W_{rcb}$ and the left side barrier offset distance $W_{lcb}$. As indicated in Equation 14-37 and Equation 14-
38, this distance is included as a divisor in the exponential term. This relationship implies that the correlation between distance and crash frequency is an inverse one (i.e., crash frequency decreases with increasing distance to the barrier). When multiple sections of barrier exist along the segment, a length-weighted average of the reciprocal of the individual distances is needed to properly reflect this inverse relationship. The length used to weight the average is the barrier length.

Additional key variables include the proportion of segment length with a barrier present on the right side \( P_{rb} \) and the proportion of segment length with a barrier present on the left side \( P_{lb} \). Equations for calculating these proportions and the aforementioned distances are described in the following paragraphs.

The length of segment \( L \) used in the following equations is equal to that of the ramp segment \( L_r \) or C-D road segment \( L_{rcd} \), as appropriate for the CMF to which the calculated value will be applied.

The following equations should be used to estimate \( W_{rcb} \) and \( P_{rb} \).

\[
W_{rcb} = \frac{\sum L_{rb,i}}{\sum W_{off,r,i} - W_{rs}} \\
P_{rb} = \frac{\sum L_{rb,i}}{L}
\]

Equation 14-74

Equation 14-75

Where:

\( W_{rcb} \) = distance from edge of right shoulder to barrier face (ft);

\( P_{rb} \) = proportion of segment length with a barrier present on the right side;

\( L \) = length of segment (mi);

\( L_{rb,i} \) = length of right side lane paralleled by barrier \( i \) (mi);

\( W_{rs} \) = right shoulder width (ft); and

\( W_{off,r,i} \) = horizontal clearance from the edge of the traveled way to the face of right side barrier \( i \) (ft).

Any clearance distance (\( = W_{off,r,i} - W_{rs} \)) that is less than 0.25 ft should be set to 0.25 ft.

The following equations should be used to estimate \( W_{lb} \) and \( P_{lb} \).

\[
W_{lb} = \frac{\sum L_{lb,i}}{\sum W_{off,l,i} - W_{ls}} \\
P_{lb} = \frac{\sum L_{lb,i}}{L}
\]

Equation 14-76

Equation 14-77

Where:

\( W_{lb} \) = distance from edge of left shoulder to barrier face (ft);
\[ P_{lb} = \text{proportion of segment length with a barrier present on the left side}; \]
\[ L = \text{length of segment (mi)}; \]
\[ L_{lb,i} = \text{length of left side lane paralleled by barrier } i \text{ (mi)}; \]
\[ W_{ls} = \text{left shoulder width (ft)}; \text{ and} \]
\[ W_{off, l, i} = \text{horizontal clearance from the edge of the traveled way to the face of left side barrier } i \text{ (ft)}. \]

Any clearance distance (\( = W_{off, l, i} - W_{ls} \)) that is less than 0.25 ft should be set to 0.25 ft.

### 14.8. SEVERITY DISTRIBUTION FUNCTIONS

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

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

\[ N_{e,w,x,y,i} = N_{e,w,x,y,fi} \times P_{w,ac,at,j} \]  
Equation 14-78

Where:

\[ N_{e,w,x,y,j} = \text{expected average crash frequency for site type } w, \text{cross section or control type } x, \text{crash type } y, \text{and severity level } j \text{ (} j = K: \text{fatal, } A: \text{incapacitating injury, } B: \text{non-incapacitating injury, } C: \text{possible injury}) \text{ (crashes/yr)}; \]
\[ N_{e,w,x,y,fi} = \text{expected average crash frequency for site type } w, \text{cross section or control type } x, \text{crash type } y, \text{and fatal-and-injury crashes } fi \text{ (crashes/yr)}; \text{ and} \]
\[ P_{w,ac,at,j} = \text{probability of the occurrence of severity level } j \text{ (} j = K: \text{fatal, } A: \text{incapacitating injury, } B: \text{non-incapacitating injury, } C: \text{possible injury}) \text{ for all crash types } at \text{ at site type } w \text{ with any cross section } ac. \]

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

### 14.8.1. Severity Distribution Functions for Ramp Segments

The SDFs for ramp and C-D road segments are described by the following equations.

\[ P_{rps+cds,ac,at,K} = \frac{\exp(V_{K+A})}{C_{cds}_{rps+cds}} \times P_{K+A, rps+cds, ac, at} \]  
Equation 14-79
\[
P_{\text{rps+cds,ac,at},A} = \frac{\exp(V_{K+A})}{C_{\text{sdf, rps+cds}}} \times (1.0 - \exp(V_{K+A}) + \exp(V_P)) \quad \text{Equation 14-80}
\]

\[
P_{\text{rps+cds,ac,at},B} = \frac{\exp(V_P)}{C_{\text{sdf, rps+cds}}} \quad \text{Equation 14-81}
\]

\[
P_{\text{rps+cds,ac,at},C} = 1.0 - (P_K + P_A + P_B) \quad \text{Equation 14-82}
\]

Where:

\[V_j = \text{systematic component of crash severity likelihood for severity level } j;\]

\[P_{K|K+A, rps+cds, ac, at} = \text{probability of a fatal } K \text{ crash given that the crash has a severity of either fatal or incapacitating injury } A \text{ on a ramp or C-D road segment based on all crash types } at \text{ and any cross section } ac; \text{ and}\]

\[C_{\text{sdf, rps+cds}} = \text{calibration factor to adjust SDF for local conditions for ramp and C-D road segments.}\]

The first term Equation 14-79 estimates the probability of a fatal or incapacitating injury crash. The second term (i.e., \(P_{K|K+A}\)) is used to convert the estimate into the probability of a fatal crash. A value of 0.248 is used for \(P_{K|K+A}\) based on an analysis of fatal and incapacitating injury crashes on ramps and C-D road segments.

A model for estimating the systematic component of crash severity \(V_j\) for ramp and C-D road segments is described by the following equation.

\[V_j = a + \left( b \times \frac{P_{lb} + P_{rb}}{2} \right) + (c \times n) + (d \times I_{rural}) + (e \times I_{extr}) \quad \text{Equation 14-83}\]

Where:

\[P_{lb} = \text{proportion of segment length with a barrier present on the left side;}\]

\[P_{rb} = \text{proportion of segment length with a barrier present on the right side;}\]

\[n = \text{number of through lanes on the segment (lanes);}\]

\[I_{rural} = \text{area type indicator variable (= 1.0 if area is rural, 0.0 if it is urban);}\]

\[I_{extr} = \text{exit ramp indicator variable (= 1.0 if segment is an exit ramp, 0.0 otherwise);}\]

\[a, b, c, d, e = \text{regression coefficients.}\]

The SDF regression coefficients in Equation 14-83 are provided in Table 14-43. Guidance for computing the variables \(P_{lb}\) and \(P_{rb}\) is provided in Section 14.7.3.
Table 14-43. SDF Coefficients for Ramp Segments

<table>
<thead>
<tr>
<th>Severity Level (j)</th>
<th>Variable</th>
<th>Regression Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Fatal or incapacitating injury (K+A)</td>
<td>$V_{K+A}$</td>
<td>-1.537</td>
</tr>
<tr>
<td>Non-incapacitating injury (B)</td>
<td>$V_B$</td>
<td>0.236</td>
</tr>
</tbody>
</table>

The sign of any regression coefficient in Table 14-43 indicates the change in the proportion of crashes associated with a change in the corresponding variable. For example, the negative coefficient associated with barrier presence indicates that the proportion of fatal $K$ and incapacitating injury $A$ crashes decreases with an increase in the proportion of barrier present on the segment. A similar trend is indicated for barrier presence on non-incapacitating injury $B$ crashes. By inference, the proportion of possible injury $C$ crashes increases with an increase in the proportion of barrier present.

14.8.2. Severity Distribution Functions for Ramp Terminals

The SDFs for crossroad ramp terminals are described by the following equations.

$$P_{aS, x, at, K} = \frac{\exp(V_{K+A})}{1.0 + \exp(V_{K+A}) + \exp(V_B)} \times P_K|K+A, aS, x, at$$  \hspace{1cm} \text{Equation 14-84}  \\

$$P_{aS, x, at, A} = \frac{\exp(V_{K+A})}{1.0 + \exp(V_{K+A}) + \exp(V_B)} \times (1.0 - P_K|K+A, aS, x, at)$$  \hspace{1cm} \text{Equation 14-85}  \\

$$P_{aS, x, at, B} = \frac{\exp(V_B)}{1.0 + \exp(V_{K+A}) + \exp(V_B)}$$  \hspace{1cm} \text{Equation 14-86}  \\

$$P_{aS, x, at, C} = 1.0 - (P_K + P_A + P_B)$$  \hspace{1cm} \text{Equation 14-87}  \\

Where:

- $V_j$ = systematic component of crash severity likelihood for severity level $j$;
- $P_K|K+A, aS, x, at$ = probability of a fatal $K$ crash given that the crash has a severity of either fatal or incapacitating injury $A$ for all ramp terminal sites $aS$ based on all crash types $at$ and control type $x$ ($x = ST$: one-way stop control; $SGn$: signal control, $n$-lane crossroad); and
- $C_{aS, x}$ = calibration factor to adjust SDF for local conditions for all ramp terminal sites $aS$ with control type $x$ ($x = ST$: stop control, $SGn$: signal control, $n$-lane crossroad).

The first term Equation 14-84 estimates the probability of a fatal or incapacitating injury crash. The second term (i.e., $P_K|K+A$) is used to convert the estimate into the probability of a fatal crash. For signal-controlled ramp terminals, a value of 0.0385 is used for $P_K|K+A$ based on an analysis of fatal and incapacitating injury crashes at signalized ramp terminals. For one-way stop-controlled ramp terminals, a value of 0.160 is used for $P_K|K+A$ based on a similar analysis.
A model for estimating the systematic component of crash severity \( V_j \) for crossroad ramp terminals is described by the following equation.

\[
V_j = a + (b \times I_{p,lt}) + (c \times [n_{dw} + n_{ps}]) + (d \times I_{ps}) + (e \times I_{rural})
\]

Equation 14-88

Where:

\( I_{p,lt} \) = protected left-turn operation indicator variable for crossroad (= 1.0 if protected operation exists, 0.0 otherwise);

\( n_{dw} \) = number of unsignalized driveways on the crossroad leg outside of the interchange and within 250 ft of the ramp terminal;

\( n_{ps} \) = number of unsignalized public street approaches to the crossroad leg outside of the interchange and within 250 ft of the ramp terminal; and

\( I_{ps} \) = non-ramp public street leg indicator variable (= 1.0 if leg is present, 0.0 otherwise).

The SDF regression coefficients in Equation 14-88 are provided in Table 14-44.

Driveways and approaches on both sides of the leg should be counted when they are within 250 ft of the ramp terminal. The count of driveways should only include active driveways (i.e., those driveways with an average daily volume of 10 veh/day or more).

<table>
<thead>
<tr>
<th>Control Type (x)</th>
<th>Severity Level (j)</th>
<th>Variable</th>
<th>( a )</th>
<th>( b )</th>
<th>( c )</th>
<th>( d )</th>
<th>( e )</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-way stop control (ST)</td>
<td>Fatal or incapacitating inj. (K+A)</td>
<td>( V_{K+A} )</td>
<td>-3.168</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.891</td>
</tr>
<tr>
<td>Non-incapacitating injury (B)</td>
<td>( V_B )</td>
<td>-1.476</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.221</td>
<td></td>
</tr>
<tr>
<td>Signal control, all lanes (SGn)</td>
<td>Fatal or incapacitating inj. (K+A)</td>
<td>( V_{K+A} )</td>
<td>-3.257</td>
<td>-0.288</td>
<td>0.0991</td>
<td>1.171</td>
<td>0.619</td>
</tr>
<tr>
<td>Non-incapacitating injury (B)</td>
<td>( V_B )</td>
<td>-1.511</td>
<td>-0.193</td>
<td>0.149</td>
<td>0.741</td>
<td>0.416</td>
<td></td>
</tr>
</tbody>
</table>

The variable \( I_{p,lt} \) is equal to 1.0 if protected-only left-turn operation is provided on each crossroad leg with a left-turn movement. If permissive or protected-permissive operation is provided on either leg, then the variable equals 0.0.

The variable \( I_{ps} \) is equal to 1.0 if the ramp terminal has a fourth leg that (a) is a public street serving two-way traffic and (b) intersects with the crossroad at the terminal. 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.

The sign of any regression coefficient in Table 14-44 indicates the change in the proportion of crashes associated with a change in the corresponding variable. For example, the negative coefficient associated with protected left-turn operation indicates that the proportion of fatal \( K \) and incapacitating injury \( A \) crashes decreases when protected-only left-turn operation is provided. A similar trend is indicated for protected-only left-turn operation on non-incapacitating injury \( B \) crashes. By inference, the proportion of possible injury \( C \) crashes increases when protected-only left-turn operation is provided.
14.9. CALIBRATION OF THE SPFS AND SDFs TO LOCAL CONDITIONS

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

The SPF calibration factors will have values greater than 1.0 for segments or terminals that, on average, experience more crashes than those used in the development of the SPFs. Similarly, the calibration factors for segments or terminals that experience fewer crashes on average than those used in the development of the SPFs will have values less than 1.0. The calibration procedures for SPFs are presented in Section A.1.1 of Appendix A to Part C.

The SDF calibration factors will have values greater than 1.0 for segments or terminals that, on average, experience more severe crashes than those used in the development of the SDFs. Similarly, the calibration factors for segments or terminals that experience fewer severe crashes on average than those used in the development of the SDFs will have values less than 1.0. The calibration procedures for SDFs are presented in Section A.1.4 of Appendix A to Part C.

Calibration factors provide one method of using local crash data to improve the estimated crash frequency for individual agencies or locations. Several other default values used in the methodology, such as crash type distribution, can also be replaced with locally derived values. The derivation of values for these parameters is addressed in the calibration procedure in Section A.1.3 of Appendix A to Part C.

14.10. INTERIM PREDICTIVE METHOD FOR ALL-WAY STOP CONTROL

Sufficient research has not yet been conducted to form the basis for development of a predictive method for crossroad ramp terminals with all-way stop control. An interim method is presented in this section. It consists of the same steps as described previously in Section 14.4. The discussion below highlights the modifications to these steps when they are applied to an all-way stop-controlled ramp terminal.

Steps 1 to 18—Evaluate the Crossroad Ramp Terminal as One-Way Stop Control. Apply the predictive method described in Section 14.4 to the subject crossroad ramp terminal. The subject crossroad ramp terminal has all-way stop control but it is evaluated using the predictive method for one-way stop control.

Step 10—The following list identifies the CMFs that can be used in Step 10 of the predictive method to evaluate all-way stop-controlled ramp terminals.

- Exit ramp capacity.
- Access point frequency.
- Segment length.
- Median width.

The Crossroad left-turn lane CMF, Crossroad right-turn lane CMF, and Skew angle CMF cannot be used to evaluate all-way stop-controlled ramp terminals.

In addition, the All-way stop control CMF is used in Step 10 of the predictive method. This CMF has a value of 0.686 when applied to fatal-and-injury crashes. Research has not established a value for this CMF when applied to property-damage-only crashes, so the unadjusted estimate from the predictive method is considered to be equally applicable to all-way stop-controlled ramp terminals.
Step 13—The crash-type distribution in Table 14-45 can be used in Step 13 of the predictive method, if desired, to compute the expected average crash frequency for each of ten crash types (e.g., head-on, fixed object).

**Table 14-45. Default Distribution of All-Way Stop-Controlled Ramp Terminal Crashes by Crash Type**

<table>
<thead>
<tr>
<th>Area Type</th>
<th>Crash Type</th>
<th>Crash Type Category</th>
<th>Proportion of Crashes by Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>Multiple vehicle</td>
<td>Head-on</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right-angle</td>
<td>0.500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rear-end</td>
<td>0.500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sideswipe</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other multiple-vehicle</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with animal</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with fixed object</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with other object</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash with parked vehicle</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other single-vehicle</td>
<td>0.000</td>
</tr>
<tr>
<td>Single</td>
<td>Multiple vehicle</td>
<td>Head-on</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right-angle</td>
<td>0.182</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rear-end</td>
<td>0.727</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sideswipe</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other multiple-vehicle</td>
<td>0.000</td>
</tr>
<tr>
<td>Urban</td>
<td>Multiple vehicle</td>
<td>Head-on</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right-angle</td>
<td>0.182</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rear-end</td>
<td>0.727</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sideswipe</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other multiple-vehicle</td>
<td>0.000</td>
</tr>
<tr>
<td>Single</td>
<td>Multiple vehicle</td>
<td>Head-on</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right-angle</td>
<td>0.182</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rear-end</td>
<td>0.727</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sideswipe</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other multiple-vehicle</td>
<td>0.000</td>
</tr>
</tbody>
</table>

**14.11. LIMITATIONS OF PREDICTIVE METHOD IN CHAPTER 14**

The limitations of the predictive method which apply generally across all of the Part C chapters are discussed in Section C.14 of Part C—Introduction and Applications Guidance chapter. This section discusses limitations of the predictive models described this chapter.

The predictive method in Chapter 14 does not account for the influence of the following conditions on ramp safety:
- Ramp or C-D road segments in rural areas with 2 or more lanes.
- Ramp or C-D road segments in urban areas with 3 or more lanes.
- Ramps and C-D roads providing two-way travel.
- Ramp metering.
- A high-occupancy vehicle (HOV) bypass lane on a ramp or C-D road.
- A frontage-road segment.
- A frontage-road ramp terminal.
- A frontage-road crossroad terminal.
- A crossroad speed-change lane.
- A crossroad ramp terminal with 3 or more left-turn lanes on a crossroad approach.
- A crossroad ramp terminal where the crossroad provides one-way travel.
- The crossroad ramp terminal formed by a single-point urban interchange or roundabout.

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

### 14.12. APPLICATION OF CHAPTER 14 PREDICTIVE METHOD

The predictive method presented in Chapter 14 is applied to a ramp by following the 18 steps presented in Section 14.4. Worksheets are provided in Appendix 14A for applying calculations in the predictive method steps specific to Chapter 14. All computations of crash frequencies within these worksheets are conducted with values expressed to three decimal places. This level of precision is needed only for consistency in computations. In the last stage of computations, rounding the final estimates of expected average crash frequency to one decimal place is appropriate.

### 14.13. SUMMARY

The predictive method for ramps is applied by following the 18 steps of the predictive method presented in Section 14.4. It is used to estimate the expected average crash frequency for a series of contiguous sites, or a single individual site. If a ramp is being evaluated, then it is divided into a series of sites in Step 5 of the predictive method. Predictive models are applied in Steps 9, 10, and 11 of the method to estimate the expected average crash frequency of each site.

Each predictive model consists of a safety performance function (SPF), crash modification factors (CMFs), a severity distribution function (SDF), and calibration factors. The SPF is selected in Step 9. It is used to estimate the predicted average crash frequency for a site with base conditions. CMFs are selected in Step 10. They are combined with the estimate from the SPF to produce the expected average crash frequency for the subject site. Optionally, the SDFs are selected in Step 13. They can be used to estimate the expected average crash frequency for one or more crash severity levels (i.e., fatal, incapacitating injury, non-incapacitating injury, or possible injury crash). Optionally, the crash type distribution can be used in Step 13 to estimate the expected crash frequency for one or more crash types (e.g., head-on, fixed object).
When observed crash data are available, the EB Method is applied in Step 13 or 15 of the predictive method to improve the reliability of the estimated expected average crash frequency. The EB Method can be applied at the site-specific level in Step 13, or at the project level in Step 15. The choice of level will depend on (a) the required reliability of the estimate and (b) the accuracy with which each reported crash can be associated with an individual site. The EB Method is described in Part C, Appendix A.2.

The SPF is calibrated to the specific state or geographic region in which the project is located. Calibration accounts for differences in state or regional crash frequencies, relative to the states and regions represented in the regression coefficients documented in Chapter 14. The process for determining calibration factors for the predictive models is described in Part C, Appendix A.1.

Section 14.14 presents several sample problems that detail the application of the predictive method. A series of worksheets are used to guide the method application and document the calculations. The use of these worksheets is illustrated in the sample problems. Appendix 14A contains blank worksheets that can be copied to document future method applications.

14.14. SAMPLE PROBLEMS
In this section, six sample problems are presented using the predictive method steps for ramp facilities. Sample Problems 1 through 3 illustrate how to calculate the predicted average crash frequency for ramp segments. Sample Problems 4 through 6 illustrate how to calculate the predicted average crash frequency for ramp terminals.

**Table 14-46. List of Sample Problems in Chapter 14**

<table>
<thead>
<tr>
<th>Problem No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Predicted average crash frequency for a one-lane exit ramp segment</td>
</tr>
<tr>
<td>2</td>
<td>Predicted average crash frequency for a two-lane C-D road segment</td>
</tr>
<tr>
<td>3</td>
<td>Predicted average crash frequency for a one-lane entrance ramp segment</td>
</tr>
<tr>
<td>4</td>
<td>Predicted average crash frequency for a D4 ramp terminal with signal control</td>
</tr>
<tr>
<td>5</td>
<td>Predicted average crash frequency for a A4 ramp terminal with one-way stop control</td>
</tr>
<tr>
<td>6</td>
<td>Predicted average crash frequency for a B2 ramp terminal with all-way stop control</td>
</tr>
</tbody>
</table>

14.14.1. Sample Problem 1

**The Site/Facility**
A one-lane urban exit ramp segment.

**The Question**
What is the predicted average crash frequency of the ramp segment for a one-year period?

**The Facts**
The study year is 2011. The conditions present during this year are provided in the following list.

- 0.15-mi length
- 6,750 veh/day
65-mi/h average speed on freeway mainline

Signal control at crossroad ramp terminal

One off-segment horizontal curve
- 400-ft radius
- 0.025-mi length
- Beginning at milepost 0.07

One in-segment horizontal curve
- 400-ft radius
- 0.07-mi length, entirely on the segment
- Beginning at milepost 0.19

14-ft lane width

8-ft right shoulder width

4-ft left shoulder width

No lane adds or lane drops

No barrier on the right or left sides of the roadway

No ramp entrances or exits in the segment

No weaving section

Assumptions
- Crash type distributions used are the default values presented in Table 14-6 and Table 14-9.

- The calibration factor is 1.00.

Results
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the ramp segment in Sample Problem 1 is determined to be 0.2 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 0.2 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the ramp segment in Sample Problem 1, only Steps 9 through 13 are conducted. No other steps are necessary because only one ramp segment is analyzed for a one-year period and the EB Method is not applied.
Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site’s facility type and traffic control features.

For a one-lane urban exit ramp segment, SPF values for multiple-vehicle and single-vehicle crashes are determined.

Multiple-Vehicle Crashes

The SPF for multiple-vehicle fatal-and-injury crashes is calculated from Equation 14-20 and Table 14-5 as follows:

\[ N_{mv, rps, 1EX, fi} = L_r \times \exp \left( a + b \times \ln (c \times AADT_r) + d \times AADT_r \right) \]

\[ = 0.15 \times \exp \left( -4.971 + 0.524 \times \ln (0.001 \times 6,750) + 0.0699 \times 0.001 \times 6,750 \right)\]

\[ = 0.005 \text{ crashes/year} \]

Similarly, the SPF for multiple-vehicle property-damage-only crashes is calculated from Equation 14-20 and Table 14-5 to yield the following result:

\[ N_{mv, rps, 1EX, pdo} = 0.013 \text{ crashes/year} \]

Single-Vehicle Crashes

The SPF for single-vehicle fatal-and-injury crashes is calculated from Equation 14-24 and Table 14-8 as follows:

\[ N_{sv, rps, 1EX, fi} = L_r \times \exp \left( a + b \times \ln (c \times AADT_r) \right) \]

\[ = 0.15 \times \exp \left( -1.645 + 0.718 \times \ln (0.001 \times 6,750) \right) \]

\[ = 0.114 \text{ crashes/year} \]

Similarly, the SPF for single-vehicle property-damage-only crashes is calculated from Equation 14-24 and Table 14-8 to yield the following result:

\[ N_{sv, rps, 1EX, pdo} = 0.124 \text{ crashes/year} \]

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

Each CMF used in the calculation of the predicted average crash frequency of the ramp segment is calculated in this step.

Horizontal Curve (CMF1, rps, 1EX, y, z)

The limited curve speed for the off-segment horizontal curve (curve 1) is computed using Equation 14-59 as follows:

\[ v_{max, 1} = 3.24 \times (32.2 \times R_1)^{0.30} \]

\[ = 3.24 \times (32.2 \times 400)^{0.30} \]

\[ = 55.4 \text{ ft/s} \]

The in-segment horizontal curve (curve 2) has the same radius as curve 1. Hence, its limited speed \( v_{max, 2} \) is also equal to 55.4 ft/s.
The average entry speed at curve 1 is computed using Equation 14-64 and the default values in Table 14-42 as follows:

\[ v_{ent,1} = (1.47 \times V_{frwy} - 0.034 \times 5.280 \times X_1) \geq 1.47 \times V_{xroad} \]
\[ = (1.47 \times 65 - 0.034 \times 5.280 \times 0.07) \geq 1.47 \times 15 \]
\[ = 83.0 \text{ ft/s} \]

The average exit speed at curve 1 is computed using Equation 14-65 as follows:

\[ v_{ext,1} = (v_{ent,1} - 0.034 \times 5.280 \times L_{c,1}) \leq v_{max,1} \text{ and } \geq 1.47 \times V_{xroad} \]
\[ = (83.0 - 0.034 \times 5.280 \times 0.025) \leq 55.4 \text{ and } \geq 1.47 \times 15 \]
\[ = 55.4 \text{ ft/s} \]

The average entry speed at curve 2 is computed using Equation 14-66 and the default values in Table 14-42 as follows:

\[ v_{ent,2} = v_{ent,i-1} - 0.034 \times 5.280 \times (X_i - X_{i-1} - L_{c,i-1}) \geq 1.47 \times V_{xroad} \]
\[ = 55.4 - 0.034 \times 5.280 \times (0.19 - 0.07 - 0.025) \geq 1.47 \times 15 \]
\[ = 38.3 \text{ ft/s} \]

\( CMF_{1, rps, lEX, y, fi} \) is calculated using Equation 14-33 as follows:

\[ CMF_{1, rps, lEX, y, fi} = 1.0 + a \times \frac{1000}{32.2} \left[ \sum_{i=1}^{m} \left( \frac{v_{ent,i}}{R_i} \right)^2 \times P_{c,i} \right] \]

Only curve 2 is included in the summation term. Curve 1 is not on the segment, but its presence upstream of the segment affects vehicle speeds in curve 2. From Table 14-24, \( a = 0.779 \) for multiple-vehicle fatal-and-injury crashes. \( CMF_{1, rps, lEX, mv, fi} \) is calculated as follows:

\[ CMF_{1, rps, lEX, mv, fi} = 1.0 + 0.779 \times \frac{1000}{32.2} \left( \frac{38.3}{400} \right)^2 \times \frac{0.07}{0.15} \]
\[ = 1.104 \]

Calculations using the other coefficients from Table 14-24 yield the following results:

\[ CMF_{1, rps, lEX, sv, fi} = 1.320 \]
\[ CMF_{1, rps, lEX, mv, pdo} = 1.073 \]
\[ CMF_{1, rps, lEX, sv, pdo} = 1.418 \]

**Lane Width (CMF_{2, rps, lEX, y, z})**
The segment has 14-ft lanes, which is the base condition for the lane width CMF. Hence, \( CMF_{2, rps, lEX, y, fi} \) and \( CMF_{2, rps, lEX, y, pdo} \) are equal to 1.000.
Right Shoulder Width (CMF$_{3, rps, 1EX, y, z}$)
The segment has 8-ft right shoulders, which is the base condition for the right shoulder width CMF. Hence, CMF$_{3, rps, 1EX, y, fi}$ and CMF$_{3, rps, 1EX, y, pdo}$ are equal to 1.000.

Left Shoulder Width (CMF$_{4, rps, 1EX, y, z}$)
The segment has 4-ft left shoulders, which is the base condition for the left shoulder width CMF. Hence, CMF$_{4, rps, 1EX, y, fi}$ and CMF$_{4, rps, 1EX, y, pdo}$ are equal to 1.000.

Right Side Barrier (CMF$_{5, rps, 1EX, y, z}$)
The segment does not have right side barrier. Hence, CMF$_{5, rps, 1EX, y, fi}$ and CMF$_{5, rps, 1EX, y, pdo}$ are equal to 1.000.

Left Side Barrier (CMF$_{6, rps, 1EX, y, z}$)
The segment does not have left side barrier. Hence, CMF$_{6, rps, 1EX, y, fi}$ and CMF$_{6, rps, 1EX, y, pdo}$ are equal to 1.000.

Lane Add or Drop (CMF$_{7, rps, 1EX, y, fi}$)
The segment does not have a lane add or a lane drop. Hence, CMF$_{7, rps, 1EX, y, fi}$ is equal to 1.000.

Ramp Speed-Change Lane (CMF$_{8, rps, 1EX, mv, fi}$)
The segment does not have a speed-change lane. Hence, CMF$_{8, rps, 1EX, mv, fi}$ is equal to 1.000.

Multiple-Vehicle Crashes
The CMFs are applied to the multiple-vehicle fatal-and-injury SPF as follows:

\[
N_{p^*, rps, 1EX, mv, fi} = N_{spf, rps, 1EX, mv, fi} \times \left( \text{CMF}_{1, rps, 1EX, mv, fi} \times \cdots \times \text{CMF}_{8, rps, 1EX, mv, fi} \right)
\]

\[= 0.005 \times (1.104 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000)\]
\[= 0.005 \times 1.104\]
\[= 0.005 \text{ crashes/year}\]

The CMFs are applied to the multiple-vehicle property-damage-only SPF as follows:

\[
N_{p^*, rps, 1EX, mv, pdo} = N_{spf, rps, 1EX, mv, pdo} \times \left( \text{CMF}_{1, rps, 1EX, mv, pdo} \times \cdots \times \text{CMF}_{8, rps, 1EX, mv, pdo} \right)
\]

\[= 0.013 \times (1.073 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000)\]
\[= 0.013 \times 1.073\]
\[= 0.014 \text{ crashes/year}\]

Single-Vehicle Crashes
The CMFs are applied to the single-vehicle fatal-and-injury SPF as follows:

\[
N_{p^*, rps, 1EX, sv, fi} = N_{spf, rps, 1EX, sv, fi} \times \left( \text{CMF}_{1, rps, 1EX, sv, fi} \times \cdots \times \text{CMF}_{8, rps, 1EX, sv, fi} \right)
\]

\[= 0.114 \times (1.320 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000)\]
\[= 0.114 \times 1.320\]
\[= 0.151 \text{ crashes/year}\]

The CMFs are applied to the single-vehicle property-damage-only SPF as follows:
Step 11 – Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor of 1.00 has been determined for local conditions. As a result, 
\( N_{p^*, rps, 1EX, sv, pdo} = N_{spf, rps, 1EX, sv, pdo} \times (CMF_{1, rps, 1EX, sv, pdo} \times \ldots \times CMF_{8, rps, 1EX, sv, pdo}) \)
\( = 0.124 \times (1.418 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000) \)
\( = 0.124 \times 1.418 \)
\( = 0.176 \) crashes/year

**Calculation of Predicted Average Crash Frequency**
The predicted average crash frequency is calculated using Equation 14-1 based on the results obtained in
Steps 9 through 11 as follows.

Fatal-and-injury crashes:
\( N_{p, rps, 1EX, at, fi} = N_{p, rps, 1EX, mv, fi} + N_{p, rps, 1EX, sv, fi} \)
\( = 0.005 + 0.151 \)
\( = 0.156 \) crashes/year

Property-damage-only crashes:
\( N_{p, rps, 1EX, at, pdo} = N_{p, rps, 1EX, mv, pdo} + N_{p, rps, 1EX, sv, pdo} \)
\( = 0.014 + 0.176 \)
\( = 0.190 \) crashes/year

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.
The study period is one year (2011), so steps 8 through 11 need not be repeated.

Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.
This step consists of three optional sets of calculations—site-specific EB Method, severity distribution
functions, and crash type distribution.

Apply the site-specific EB Method to a future time period, if appropriate.
The site-specific EB Method is not applied in this sample problem because crash data are not available.

Apply the severity distribution functions (SDFs), if desired.
To apply the SDFs, the systematic component of crash severity likelihood \( V_j \) is computed for each severity
level \( j \) using Equation 14-83 as follows:
\[ V_j = a + \left( b \times \frac{P_{ab}}{2} \right) + (c \times n) + (d \times I_{ural}) + (e \times I_{extr}) \]
The coefficients \( a, b, c, d, \) and \( e \) are obtained from Table 14-43 for each severity level \( j \). The segment does not have barrier, so \( P_{bl} \) and \( P_{rb} \) are equal to 0.0. \( V_j \) is computed for fatal and incapacitating injury crashes as follows:

\[
V_{K+A} = -1.537 + \left[-0.481 \times \left(\frac{0.0 + 0.0}{2}\right)\right] + (-0.228 \times 1.0) + (0.668 \times 0.0) + (0.426 \times 1.0)
\]
\[
= -1.339
\]

Similar calculations using the coefficients from Table 14-43 for non-incapacitating injury crashes yield the following results:

\( V_B = -0.199 \)

Using these computed \( V_{K+A} \) and \( V_B \) values, and assuming a calibration factor \( C_{sdjf.rps+cds} \) of 1.0, the probability of occurrence of a fatal crash is computed using Equation 14-79 as follows:

\[
P_{rps+cds,ac,at,K} = \frac{\exp(V_{K+A})}{1.0 + \exp(V_{K+A}) + \exp(V_B)} \times P_{K[K+A,rps+cds,ac,at]}
\]
\[
= \frac{\exp(-1.339)}{1.0 + \exp(-1.339) + \exp(-0.199)} \times 0.248
\]
\[
= 0.032
\]

Similar calculations using Equation 14-80 and Equation 14-81 yield the following results:

\( P_{rps+cds,ac,at,A} = 0.096 \)

\( P_{rps+cds,ac,at,B} = 0.391 \)

The probability of occurrence of a possible-injury crash is computed using Equation 14-82 as follows:

\[
P_{rps+cds,ac,at,C} = 1.0 - (P_{rps+cds,ac,at,K} + P_{rps+cds,ac,at,A} + P_{rps+cds,ac,at,B})
\]
\[
= 1.0 - (0.032 + 0.096 + 0.391)
\]
\[
= 0.481
\]

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 14-78 as follows:

\[
N_{e, rps,1EX,at,K} = N_{e, rps,1EX,at,j} \times P_{rps+cds,ac,at,K}
\]
\[
= 0.156 \times 0.032
\]
\[
= 0.005 \text{ crashes/year}
\]

Similar calculations using Equation 14-78 and the probabilities of occurrences of the other crash severities yield the following results:

\( N_{e, rps,1EX,at,A} = 0.015 \text{ crashes/year} \)
Apply the crash type distribution, if desired.
The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 14-6 and Table 14-9 by the predicted average crash frequencies obtained in Step 11.

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

- Table 14-47. Ramp Segment Worksheet (1 of 4)—Sample Problem 1
- Table 14-48. Ramp Segment Worksheet (2 of 4)—Sample Problem 1
- Table 14-49. Ramp Segment Worksheet (3 of 4)—Sample Problem 1
- Table 14-50. Ramp Segment Worksheet (4 of 4)—Sample Problem 1

Filled versions of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 14 Appendix A.

Table 14-47 is a summary of general information about the ramp segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 1. The input data include area type, crash data, basic roadway data, and alignment data.

Table 14-48 is a summary of general information about the ramp segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 1. The input data include cross section data, roadside data, ramp access data, and traffic data.

Table 14-49 is a tabulation of the CMF and SPF computations for Sample Problem 1.

Table 14-50 is a tabulation of the crash severity and crash type distributions for Sample Problem 1.
### Table 14-47. Ramp Segment Worksheet (1 of 4)—Sample Problem 1

<table>
<thead>
<tr>
<th>General Information</th>
<th>Location Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Roadway</td>
</tr>
<tr>
<td>Agency or company</td>
<td>Roadway section</td>
</tr>
<tr>
<td>Date performed</td>
<td>Study year</td>
</tr>
<tr>
<td>Area type</td>
<td>X Urban Rural</td>
</tr>
</tbody>
</table>

#### Input Data

<table>
<thead>
<tr>
<th>Crash Data</th>
<th>Crash Period</th>
<th>Study Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash data time period</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Count of multiple-vehicle FI crashes $N_{o, w, n, m, f}$</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Count of single-vehicle FI crashes $N_{o, w, n, m, f}$</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Count of multiple-vehicle PDO crashes $N_{o, w, n, m, pdo}$</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Count of single-vehicle PDO crashes $N_{o, w, n, m, pdo}$</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

#### Basic Roadway Data

<table>
<thead>
<tr>
<th>Number of through lanes $n$</th>
<th>1</th>
<th>Same value for crash period and study year.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment length $L$ (mi)</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Average traffic speed on the freeway $V_{frwy}$ (mi/h)</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>Segment type</td>
<td>Exit</td>
<td>Choices: Entrance, Exit, C-D road, Connector</td>
</tr>
<tr>
<td>Type of control at crossroad ramp terminal</td>
<td>--</td>
<td>Signal</td>
</tr>
</tbody>
</table>

#### Alignment Data

##### Horizontal Curve Data

   | Curve radius $R_{1}$ (ft) | -- | 400 | If “In segment” or “Off segment”, enter data for curve radius, length, and milepost. |
   | Length of curve $L_{c1}$ (mi) | -- | 0.025 | |
   | Length of curve in segment $L_{c1, seg}$ (mi) | -- | -- | |
   | Milepost of beginning of curve in dir. of travel $X_{1}$ (mi) | -- | 0.07 | |

2. Presence of horizontal curve 2 | -- | In Seg. | Choices: No, In segment, Off segment |
   | Curve radius $R_{2}$ (ft) | -- | 400 | If “In segment” or “Off segment”, enter data for curve radius, length, and milepost. |
   | Length of curve $L_{c2}$ (mi) | -- | 0.07 | |
   | Length of curve in segment $L_{c2, seg}$ (mi) | -- | 0.07 | |
   | Milepost of beginning of curve in dir. of travel $X_{2}$ (mi) | -- | 0.19 | |

3. Presence of horizontal curve 3 | -- | No | Choices: No, In segment, Off segment |
   | Curve radius $R_{3}$ (ft) | -- | -- | If “In segment” or “Off segment”, enter data for curve radius, length, and milepost. |
   | Length of curve $L_{c3}$ (mi) | -- | -- | |
   | Length of curve in segment $L_{c3, seg}$ (mi) | -- | -- | |
   | Milepost of beginning of curve in dir. of travel $X_{3}$ (mi) | -- | -- | |

4. Presence of horizontal curve 4 | -- | No | Choices: No, In segment, Off segment |
   | Curve radius $R_{4}$ (ft) | -- | -- | If “In segment” or “Off segment”, enter data for curve radius, length, and milepost. |
   | Length of curve $L_{c4}$ (mi) | -- | -- | |
   | Length of curve in segment $L_{c4, seg}$ (mi) | -- | -- | |
   | Milepost of beginning of curve in dir. of travel $X_{4}$ (mi) | -- | -- | |
### Table 14-48. Ramp Segment Worksheet (2 of 4)—Sample Problem 1

**Input Data**

<table>
<thead>
<tr>
<th>Cross Section Data</th>
<th>Crash Period</th>
<th>Study Year</th>
<th>Complete the study year column. Complete the crash period column if the EB Method is used.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane width $W_l$ (ft)</td>
<td>--</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Right shoulder width $W_{rs}$ (ft)</td>
<td>--</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Left shoulder width $W_{ls}$ (ft)</td>
<td>--</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Presence of lane add or lane drop</td>
<td>--</td>
<td>No</td>
<td>Choices: No, Lane add, Lane drop.</td>
</tr>
<tr>
<td>Length of taper in segment $L_{a,l.add},seg$ or $L_{d,l.drop},seg$ (mi)</td>
<td>--</td>
<td>--</td>
<td>If “Lane add” or “Lane drop”, enter length.</td>
</tr>
</tbody>
</table>

**Roadside Data**

| Presence of barrier on right side of roadway | -- | Y/N | N | Y/N | If Yes, then use the ramp barrier worksheet. |
| Presence of barrier on left side of roadway | -- | Y/N | N | Y/N | If Yes, then use the ramp barrier worksheet. |

**Ramp Access Data**

<table>
<thead>
<tr>
<th>Ramp Entrance</th>
<th>Presence of speed-change lane in segment</th>
<th>--</th>
<th>Y/N</th>
<th>N</th>
<th>Y/N</th>
<th>If Yes, then enter data in the next row.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ent. ramp</td>
<td>Length of s-c lane in segment $L_{s-c,l.add},seg$ (mi)</td>
<td>--</td>
<td>--</td>
<td></td>
<td></td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Exit ramp</td>
<td>Presence of speed-change lane in segment</td>
<td>--</td>
<td>Y/N</td>
<td>N</td>
<td>Y/N</td>
<td>If Yes, then enter data in the next row.</td>
</tr>
<tr>
<td></td>
<td>Length of s-c lane in segment $L_{s-c,l.drop},seg$ (mi)</td>
<td>--</td>
<td>--</td>
<td></td>
<td></td>
<td>----------------------------------------</td>
</tr>
</tbody>
</table>

| Weave | Presence of a weaving section in segment | -- | Y/N | -- | Y/N | If Yes, then enter data in the next two rows. |
|       | Length of weaving section $L_{w,wev}$ (mi) | -- | --  |   |     |----------------------------------------|
|       | Length of weaving section in seg. $L_{w,wev,seg}$ (mi) | -- | --  |   |     |----------------------------------------|

**Traffic Data**

| Segment AADT $AADT_r$ or $AADT_c$ (veh/day) | -- | 6,750 |
### Table 14-49. Ramp Segment Worksheet (3 of 4)—Sample Problem 1

#### Crash Modification Factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Multiple Vehicle</td>
<td>Single Vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal curve CMF₁, w, x, y, z</td>
<td>14-33</td>
<td>--</td>
<td>1.104</td>
</tr>
<tr>
<td>Lane width CMF₂, w, x, y, f₁</td>
<td>14-34</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Right shoulder width CMF₃, w, x, y, z</td>
<td>14-35</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Left shoulder width CMF₄, w, x, y, z</td>
<td>14-36</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Right side barrier CMF₅, w, x, y, z</td>
<td>14-37</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Left side barrier CMF₆, w, x, y, z</td>
<td>14-38</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Lane add or drop CMF₇, w, x, y, f₂</td>
<td>14-39</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Ramp speed-change lane CMF₈, w, x, y, f₃</td>
<td>14-40</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Weaving section CMF₉, cds, ac, y, z</td>
<td>14-41</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Combined CMF (multiply all CMFs evaluated)</td>
<td>--</td>
<td>1.104</td>
<td>--</td>
</tr>
</tbody>
</table>

#### Expected Average Crash Frequency

<table>
<thead>
<tr>
<th>Factor</th>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Multiple Vehicle</td>
<td>Single Vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calibration factor C_w, x, y, z</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Overdispersion parameter k_w, x, y, z</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Observed crash count N^o_w, x, y, z (cr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Reference year r</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Predicted average crash freq. for reference year N_p_w, x, y, z, r (cr/yr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Predicted number of crashes for crash period (sum all years) N^r_p_w, x, y, z (cr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Equivalent years associated with crash count C^e_w, x, y, z, f (yr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Adjusted average crash freq. for ref. year given N^e_w, x, y, z, f (cr/yr)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Study year s</td>
<td>2011</td>
<td>2011</td>
<td>2011</td>
</tr>
<tr>
<td>Predicted average crash freq. for study year N^p_w, x, y, z, f (cr/yr)</td>
<td>0.005</td>
<td>0.151</td>
<td>0.014</td>
</tr>
<tr>
<td>Expected average crash freq. for study year N^e_w, x, y, z, f (cr/yr)</td>
<td>0.005</td>
<td>0.151</td>
<td>0.014</td>
</tr>
<tr>
<td>Expected average crash freq. for study year (all crash types) N^e_w, x, at, z, f (cr/yr)</td>
<td>0.156</td>
<td>0.189</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**

a – If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.
Table 14-50. Ramp Segment Worksheet (4 of 4)—Sample Problem 1

Expected Average Crash Frequency

<table>
<thead>
<tr>
<th>Crash Severity Distribution</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Total FI</th>
<th>PDO</th>
<th>Total FI + PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion by injury level</td>
<td>0.032</td>
<td>0.096</td>
<td>0.391</td>
<td>0.481</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected average crash freq. for study year (all crash types) ( N_{e, w, x, y, at, z, s} ) (cr/yr)</td>
<td>0.005</td>
<td>0.015</td>
<td>0.061</td>
<td>0.075</td>
<td>0.156</td>
<td>0.189</td>
<td>0.345</td>
</tr>
</tbody>
</table>

Crash Type Distribution

<table>
<thead>
<tr>
<th>Crash Type Category</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion</td>
<td>Expected Average Crash Frequency for Study Year ( N_{e, w, x, y, fi, s} ) (cr/yr)</td>
<td>Proportion</td>
<td>Expected Average Crash Frequency for Study Year ( N_{e, w, x, y, pdo, s} ) (cr/yr)</td>
</tr>
<tr>
<td>Multiple-Vehicle Crashes 14-6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head-on</td>
<td>0.015</td>
<td>0.000</td>
<td>0.009</td>
</tr>
<tr>
<td>Right-angle</td>
<td>0.010</td>
<td>0.000</td>
<td>0.005</td>
</tr>
<tr>
<td>Rear-end</td>
<td>0.707</td>
<td>0.003</td>
<td>0.550</td>
</tr>
<tr>
<td>Sideswipe</td>
<td>0.129</td>
<td>0.001</td>
<td>0.335</td>
</tr>
<tr>
<td>Other multiple-vehicle crashes</td>
<td>0.139</td>
<td>0.001</td>
<td>0.101</td>
</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>0.005</td>
<td>1.000</td>
</tr>
</tbody>
</table>

| Single-Vehicle Crashes 14-9   |                  |                      |       |
| Crash with animal             | 0.003            | 0.000                | 0.005 | 0.001 | 0.001 |
| Crash with fixed object       | 0.718            | 0.108                | 0.834 | 0.146 | 0.254 |
| Crash with other object       | 0.015            | 0.002                | 0.023 | 0.004 | 0.006 |
| Crash with parked vehicle     | 0.012            | 0.002                | 0.012 | 0.002 | 0.004 |
| Other single-vehicle crashes  | 0.252            | 0.038                | 0.126 | 0.022 | 0.060 |
| Total                         | 1.000            | 0.151                | 1.000 | 0.175 | 0.326 |

Note:

a – If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.

14.14.2. Sample Problem 2

The Site/Facility
A two-lane urban C-D road segment.

The Question
What is the predicted average crash frequency of the C-D road segment for a one-year period?

The Facts
The study year is 2011. The conditions present during this year are provided in the following list.

- 0.08-mi length
- 5,500 veh/day
- 60-mi/h average speed on freeway mainline
- One off-segment horizontal curve
  - 1,100-ft radius
  - 0.08-mi length
  - Beginning at milepost 0.09
- 14-ft lane width
- 8-ft right shoulder width
- 4-ft left shoulder width
- No lane adds or lane drops
- No barrier on the right or left sides of the roadway
- No ramp entrances or exits in the segment
- 0.08-mi weaving section along entire length of segment

**Assumptions**
- Crash type distributions used are the default values presented in Table 14-6 and Table 14-9.
- The calibration factor is 1.00.

**Results**
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the C-D road segment in Sample Problem 2 is determined to be 0.1 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 0.2 crashes per year (rounded to one decimal place).

**Steps**

**Step 1 through 8**
To determine the predicted average crash frequency of the C-D road segment in Sample Problem 2, only Steps 9 through 13 are conducted. No other steps are necessary because only one C-D road segment is analyzed for a one-year period and the EB Method is not applied.

**Step 9 — For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site’s facility type and traffic control features.**
For a two-lane urban C-D road segment, SPF values for multiple-vehicle and single-vehicle crashes are determined.

**Multiple-Vehicle Crashes**
The SPF for multiple-vehicle fatal-and-injury crashes is calculated from Equation 14-22 and Table 14-7 as follows:
Similarly, the SPF for multiple-vehicle property-damage-only crashes is calculated from Equation 14-22 and Table 14-7 to yield the following result:

\[ N_{spf, cds, 2, mv, pdo} = 0.057 \text{ crashes/year} \]

**Single-Vehicle Crashes**
The SPF for single-vehicle fatal-and-injury crashes is calculated from Equation 14-26 and Table 14-10 as follows:

\[ N_{spf, cds, 2, sv, fi} = L_{cd} \times \exp(a + b \times \ln[c \times AADT_c] + d[c \times AADT_c]) \]
\[ = 0.08 \times \exp(-2.515 + 0.524 \ln[0.001 \times 5.500] + 0.0699[0.001 \times 5.500]) \]
\[ = 0.015 \text{ crashes/year} \]

Similarly, the SPF for single-vehicle property-damage-only crashes is calculated from Equation 14-26 and Table 14-10 to yield the following result:

\[ N_{spf, cds, 2, sv, pdo} = 0.025 \text{ crashes/year} \]

**Step 10 – Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site-specific geometric design and traffic control features.**
Each CMF used in the calculation of the predicted average crash frequency of the ramp segment is calculated in this step.

**Horizontal Curve (CMF1, cds, 2, y, z)**
\( CMF_{1, cds, 2, y, z} \) is calculated using Equation 14-33 as follows:

\[ CMF_{1, cds, 2, y, z} = 1.000 \times \frac{1.000}{32.2} \sum_{i=1}^{m} \left( \frac{V_{\text{em},i}}{R_i} \right)^2 \times P_{c, i} \]

Only in-segment curves are included in the summation term. The C-D road has a curve upstream of the segment being analyzed, but there are no curves on the segment. Hence, \( CMF_{1, cds, 2, y, z} \) is equal to 1.000.

**Lane Width (CMF2, cds, 2, y, z)**
The segment has 14-ft lanes, which is the base condition for the lane width CMF. Hence, \( CMF_{2, cds, 2, y, fi} \) and \( CMF_{2, cds, 2, y, pdo} \) are equal to 1.000.

**Right Shoulder Width (CMF3, cds, 2, y, z)**
The segment has 8-ft right shoulders, which is the base condition for the right shoulder width CMF. Hence, \( CMF_{3, cds, 2, y, fi} \) and \( CMF_{3, cds, 2, y, pdo} \) are equal to 1.000.

**Left Shoulder Width (CMF4, cds, 2, y, z)**
The segment has 4-ft left shoulders, which is the base condition for the left shoulder width CMF. Hence, \( CMF_{4, cds, 2, y, fi} \) and \( CMF_{4, cds, 2, y, pdo} \) are equal to 1.000.
Right Side Barrier (CMF5, cds, 2, y, z)
The segment does not have right side barrier. Hence, CMF5, rps, IEX, y, fi and CMF5, rps, IEX, y, pdo are equal to 1.000.

Left Side Barrier (CMF6, rps, IEX, y, z)
The segment does not have left side barrier. Hence, CMF6, cds, 2, y, fi and CMF6, cds, 2, y, pdo are equal to 1.000.

Lane Add or Drop (CMF7, cds, 2, y, fi)
The segment does not have a lane add or a lane drop. Hence, CMF7, cds, 2, y, fi is equal to 1.000.

Ramp Speed-Change Lane (CMF8, cds, 2, mv, fi)
The segment does not have a speed-change lane. Hence, CMF8, cds, 2, mv, fi is equal to 1.000.

Weaving Section (CMF9, cds, 2, at, z)
CMF9, cds, 2, at, z is calculated using Equation 14-41 as follows:

\[
CMF9, cds, 2, at, z = (1.0 - P_{wev}) \times 1.0 + P_{wev} \times \exp \left( \frac{a + b \times \ln(c \times AADT_c)}{L_{wev}} \right)
\]

From Table 14-31, \(a = 0.191\), \(b = -0.0715\), and \(c = 0.001\) for multiple-vehicle fatal-and-injury crashes. CMF9, cds, 2, at, z is calculated as follows:

\[
CMF9, cds, 2, at, fi = (1.0 - 1.0) \times 1.0 + 1.0 \times \exp \left( \frac{0.191 - 0.0715 \times \ln(0.001 \times 5,500)}{0.08} \right)
\]

\[
= 2.372
\]

Similar calculations using the property-damage-only coefficients from Table 14-31 yield the following results:

\[
CMF9, cds, 2, at, pdo = 3.009
\]

Multiple-Vehicle Crashes
The CMFs are applied to the multiple-vehicle fatal-and-injury SPF as follows:

\[
N^{*}_{p, cds, 2, mv, fi} = N_{spf, cds, 2, mv, fi} \times \left( \text{CMF}_{1, cds, 2, mv, fi} \times \ldots \times \text{CMF}_{9, cds, 2, mv, fi} \right)
\]

\[
= 0.023 \times (1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 2.372)
\]

\[
= 0.023 \times 2.372
\]

\[
= 0.055 \text{ crashes/year}
\]

The CMFs are applied to the multiple-vehicle property-damage-only SPF as follows:

\[
N^{*}_{p, cds, 2, mv, pdo} = N_{spf, cds, 2, mv, pdo} \times \left( \text{CMF}_{1, cds, 2, mv, pdo} \times \ldots \times \text{CMF}_{9, cds, 2, mv, pdo} \right)
\]

\[
= 0.057 \times (1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 3.009)
\]

\[
= 0.057 \times 3.009
\]

\[
= 0.172 \text{ crashes/year}
\]
Single-Vehicle Crashes
The CMFs are applied to the single-vehicle fatal-and-injury SPF as follows:

\[ N_{p*, 	ext{cds, 2, sv, fi}} = N_{p, 	ext{cds, 2, sv, fi}} \times (CMF_{1, 	ext{cds, 2, sv, fi}} \times \ldots \times CMF_{9, 	ext{cds, 2, sv, fi}}) \]

\[ = 0.015 \times (1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 2.372) \]

\[ = 0.015 \times 2.372 \]

\[ = 0.036 \text{ crashes/year} \]

The CMFs are applied to the single-vehicle property-damage-only SPF as follows:

\[ N_{p*, 	ext{cds, 2, sv, pdo}} = N_{p, 	ext{cds, 2, sv, pdo}} \times (CMF_{1, 	ext{cds, 2, sv, pdo}} \times \ldots \times CMF_{9, 	ext{cds, 2, sv, pdo}}) \]

\[ = 0.025 \times (1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 3.009) \]

\[ = 0.025 \times 3.009 \]

\[ = 0.075 \text{ crashes/year} \]

Step 11 – Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor of 1.00 has been determined for local conditions. As a result,
\[ N_{p, 	ext{cds, 2, y, z}} = N_{p*, 	ext{cds, 2, y, z}} \] for both crash types \( y \) (\( y = \text{mv} \): multiple-vehicle, \( sv \): single-vehicle) and both crash severities \( z \) (\( z = \text{fi} \): fatal-and-injury, \( pdo \): property-damage-only). See Part C Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 14-1 based on the results obtained in Steps 9 through 11 as follows.

Fatal-and-injury crashes:

\[ N_{p, 	ext{cds, 2, at, fi}} = N_{p, 	ext{cds, 2, at, fi}} + N_{p, 	ext{cds, 2, sv, fi}} \]

\[ = 0.055 + 0.036 \]

\[ = 0.091 \text{ crashes/year} \]

Property-damage-only crashes:

\[ N_{p, 	ext{cds, 2, at, pdo}} = N_{p, 	ext{cds, 2, at, pdo}} + N_{p, 	ext{cds, 2, sv, pdo}} \]

\[ = 0.172 + 0.075 \]

\[ = 0.247 \text{ crashes/year} \]

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.
The study period is one year (2011), so steps 8 through 11 need not be repeated.

Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.
This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

Apply the site-specific EB Method to a future time period, if appropriate.
The site-specific EB Method is not applied in this sample problem because crash data are not available.
Apply the severity distribution functions (SDFs), if desired.

To apply the SDFs, the systematic component of crash severity likelihood $V_j$ is computed for each severity level $j$ using Equation 14-83 as follows:

$$V_j = a + \left(b \times \frac{P_{bl} + P_{rb}}{2}\right) + (c \times n) + (d \times I_{rural}) + (e \times I_{exc})$$

The coefficients $a$, $b$, $c$, $d$, and $e$ are obtained from Table 14-43 for each severity level $j$. The segment does not have barrier, so $P_{bl}$ and $P_{rb}$ are equal to 0.0. $V_j$ is computed for fatal and incapacitating injury crashes as follows:

$$V_{K+A} = -1.537 + \left(-0.481 \times \frac{0.0+0.0}{2}\right) + (-0.228 \times 2.0) + (0.668 \times 0.0) + (0.426 \times 0.0)$$

$$= -1.993$$

Similar calculations using the coefficients from Table 14-43 for non-incapacitating injury crashes yield the following results:

$$V_B = -0.634$$

Using these computed $V_{K+A}$ and $V_B$ values, and assuming a calibration factor $C_{sdf,rps+cds}$ of 1.0, the probability of occurrence of a fatal crash is computed using Equation 14-79 as follows:

$$P_{rps+cds,ac,at,K} = \frac{\frac{\exp(V_{K+A})}{1.0} \times P_{K|K+A, rps+cds, ac, at}}{\frac{1.0}{C_{sdf, rps+cds}} + \exp(V_{K+A}) + \exp(V_B)}$$

$$= \frac{\exp(-1.993)}{1.0 + \exp(-1.993) + \exp(-0.634)} \times 0.248$$

$$= 0.022$$

Similar calculations using Equation 14-80 and Equation 14-81 yield the following results:

$$P_{rps+cds,ac,at,A} = 0.065$$

$$P_{rps+cds,ac,at,B} = 0.315$$

The probability of occurrence of a possible-injury crash is computed using Equation 14-82 as follows:

$$P_{rps+cds,ac,at,C} = 1.0 - (P_{rps+cds,ac,at,K} + P_{rps+cds,ac,at,A} + P_{rps+cds,ac,at,B})$$

$$= 1.0 - (0.022 + 0.065 + 0.315)$$

$$= 0.598$$

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 14-78 as follows:
\[ N_{e,cds,2,at,K} = N_{e,cds,2,at,f} \times P_{pop+cds,at,K} \]
\[ = 0.091 \times 0.022 \]
\[ = 0.002 \text{ crashes/year} \]

Similar calculations using Equation 14-78 and the probabilities of occurrences of the other crash severities yield the following results:

\[ N_{e,cds,2,at,A} = 0.006 \text{ crashes/year} \]

\[ N_{e,cds,2,at,B} = 0.029 \text{ crashes/year} \]

\[ N_{e,cds,2,at,C} = 0.055 \text{ crashes/year} \]

*Apply the crash type distribution, if desired.*

The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 14-6 and Table 14-9 by the predicted average crash frequencies obtained in Step 11.

**Worksheets**

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

- Table 14-51. Ramp Segment Worksheet (1 of 4)—Sample Problem 2
- Table 14-52. Ramp Segment Worksheet (2 of 4)—Sample Problem 2
- Table 14-53. Ramp Segment Worksheet (3 of 4)—Sample Problem 2
- Table 14-54. Ramp Segment Worksheet (4 of 4)—Sample Problem 2

Filled versions of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 14 Appendix A.

Table 14-51 is a summary of general information about the ramp segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 2. The input data include area type, crash data, basic roadway data, and alignment data.

Table 14-52 is a summary of general information about the ramp segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 2. The input data include cross section data, roadside data, ramp access data, and traffic data.

Table 14-53 is a tabulation of the CMF and SPF computations for Sample Problem 2.

Table 14-54 is a tabulation of the crash severity and crash type distributions for Sample Problem 2.
Table 14-51. Ramp Segment Worksheet (1 of 4)—Sample Problem 2

<table>
<thead>
<tr>
<th>General Information</th>
<th>Location Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Roadway</td>
</tr>
<tr>
<td>Agency or company</td>
<td>Roadway section</td>
</tr>
<tr>
<td>Date performed</td>
<td>Study year</td>
</tr>
<tr>
<td>Area type</td>
<td>X Urban Rural</td>
</tr>
</tbody>
</table>

### Input Data

#### Crash Data

<table>
<thead>
<tr>
<th>Crash Data</th>
<th>Crash Period</th>
<th>Study Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash data time period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count of multiple-vehicle FI crashes (N_{o, w, n, mv, fi})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count of single-vehicle FI crashes (N_{o, w, n, sv, fi})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count of multiple-vehicle PDO crashes (N_{o, w, n, mv, pdo})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count of single-vehicle PDO crashes (N_{o, w, n, sv, pdo})</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Basic Roadway Data

<table>
<thead>
<tr>
<th>Basic Roadway Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of through lanes (n)</td>
<td>2</td>
</tr>
<tr>
<td>Segment length (L) (mi)</td>
<td>0.08</td>
</tr>
<tr>
<td>Average traffic speed on the freeway (V_{frwy}) (mi/h)</td>
<td>60</td>
</tr>
<tr>
<td>Segment type</td>
<td>C-D Road</td>
</tr>
<tr>
<td>Type of control at crossroad ramp terminal</td>
<td>--</td>
</tr>
</tbody>
</table>

#### Alignment Data

<table>
<thead>
<tr>
<th>Alignment Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Curve Data</td>
<td></td>
</tr>
<tr>
<td>Presence of horizontal curve 1</td>
<td>Off Seg.</td>
</tr>
<tr>
<td>Curve radius (R_1) (ft)</td>
<td>1,100</td>
</tr>
<tr>
<td>Length of curve (L_{c1}) (mi)</td>
<td>0.08</td>
</tr>
<tr>
<td>Length of curve in segment (L_{c1, seg}) (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Milepost of beginning of curve in dir. of travel (X_1) (mi)</td>
<td>0.09</td>
</tr>
<tr>
<td>Presence of horizontal curve 2</td>
<td>No</td>
</tr>
<tr>
<td>Curve radius (R_2) (ft)</td>
<td>--</td>
</tr>
<tr>
<td>Length of curve (L_{c2}) (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Length of curve in segment (L_{c2, seg}) (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Milepost of beginning of curve in dir. of travel (X_2) (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Presence of horizontal curve 3</td>
<td>No</td>
</tr>
<tr>
<td>Curve radius (R_3) (ft)</td>
<td>--</td>
</tr>
<tr>
<td>Length of curve (L_{c3}) (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Length of curve in segment (L_{c3, seg}) (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Milepost of beginning of curve in dir. of travel (X_3) (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Presence of horizontal curve 4</td>
<td>No</td>
</tr>
<tr>
<td>Curve radius (R_4) (ft)</td>
<td>--</td>
</tr>
<tr>
<td>Length of curve (L_{c4}) (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Length of curve in segment (L_{c4, seg}) (mi)</td>
<td>--</td>
</tr>
<tr>
<td>Milepost of beginning of curve in dir. of travel (X_4) (mi)</td>
<td>--</td>
</tr>
</tbody>
</table>
Table 14-52. Ramp Segment Worksheet (2 of 4)—Sample Problem 2

### Input Data

<table>
<thead>
<tr>
<th>Cross Section Data</th>
<th>Crash Period</th>
<th>Study Year</th>
<th>Complete the study year column. Complete the crash period column if the EB Method is used.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane width $W_l$ (ft)</td>
<td>--</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Right shoulder width $W_{rs}$ (ft)</td>
<td>--</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Left shoulder width $W_{ls}$ (ft)</td>
<td>--</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Presence of lane add or lane drop</td>
<td>--</td>
<td>No</td>
<td>Choices: No, Lane add, Lane drop</td>
</tr>
<tr>
<td>Length of taper in segment $L_{add, seg}$ or $L_{drop, seg}$ (mi)</td>
<td>--</td>
<td>--</td>
<td>If “Lane add” or “Lane drop”, enter length.</td>
</tr>
</tbody>
</table>

### Roadside Data

| Presence of barrier on right side of roadway | -- | Y/N | N | Y/N | If Yes, then use the ramp barrier worksheet. |
| Presence of barrier on left side of roadway  | -- | Y/N | N | Y/N | If Yes, then use the ramp barrier worksheet. |

### Ramp Access Data

#### Ramp Entrance

| Presence of speed-change lane in segment | -- | Y/N | N | Y/N | If Yes, then enter data in the next row. |
| Length of s-c lane in segment $L_{on, seg}$ (mi) | -- | -- | -- | -- |

#### Exit ramp

| Presence of speed-change lane in segment | -- | Y/N | N | Y/N | If Yes, then enter data in the next row. |
| Length of s-c lane in segment $L_{on, seg}$ (mi) | -- | -- | -- | -- |

#### Weave

| Presence of a weaving section in segment | -- | Y/N | Y | Y/N | If Yes, then enter data in the next two rows. |
| Length of weaving section $L_{wev}$ (mi) | -- | 0.08 | -- | -- |
| Length of weaving section in seg. $L_{wev, seg}$ (mi) | -- | 0.08 | -- | -- |

### Traffic Data

| Segment AADT $AADT_r$ or $AADT_c$ (veh/day) | -- | 5,500 |
## Table 14-53. Ramp Segment Worksheet (3 of 4)—Sample Problem 2

### Crash Modification Factors

<table>
<thead>
<tr>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Multiple Vehicle</td>
<td>Single Vehicle</td>
</tr>
<tr>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
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<td></td>
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</tr>
</tbody>
</table>

**Horizontal curve** $CMF_{1, w, x, y, z}$ 14-33

**Lane width** $CMF_{2, w, x, y, f_l}$ 14-34

**Right shoulder width** $CMF_{3, w, x, y, z}$ 14-35

**Left shoulder width** $CMF_{4, w, x, y, z}$ 14-36

**Right side barrier** $CMF_{5, w, x, y, z}$ 14-37

**Left side barrier** $CMF_{6, w, x, y, z}$ 14-38

**Lane add or drop** $CMF_{7, w, x, y, f_l}$ 14-39

**Ramp speed-change lane** $CMF_{8, w, x, y, m, f_l}$ 14-40

**Weaving section** $CMF_{9, c, d, a, y, z}$ 14-41

**Combined CMF (multiply all CMFs evaluated)**

### Expected Average Crash Frequency *

<table>
<thead>
<tr>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Multiple Vehicle</td>
<td>Single Vehicle</td>
</tr>
<tr>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Calibration factor** $C_{w, x, y, z}$

**Overdispersion parameter** $k_{w, x, y, z}$

**Observed crash count** $N^*_{o, w, x, y, z}$ (cr)

**Reference year** $r$

**Predicted average crash freq. for reference year** $N_{p, w, x, y, z, r}$ (cr/yr)

**Predicted number of crashes for crash period (sum all years)** $N^*_{p, w, x, y, z}$ (cr)

**Equivalent years associated with crash count** $C_{b, w, x, y, z, r}$ (yr)

**Adjusted average crash freq. for ref. year given** $N_{e, w, x, y, z, r}$ (cr/yr)

**Study year** $s$

**Predicted average crash freq. for study year** $N_{p, w, x, y, z, s}$ (cr/yr)

**Expected average crash freq. for study year** $N_{e, w, x, y, z, s}$ (cr/yr)

**Expected average crash freq. for study year (all crash types)** $N_{e, w, x, a, z, s}$ (cr/yr)

### Note:

* If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.

---

**Expected Average Crash Frequency**: Calculate expected average crash frequency for each category by applying the appropriate crash modification factors and considering the study and crash periods as necessary.
**Table 14-54. Ramp Segment Worksheet (4 of 4)—Sample Problem 2**

**Expected Average Crash Frequency**

<table>
<thead>
<tr>
<th>Crash Severity Distribution</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Total FI</th>
<th>PDO</th>
<th>Total FI + PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion by injury level</td>
<td>0.022</td>
<td>0.065</td>
<td>0.315</td>
<td>0.598</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected average crash freq. for study year (all crash types) ( N_{e, w, x, y, at, z, s} ) (cr/yr)</td>
<td>0.002</td>
<td>0.006</td>
<td>0.029</td>
<td>0.055</td>
<td>0.091</td>
<td>0.247</td>
<td>0.338</td>
</tr>
</tbody>
</table>

**Crash Type Distribution**

<table>
<thead>
<tr>
<th>Crash Type Category</th>
<th>Table</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Multiple-Vehicle Crashes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head-on</td>
<td>0.015</td>
<td>0.001</td>
<td>0.009</td>
<td>0.002</td>
</tr>
<tr>
<td>Right-angle</td>
<td>0.010</td>
<td>0.001</td>
<td>0.005</td>
<td>0.001</td>
</tr>
<tr>
<td>Rear-end</td>
<td>0.707</td>
<td>0.039</td>
<td>0.550</td>
<td>0.095</td>
</tr>
<tr>
<td>Sideswipe</td>
<td>0.129</td>
<td>0.007</td>
<td>0.335</td>
<td>0.058</td>
</tr>
<tr>
<td>Other multiple-vehicle crashes</td>
<td>0.139</td>
<td>0.008</td>
<td>0.101</td>
<td>0.017</td>
</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>0.055</td>
<td>1.000</td>
<td>0.172</td>
</tr>
</tbody>
</table>

| **Single-Vehicle Crashes** |       |                  |                      |       |
| Crash with animal     | 0.003 | 0.000            | 0.005                | 0.000 | 0.000 |
| Crash with fixed object | 0.718 | 0.026            | 0.834                | 0.062 | 0.088 |
| Crash with other object | 0.015 | 0.001            | 0.023                | 0.002 | 0.002 |
| Crash with parked vehicle | 0.012 | 0.000            | 0.012                | 0.001 | 0.001 |
| Other single-vehicle crashes | 0.252 | 0.009 | 0.126 | 0.009 | 0.019 |
| Total                | 1.000 | 0.036            | 1.000                | 0.075 | 0.111 |

**Note:**

a – If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.

### 14.14.3. Sample Problem 3

**The Site/Facility**

A one-lane urban entrance ramp segment.

**The Question**

What is the predicted average crash frequency of the ramp segment for a one-year period?

**The Facts**

The study year is 2011. The conditions present during this year are provided in the following list.

- 0.3-mi length
- 7,250 veh/day
65-mi/h average speed on freeway mainline

Yield control at crossroad ramp terminal

One in-segment horizontal curve

- 475-ft radius
- 0.08-mi length, entirely on the segment
- Beginning at milepost 0.07

14-ft lane width

8-ft right shoulder width

4-ft left shoulder width

No lane adds or lane drops

Barrier on both sides of the roadway

- Right-side barrier length: 0.15 mi
- Right-side barrier offset: 9 ft
- Left-side barrier length: 0.15 mi
- Left-side barrier offset: 5 ft

No ramp entrances or exits in the segment

No weaving section

Assumptions

- Crash type distributions used are the default values presented in Table 14-6 and Table 14-9.
- The calibration factor is 1.00.

Results

Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the ramp segment in Sample Problem 3 is determined to be 0.3 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 0.5 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8

To determine the predicted average crash frequency of the ramp segment in Sample Problem 3, only Steps 9 through 13 are conducted. No other steps are necessary because only one ramp segment is analyzed for a one-year period and the EB Method is not applied.
Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site’s facility type and traffic control features. 
For a one-lane urban exit ramp segment, SPF values for multiple-vehicle and single-vehicle crashes are determined.

Multiple-Vehicle Crashes
The SPF for multiple-vehicle fatal-and-injury crashes is calculated from Equation 14-20 and Table 14-5 as follows:

\[ N_{spf, mv, fi} = L \times \exp(a + b \times \ln(c \times AADT_r) + d \times AADT_r) \]

\[ = 0.3 \times \exp(-3.505 + 0.524 \times \ln(0.001 \times 7,250) + 0.0699 \times (0.001 \times 7,250)) \]

\[ = 0.042 \text{ crashes/year} \]

Similarly, the SPF for multiple-vehicle property-damage-only crashes is calculated from Equation 14-20 and Table 14-5 to yield the following result:

\[ N_{spf, mv, pdo} = 0.079 \text{ crashes/year} \]

Single-Vehicle Crashes
The SPF for single-vehicle fatal-and-injury crashes is calculated from Equation 14-24 and Table 14-8 as follows:

\[ N_{spf, sv, fi} = L \times \exp(a + b \times \ln(c \times AADT_r) \times AADT_r) \]

\[ = 0.3 \times \exp(-1.966 + 0.718 \times \ln(0.001 \times 7,250)) \]

\[ = 0.174 \text{ crashes/year} \]

Similarly, the SPF for single-vehicle property-damage-only crashes is calculated from Equation 14-24 and Table 14-8 to yield the following result:

\[ N_{spf, sv, pdo} = 0.211 \text{ crashes/year} \]

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

Horizontal Curve (CMF, rps, 1EN, y, z )
The limited curve speed for the in-segment horizontal curve is computed using Equation 14-59 as follows:

\[ v_{max, r} = 3.24 \times (32.2 \times R_t)^{0.30} \]

\[ = 3.24 \times (32.2 \times 475)^{0.30} \]

\[ = 58.3 \text{ ft/s} \]
The average entry speed at the curve is computed using Equation 14-60 and the default values in Table 14-42 as follows:

\[
v_{\text{ent},1} = \left[(1.47 \times V_{\text{road}})^3 + 495 \times 5.280 \times X_1\right]^{1/3} \leq 1.47 \times V_{\text{frwy}}
\]

\[
= \left(1.47 \times 15\right)^3 + 495 \times 5.280 \times 0.07 \right)^{1/3} \leq 1.47 \times 65
\]

\[
= 57.9 \text{ ft/s}
\]

The average exit speed at curve 1 is computed using Equation 14-61 as follows:

\[
v_{\text{ext},1} = \left(v_{\text{ext},1}^3 + 495 \times 5.280 \times L_{c,1}\right)^{1/3} \leq v_{\text{max},1} \text{ and } \leq 1.47 \times V_{\text{frwy}}
\]

\[
= \left(57.9^3 + 495 \times 5.280 \times 0.3\right)^{1/3} \leq 58.3 \text{ and } \leq 1.47 \times 65
\]

\[
= 58.3 \text{ ft/s}
\]

\(CMF_{1, \text{rps, IEN, } y, fi}\) is calculated using Equation 14-33 as follows:

\[
CMF_{1, \text{rps, IEN, } y, fi} = 1.0 + a \times \left[\sum_{i=1}^{m} \left(\frac{v_{\text{ent},i}}{R_i}\right)^2 \times P_{c,i}\right]
\]

From Table 14-24, \(a = 0.779\) for multiple-vehicle fatal-and-injury crashes and 2.406 for single-vehicle fatal-and-injury crashes. \(CMF_{1, \text{rps, IEN, } mv, fi}\) is calculated as follows:

\[
CMF_{1, \text{rps, IEN, } mv, fi} = 1.0 + 0.779 \times \left[\frac{1.000 \times \left(\frac{57.9}{475}\right)^2 \times 0.08}{32.2}\right]
\]

\[
= 1.096
\]

Calculations using the other coefficients from Table 14-24 yield the following results:

\(CMF_{1, \text{rps, IEN, } sv, fi} = 1.296\)

\(CMF_{1, \text{rps, IEN, } mv, pdo} = 1.067\)

\(CMF_{1, \text{rps, IEN, } sv, pdo} = 1.385\)

**Lane Width (CMF_{2, \text{rps, IEN, } y, z})**

The segment has 14-ft lanes, which is the base condition for the lane width CMF. Hence, \(CMF_{2, \text{rps, IEN, } y, fi}\) and \(CMF_{2, \text{rps, IEN, } y, pdo}\) are equal to 1.000.

**Right Shoulder Width (CMF_{3, \text{rps, IEN, } y, z})**

The segment has 8-ft right shoulders, which is the base condition for the right shoulder width CMF. Hence, \(CMF_{3, \text{rps, IEN, } y, fi}\) and \(CMF_{3, \text{rps, IEN, } y, pdo}\) are equal to 1.000.

**Left Shoulder Width (CMF_{4, \text{rps, IEN, } y, z})**

The segment has 4-ft left shoulders, which is the base condition for the left shoulder width CMF. Hence, \(CMF_{4, \text{rps, IEN, } y, fi}\) and \(CMF_{4, \text{rps, IEN, } y, pdo}\) are equal to 1.000.
Right Side Barrier ($CMF_{5, rps, IEN, y, fi}$)

$CMF_{5, rps, IEN, y, fi}$ is calculated using Equation 14-37 as follows:

$$
CMF_{5, rps, IEN, y, fi} = (1.0 - P_{rb}) \times 1.0 + P_{rb} \times \exp \left( \frac{a}{W_{rcb}} \right)
$$

The distance from the edge of the right shoulder to the barrier face $W_{rcb}$ is computed using Equation 14-74 as follows:

$$
W_{rcb} = \frac{\sum L_{rb, i}}{\sum W_{off, r, i} - W_{rs}}
$$

From Table 14-28, $a = 0.210$ for multiple-vehicle crashes. $CMF_{5, rps, IEN, y, fi}$ is calculated as follows:

$$
CMF_{5, rps, IEN, y, fi} = \left(1.0 - \frac{0.15}{0.3}\right) \times 1.0 + \frac{0.15}{0.3} \times \exp \left( \frac{0.210}{1.0} \right) = 1.117
$$

Similar calculations using the property-damage-only coefficients from Table 14-28 yield the following results:

$$
CMF_{5, rps, IEN, y, pdo} = 1.106
$$

Left Side Barrier ($CMF_{6, rps, IEN, y, z}$)

$CMF_{6, rps, IEN, y, z}$ is calculated using Equation 14-38 as follows:

$$
CMF_{6, rps, IEN, y, z} = (1.0 - P_{lb}) \times 1.0 + P_{lb} \times \exp \left( \frac{a}{W_{lcb}} \right)
$$

The distance from the edge of the right shoulder to the barrier face $W_{lcb}$ is computed using Equation 14-76 as follows:

$$
W_{lcb} = \frac{\sum L_{lb, i}}{\sum W_{off, l, i} - W_{ls}}
$$

From Table 14-28, $a = 0.210$ for multiple-vehicle crashes. $CMF_{6, rps, IEN, y, z}$ is calculated as follows:

$$
CMF_{6, rps, IEN, y, z} = \left(1.0 - \frac{0.15}{0.3}\right) \times 1.0 + \frac{0.15}{0.3} \times \exp \left( \frac{0.210}{1.0} \right) = 1.117
$$

Similar calculations using the property-damage-only coefficients from Table 14-28 yield the following results:

$$
CMF_{6, rps, IEN, y, pdo} = 1.106
$$
From Table 14-29, $\alpha = 0.210$ for multiple-vehicle crashes. $CMF_{6, rps, IEN, y, fi}$ is calculated as follows:

$$CMF_{6, rps, IEN, y, fi} = \left(1.0 - \frac{0.15}{0.3}\right) \times 1.0 + \frac{0.15}{0.3} \times \exp \left(\frac{0.210}{1.0}\right)$$

$$= 1.117$$

Similar calculations using the property-damage-only coefficients from Table 14-29 yield the following results:

$$CMF_{6, rps, IEN, y, pdo} = 1.106$$

**Lane Add or Drop (CMF$_7$, rps, IEN, y, fi)**

The segment does not have a lane add or a lane drop. Hence, $CMF_{7, rps, IEN, y, fi}$ is equal to 1.000.

**Ramp Speed-Change Lane (CMF$_8$, rps, IEN, mv, fi)**

The segment does not have a speed-change lane. Hence, $CMF_{8, rps, IEN, mv, fi}$ is equal to 1.000.

**Multiple-Vehicle Crashes**

The CMFs are applied to the multiple-vehicle fatal-and-injury SPF as follows:

$$N_{p^*, rps, IEN, mv, fi} = N_{spf, rps, IEN, mv, fi} \times \left(\prod_{k=1}^{8} CMF_{k, rps, IEN, mv, fi}\right)$$

$$= 0.042 \times (1.096 \times 1.000 \times 1.000 \times 1.117 \times 1.117 \times 1.000 \times 1.000)$$

$$= 0.042 \times 1.367$$

$$= 0.058 \text{ crashes/year}$$

The CMFs are applied to the multiple-vehicle property-damage-only SPF as follows:

$$N_{p^*, rps, IEN, mv, pdo} = N_{spf, rps, IEN, mv, pdo} \times \left(\prod_{k=1}^{8} CMF_{k, rps, IEN, mv, pdo}\right)$$

$$= 0.079 \times (1.067 \times 1.000 \times 1.000 \times 1.106 \times 1.106 \times 1.000 \times 1.000)$$

$$= 0.079 \times 1.305$$

$$= 0.104 \text{ crashes/year}$$

**Single-Vehicle Crashes**

The CMFs are applied to the single-vehicle fatal-and-injury SPF as follows:

$$N_{p^*, rps, IEN, sv, fi} = N_{spf, rps, IEN, sv, fi} \times \left(\prod_{k=1}^{8} CMF_{k, rps, IEN, sv, fi}\right)$$

$$= 0.174 \times (1.296 \times 1.000 \times 1.000 \times 1.117 \times 1.117 \times 1.000 \times 1.000)$$

$$= 0.174 \times 1.617$$

$$= 0.281 \text{ crashes/year}$$
The CMFs are applied to the single-vehicle property-damage-only SPF as follows:

\[
N_{p, rps, 1EN, sv, pdo} = N_{p, rps, 1EN, sv, pdo} \times \left( \text{CMF}_{1, rps, 1EN, sv, pdo} \times \ldots \times \text{CMF}_{8, rps, 1EN, sv, pdo} \right)
\]

\[
= 0.211 \times (1.385 \times 1.000 \times 1.000 \times 1.000 \times 1.106 \times 1.106 \times 1.000 \times 1.000)
\]

\[
= 0.211 \times 1.694
\]

\[
= 0.358 \text{ crashes/yr}
\]

**Step 11 – Multiply the result obtained in Step 10 by the appropriate calibration factor.**
It is assumed that a calibration factor of 1.00 has been determined for local conditions. As a result, \(N_{p, rps, 1EN, y, z} = N_{p, rps, 1EN, y, z}\) for both crash types \(y = mv: \text{multiple-vehicle, } sv: \text{single-vehicle}\) and both crash severities \(z = fi: \text{fatal-and-injury, pdo: property-damage-only}\). See Part C Appendix A.1 for further discussion on calibration of the predicted models.

**Calculation of Predicted Average Crash Frequency**
The predicted average crash frequency is calculated using Equation 14-1 based on the results obtained in Steps 9 through 11 as follows.

**Fatal-and-injury crashes:**

\[
N_{p, rps, 1EN, at, fi} = N_{p, rps, 1EN, mv, fi} + N_{p, rps, 1EN, sv, fi}
\]

\[
= 0.058 + 0.281
\]

\[
= 0.339 \text{ crashes/yr}
\]

**Property-damage-only crashes:**

\[
N_{p, rps, 1EN, at, pdo} = N_{p, rps, 1EN, mv, pdo} + N_{p, rps, 1EN, sv, pdo}
\]

\[
= 0.104 + 0.358
\]

\[
= 0.462 \text{ crashes/yr}
\]

**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.**
The study period is one year (2011), so steps 8 through 11 need not be repeated.

**Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.**
This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

*Apply the site-specific EB Method to a future time period, if appropriate.*
The site-specific EB Method is not applied in this sample problem because crash data are not available.

*Apply the severity distribution functions (SDFs), if desired.*
To apply the SDFs, the systematic component of crash severity likelihood \(V_j\) is computed for each severity level \(j\) using Equation 14-83 as follows:

\[
V_j = a + \left( b \times \frac{P_{lb} + P_{lh}}{2} \right) + (c \times n) + (d \times I_{rural}) + (e \times I_{urb})
\]
The coefficients \( a, b, c, d, \) and \( e \) are obtained from Table 14-43 for each severity level \( j \). \( V_j \) is computed for fatal and incapacitating injury crashes as follows:

\[
V_{K+A} = -1.537 + \left( -0.481 \times \frac{0.5 + 0.5}{2} \right) + \left( -0.228 \times 1.0 \right) + \left( 0.668 \times 0.0 \right) + \left( 0.426 \times 0.0 \right)
\]

\[= -2.006 \]

Similar calculations using the coefficients from Table 14-43 for non-incapacitating injury crashes yield the following results:

\[V_{B} = -0.415\]

Using these computed \( V_{K+A} \) and \( V_{B} \) values, and assuming a calibration factor \( C_{sdf,rps+cds} \) of 1.0, the probability of occurrence of a fatal crash is computed using Equation 14-79 as follows:

\[
P_{rps+cds,ac,at,K} = \frac{\exp(V_{K+A})}{\frac{1.0}{C_{sdf,rps+cds}} + \exp(V_{K+A}) + \exp(V_{B})} \times P_{K|K+A,rps+cds,ac,at}
\]

\[= \frac{\exp(-2.006)}{1.0 + \exp(-2.006) + \exp(-0.415)} \times 0.248 \]

\[= 0.018 \]

Similar calculations using Equation 14-80 and Equation 14-81 yield the following results:

\[P_{rps+cds,ac,at,A} = 0.056\]

\[P_{rps+cds,ac,at,B} = 0.369\]

The probability of occurrence of a possible-injury crash is computed using Equation 14-82 as follows:

\[
P_{rps+cds,ac,at,C} = 1.0 - (P_{rps+cds,ac,at,K} + P_{rps+cds,ac,at,A} + P_{rps+cds,ac,at,B})
\]

\[= 1.0 - (0.018 + 0.056 + 0.369) \]

\[= 0.557 \]

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 14-78 as follows:

\[
N_{e,rps,EN,at,K} = N_{e,rps,EN,at} \times P_{rps+cds,ac,at,K}
\]

\[= 0.339 \times 0.018 \]

\[= 0.006 \text{ crashes/year} \]

Similar calculations using Equation 14-78 and the probabilities of occurrences of the other crash severities yield the following results:

\[N_{e,rps,EN,at,A} = 0.019 \text{ crashes/year} \]
\[ N_{e,rpt,3EN,at,B} = 0.125 \text{ crashes/year} \]

\[ N_{e,rpt,3EN,at,C} = 0.189 \text{ crashes/year} \]

**Apply the crash type distribution, if desired.**

The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 14-6 and Table 14-9 by the predicted average crash frequencies obtained in Step 11.

**Worksheets**

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

- Table 14-55. Ramp Segment Worksheet (1 of 4)—Sample Problem 3
- Table 14-56. Ramp Segment Worksheet (2 of 4)—Sample Problem 3
- Table 14-57. Ramp Segment Worksheet (3 of 4)—Sample Problem 3
- Table 14-58. Ramp Segment Worksheet (4 of 4)—Sample Problem 3
- Table 14-59. Ramp Barrier Worksheet—Sample Problem 3

Filled versions of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 14 Appendix A.

Table 14-55 is a summary of general information about the ramp segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 3. The input data include area type, crash data, basic roadway data, and alignment data.

Table 14-56 is a summary of general information about the ramp segment, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 3. The input data include cross section data, roadside data, ramp access data, and traffic data.

Table 14-57 is a tabulation of the CMF and SPF computations for Sample Problem 3.

Table 14-58 is a tabulation of the crash severity and crash type distributions for Sample Problem 3.

Table 14-59 is used to complete the barrier calculations for Sample Problem 3.
### Table 14-55. Ramp Segment Worksheet (1 of 4)—Sample Problem 3

<table>
<thead>
<tr>
<th>General Information</th>
<th>Location Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Roadway</td>
</tr>
<tr>
<td>Agency or company</td>
<td>Roadway section</td>
</tr>
<tr>
<td>Date performed</td>
<td>Study year</td>
</tr>
<tr>
<td>Area type</td>
<td>X Urban Rural</td>
</tr>
</tbody>
</table>

#### Input Data

**Crash Data**
- Count of multiple-vehicle FI crashes $N_{o,w,n,m,v,fi}$ --
- Count of single-vehicle FI crashes $N_{o,w,n,m,f}$ --
- Count of multiple-vehicle PDO crashes $N_{o,w,n,m,pdo}$ --
- Count of single-vehicle PDO crashes $N_{o,w,n,m,pdo}$ --

**Basic Roadway Data**
- Number of through lanes $n$ 1
- Segment length $L$ (mi) 0.3
- Average traffic speed on the freeway $V_{frwy}$ (mi/h) 65
- Segment type Entrance
- Type of control at crossroad ramp terminal Yield

**Alignment Data**

<table>
<thead>
<tr>
<th>Horizontal Curve Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence of horizontal curve 1 -- In Seg.</td>
</tr>
<tr>
<td>Curve radius $R_1$ (ft) --</td>
</tr>
<tr>
<td>Length of curve $L_{c1}$ (mi) --</td>
</tr>
<tr>
<td>Length of curve in segment $L_{c1,seg}$ (mi) --</td>
</tr>
<tr>
<td>Milepost of beginning of curve in dir. of travel $X_1$ (mi) --</td>
</tr>
<tr>
<td>Presence of horizontal curve 2 -- No</td>
</tr>
<tr>
<td>Curve radius $R_2$ (ft) -- --</td>
</tr>
<tr>
<td>Length of curve $L_{c2}$ (mi) -- --</td>
</tr>
<tr>
<td>Length of curve in segment $L_{c2,seg}$ (mi) -- --</td>
</tr>
<tr>
<td>Milepost of beginning of curve in dir. of travel $X_2$ (mi) -- --</td>
</tr>
<tr>
<td>Presence of horizontal curve 3 -- No</td>
</tr>
<tr>
<td>Curve radius $R_3$ (ft) -- --</td>
</tr>
<tr>
<td>Length of curve $L_{c3}$ (mi) -- --</td>
</tr>
<tr>
<td>Length of curve in segment $L_{c3,seg}$ (mi) -- --</td>
</tr>
<tr>
<td>Milepost of beginning of curve in dir. of travel $X_3$ (mi) -- --</td>
</tr>
<tr>
<td>Presence of horizontal curve 4 -- No</td>
</tr>
<tr>
<td>Curve radius $R_4$ (ft) -- --</td>
</tr>
<tr>
<td>Length of curve $L_{c4}$ (mi) -- --</td>
</tr>
<tr>
<td>Length of curve in segment $L_{c4,seg}$ (mi) -- --</td>
</tr>
<tr>
<td>Milepost of beginning of curve in dir. of travel $X_4$ (mi) -- --</td>
</tr>
</tbody>
</table>
Table 14-6. Ramp Segment Worksheet (2 of 4)—Sample Problem 3

<table>
<thead>
<tr>
<th>Input Data</th>
<th>Crash Period</th>
<th>Study Year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cross Section Data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane width $W_l$ (ft)</td>
<td>--</td>
<td>14</td>
</tr>
<tr>
<td>Right shoulder width $W_{rs}$ (ft)</td>
<td>--</td>
<td>8</td>
</tr>
<tr>
<td>Left shoulder width $W_{ls}$ (ft)</td>
<td>--</td>
<td>4</td>
</tr>
<tr>
<td>Presence of lane add or lane drop</td>
<td>--</td>
<td>No</td>
</tr>
<tr>
<td>Length of taper in segment $L_{add, seg}$ or $L_{drop, seg}$ (mi)</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

| Presence of lane add or lane drop | No Choices: No, Lane add, Lane drop |
| Length of taper in segment $L_{add, seg}$ or $L_{drop, seg}$ (mi) | -- |

| Roadside Data |              |            |
| Presence of barrier on right side of roadway | -- | Y/N | Y |
| Presence of barrier on left side of roadway | -- | Y/N | Y |

| Ramp Access Data |              |            |
| Ramp Entrance |              |            |
| Presence of speed-change lane in segment | -- | Y/N | N |
| Length of s-c lane in segment $L_{on,seg}$ (mi) | -- | -- |

Exit ramp
| Presence of speed-change lane in segment | -- | Y/N | N |
| Length of s-c lane in segment $L_{on,seg}$ (mi) | -- | -- |

| Presence of a weaving section in segment | -- | Y/N | -- |
| Length of weaving section $L_{wev}$ (mi) | -- | -- |
| Length of weaving section in seg. $L_{wev, seg}$ (mi) | -- | -- |

| Traffic Data |              |
| Segment AADT $AADTr$ or $AADT_c$ (veh/day) | -- | 7,250 |

Complete the study year column. Complete the crash period column if the EB Method is used.
### Table 14-57. Ramp Segment Worksheet (3 of 4)—Sample Problem 3

#### Crash Modification Factors

<table>
<thead>
<tr>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Multiple Vehicle</strong></td>
<td><strong>Single Vehicle</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Crash Period</strong></td>
<td><strong>Study Year</strong></td>
</tr>
<tr>
<td>Horizontal curve $CMF_{1, w, x, y, z}$</td>
<td>14-33</td>
<td>--</td>
</tr>
<tr>
<td>Lane width $CMF_{2, w, x, y, z}$</td>
<td>14-34</td>
<td>--</td>
</tr>
<tr>
<td>Right shoulder width $CMF_{3, w, x, y, z}$</td>
<td>14-35</td>
<td>--</td>
</tr>
<tr>
<td>Left shoulder width $CMF_{4, w, x, y, z}$</td>
<td>14-36</td>
<td>--</td>
</tr>
<tr>
<td>Right side barrier $CMF_{5, w, x, y, z}$</td>
<td>14-37</td>
<td>--</td>
</tr>
<tr>
<td>Left side barrier $CMF_{6, w, x, y, z}$</td>
<td>14-38</td>
<td>--</td>
</tr>
<tr>
<td>Lane add or drop $CMF_{7, w, x, y, z}$</td>
<td>14-39</td>
<td>--</td>
</tr>
<tr>
<td>Ramp speed-change lane $CMF_{8, w, x, y, z}$</td>
<td>14-40</td>
<td>--</td>
</tr>
<tr>
<td>Weaving section $CMF_{9, w, x, y, z}$</td>
<td>14-41</td>
<td>--</td>
</tr>
<tr>
<td>Combined CMF (multiply all CMFs evaluated)</td>
<td>14-37</td>
<td>--</td>
</tr>
</tbody>
</table>

#### Expected Average Crash Frequency *

<table>
<thead>
<tr>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Multiple Vehicle</strong></td>
<td><strong>Single Vehicle</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Crash Period</strong></td>
<td><strong>Study Year</strong></td>
</tr>
<tr>
<td>Calibration factor $C_{w, x, y, z}$</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Overdispersion parameter $k_{w, x, y, z}$</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Observed crash count $N^{*}_{w, x, y, z}$ (cr)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Reference year $r$</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Predicted average crash freq. for reference year $N^{p, w, x, y, z, r}$ (cr/yr)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Predicted number of crashes for crash period (sum all years) $N^{p, w, x, y, z}$ (cr)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Equivalent years associated with crash count $C_{r, w, x, y, z}$ (yr)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Adjusted average crash freq. for ref. year given $N^{a, w, x, y, z, r}$ (cr/yr)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Study year $s$</td>
<td>2011</td>
<td>2011</td>
</tr>
<tr>
<td>Predicted average crash freq. for study year $N^{p, w, x, y, z, s}$ (cr/yr)</td>
<td>0.058</td>
<td>0.281</td>
</tr>
<tr>
<td>Expected average crash freq. for study year $N^{e, w, x, y, z, s}$ (cr/yr)</td>
<td>0.058</td>
<td>0.281</td>
</tr>
</tbody>
</table>

**Note:**

a – If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e.”
Table 14-58. Ramp Segment Worksheet (4 of 4)—Sample Problem 3

Expected Average Crash Frequency $^a$

**Crash Severity Distribution**

<table>
<thead>
<tr>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Total FI</th>
<th>PDO</th>
<th>Total FI + PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.018</td>
<td>0.056</td>
<td>0.369</td>
<td>0.557</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.006</td>
<td>0.019</td>
<td>0.125</td>
<td>0.189</td>
<td>0.339</td>
<td>0.462</td>
<td>0.801</td>
</tr>
</tbody>
</table>

**Expected average crash freq. for study year (all crash types) $N_{e, w, x, y, z, s}$ (cr/yr)**

<table>
<thead>
<tr>
<th>Crash Type Category</th>
<th>Table</th>
<th>Proportion</th>
<th>Expected Average Crash Frequency for Study Year $N_{e, w, x, y, z, s}$ (cr/yr)</th>
<th>Proportion</th>
<th>Expected Average Crash Frequency for Study Year $N_{e, w, x, y, pdo, s}$ (cr/yr)</th>
<th>Expected Average Crash Frequency for Study Year $N_{e, w, x, y, as, s}$ (cr/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head-on</td>
<td>0.015</td>
<td>0.001</td>
<td>0.009</td>
<td>0.001</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Right-angle</td>
<td>0.010</td>
<td>0.001</td>
<td>0.005</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Rear-end</td>
<td>0.707</td>
<td>0.041</td>
<td>0.550</td>
<td>0.057</td>
<td>0.098</td>
<td></td>
</tr>
<tr>
<td>Sideswipe</td>
<td>0.129</td>
<td>0.007</td>
<td>0.335</td>
<td>0.035</td>
<td>0.042</td>
<td></td>
</tr>
<tr>
<td>Other multiple-vehicle crashes</td>
<td>0.139</td>
<td>0.008</td>
<td>0.101</td>
<td>0.011</td>
<td>0.019</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>0.058</td>
<td>1.000</td>
<td>0.104</td>
<td>0.162</td>
<td></td>
</tr>
</tbody>
</table>

**Single-Vehicle Crashes** 14-9

<table>
<thead>
<tr>
<th>Crash Type Category</th>
<th>Table</th>
<th>Proportion</th>
<th>Expected Average Crash Frequency for Study Year $N_{e, w, x, y, z, s}$ (cr/yr)</th>
<th>Proportion</th>
<th>Expected Average Crash Frequency for Study Year $N_{e, w, x, y, pdo, s}$ (cr/yr)</th>
<th>Expected Average Crash Frequency for Study Year $N_{e, w, x, y, as, s}$ (cr/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash with animal</td>
<td>0.003</td>
<td>0.001</td>
<td>0.005</td>
<td>0.002</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>Crash with fixed object</td>
<td>0.718</td>
<td>0.202</td>
<td>0.834</td>
<td>0.299</td>
<td>0.501</td>
<td></td>
</tr>
<tr>
<td>Crash with other object</td>
<td>0.015</td>
<td>0.004</td>
<td>0.023</td>
<td>0.008</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>Crash with parked vehicle</td>
<td>0.012</td>
<td>0.003</td>
<td>0.012</td>
<td>0.004</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>Other single-vehicle crashes</td>
<td>0.252</td>
<td>0.071</td>
<td>0.126</td>
<td>0.045</td>
<td>0.116</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>0.282</td>
<td>1.000</td>
<td>0.358</td>
<td>0.640</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**

$a$ – If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.
Table 14-59. Ramp Barrier Worksheet—Sample Problem 3

### Input Data

<table>
<thead>
<tr>
<th>Segment length $L$ (mi)</th>
<th>0.3</th>
<th>Crash period</th>
<th>X</th>
<th>Study year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left shoulder width $W_L$ (ft)</td>
<td>4</td>
<td>Right shoulder width $W_R$ (ft)</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

### Individual Right Side Barrier Element Data

<table>
<thead>
<tr>
<th>Barrier Location</th>
<th>Length $L_{rb, i}$ (mi)</th>
<th>Width from Edge of Traveled Way to Face of Right Side Barrier $W_{off, r, i}$ (ft)</th>
<th>Ratio $L_{rb, i} / (W_{off, r, i} - W_R)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bridge</td>
<td>0.10</td>
<td>9</td>
<td>0.10</td>
</tr>
<tr>
<td>2. Sign support</td>
<td>0.05</td>
<td>9</td>
<td>0.05</td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum1</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Individual Left Side Barrier Element Data

<table>
<thead>
<tr>
<th>Barrier Location</th>
<th>Length $L_{lb, i}$ (mi)</th>
<th>Width from Edge of Traveled Way to Face of Left Side Barrier $W_{off, l, i}$ (ft)</th>
<th>Ratio $L_{lb, i} / (W_{off, l, i} - W_L)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bridge</td>
<td>0.10</td>
<td>5</td>
<td>0.10</td>
</tr>
<tr>
<td>2. Sign support</td>
<td>0.05</td>
<td>5</td>
<td>0.05</td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum3</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Right Side Barrier Calculations

Proportion of segment length with barrier in median $P_{rb} = \text{Sum1} / L$

Width from edge of shoulder to barrier face $W_{rb} = \text{Sum1} / \text{Sum2}$ (ft)

1.000

### Left Side Barrier Calculations

Proportion of segment length with barrier in median $P_{lb} = \text{Sum3} / L$

Width from edge of shoulder to barrier face $W_{lb} = \text{Sum3} / \text{Sum4}$ (ft)

1.000

14.14.4. Sample Problem 4

**The Site/Facility**

A signalized diamond interchange ramp terminal on an urban arterial.

**The Question**

What is the predicted average crash frequency of the ramp terminal for a one-year period?

**The Facts**

The study year is 2011. The conditions present during this year are provided in the following list.

- D4 configuration
- No non-ramp public street leg present
- 1.0 mi to the next public street intersection on the outside crossroad leg
- 0.1 mi to the adjacent ramp terminal
- Protected-permissive left-turn operational mode on the inside crossroad leg
  - 12-ft left-turn bay present
- Signal control for the exit ramp right-turn movement
- 12-ft crossroad median width
- 4 through lanes on the crossroad (2 on each approach)
- 3 lanes on the exit ramp approach (developed at a distance of 150 ft from the ramp terminal)
- No right-turn channelization or bays
- No driveways present
- 28,000 veh/day on the crossroad (same for both legs)
- 7,100 veh/day on the exit ramp leg
- 6,750 veh/day on the entrance ramp leg

**Assumptions**
- Crash type distributions used are the default values presented in Table 14-16.
- The calibration factor is 1.00.

**Results**
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the ramp terminal in Sample Problem 4 is determined to be 5.3 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 7.1 crashes per year (rounded to one decimal place).

**Steps**

**Step 1 through 8**
To determine the predicted average crash frequency of the ramp terminal in Sample Problem 4, only Steps 9 through 13 are conducted. No other steps are necessary because only one ramp terminal is analyzed for a one-year period and the EB Method is not applied.

**Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site’s facility type and traffic control features.**
For a ramp terminal, an SPF value for all crash types is determined. The SPF for fatal-and-injury crashes is calculated from Equation 14-28 and Table 14-15 as follows:
CHAPTER 14—PREDICTIVE METHOD FOR RAMPS

\[ N_{nf, \text{D4,SG4,at,fi}} = \exp(a \times b \times \ln(c \times \text{AADT}_{std}) + d \times \ln(c \times \text{AADT}_e + c \times \text{AADT}_t)) \]
\[ = \exp(-2.335 + 1.191 \times \ln(0.001 \times 28,000) + 0.131 \times \ln(0.001 \times 7,100 + 0.001 \times 6,750)) \]
\[ = 7.228 \text{ crashes/year} \]

Similarly, the SPF for property-damage-only crashes is calculated from Equation 14-28 and Table 14-15 to yield the following result:

\[ N_{nf, \text{D4,SG4,at,pdo}} = 9.869 \text{ crashes/year} \]

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

Each CMF used in the calculation of the predicted average crash frequency of the ramp terminal is calculated in this step.

**Exit Ramp Capacity (CMF\(_{10, \text{D4,SG4,at,fi}}\))**

CMF\(_{10, \text{D4,SG4,at,fi}}\) is calculated from Equation 14-42 as follows:

\[
CMF_{10, \text{D4,SG4,at,fi}} = (1.0 - P_{ex}) \times 1.0 + P_{ex} \times \exp\left( a \times \frac{c \times \text{AADT}_{ex}}{n_{ex,\text{eff}}} \right)
\]

For a signalized exit-ramp right-turn movement, the effective number of lanes serving exit ramp traffic \(n_{ex, \text{eff}}\) is computed using the second portion of Equation 14-43 as follows:

\[
\begin{align*}
    n_{ex, \text{eff}} &= 0.5 \times n_{ex} \\
    &= 0.5 \times 3 \\
    &= 1.5
\end{align*}
\]

The proportion of total leg AADT on the exit ramp leg \(P_{ex}\) is computed using Equation 14-44 as follows:

\[
P_{ex} = \frac{\text{AADT}_{ex}}{\text{AADT}_{in} + \text{AADT}_{out} + \text{AADT}_{en} + \text{AADT}_{ex}}
\]
\[= \frac{7,100}{28,000 + 28,000 + 6,750 + 7,100} \]
\[= 0.102\]

From Table 14-32, \(a = 0.0668\) and \(c = 0.001\) for signal-controlled ramp terminals. CMF\(_{10, \text{D4,SG4,at,fi}}\) is calculated as follows:

\[
CMF_{10, \text{D4,SG4,at,fi}} = (1.0 - 0.102) \times 1.0 + 0.102 \times \exp\left( 0.0668 \times \frac{0.001 \times 7,100}{1.5} \right)
\]
\[= 1.038\]

**Crossroad Left-Turn Lane (CMF\(_{11, \text{D4,SG4,at,z}}\))**

CMF\(_{11, \text{D4,SG4,at,z}}\) is calculated from Equation 14-45 as follows:

\[
CMF_{11, \text{D4,SG4,at,z}} = \left[ (1.0 - P_{in}) \times 1.0 + P_{in} \times a \right]^{\text{bay,0,in}} \times \left[ (1.0 - P_{out}) \times 1.0 + P_{out} \times a \right]^{\text{bay,0,out}}
\]
The proportion of total leg AADT on the crossroad leg between ramps $P_{in}$ is computed using Equation 14-46 as follows:

$$P_{in} = \frac{AADT_{in}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}}$$

$$= \frac{28,000}{28,000 + 28,000 + 6,750 + 7,100} = 0.401$$

The proportion of total leg AADT on the crossroad leg outside of the interchange $P_{out}$ is computed using Equation 14-47 as follows:

$$P_{out} = \frac{AADT_{out}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}}$$

$$= \frac{28,000}{28,000 + 28,000 + 6,750 + 7,100} = 0.401$$

From Table 14-33, $a = 0.65$ for signal-controlled ramp terminals. $CMF_{11, D4, SG4, at, fi}$ is calculated as follows:

$$CMF_{11, D4, SG4, at, fi} = \left[(1.0 - 0.401) \times 1.0 + 0.401 \times 0.65 \right]^{1} \times \left[(1.0 - 0.401) \times 1.0 + 0.401 \times 0.65 \right]^{0}$$

$$= 0.860$$

Similar calculations using the property-damage-only coefficient from Table 14-33 yield the following results:

$$CMF_{11, D4, SG4, at, pdo} = 0.872$$

**Crossroad Right-Turn Lane (CMF$_{12, D4, SG4, at, z}$)**

The ramp terminal does not have right-turn lanes or bays on the crossroad legs, which is the base condition for the crossroad right-turn lane CMF. Hence, $CMF_{12, D4, SG4, at, fi}$ and $CMF_{12, D4, SG4, at, pdo}$ are equal to 1.000.

**Access Point Frequency (CMF$_{13, D4, SG4, at, z}$)**

The ramp terminal has no unsignalized driveways or unsignalized public street approaches on the outside leg, which are the base conditions for the access point frequency CMF. Hence, $CMF_{13, D4, SG4, at, fi}$ and $CMF_{13, D4, SG4, at, pdo}$ are equal to 1.000.

**Segment Length (CMF$_{14, D4, SG4, at, z}$)**

$CMF_{14, D4, SG4, at, fi}$ is calculated from Equation 14-50 as follows:

$$CMF_{14, D4, SG4, at, fi} = \exp\left(\alpha \times \left[\frac{1.0}{L_{rmp}} + \frac{1.0}{L_{str}} - 0.333\right]\right)$$
From Table 14-36, \( \alpha = -0.0185 \) for fatal-and-injury crashes. \( CMF_{14, D4, SG4, at, fi} \) is calculated as follows:

\[
CMF_{14, D4, SG4, at, fi} = \exp\left(-0.0185 \times \left[ \frac{1.0}{0.1} + \frac{1.0}{1.0} - 0.333 \right] \right) = 0.821
\]

Similar calculations using the property-damage-only coefficient from Table 14-36 yield the following results:

\[
CMF_{14, D4, SG4, at, pdo} = 0.820
\]

**Median Width (CMF_{15, D4, SG4, at, z})**

The crossroad has a 12-ft median, which is the base condition for the median width CMF. Hence, \( CMF_{15, D4, SG4, at, fi} \) and \( CMF_{15, D4, SG4, at, pdo} \) are equal to 1.000.

**Protected Left-Turn Operation (CMF_{16, D4, SG4, at, z})**

Protected-only left-turn operational mode is not used on the crossroad legs, which is the base condition for the protected left-turn operation CMF. Hence, \( CMF_{16, D4, SG4, at, fi} \) and \( CMF_{16, D4, SG4, at, pdo} \) are equal to 1.000.

**Channelized Right Turn on Crossroad (CMF_{17, D4, SG4, at, z})**

Right-turn channelization is not used on the crossroad legs, which is the base condition for the channelized right turn on crossroad CMF. Hence, \( CMF_{17, D4, SG4, at, fi} \) and \( CMF_{17, D4, SG4, at, pdo} \) are equal to 1.000.

**Channelized Right Turn on Exit Ramp (CMF_{18, D4, SG4, at, z})**

Right-turn channelization is not used on the exit-ramp leg, which is the base condition for the channelized right turn on exit ramp CMF. Hence, \( CMF_{18, D4, SG4, at, fi} \) and \( CMF_{18, D4, SG4, at, pdo} \) are equal to 1.000.

**Non-Ramp Public Street Leg (CMF_{19, D4, SG4, at, z})**

A non-ramp public street leg is not present at the ramp terminal, which is the base condition for the non-ramp public street leg CMF. Hence, \( CMF_{19, D4, SG4, at, fi} \) and \( CMF_{19, D4, SG4, at, pdo} \) are equal to 1.000.

**Crashes**

The CMFs are applied to the fatal-and-injury SPF as follows:

\[
N^*_{p, D4, SG4, at, fi} = N_{spf, D4, SG4, at, fi} \times (CMF_{10, D4, SG4, at, fi} \times \ldots \times CMF_{19, D4, SG4, at, fi})
\]
\[
= 7.228 \times (1.038 \times 0.860 \times 1.000 \times 0.821 \times 1.000 \times 1.000 \times 1.000 \times 1.000) = 7.228 \times 0.733 = 5.294 \text{ crashes/year}
\]

The CMFs are applied to the property-damage-only SPF as follows:

\[
N^*_{p, D4, SG4, at, pdo} = N_{spf, D4, SG4, at, pdo} \times (CMF_{10, D4, SG4, at, pdo} \times \ldots \times CMF_{19, D4, SG4, at, pdo})
\]
\[
= 9.869 \times (1.000 \times 0.872 \times 1.000 \times 0.820 \times 1.000 \times 1.000 \times 1.000 \times 1.000) = 9.869 \times 0.715 = 7.052 \text{ crashes/year}
\]
Step 11 – Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor of 1.00 has been determined for local conditions. See Part C Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 14-1 based on the results obtained in Steps 9 through 11 as follows.

Fatal-and-injury crashes:

\[ N_{p, D4, SG4, at, fi} = N_{p^*, D4, SG4, at, fi} \times C_{D4, SG4, at, fi} \]
\[ = 5.294 \times 1.00 \]
\[ = 5.294 \text{ crashes/year} \]

Property-damage-only crashes:

\[ N_{p, D4, SG4, at, pdo} = N_{p^*, D4, SG4, at, pdo} \times C_{D4, SG4, at, pdo} \]
\[ = 7.052 \times 1.00 \]
\[ = 7.052 \text{ crashes/year} \]

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.
The study period is one year (2011), so steps 8 through 11 need not be repeated.

Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.
This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

Apply the site-specific EB Method to a future time period, if appropriate.
The site-specific EB Method is not applied in this sample problem because crash data are not available.

Apply the severity distribution functions (SDFs), if desired.
To apply the SDFs, the systematic component of crash severity likelihood \( V_j \) is computed for each severity level \( j \) using Equation 14-88 as follows:

\[ V_j = a + (b \times I_{p, lb}) + (c \times (n_{dw} + n_{ps})) + (d \times I_{ps}) + (e \times I_{rural}) \]

The coefficients \( a, b, c, d, \) and \( e \) are obtained from Table 14-44 for each severity level \( j \). \( V_j \) is computed for fatal and incapacitating injury crashes as follows:

\[ V_{K+A} = -3.257 + (-0.288 \times 0.0) + (0.0991 \times [0.0 + 0.0]) + (1.171 \times 0.0) + (0.619 \times 0.0) \]
\[ = -3.257 \]

Similar calculations using the coefficients from Table 14-44 for non-incapacitating injury crashes yield the following results:

\[ V_B = -1.511 \]
Using these computed $V_{K+A}$ and $V_B$ values, and assuming a calibration factor $C_{sdf, aS, x}$ of 1.0, the probability of occurrence of a fatal crash is computed using Equation 14-84 as follows:

$$P_{aS, SG, at, K} = \frac{\exp(V_{K+A})}{1.0 + \exp(V_{K+A}) + \exp(V_B)} \times P_{K[K+A, aS, x, at], K}$$

$$= \frac{\exp(-3.257)}{1.0 + \exp(-3.257) + \exp(-1.511)} \times 0.0385$$

$$= 0.001$$

Similar calculations using Equation 14-85 and Equation 14-86 yield the following results:

$$P_{aS, SG, at, A} = 0.029$$

$$P_{aS, SG, at, B} = 0.175$$

The probability of occurrence of a possible-injury crash is computed using Equation 14-87 as follows:

$$P_{aS, SG, at, C} = 1.0 - (P_{aS, SG, at, K} + P_{aS, SG, at, A} + P_{aS, SG, at, B})$$

$$= 1.0 - (0.001 + 0.029 + 0.175)$$

$$= 0.794$$

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 14-78 as follows:

$$N_{e, D4, SG4, at, K} = N_{e, D4, SG4, at, f} \times P_{aS, SG, at, K}$$

$$= 5.294 \times 0.001$$

$$= 0.006\text{ crashes/year}$$

Similar calculations using Equation 14-78 and the probabilities of occurrences of the other crash severities yield the following results:

$$N_{e, D4, SG, at, A} = 0.156\text{ crashes/year}$$

$$N_{e, D4, SG, at, B} = 0.928\text{ crashes/year}$$

$$N_{e, D4, SG, at, C} = 4.204\text{ crashes/year}$$

**Apply the crash type distribution, if desired.**

The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 14-16 by the predicted average crash frequencies obtained in Step 11.
Worksheets
The step-by-step instructions are provided to illustrate the predictive method for calculating the predicted average crash frequency for a ramp terminal. To apply the predictive method steps to multiple terminals, a series of worksheets are provided for determining the predicted average crash frequency. The worksheets include:

- Table 14-60. Ramp Terminal Worksheet (1 of 4)—Sample Problem 4
- Table 14-61. Ramp Terminal Worksheet (2 of 4)—Sample Problem 4
- Table 14-62. Ramp Terminal Worksheet (3 of 4)—Sample Problem 4
- Table 14-63. Ramp Terminal Worksheet (4 of 4)—Sample Problem 4

Filled versions of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 14 Appendix A.

Table 14-60 is a summary of general information about the ramp terminal, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 4. The input data include area type, crash data, basic intersection data, alignment data, traffic control data, and cross section data.

Table 14-61 is a summary of general information about the ramp terminal, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 4. The input data include cross section data, access data, and traffic data.

Table 14-62 is a tabulation of the CMF and SPF computations for Sample Problem 4.

Table 14-63 is a tabulation of the crash severity and crash type distributions for Sample Problem 4.
### Table 14-60. Ramp Terminal Worksheet (1 of 4)—Sample Problem 4

<table>
<thead>
<tr>
<th>General Information</th>
<th>Location Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Roadway</td>
</tr>
<tr>
<td>Agency or company</td>
<td>Intersection</td>
</tr>
<tr>
<td>Date performed</td>
<td>Study year</td>
</tr>
<tr>
<td>Area type</td>
<td>X Urban Rural</td>
</tr>
</tbody>
</table>

#### Input Data

##### Crash Data

<table>
<thead>
<tr>
<th>Crash Data</th>
<th>Crash Period</th>
<th>Study Year</th>
<th>Complete the study year column. Complete the crash period column if the EB Method is used.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash data time period</td>
<td>--</td>
<td>--</td>
<td>First year -- Last year --</td>
</tr>
<tr>
<td>Count of FI crashes $N_{o, w, x, at, f}$</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Count of PDO crashes $N_{o, w, x, at, pdo}$</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
</tbody>
</table>

##### Basic Intersection Data

| Basic Intersection Data | | |
|-------------------------|-------------------|
| Ramp terminal configuration | D4 Choices: D3ex, D3en, D4, A4, B4, A2, B2 Same choice for crash period and study year. |
| Ramp terminal traffic control mode | Signal Choices: Signal, One-way-stop, All-way stop |
| Presence of a non-ramp public street leg $I_{pi}$ | -- Y/N N Y/N |

##### Alignment Data

<table>
<thead>
<tr>
<th>Alignment Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Exit ramp skew angle $I_{e}$ (degrees)</td>
<td>-- --</td>
</tr>
<tr>
<td>Distance to the next public street intersection on the outside crossroad leg $L_{aj}$ (mi)</td>
<td>-- 1.0</td>
</tr>
<tr>
<td>Distance to the adjacent ramp terminal $L_{armp}$ (mi)</td>
<td>-- 0.1</td>
</tr>
</tbody>
</table>

##### Traffic Control

<table>
<thead>
<tr>
<th>Traffic Control</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Left-Turn Operational Mode</td>
<td></td>
</tr>
<tr>
<td>Crossroad Inside approach Prot.-only mode $I_{p, h, in}$</td>
<td>Y/N N Y/N</td>
</tr>
<tr>
<td>Outside approach Prot.-only mode $I_{p, h, out}$</td>
<td>Y/N -- Y/N</td>
</tr>
<tr>
<td>Right-Turn Control Mode</td>
<td></td>
</tr>
<tr>
<td>Ramp Exit ramp approach Right-turn control mode</td>
<td>Signal Choices: Signal, Stop, Yield, Merge, Free</td>
</tr>
</tbody>
</table>

##### Cross Section Data

<table>
<thead>
<tr>
<th>Cross Section Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossroad median width $W_m$ (ft)</td>
<td>12</td>
</tr>
</tbody>
</table>

##### Number of Lanes

<table>
<thead>
<tr>
<th>Number of Lanes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossroad Inside approach Through lanes $n_{h, in}$</td>
<td>2 Same choice for crash period and study year.</td>
</tr>
<tr>
<td>Outside approach Through lanes $n_{h, out}$</td>
<td>2 Same choice for crash period and study year.</td>
</tr>
<tr>
<td>Ramp Exit ramp approach All lanes $n_{ex}$</td>
<td>3 Same choice for crash period and study year.</td>
</tr>
</tbody>
</table>

##### Right-Turn Channelization

<table>
<thead>
<tr>
<th>Right-Turn Channelization</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossroad Inside approach Chan. present $I_{ch, in}$</td>
<td>Y/N -- Y/N</td>
</tr>
<tr>
<td>Outside approach Chan. present $I_{ch, out}$</td>
<td>Y/N N Y/N</td>
</tr>
<tr>
<td>Ramp Exit ramp approach Chan. present $I_{ch, ex}$</td>
<td>Y/N N Y/N</td>
</tr>
</tbody>
</table>
Table 14-61. Ramp Terminal Worksheet (2 of 4)—Sample Problem 4

<table>
<thead>
<tr>
<th>Input Data</th>
<th>Crash Period</th>
<th>Study Year</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cross Section Data</strong></td>
<td></td>
<td></td>
<td>Complete the study year column. Complete the crash period column if the EB Method is used.</td>
</tr>
<tr>
<td>Left-Turn Lane or Bay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossroad</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inside approach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane or bay present $I_{int,b,in}$</td>
<td>--</td>
<td>Y/N</td>
<td>Y/N If Yes, then enter data in the next row.</td>
</tr>
<tr>
<td>Lane or bay width $W_{b,in}$ (ft)</td>
<td>--</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Outside approach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane or bay present $I_{int,b,out}$</td>
<td>--</td>
<td>Y/N</td>
<td>Y/N If Yes, then enter data in the next row.</td>
</tr>
<tr>
<td>Lane or bay width $W_{b,out}$ (ft)</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Right-Turn Lane or Bay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossroad</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inside approach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane or bay present $I_{int,r,in}$</td>
<td>--</td>
<td>Y/N</td>
<td>Y/N</td>
</tr>
<tr>
<td>Outside approach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane or bay present $I_{int,r,out}$</td>
<td>--</td>
<td>Y/N</td>
<td>Y/N</td>
</tr>
<tr>
<td>Access Data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of driveways on the outside crossroad leg $n_{dwr}$</td>
<td>--</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Number of public street approaches on the outside crossroad leg $n_{ps}$</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Traffic Data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossroad</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inside leg</td>
<td>$AADT_{in}$ (veh/day)</td>
<td>--</td>
<td>28,000</td>
</tr>
<tr>
<td>Outside leg</td>
<td>$AADT_{out}$ (veh/day)</td>
<td>--</td>
<td>28,000</td>
</tr>
<tr>
<td>Ramp</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exit ramp</td>
<td>$AADT_{ex}$ (veh/day)</td>
<td>--</td>
<td>7,100</td>
</tr>
<tr>
<td>Entrance ramp</td>
<td>$AADT_{ex}$ (veh/day)</td>
<td>--</td>
<td>6,750</td>
</tr>
</tbody>
</table>
**Table 14-62. Ramp Terminal Worksheet (3 of 4)—Sample Problem 4**

<table>
<thead>
<tr>
<th>Crash Modification Factors</th>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td><strong>Signal Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exit ramp capacity CMF10 w, SGn, at, fi</td>
<td>14-42</td>
<td>--</td>
<td>1.038</td>
</tr>
<tr>
<td>Crossroad left-turn lane CMF11 w, SGn, at, z</td>
<td>14-45</td>
<td>--</td>
<td>0.860</td>
</tr>
<tr>
<td>Crossroad right-turn lane CMF12 w, SGn, at, z</td>
<td>14-48</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Access point frequency CMF13 w, SGn, at, z</td>
<td>14-49</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Segment length CMF14 w, SGn, at, z</td>
<td>14-50</td>
<td>--</td>
<td>0.821</td>
</tr>
<tr>
<td>Median width CMF15 w, SGn, at, z</td>
<td>14-51</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Protected left-turn operation CMF16 w, SGn, at, z</td>
<td>14-53</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Chan. right turn on crossroad CMF17 w, SGn, at, z</td>
<td>14-55</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Chan. right turn on exit ramp CMF18 w, SGn, at, z</td>
<td>14-56</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Non-ramp public street leg CMF19 w, SGn, at, z</td>
<td>14-57</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td><strong>Stop Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exit ramp capacity CMF10 w, ST, at, fi</td>
<td>14-42</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Crossroad left-turn lane CMF11 w, ST, at, z</td>
<td>14-45</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Crossroad right-turn lane CMF12 w, ST, at, z</td>
<td>14-48</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Access point frequency CMF13 w, ST, at, z</td>
<td>14-49</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Segment length CMF14 w, ST, at, fi</td>
<td>14-50</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Median width CMF15 w, ST, at, fi</td>
<td>14-51</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Skew angle CMF20 w, ST, at, fi</td>
<td>14-58</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>All-way stop-control (exclude CMF10, CMF12, CMF18)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Combined CMF (multiply all CMFs evaluated)</td>
<td>--</td>
<td>0.733</td>
<td>--</td>
</tr>
</tbody>
</table>

**Expected Average Crash Frequency**

<table>
<thead>
<tr>
<th></th>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td>Calibration factor CaS, x, at, z</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Overdispersion parameter kw, x, at, z</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Observed crash count No, w, x, at, z (cr)</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Reference year r</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Predicted average crash freq. for reference year Np, w, x, at, z, r (cr/yr)</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Predicted number of crashes for crash period (sum all years) Np, w, x, y, z, r (cr)</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Equivalent years associated with crash count Cb, w, x, at, z, r (yr)</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Adjusted average crash freq. for ref. year given Np, w, x, at, z, r (cr/yr)</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Study year s</td>
<td>2011</td>
<td>2011</td>
<td></td>
</tr>
<tr>
<td>Predicted average crash freq. for study year Np, w, x, at, z, s (cr/yr)</td>
<td>5.294</td>
<td>7.052</td>
<td></td>
</tr>
<tr>
<td>Expected average crash freq. for study year Ne, w, x, at, z, s (cr/yr)</td>
<td>5.294</td>
<td>7.052</td>
<td></td>
</tr>
</tbody>
</table>

Note: a – If the EB Method is not used, then substitute “predicted” for “expected” and substitute the subscript “p” for the subscript “e”.
Table 14-63. Ramp Terminal Worksheet (4 of 4)—Sample Problem 4

Expected Average Crash Frequency

<table>
<thead>
<tr>
<th>Crash Severity Distribution</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Total FI</th>
<th>PDO</th>
<th>Total FI + PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion by injury level</td>
<td>0.001</td>
<td>0.029</td>
<td>0.175</td>
<td>0.794</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected average crash freq. for study year ( N_{e, w, x, a, z, f} ) (cr/yr)</td>
<td>0.006</td>
<td>0.156</td>
<td>0.928</td>
<td>4.204</td>
<td>5.294</td>
<td>7.052</td>
<td>12.346</td>
</tr>
</tbody>
</table>

Crash Type Distribution

<table>
<thead>
<tr>
<th>Crash Type Category</th>
<th>Table 14-16, 14-21, or 14-45</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proportion</td>
<td>Expected Average Crash Frequency for Study Year ( N_{e, w, x, a, f} ) (cr/yr)</td>
<td>Proportion</td>
<td>Expected Average Crash Frequency for Study Year ( N_{e, w, x, a, pd} ) (cr/yr)</td>
</tr>
<tr>
<td>Multiple-Vehicle Crashes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head-on</td>
<td>0.011</td>
<td>0.058</td>
<td>0.007</td>
<td>0.049</td>
</tr>
<tr>
<td>Right-angle</td>
<td>0.260</td>
<td>1.376</td>
<td>0.220</td>
<td>1.551</td>
</tr>
<tr>
<td>Rear-end</td>
<td>0.625</td>
<td>3.309</td>
<td>0.543</td>
<td>3.829</td>
</tr>
<tr>
<td>Sideswipe</td>
<td>0.042</td>
<td>0.222</td>
<td>0.149</td>
<td>1.051</td>
</tr>
<tr>
<td>Other multiple-vehicle crashes</td>
<td>0.009</td>
<td>0.048</td>
<td>0.020</td>
<td>0.141</td>
</tr>
<tr>
<td>Single-Vehicle Crashes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crash with animal</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Crash with fixed object</td>
<td>0.033</td>
<td>0.175</td>
<td>0.050</td>
<td>0.353</td>
</tr>
<tr>
<td>Crash with other object</td>
<td>0.001</td>
<td>0.005</td>
<td>0.002</td>
<td>0.014</td>
</tr>
<tr>
<td>Crash with parked vehicle</td>
<td>0.001</td>
<td>0.005</td>
<td>0.002</td>
<td>0.014</td>
</tr>
<tr>
<td>Other single-vehicle crashes</td>
<td>0.018</td>
<td>0.095</td>
<td>0.007</td>
<td>0.049</td>
</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>0.281</td>
<td>1.000</td>
<td>0.430</td>
</tr>
</tbody>
</table>

14.14.5. Sample Problem 5

The Site/Facility
A one-way stop-controlled partial cloverleaf interchange ramp terminal on an urban arterial.

The Question
What is the predicted average crash frequency of the ramp terminal for a one-year period?

The Facts
The study year is 2011. The conditions present during this year are provided in the following list.

- A4 configuration
- 1.0 mi to the next public street intersection on the outside crossroad leg
- 0.09 mi to the adjacent ramp terminal
- 0-degree skew angle on exit-ramp approach
Merge control for the exit ramp right-turn movement
- 12-ft crossroad median width
- 4 through lanes on the crossroad
- 2 lanes on the exit ramp approach (developed at a distance of 200 ft from the ramp terminal)
- No right-turn channelization or bays
- 21,500 veh/day on the crossroad (same for both legs)
- 3,400 veh/day on the exit ramp leg
- 3,750 veh/day on the entrance ramp leg

Assumptions
- Crash type distributions used are the default values presented in Table 14-21.
- The calibration factor is 1.00.

Results
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the ramp terminal in Sample Problem 5 is determined to be 1.2 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 2.7 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the ramp terminal in Sample Problem 5, only Steps 9 through 13 are conducted. No other steps are necessary because only one ramp terminal is analyzed for a one-year period and the EB Method is not applied.

Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site’s facility type and traffic control features.
For a ramp terminal, an SPF value for all crash types is determined. The SPF for fatal-and-injury crashes is calculated from Equation 14-31 and Table 14-18 as follows:

$$N_{spf, A4, ST, at, fi} = \exp(a + b \times \ln[c \times AADT_{xrd}] + d \times \ln[c \times AADT_{ex} + c \times AADT_{en}])$$

$$= \exp(-3.223 + 0.582 \times \ln[0.001 \times 21,500] + 0.899 \times \ln[0.001 \times 3,400 + 0.001 \times 3,750])$$

$$= 1.392 \text{ crashes/year}$$

Similarly, the SPF for property-damage-only crashes is calculated from Equation 14-31 and Table 14-18 to yield the following result:

$$N_{spf, A4, ST, at, pdo} = 2.715 \text{ crashes/year}$$
Step 10 – Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site-specific geometric design and traffic control features.

Each CMF used in the calculation of the predicted average crash frequency of the ramp terminal is calculated in this step.

**Exit Ramp Capacity (CMF\_10, A4, ST, at, fi)**

CMF\_10, A4, ST, at, fi is calculated from Equation 14-42 as follows:

\[
CMF_{10, A4, ST, at, fi} = (1.0 - P_{ex}) \times 1.0 + P_{ex} \times \exp \left( \frac{a \times c \times AADT_{ex}}{n_{ex, eff}} \right)
\]

For a merge-controlled exit-ramp right-turn movement, the effective number of lanes serving exit ramp traffic \(n_{ex, eff}\) is computed using the first portion of Equation 14-43 as follows:

\[
\begin{align*}
\left( 0.5 \times n_{ex} - 1.0 \right) + 1.0 & = 0.5 \times (2 - 1.0) + 1.0 \\
& = 1.5
\end{align*}
\]

The proportion of total leg AADT on the exit ramp leg \(P_{ex}\) is computed using Equation 14-44 as follows:

\[
P_{ex} = \frac{AADT_{ex}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}}
\]

\[
= \frac{3,400}{21,500 + 21,500 + 3,750 + 3,400}
\]

\[
= 0.068
\]

From Table 14-32, \(a = 0.151\) and \(c = 0.001\) for one-way stop-controlled ramp terminals. CMF\_10, A4, ST, at, fi is calculated as follows:

\[
CMF_{10, A4, ST, at, fi} = (1.0 - 0.068) \times 1.0 + 0.068 \times \exp \left( 0.151 \times \frac{0.001 \times 3,400}{1.5} \right)
\]

\[
= 1.028
\]

**Crossroad Left-Turn Lane (CMF\_11, A4, ST, at, z)**

The ramp terminal does not have left-turn lanes or bays on the crossroad legs, which is the base condition for the crossroad left-turn lane CMF. Hence, CMF\_11, A4, ST, at, fi and CMF\_11, A4, ST, at, pdo are equal to 1.000.

**Crossroad Right-Turn Lane (CMF\_12, A4, ST, at, z)**

The ramp terminal does not have right-turn lanes or bays on the crossroad legs, which is the base condition for the crossroad right-turn lane CMF. Hence, CMF\_12, A4, ST, at, fi and CMF\_12, A4, ST, at, pdo are equal to 1.000.

**Access Point Frequency (CMF\_13, A4, ST, at, fi)**

The ramp terminal has no unsignalized public street approaches on the outside leg, which is the base condition for the access point frequency CMF. Hence, CMF\_13, A4, ST, at, fi is equal to 1.000.
Segment Length (CMF$_{14,A4,ST,at,fi}$)

CMF$_{14,A4,ST,at,fi}$ is calculated from Equation 14-50 as follows:

$$CMF_{14,A4,ST,at,fi} = \exp\left( a \times \left[ \frac{1.0}{L_{rmp}} + \frac{1.0}{L_{str}} - 0.333 \right] \right)$$

From Table 14-36, $a = -0.0141$ for fatal-and-injury crashes. CMF$_{14,A4,ST,at,fi}$ is calculated as follows:

$$CMF_{14,A4,ST,at,fi} = \exp\left( -0.0141 \times \left[ \frac{1.0}{0.09} + \frac{1.0}{1.0} - 0.333 \right] \right) = 0.847$$

Median Width (CMF$_{15,A4,ST,at,fi}$)

The crossroad has a 12-ft median, which is the base condition for the median width CMF. Hence, CMF$_{15,A4,ST,at,fi}$ is equal to 1.000.

Skew Angle (CMF$_{20,A4,ST,at,fi}$)

The ramp terminal has no skew, which is the base condition for the skew angle CMF. Hence, CMF$_{20,A4,ST,at,fi}$ is equal to 1.000.

Crashes

The CMFs are applied to the fatal-and-injury SPF as follows:

$$N_{p^+, A4,ST,at,fi} = N_{spf, A4,ST,at,fi} \times \left( CMF_{10,A4,ST,at,fi} \times \ldots \times CMF_{15,A4,ST,at,fi} \times CMF_{20,A4,ST,at,fi} \right)$$

$$= 1.392 \times (1.028 \times 1.000 \times 1.000 \times 0.847 \times 1.000 \times 1.000)$$

$$= 1.392 \times 0.871$$

$$= 1.212 \text{ crashes/year}$$

The CMFs are applied to the property-damage-only SPF as follows:

$$N_{p^+, A4,ST,at,pdo} = N_{spf, A4,ST,at,pdo} \times \left( CMF_{11,A4,ST,at,pdo} \times CMF_{12,A4,ST,at,pdo} \right)$$

$$= 2.715 \times (1.000 \times 1.000)$$

$$= 2.715 \times 1.000$$

$$= 2.715 \text{ crashes/year}$$

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

It is assumed that a calibration factor of 1.00 has been determined for local conditions. See Part C Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated using Equation 14-1 based on the results obtained in Steps 9 through 11 as follows.
Fatal-and-injury crashes:

\[ N_{p, A4, ST, at, \text{fi}} = N_{p^*, A4, ST, at, \text{fi}} \times C_{A4, ST, at, \text{fi}} \]
\[ = 1.212 \times 1.00 \]
\[ = 1.212 \text{ crashes/year} \]

Property-damage-only crashes:

\[ N_{p, A4, ST, at, pdo} = N_{p^*, A4, ST, at, pdo} \times C_{A4, ST, at, pdo} \]
\[ = 2.715 \times 1.00 \]
\[ = 2.715 \text{ crashes/year} \]

**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.**

The study period is one year (2011), so steps 8 through 11 need not be repeated.

**Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.**

This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

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

The site-specific EB Method is not applied in this sample problem because crash data are not available.

*Apply the severity distribution functions (SDFs), if desired.*

To apply the SDFs, the systematic component of crash severity likelihood \( V_j \) is computed for each severity level \( j \) using Equation 14-88 as follows:

\[ V_j = a + (b \times I_{p,lt}) + (c \times (n_{dw} + n_{ps})) + (d \times I_{ps}) + (e \times I_{rural}) \]

The coefficients \( a, b, c, d, \) and \( e \) are obtained from Table 14-44 for each severity level \( j \). \( V_j \) is computed for fatal and incapacitating injury crashes as follows:

\[ V_{K+A} = -3.168 + (0.00 \times 0.0) + (0.00 \times (0.0 + 0.0)) + (0.00 \times 0.0) + (0.891 \times 0.0) \]
\[ = -3.168 \]

Similar calculations using the coefficients from Table 14-44 for non-incapacitating injury crashes yield the following results:

\[ V_B = -1.476 \]

Using these computed \( V_{K+A} \) and \( V_B \) values, and assuming a calibration factor \( C_{SDF, aS, x} \) of 1.0, the probability of occurrence of a fatal crash is computed using Equation 14-84 as follows:
\[ P_{aS, ST, at, K} = \frac{\exp(V_{K+A})}{C_{sdf, aS, x}} + \exp(V_{K+A}) + \exp(V_B) \times P_{K+A, aS, x, at} \]

\[ = \frac{\exp(-3.168)}{1.0} + \exp(-3.168) + \exp(-1.476) \times 0.160 \]

\[ = 0.005 \]

Similar calculations using Equation 14-85 and Equation 14-86 yield the following results:

\[ P_{aS, ST, at, A} = 0.028 \]

\[ P_{aS, ST, at, B} = 0.180 \]

The probability of occurrence of a possible-injury crash is computed using Equation 14-87 as follows:

\[ P_{aS, ST, at, C} = 1.0 - (P_{aS, ST, at, K} + P_{aS, ST, at, A} + P_{aS, ST, at, B}) \]

\[ = 1.0 - (0.005 + 0.028 + 0.180) \]

\[ = 0.787 \]

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 14-78 as follows:

\[ N_{e, A4, ST, at, K} = N_{e, A4, ST, at, fi} \times P_{aS, ST, at, K} \]

\[ = 1.212 \times 0.005 \]

\[ = 0.006 \text{ crashes/year} \]

Similar calculations using Equation 14-78 and the probabilities of occurrences of the other crash severities yield the following results:

\[ N_{e, A4, ST, at, A} = 0.034 \text{ crashes/year} \]

\[ N_{e, A4, ST, at, B} = 0.218 \text{ crashes/year} \]

\[ N_{e, A4, ST, at, C} = 0.954 \text{ crashes/year} \]

*Apply the crash type distribution, if desired.*

The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 14-21 by the predicted average crash frequencies obtained in Step 11.

*Worksheets*

The step-by-step instructions are provided to illustrate the predictive method for calculating the predicted average crash frequency for a ramp terminal. To apply the predictive method steps to multiple terminals, a series of worksheets are provided for determining the predicted average crash frequency. The worksheets include:

- Table 14-64. Ramp Terminal Worksheet (1 of 4)—Sample Problem 5
Table 14-65. Ramp Terminal Worksheet (2 of 4)—Sample Problem 5
Table 14-66. Ramp Terminal Worksheet (3 of 4)—Sample Problem 5
Table 14-67. Ramp Terminal Worksheet (4 of 4)—Sample Problem 5

Filled versions of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 14 Appendix A.

Table 14-64 is a summary of general information about the ramp terminal, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 5. The input data include area type, crash data, basic intersection data, alignment data, traffic control data, and cross section data.

Table 14-65 is a summary of general information about the ramp terminal, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 5. The input data include cross section data, access data, and traffic data.

Table 14-66 is a tabulation of the CMF and SPF computations for Sample Problem 5.

Table 14-67 is a tabulation of the crash severity and crash type distributions for Sample Problem 5.
Table 14-64. Ramp Terminal Worksheet (1 of 4)—Sample Problem 5

<table>
<thead>
<tr>
<th>General Information</th>
<th>Location Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Roadway</td>
</tr>
<tr>
<td>Agency or company</td>
<td>Intersection</td>
</tr>
<tr>
<td>Date performed</td>
<td>Study year</td>
</tr>
<tr>
<td>Area type</td>
<td>X Urban Rural</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Input Data</th>
<th>Crash Data</th>
<th>Study Year</th>
<th>Complete the study year column. Complete the crash period column if the EB Method is used.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash data time period</td>
<td></td>
<td>First year</td>
<td>-- Last year</td>
</tr>
<tr>
<td>Count of FI crashes $N^r_{a, w, x, at, f}$</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Count of PDO crashes $N^r_{a, w, x, at, pdo}$</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Basic Intersection Data</th>
<th>Ramp terminal configuration</th>
<th>A4</th>
<th>Choices: D3ex, D3en, D4, A4, B4, A2, B2 Same choice for crash period and study year.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ramp terminal traffic control mode</td>
<td>One-way-stop</td>
<td>Choices: Signal, One-way-stop, All-way stop</td>
</tr>
<tr>
<td>Presence of a non-ramp public street leg $I_{pr}$</td>
<td>--</td>
<td>Y/N</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alignment Data</th>
<th>Exit ramp skew angle $I_{sk}$ (degrees)</th>
<th>--</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distance to the next public street intersection on the outside crossroad leg $L_{str}$ (mi)</td>
<td>--</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Distance to the adjacent ramp terminal $L_{rmp}$ (mi)</td>
<td>--</td>
<td>0.09</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic Control</th>
<th>Left-Turn Operational Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crossroad</td>
</tr>
<tr>
<td></td>
<td>Outside approach</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Right-Turn Control Mode</th>
<th>Ramp Exit ramp approach</th>
<th>Right-turn control mode</th>
<th>Merge</th>
<th>Choices: Signal, Stop, Yield, Merge, Free</th>
</tr>
</thead>
</table>

| Cross Section Data | Crossroad median width $W_{m}$ (ft) | -- | 12 |

<table>
<thead>
<tr>
<th>Number of Lanes</th>
<th>Crossroad</th>
<th>Through lanes $n_{th, in}$</th>
<th>2</th>
<th>Same choice for crash period and study year.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outside approach</td>
<td>Through lanes $n_{th, out}$</td>
<td>2</td>
<td>Same choice for crash period and study year.</td>
</tr>
<tr>
<td></td>
<td>Ramp Exit ramp approach</td>
<td>All lanes $n_{ex}$</td>
<td>2</td>
<td>Same choice for crash period and study year.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Right-Turn Channelization</th>
<th>Crossroad</th>
<th>Chan. present $I_{ch, in}$</th>
<th>Y/N</th>
<th>--</th>
<th>Y/N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outside approach</td>
<td>Chan. present $I_{ch, out}$</td>
<td>Y/N</td>
<td>--</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>Ramp Exit ramp approach</td>
<td>Chan. present $I_{ch, ex}$</td>
<td>Y/N</td>
<td>--</td>
<td>Y/N</td>
</tr>
</tbody>
</table>
**Table 14-65. Ramp Terminal Worksheet (2 of 4)—Sample Problem 5**

### Input Data

<table>
<thead>
<tr>
<th>Cross Section Data</th>
<th>Crash Period</th>
<th>Study Year</th>
<th>Complete the study year column. Complete the crash period column if the EB Method is used.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Left-Turn Lane or Bay</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossroad</td>
<td>Inside approach</td>
<td>Lane or bay present $I_{int, b, in}$</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>Lane or bay width $W_{b, in}$ (ft)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Outside approach</td>
<td>Lane or bay present $I_{int, b, out}$</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>Lane or bay width $W_{b, out}$ (ft)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Right-Turn Lane or Bay</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossroad</td>
<td>Inside approach</td>
<td>Lane or bay present $I_{int, b, out}$</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>Outside approach</td>
<td>Lane or bay present $I_{int, b, out}$</td>
<td>Y/N</td>
</tr>
</tbody>
</table>

### Access Data

<table>
<thead>
<tr>
<th></th>
<th>Number of driveways on the outside crossroad leg $n_{drw}$</th>
<th>--</th>
<th>--</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of public street approaches on the outside crossroad leg $n_{ps}$</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
</tbody>
</table>

### Traffic Data

<table>
<thead>
<tr>
<th></th>
<th>Inside leg $AADT_{in}$ (veh/day)</th>
<th>--</th>
<th>21,500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside leg</td>
<td>$AADT_{out}$ (veh/day)</td>
<td>--</td>
<td>21,500</td>
</tr>
<tr>
<td><strong>Ramp</strong></td>
<td>Exit ramp $AADT_{ex}$ (veh/day)</td>
<td>--</td>
<td>3,400</td>
</tr>
<tr>
<td></td>
<td>Entrance ramp $AADT_{en}$ (veh/day)</td>
<td>--</td>
<td>3,750</td>
</tr>
</tbody>
</table>
### Table 14-66. Ramp Terminal Worksheet (3 of 4)—Sample Problem 5

<table>
<thead>
<tr>
<th>Crash Modification Factors</th>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td><strong>Signal Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exit ramp capacity $CMF_{10, u, SGn, at, fi}$</td>
<td>14-42</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Crossroad left-turn lane $CMF_{11, u, SGn, at, z}$</td>
<td>14-45</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Crossroad right-turn lane $CMF_{12, u, SGn, at, z}$</td>
<td>14-48</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Access point frequency $CMF_{13, u, SGn, at, z}$</td>
<td>14-49</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Segment length $CMF_{14, u, SGn, at, z}$</td>
<td>14-50</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Median width $CMF_{15, u, SGn, at, z}$</td>
<td>14-51</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Protected left-turn operation $CMF_{16, w, SGn, at, z}$</td>
<td>14-53</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Chan. right turn on crossroad $CMF_{17, u, SGn, at, z}$</td>
<td>14-55</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Chan. right turn on exit ramp $CMF_{18, w, SGn, at, z}$</td>
<td>14-56</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Non-ramp public street leg $CMF_{19, w, SGn, at, z}$</td>
<td>14-57</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Stop Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exit ramp capacity $CMF_{10, u, ST, at, fi}$</td>
<td>14-42</td>
<td>--</td>
<td>1.028</td>
</tr>
<tr>
<td>Crossroad left-turn lane $CMF_{11, u, ST, at, z}$</td>
<td>14-45</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Crossroad right-turn lane $CMF_{12, u, ST, at, z}$</td>
<td>14-48</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Access point frequency $CMF_{13, u, ST, at, z}$</td>
<td>14-49</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Segment length $CMF_{14, u, ST, at, z}$</td>
<td>14-50</td>
<td>--</td>
<td>0.847</td>
</tr>
<tr>
<td>Median width $CMF_{15, u, ST, at, z}$</td>
<td>14-51</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>Skew angle $CMF_{20, u, ST, at, fi}$</td>
<td>14-58</td>
<td>--</td>
<td>1.000</td>
</tr>
<tr>
<td>All-way stop-control (exclude $CMF_{11}, CMF_{12}, CMF_{20}$)</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Combined CMF (multiply all CMFs evaluated)</td>
<td>--</td>
<td>0.871</td>
<td></td>
</tr>
</tbody>
</table>

### Expected Average Crash Frequency *

<table>
<thead>
<tr>
<th></th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td>Calibration factor $C_{x, x, at, z}$</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Overdispersion parameter $k_{w, x, at, z}$</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Observed crash count $N_{o, w, x, at, z}$ (cr)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Reference year $r$</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Predicted average crash freq. for reference year $N_{p, w, x, at, z}$ (cr/yr)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Predicted number of crashes for crash period (sum all years) $N_{p, w, x, at, z}$ (cr)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Equivalent years associated with crash count $C_{b, w, x, at, z}$ (yr)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Adjusted average crash freq. for ref. year given $N_{o, w, x, at, z}$ (cr/yr)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Study year $s$</td>
<td></td>
<td>2011</td>
</tr>
<tr>
<td>Predicted average crash freq. for study year $N_{p, w, x, at, z}$ (cr/yr)</td>
<td>1.212</td>
<td>2.715</td>
</tr>
<tr>
<td>Expected average crash freq. for study year $N_{e, w, x, at, z}$ (cr/yr)</td>
<td>1.212</td>
<td>2.715</td>
</tr>
</tbody>
</table>

Note: a - If the EB Method is not used, then substitute “predicted” for “expected” and substitute the subscript “p” for the subscript “e”.

---

**CHAPTER 14—PREDICTIVE METHOD FOR RAMPS**

14-141
Table 14-67. Ramp Terminal Worksheet (4 of 4)—Sample Problem 5

Expected Average Crash Frequency

<table>
<thead>
<tr>
<th>Crash Severity Distribution</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Total FI</th>
<th>PDO</th>
<th>Total FI + PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion by injury level</td>
<td>0.005</td>
<td>0.028</td>
<td>0.180</td>
<td>0.787</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected average crash freq. for study year $N_e, w, x, at, z, s$ (cr/yr)</td>
<td>0.006</td>
<td>0.034</td>
<td>0.218</td>
<td>0.954</td>
<td>1.212</td>
<td>2.715</td>
<td>3.927</td>
</tr>
</tbody>
</table>

Crash Type Distribution

<table>
<thead>
<tr>
<th>Crash Type Category</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proportion</td>
<td>Expected Average Crash Frequency for Study Year $N_e, w, x, at, f, i, s$ (cr/yr)</td>
<td>Proportion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Expected Average Crash Frequency for Study Year $N_e, w, x, at, pdo, s$ (cr/yr)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Expected Average Crash Frequency for Study Year $N_e, w, x, at, as, s$ (cr/yr)</td>
<td></td>
</tr>
<tr>
<td>Multiple-Vehicle Crashes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head-on</td>
<td>0.017</td>
<td>0.021</td>
<td>0.012</td>
</tr>
<tr>
<td>Right-angle</td>
<td>0.458</td>
<td>0.055</td>
<td>0.378</td>
</tr>
<tr>
<td>Rear-end</td>
<td>0.373</td>
<td>0.452</td>
<td>0.377</td>
</tr>
<tr>
<td>Sideswipe</td>
<td>0.025</td>
<td>0.030</td>
<td>0.079</td>
</tr>
<tr>
<td>Other multiple-vehicle crashes</td>
<td>0.017</td>
<td>0.021</td>
<td>0.016</td>
</tr>
<tr>
<td>Single-Vehicle Crashes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crash with animal</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Crash with fixed object</td>
<td>0.085</td>
<td>0.103</td>
<td>0.110</td>
</tr>
<tr>
<td>Crash with other object</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Crash with parked vehicle</td>
<td>0.000</td>
<td>0.000</td>
<td>0.008</td>
</tr>
<tr>
<td>Other single-vehicle crashes</td>
<td>0.025</td>
<td>0.030</td>
<td>0.020</td>
</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>1.212</td>
<td>1.000</td>
</tr>
</tbody>
</table>


The Site/Facility
An all-way stop-controlled partial cloverleaf interchange ramp terminal on an urban arterial.

The Question
What is the predicted average crash frequency of the ramp terminal for a one-year period?

The Facts
The study year is 2011. The conditions present during this year are provided in the following list.

- B2 configuration
- 1.0 mi to the next public street intersection on the outside crossroad leg
- 0.15 mi to the adjacent ramp terminal
- Stop control for the exit ramp right-turn movement
12-ft crossroad median width
- 4 through lanes on the crossroad
- 2 lanes on the exit ramp approach (developed at a distance of 125 ft from the ramp terminal)
- 14,000 veh/day on the crossroad (same for both legs)
- 1,450 veh/day on the exit ramp leg
- 1,300 veh/day on the entrance ramp leg

Assumptions
- Crash type distributions used are the default values presented in Table 14-45.
- The calibration factor is 1.00.

Results
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the ramp terminal in Sample Problem 6 is determined to be 0.2 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 0.9 crashes per year (rounded to one decimal place).

As stated in the interim predictive method for all-way stop control in Section 14.10, the ramp terminal is evaluated as a one-way stop-controlled terminal, but with a smaller set of CMFs in Step 10. None of the CMFs apply to the property-damage-only SPF.

Steps
Step 1 through 8
To determine the predicted average crash frequency of the ramp terminal in Sample Problem 6, only Steps 9 through 13 are conducted. No other steps are necessary because only one ramp terminal is analyzed for a one-year period and the EB Method is not applied.

Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site’s facility type and traffic control features.
For a ramp terminal, an SPF value for all crash types is determined. The SPF for fatal-and-injury crashes is calculated from Equation 14-31 and Table 14-17 as follows:

\[
N_{sfp, B2, ST, at, fi} = \exp\left(a + b \times \ln[AADT_{arv}] + d \times \ln[AADT_{ex} + c \times AADT_{en}]\right)
\]

\[
= \exp\left(-2.687 + 0.260 \times \ln[0.001 \times 14,000] + 0.947 \times \ln[0.001 \times 1,450 + 0.001 \times 1,300]\right)
\]

\[
= 0.352 \text{ crashes/year}
\]

Similarly, the SPF for property-damage-only crashes is calculated from Equation 14-31 and Table 14-17 to yield the following result:

\[
N_{sfp, B2, ST, at, pdo} = 0.881 \text{ crashes/year}
\]
Step 10 – Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site-specific geometric design and traffic control features.

Each CMF used in the calculation of the predicted average crash frequency of the ramp terminal is calculated in this step.

Exit Ramp Capacity (CMF<sub>10, B2, ST, at, fi </sub>)

CMF<sub>10, B2, ST, at, fi </sub> is calculated from Equation 14-42 as follows:

\[
CMF_{10, B2, ST, at, fi} = (1.0 - P_{ex}) \times 1.0 + P_{ex} \times \exp \left( a \times \frac{c \times AADT_{ex}}{n_{ex, eff}} \right)
\]

For a stop-controlled exit-ramp right-turn movement, the effective number of lanes serving exit ramp traffic \( n_{ex, eff} \) is computed using the second portion of Equation 14-43 as follows:

\[
0.5 \times n_{ex} = 0.5 \times 2 = 1.0
\]

The proportion of total leg AADT on the exit ramp leg \( P_{ex} \) is computed using Equation 14-44 as follows:

\[
P_{ex} = \frac{AADT_{ex}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}}
\]

\[
= \frac{1,450}{14,000 + 14,000 + 1,300 + 1,450}
\]

\[
= 0.047
\]

From Table 14-32, \( a = 0.151 \) and \( c = 0.001 \) for one-way stop-controlled ramp terminals. \( CMF_{10, B2, ST, at, fi} \) is calculated as follows:

\[
CMF_{10, B2, ST, at, fi} = (1.0 - 0.047) \times 1.0 + 0.047 \times \exp \left( 0.151 \times \frac{0.001 \times 1,450}{1.0} \right)
\]

\[
= 1.012
\]

Access Point Frequency (CMF<sub>13, B2, ST, at, fi </sub>)

The ramp terminal has no unsignalized public street approaches on the outside leg, which is the base condition for the access point frequency CMF. Hence, \( CMF_{13, B2, ST, at, fi} \) is equal to 1.000.

Segment Length (CMF<sub>14, B2, ST, at, fi </sub>)

CMF<sub>14, B2, ST, at, fi </sub> is calculated from Equation 14-50 as follows:

\[
CMF_{14, B2, ST, at, fi} = \exp \left( a \times \frac{1.0}{L_{emp}} + \frac{1.0}{L_{str}} - 0.333 \right)
\]

From Table 14-36, \( a = -0.0141 \) for fatal-and-injury crashes. \( CMF_{14, B2, ST, at, fi} \) is calculated as follows:
\[ CMF_{14, B2, ST, at, fi} = \exp \left( -0.0141 \times \left[ \frac{1.0}{0.15} + \frac{1.0}{1.0} - 0.333 \right] \right) \]

= 0.902

**Median Width \((CMF_{15, B2, ST, at, fi})\)**

The crossroad has a 12-ft median, which is the base condition for the median width CMF. Hence, \(CMF_{15, B2, ST, at, fi}\) is equal to 1.000.

**All-Way Stop Control \((CMF_{awsc})\)**

As stated in Section 14.10, the all-way stop control CMF, \(CMF_{awsc}\), is equal to 0.686. It applies to fatal-and-injury crashes only.

**Crashes**

The CMFs are applied to the fatal-and-injury SPF as follows:

\[
N_{p^*, B2, ST, at, fi} = N_{spf, B2, ST, at, fi} \times \left( CMF_{10, B2, ST, at, fi} \times CMF_{13, B2, ST, at, fi} \times CMF_{14, B2, ST, at, fi} \times CMF_{15, B2, ST, at, fi} \times CMF_{awsc} \right)
\]

= 0.352 \times (1.012 \times 1.000 \times 0.902 \times 1.000 \times 0.686)

= 0.352 \times 0.626

= 0.221 \text{ crashes/year}

The CMFs are applied to the property-damage-only SPF as follows:

\[
N_{p^*, B2, ST, at, pdo} = N_{spf, B2, ST, at, pdo}
\]

= 0.881 \text{ crashes/year}

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

It is assumed that a calibration factor of 1.00 has been determined for local conditions. See Part C Appendix A.1 for further discussion on calibration of the predicted models.

**Calculation of Predicted Average Crash Frequency**

The predicted average crash frequency is calculated using Equation 14-1 based on the results obtained in Steps 9 through 11 as follows.

Fatal-and-injury crashes:

\[
N_{p, B2, ST, at, fi} = N_{p^*, B2, ST, at, fi} \times C_{B2, ST, at, fi}
\]

= 0.221 \times 1.00

= 0.221 \text{ crashes/year}

Property-damage-only crashes:

\[
N_{p, B2, ST, at, pdo} = N_{p^*, B2, ST, at, pdo} \times C_{B2, ST, at, pdo}
\]

= 0.881 \times 1.00

= 0.881 \text{ crashes/year}
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.

The study period is one year (2011), so steps 8 through 11 need not be repeated.

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

This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

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

The site-specific EB Method is not applied in this sample problem because crash data are not available.

Apply the severity distribution functions (SDFs), if desired.

To apply the SDFs, the systematic component of crash severity likelihood $V_j$ is computed for each severity level $j$ using Equation 14-88 as follows:

$$V_j = a + (b \times I_{p,lt}) + (c \times [n_{dw} + n_{ps}]) + (d \times I_{ps}) + (e \times I_{rural})$$

The coefficients $a$, $b$, $c$, $d$, and $e$ are obtained from Table 14-44 for each severity level $j$. $V_j$ is computed for fatal and incapacitating injury crashes as follows:

$$V_{K+A} = -3.168 + (0.00 \times 0.0) + (0.00 \times [0.0 + 0.0]) + (0.00 \times 0.0) + (0.891 \times 0.0)$$

$$V_{K+A} = -3.168$$

Similar calculations using the coefficients from Table 14-44 for non-incapacitating injury crashes yield the following results:

$$V_B = -1.476$$

Using these computed $V_{K+A}$ and $V_B$ values, and assuming a calibration factor $C_{sdf, aS, x}$ of 1.0, the probability of occurrence of a fatal crash is computed using Equation 14-84 as follows:

$$P_{aS, ST, at, K} = \frac{\exp(V_{K+A})}{C_{sdf, aS, x} + \exp(V_{K+A}) + \exp(V_B)} \times P_{K+A, aS, x, at}$$

$$P_{aS, ST, at, K} = \frac{\exp(-3.168)}{1.0 + \exp(-3.168) + \exp(-1.476)} \times 0.160$$

$$P_{aS, ST, at, K} = 0.005$$

Similar calculations using Equation 14-85 and Equation 14-86 yield the following results:

$$P_{aS, ST, at, A} = 0.028$$

$$P_{aS, ST, at, B} = 0.180$$

The probability of occurrence of a possible-injury crash is computed using Equation 14-87 as follows:
The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 14-78 as follows:

\[ N_{r,B2,ST,at,K} = N_{r,B2,ST,at,f} \times P_{aS,ST,at,K} \]
\[ = 0.221 \times 0.005 \]
\[ = 0.001 \text{ crashes/year} \]

Similar calculations using Equation 14-78 and the probabilities of occurrences of the other crash severities yield the following results:

\[ N_{r,B2,ST,at,A} = 0.006 \text{ crashes/year} \]
\[ N_{r,B2,ST,at,B} = 0.040 \text{ crashes/year} \]
\[ N_{r,B2,ST,at,C} = 0.174 \text{ crashes/year} \]

Apply the crash type distribution, if desired.

The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 14-45 by the predicted average crash frequencies obtained in Step 11.

Worksheets

The step-by-step instructions are provided to illustrate the predictive method for calculating the predicted average crash frequency for a ramp terminal. To apply the predictive method steps to multiple terminals, a series of worksheets are provided for determining the predicted average crash frequency. The worksheets include:

- Table 14-68. Ramp Terminal Worksheet (1 of 4)—Sample Problem 6
- Table 14-69. Ramp Terminal Worksheet (2 of 4)—Sample Problem 6
- Table 14-70. Ramp Terminal Worksheet (3 of 4)—Sample Problem 6
- Table 14-71. Ramp Terminal Worksheet (4 of 4)—Sample Problem 6

Filled versions of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 14 Appendix A.
Table 14-70 is a tabulation of the CMF and SPF computations for Sample Problem 6.

Table 14-71 is a tabulation of the crash severity and crash type distributions for Sample Problem 6.

**Table 14-68. Ramp Terminal Worksheet (1 of 4)—Sample Problem 6**

<table>
<thead>
<tr>
<th>General Information</th>
<th>Location Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Roadway</td>
</tr>
<tr>
<td>Agency or company</td>
<td>Intersection</td>
</tr>
<tr>
<td>Date performed</td>
<td>Study year</td>
</tr>
<tr>
<td>Area type</td>
<td>X Urban Rural</td>
</tr>
</tbody>
</table>

**Input Data**

<table>
<thead>
<tr>
<th>Crash Data</th>
<th>Crash Period</th>
<th>Study Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First year</td>
<td>Last year</td>
</tr>
</tbody>
</table>

Count of FI crashes $N_{o, w, x, at, f}$

Count of PDO crashes $N_{o, w, x, at, pdo}$

**Basic Intersection Data**

<table>
<thead>
<tr>
<th>Ramp terminal configuration</th>
<th>B2</th>
<th>Choices: D3ex, D3en, D4, A4, B4, A2, B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp terminal traffic control mode</td>
<td>All-way stop</td>
<td>Choices: Signal, One-way-stop, All-way stop</td>
</tr>
<tr>
<td>Presence of a non-ramp public street leg $l_{pr}$</td>
<td>Y/N</td>
<td>--</td>
</tr>
</tbody>
</table>

**Alignment Data**

| Exit ramp skew angle $l_{sk}$ (degrees) | -- |
| Distance to the next public street intersection on the outside crossroad leg $L_{on}$ (mi) | 1.0 |
| Distance to the adjacent ramp terminal $L_{rmp}$ (mi) | 0.15 |

**Traffic Control**

**Left-Turn Operational Mode**

| Crossroad | Inside approach | Prot.-only mode $l_{p, h, in}$ | Y/N | -- | Y/N |
| Outside approach | Prot.-only mode $l_{p, h, out}$ | Y/N | -- | Y/N |

**Right-Turn Control Mode**

<table>
<thead>
<tr>
<th>Ramp</th>
<th>Exit ramp approach</th>
<th>Right-turn control mode</th>
<th>Stop</th>
<th>Choices: Signal, Stop, Yield, Merge, Free</th>
</tr>
</thead>
</table>

**Cross Section Data**

<table>
<thead>
<tr>
<th>Crossroad median width $W_m$ (ft)</th>
<th>12</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Number of Lanes</th>
<th></th>
</tr>
</thead>
</table>

| Crossroad | Inside approach | Through lanes $n_{h, in}$ | 2 | Same choice for crash period and study year. |
| Outside approach | Through lanes $n_{h, out}$ | 2 | Same choice for crash period and study year. |
| Ramp | Exit ramp approach | All lanes $n_{ex}$ | 2 | Same choice for crash period and study year. |

**Right-Turn Channelization**

| Crossroad | Inside approach | Chan. present $l_{ch, in}$ | Y/N | -- | Y/N |
| Outside approach | Chan. present $l_{ch, out}$ | Y/N | -- | Y/N |
| Ramp | Exit ramp approach | Chan. present $l_{ch, ex}$ | Y/N | -- | Y/N |
### Table 14-69. Ramp Terminal Worksheet (2 of 4)—Sample Problem 6

**Input Data**

<table>
<thead>
<tr>
<th>Cross Section Data</th>
<th>Crash Period</th>
<th>Study Year</th>
<th>Complete the study year column. Complete the crash period column if the EB Method is used.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Left-Turn Lane or Bay</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossroad</td>
<td>Inside approach</td>
<td>Lane or bay present $I_{ltn, l, in}$</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>Lane or bay width $W_{b, l, in}$ (ft)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Outside approach</td>
<td>Lane or bay present $I_{ltn, l, out}$</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>Lane or bay width $W_{b, l, out}$ (ft)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Right-Turn Lane or Bay</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossroad</td>
<td>Inside approach</td>
<td>Lane or bay present $I_{rtn, r, in}$</td>
<td>Y/N</td>
</tr>
<tr>
<td></td>
<td>Outside approach</td>
<td>Lane or bay present $I_{rtn, r, out}$</td>
<td>Y/N</td>
</tr>
<tr>
<td><strong>Access Data</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of driveways on the outside crossroad leg $n_{dw}$</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of public street approaches on the outside crossroad leg $n_{ps}$</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Traffic Data</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossroad</td>
<td>Inside leg</td>
<td>$AADT_{in}$ (veh/day)</td>
<td>14,000</td>
</tr>
<tr>
<td></td>
<td>Outside leg</td>
<td>$AADT_{out}$ (veh/day)</td>
<td>14,000</td>
</tr>
<tr>
<td>Ramp</td>
<td>Exit ramp</td>
<td>$AADT_{exit}$ (veh/day)</td>
<td>1,450</td>
</tr>
<tr>
<td></td>
<td>Entrance ramp</td>
<td>$AADT_{entr}$ (veh/day)</td>
<td>1,300</td>
</tr>
</tbody>
</table>
Table 14-70. Ramp Terminal Worksheet (3 of 4)—Sample Problem 6

### Crash Modification Factors

<table>
<thead>
<tr>
<th>CRASH MODIFICATION FACTORS</th>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td><strong>Signal Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exit ramp capacity CMF10, w, SGn, at, fi</td>
<td>14-42</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Crossroad left-turn lane CMF11, w, SGn, at, z</td>
<td>14-45</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Crossroad right-turn lane CMF12, w, SGn, at, z</td>
<td>14-48</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Access point frequency CMF13, u, SGn, at, z</td>
<td>14-49</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Segment length CMF14, u, SGn, at, z</td>
<td>14-50</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Median width CMF15, u, SGn, at, z</td>
<td>14-51</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Protected left-turn operation CMF16, w, SGn, at, z</td>
<td>14-53</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Chan. right turn on crossroad CMF17, u, SGn, at, z</td>
<td>14-55</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Chan. right turn on exit ramp CMF18, w, SGn, at, z</td>
<td>14-56</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Non-ramp public street leg CMF19, u, SGn, at, z</td>
<td>14-57</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Stop Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exit ramp capacity CMF10, w, ST, at, fi</td>
<td>14-42</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Crossroad left-turn lane CMF11, w, ST, at, z</td>
<td>14-45</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Crossroad right-turn lane CMF12, w, ST, at, z</td>
<td>14-48</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Access point frequency CMF13, u, ST, at, fi</td>
<td>14-49</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Segment length CMF14, u, ST, at, fi</td>
<td>14-50</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Median width CMF15, u, ST, at, fi</td>
<td>14-51</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Skew angle CMF20, w, ST, at, fi</td>
<td>14-58</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>All-way stop-control (exclude CMF11, CMF12, CMF19)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Combined CMF (multiply all CMFs evaluated)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

### Expected Average Crash Frequency *

<table>
<thead>
<tr>
<th>Crash Modification Factors</th>
<th>Equation</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Crash Period</td>
<td>Study Year</td>
</tr>
<tr>
<td>Calibration factor CaS, x, at, z</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Overdispersion parameter kw, x, at, z</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Observed crash count N_o, w, x, at, z (cr)</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Reference year r</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Predicted average crash freq. for reference year N_p, w, x, at, z, r (cr/yr)</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Predicted number of crashes for crash period (sum all years) N_p, w, x, y, z (cr)</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Equivalent years associated with crash count C_b, w, x, at, z, r (yr)</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Adjusted average crash freq. for ref. year given N_w, w, x, at, z, r (cr/yr)</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Study year s</td>
<td>2011</td>
<td>2011</td>
<td></td>
</tr>
<tr>
<td>Predicted average crash freq. for study year N_p, w, x, at, z, s (cr/yr)</td>
<td>0.221</td>
<td>0.221</td>
<td>0.881</td>
</tr>
<tr>
<td>Expected average crash freq. for study year N_e, w, x, at, z, s (cr/yr)</td>
<td>0.221</td>
<td>0.221</td>
<td>0.881</td>
</tr>
</tbody>
</table>

Note: a – If the EB Method is not used, then substitute “predicted” for “expected” and substitute the subscript “p” for the subscript “e”.
Table 14-71. Ramp Terminal Worksheet (4 of 4)—Sample Problem 6

Expected Average Crash Frequency

<table>
<thead>
<tr>
<th>Crash Severity Distribution</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Total FI</th>
<th>PDO</th>
<th>Total FI + PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion by injury level</td>
<td>0.005</td>
<td>0.028</td>
<td>0.180</td>
<td>0.787</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected average crash freq. for study year $N_{e, w, x, at, z, t}$ (cr/yr)</td>
<td>0.001</td>
<td>0.006</td>
<td>0.040</td>
<td>0.174</td>
<td>0.221</td>
<td>0.881</td>
<td>1.102</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crash Type Distribution</th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash Type Category</td>
<td>Proportion</td>
<td>Proportion</td>
<td>Proportion</td>
</tr>
<tr>
<td>Multiple-Vehicle Crashes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head-on</td>
<td>0.017</td>
<td>0.000</td>
<td>0.012</td>
</tr>
<tr>
<td>Right-angle</td>
<td>0.458</td>
<td>0.040</td>
<td>0.378</td>
</tr>
<tr>
<td>Rear-end</td>
<td>0.373</td>
<td>0.160</td>
<td>0.377</td>
</tr>
<tr>
<td>Sideswipe</td>
<td>0.025</td>
<td>0.000</td>
<td>0.079</td>
</tr>
<tr>
<td>Other multiple-vehicle crashes</td>
<td>0.017</td>
<td>0.000</td>
<td>0.016</td>
</tr>
</tbody>
</table>

| Single-Vehicle Crashes  |                   |                     |       |
| Crash with animal       | 0.000             | 0.000               | 0.000  | 0.000 | 0.000 |
| Crash with fixed object | 0.085             | 0.000               | 0.110  | 0.147 | 0.147 |
| Crash with other object | 0.000             | 0.000               | 0.000  | 0.000 | 0.000 |
| Crash with parked vehicle | 0.000             | 0.000               | 0.008  | 0.000 | 0.000 |
| Other single-vehicle crashes | 0.025 | 0.020 | 0.020 | 0.000 | 0.020 |
| Total                   | 1.000            | 0.221               | 1.000  | 0.881 | 1.102 |

14.15. REFERENCES


APPENDIX 14A—WORKSHEETS FOR PREDICTIVE METHOD FOR RAMPS

[Section to be completed after method is reviewed and approved.]
APPENDIX E

DRAFT HSM APPENDIX A FOR PART C
# APPENDIX A—SPECIALIZED PROCEDURES COMMON TO ALL PART C CHAPTERS

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</tr>
</thead>
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</tr>
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<td>ii</td>
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<td>1</td>
</tr>
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</tr>
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</tr>
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<td>28</td>
</tr>
<tr>
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<td>31</td>
</tr>
</tbody>
</table>
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Table A-3. Crash Distributions in Part C Predictive Models That May Be Calibrated to Local Conditions [addendum] .......................................................................................................................... 9
Appendix A—Specialized Procedures Common to All Part C Chapters

This appendix describes two specialized procedures intended for use with the predictive methods presented in Part C. One procedure is for calibrating a predictive model to local conditions. The second procedure is the empirical Bayes (EB) Method for combining observed crash frequencies with the estimate provided by the predictive models in Part C. Both of these procedures are an integral part of the predictive method in Part C, and are presented in this appendix only to avoid repetition across the chapters.

A.1. CALIBRATION OF THE PART C PREDICTIVE MODELS
The predictive models in each of Chapters 10 to 14 consist of Safety Performance Functions (SPFs), Crash Modification Factors (CMFs), and a calibration factor. Each model is developed for a specific site type (i.e., segment or intersection).

The predictive models were developed from the most complete and consistent data sets available. However, the general level of crash frequencies may vary substantially from one jurisdiction to another for a variety of reasons including climate, driver populations, animal populations, crash reporting thresholds, and crash reporting system procedures. Therefore, for these predictive models to provide results that are meaningful and accurate for each jurisdiction, it is important that they be calibrated for application in the jurisdiction in which they are applied. A procedure for determining the calibration factors for the predictive models is presented in Section A.1.1.

Some HSM users may prefer to develop SPFs with data from their jurisdiction for use in the predictive models rather than calibrating the Part C SPFs. Calibration of the Part C SPFs will provide satisfactory results. However, SPFs developed directly with data for a specific jurisdiction may provide more reliable estimates for that jurisdiction than calibration of the Part C SPFs. Guidance is presented in Section A.1.2 on the development of jurisdiction-specific SPFs that are suitable for use in a Part C predictive model.

The predictive method in each of Chapters 10 to 14 consists of a set of predictive models and default distributions. Chapters 13 and 14 also include severity distribution functions (SDFs). Most of the regression coefficients and distribution values used in the predictive methods have been determined through extensive research. Modification of the regression coefficients should only follow from equally extensive research. On the other hand, a few specific quantities, such as the distribution of crash type or the proportion of crashes occurring during night-time conditions, can vary substantially from jurisdiction to jurisdiction. Where local data are available, users may replace these default values with locally derived values. A procedure for deriving jurisdiction-specific distribution values is presented in Section A.1.3. A procedure for calibrating the SDFs is described in Section A.1.4.

A.1.1. Calibration of Predictive Models
The calibration procedure is used to derive the value of the calibration factor that is included in each Part C predictive model. A calibration factor represents the ratio of the total observed number of crashes for a selected set of sites to the total expected number of crashes for the same sites, during the same time period, using the applicable Part C predictive model. Thus, the nominal value of the calibration factor is 1.00 when
the observed and predicted number of crashes happens to be equal. When there are more crashes observed than are predicted by the predictive model, the computed calibration factor will be greater than 1.00. When there are fewer crashes observed than are predicted by the predictive model, the computed calibration factor will be less than 1.00.

It is recommended that new values of the calibration factors be derived at least every two to three years, and some HSM users may prefer to develop calibration factors on an annual basis. The calibration factor for the most recent available period is to be used for all assessments of proposed future projects. If available, calibration factors for the specific time periods included in the evaluation period are to be used in effectiveness evaluations that use the procedures presented in Chapter 9.

If the procedure in Section A.1.3 is used to calibrate a default value in a Part C predictive model to local conditions, the locally-calibrated values should be used in the calibration process described in this section.

The calibration procedure involves five steps. Each step is described in the following five subsections.

A.1.1.1. Step 1—Identify the predictive models to be calibrated. Calibration is performed separately for each predictive model described in a Part C chapter. Table A-1 identifies the combinations of site type and cross section or control type represented in each predictive model and for which calibration factors can be derived. The combinations of interest are identified by the user in this step.

[Only that portion of Table A-1 that is applicable to Chapters 13 and 14 is shown]
### Table A-1. Part C Predictive Models that Need Calibration [addendum]

<table>
<thead>
<tr>
<th>Site Type and Cross Section or Control Type</th>
<th>Calibration Factor</th>
<th>Symbol</th>
<th>Equation Number</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ROADWAY SEGMENTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freeways</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple-vehicle fatal-and-injury crashes</td>
<td>$C_{fs, ac, mv, fi}$</td>
<td>13-3</td>
<td></td>
</tr>
<tr>
<td>Multiple-vehicle property-damage-only crashes</td>
<td>$C_{fs, ac, mv, pdo}$</td>
<td>13-5</td>
<td></td>
</tr>
<tr>
<td>Single-vehicle fatal-and-injury crashes</td>
<td>$C_{fs, ac, sv, fi}$</td>
<td>13-4</td>
<td></td>
</tr>
<tr>
<td>Single-vehicle property-damage-only crashes</td>
<td>$C_{fs, ac, sv, pdo}$</td>
<td>13-6</td>
<td></td>
</tr>
<tr>
<td>Ramps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entrance ramp, multiple-vehicle fatal-and-injury crashes</td>
<td>$C_{rps, EN, mv, fi}$</td>
<td>14-3</td>
<td></td>
</tr>
<tr>
<td>Entrance ramp, multiple-vehicle property-damage-only crashes</td>
<td>$C_{rps, EN, mv, pdo}$</td>
<td>14-5</td>
<td></td>
</tr>
<tr>
<td>Entrance ramp, single-vehicle fatal-and-injury crashes</td>
<td>$C_{rps, EN, sv, fi}$</td>
<td>14-4</td>
<td></td>
</tr>
<tr>
<td>Entrance ramp, single-vehicle property-damage-only crashes</td>
<td>$C_{rps, EN, sv, pdo}$</td>
<td>14-6</td>
<td></td>
</tr>
<tr>
<td>Exit ramp, multiple-vehicle fatal-and-injury crashes</td>
<td>$C_{rps, EX, mv, fi}$</td>
<td>not shown</td>
<td></td>
</tr>
<tr>
<td>Exit ramp, multiple-vehicle property-damage-only crashes</td>
<td>$C_{rps, EX, mv, pdo}$</td>
<td>not shown</td>
<td></td>
</tr>
<tr>
<td>Exit ramp, single-vehicle fatal-and-injury crashes</td>
<td>$C_{rps, EX, sv, fi}$</td>
<td>not shown</td>
<td></td>
</tr>
<tr>
<td>Exit ramp, single-vehicle property-damage-only crashes</td>
<td>$C_{rps, EX, sv, pdo}$</td>
<td>not shown</td>
<td></td>
</tr>
<tr>
<td>C-D road, multiple-vehicle fatal-and-injury crashes</td>
<td>$C_{cds, ac, mv, fi}$</td>
<td>14-8</td>
<td></td>
</tr>
<tr>
<td>C-D road, multiple-vehicle property-damage-only crashes</td>
<td>$C_{cds, ac, mv, pdo}$</td>
<td>14-10</td>
<td></td>
</tr>
<tr>
<td>C-D road, single-vehicle fatal-and-injury crashes</td>
<td>$C_{cds, ac, sv, fi}$</td>
<td>14-9</td>
<td></td>
</tr>
<tr>
<td>C-D road, single-vehicle property-damage-only crashes</td>
<td>$C_{cds, ac, sv, pdo}$</td>
<td>14-11</td>
<td></td>
</tr>
<tr>
<td><strong>INTERSECTIONS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freeway Speed-Change Lanes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramp entrance speed-change lane, fatal-and-injury crashes</td>
<td>$C_{sc, EN, at, fi}$</td>
<td>13-8</td>
<td></td>
</tr>
<tr>
<td>Ramp entrance speed-change lane, property-damage-only crashes</td>
<td>$C_{sc, EN, at, pdo}$</td>
<td>13-9</td>
<td></td>
</tr>
<tr>
<td>Ramp exit speed-change lane, fatal-and-injury crashes</td>
<td>$C_{sc, EX, at, fi}$</td>
<td>13-11</td>
<td></td>
</tr>
<tr>
<td>Ramp exit speed-change lane, property-damage-only crashes</td>
<td>$C_{sc, EX, at, pdo}$</td>
<td>13-12</td>
<td></td>
</tr>
<tr>
<td>Crossroad Ramp Terminals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One-way stop control, fatal-and-injury crashes</td>
<td>$C_{asS, ST, at, fi}$</td>
<td>14-13</td>
<td></td>
</tr>
<tr>
<td>One-way stop control, property-damage-only crashes</td>
<td>$C_{asS, ST, at, pdo}$</td>
<td>14-14</td>
<td></td>
</tr>
<tr>
<td>Signal control, fatal-and-injury crashes</td>
<td>$C_{asS, SG, at, fi}$</td>
<td>14-16</td>
<td></td>
</tr>
<tr>
<td>Signal control, property-damage-only crashes</td>
<td>$C_{asS, SG, at, pdo}$</td>
<td>14-17</td>
<td></td>
</tr>
</tbody>
</table>
Also established in this step is the calibration period. A calibration period longer than three years is not recommended because the expected average crash frequency is likely to change over time. The calibration period should have a duration that is a multiple of 12 months to avoid seasonal effects. For ease of application, it is recommended that the calibration periods consist of one, two, or three full calendar years. It is recommended to use the same calibration period for all sites, but exceptions may be made where necessary.

A.1.1.2. Step 2—Select sites for calibration of the predictive model.
Calibration sites are selected during this step. One set of calibration sites is assembled for each predictive model identified in Step 1. A given site may be included in more than one set provided that all sites in the set are consistent with the model’s calibration factor characteristics (as listed in Table A-1). Each calibration site must be located in the agency’s jurisdiction. It is desirable that these sites be reasonably representative of the range of site characteristics to which the predictive model will be applied. However, no formal stratification by traffic volume or other site characteristics is needed in selecting the calibration sites. As such, the sites can be selected in a manner to make the data collection needed for Step 3 as efficient as practical.

Each calibration site should be selected without regard to its reported number of crashes during the calibration period. In other words, calibration sites should not be selected to intentionally limit the calibration database to include only sites with either high or low crash frequencies. Where practical, this may be accomplished by selecting calibration sites randomly from a larger set of candidate sites.

The desirable minimum sample size for the calibration database for one predictive model is 30 to 50 sites. For segments, each site should be between 0.1 and 1.0 mi in length. Lengths in this range should be long enough to have statistical validity and short enough to be realistically homogenous.

For large jurisdictions, such as entire states, with a variety of topographical and climate conditions, it may be desirable to assemble a separate set of calibration sites representing two or three different conditions. In this manner, separate calibration factors are developed for each specific terrain type or geographical region for a given predictive model. For example, a state with distinct plains and mountain regions (or with distinct dry and wet regions), might choose to develop separate calibration factors for those regions. Where separate calibration factors are developed by terrain type or region, this needs to be done consistently for all predictive models applicable to those regions.

The terms “observed” and “reported” are used interchangeably in this appendix to describe the crash reports (or records) obtained from the public agency responsible for managing these reports.

A.1.1.3. Step 3—Obtain data for each set of calibration sites for the calibration period.
This step is repeated for each predictive model identified in Step 1 and its associated set of calibration sites assembled in Step 2. For this step, a calibration database is assembled for each set of calibration sites. The calibration data are assembled for a common calibration period for all sites. The calibration database should include the following information for each site represented in the database:

- All target crashes that are reported during the calibration period.
- Site characteristics data needed to apply the predictive model for the same calibration period.

Target crashes are those crashes that are consistent with the predictive model being calibrated. For example, if the predictive model is applicable to multiple-vehicle fatal-and-injury crashes on freeway segments, then the target crashes are multiple-vehicle fatal-and-injury crashes on freeway segments.
For a given site type, the calibration database should include at least 100 target crashes per year. If this minimum is not realized then additional sites should be added to the database following the guidelines in Step 2.

The crash data used for calibration should include all crashes related to each site selected for the calibration database. Crashes should be assigned to specific sites based on the guidelines presented in Section A.2.3.

Table A-2 identifies the site characteristics data that are needed to apply the Part C predictive models. The table classifies each data element as either required or desirable for the calibration procedure. Data for each of the required elements are needed for calibration. For the desirable data elements, it is recommended that actual data be used if available. Assumptions are offered in the table when these data are not available.

[Only that portion of Table A-2 that is applicable to Chapters 13 and 14 is shown]

**Table A-2.** Data Needs for Calibration of Part C Predictive Models [addendum]

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Data Element</th>
<th>Required</th>
<th>Desirable</th>
<th>Default Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>ROADWAY SEGMENTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Area type (rural or urban)</td>
<td>X</td>
<td></td>
<td>Need actual data</td>
</tr>
<tr>
<td></td>
<td>Number of through lanes</td>
<td>X</td>
<td></td>
<td>Need actual data</td>
</tr>
<tr>
<td></td>
<td>Segment length</td>
<td>X</td>
<td></td>
<td>Need actual data</td>
</tr>
<tr>
<td></td>
<td>Length and radii of horizontal curves</td>
<td>X</td>
<td></td>
<td>Need actual data</td>
</tr>
<tr>
<td></td>
<td>Lane width</td>
<td>X</td>
<td></td>
<td>Need actual data</td>
</tr>
<tr>
<td></td>
<td>Inside and outside shoulder width</td>
<td>X</td>
<td></td>
<td>Need actual data</td>
</tr>
<tr>
<td></td>
<td>Median width</td>
<td>X</td>
<td></td>
<td>Need actual data</td>
</tr>
<tr>
<td></td>
<td>Length of rumble strips on inside and outside shoulders</td>
<td>X</td>
<td></td>
<td>Base default on agency policy</td>
</tr>
<tr>
<td>13—Freeways</td>
<td>Length of (and offset to) median barrier</td>
<td>X</td>
<td></td>
<td>Need actual data</td>
</tr>
<tr>
<td></td>
<td>Length of (and offset to) outside barrier</td>
<td>X</td>
<td></td>
<td>Need actual data</td>
</tr>
<tr>
<td></td>
<td>Clear zone width</td>
<td>X</td>
<td></td>
<td>Base default on agency policy</td>
</tr>
<tr>
<td></td>
<td>AADT of (and distance to) nearest upstream and downstream entrance ramp</td>
<td>X</td>
<td></td>
<td>Need actual data</td>
</tr>
<tr>
<td></td>
<td>AADT of (and distance to) nearest upstream and downstream exit ramp</td>
<td>X</td>
<td></td>
<td>Need actual data</td>
</tr>
<tr>
<td></td>
<td>Presence of speed-change lane</td>
<td>X</td>
<td></td>
<td>Need actual data</td>
</tr>
<tr>
<td></td>
<td>Presence and length of Type B weaving sections</td>
<td>X</td>
<td></td>
<td>Need actual data</td>
</tr>
<tr>
<td></td>
<td>Proportion of AADT that occurs during hours where lane volume exceeds 1,000 veh/h/ln</td>
<td>X</td>
<td></td>
<td>Equation for computing default is in Chapter 13, Section 13.4</td>
</tr>
</tbody>
</table>
Table A-2. Data Needs for Calibration of Part C Predictive Models

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Data Element</th>
<th>Data Need</th>
<th>Required</th>
<th>Desirable</th>
<th>Default Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>ROADWAY SEGMENTS</strong></td>
<td><strong>Data Need</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Required</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Desirable</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Default Assumption</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>For ramps and collector-distributor (C-D) roads:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Area type (rural or urban)</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number of through lanes</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Segment length</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average annual daily traffic (AADT)</td>
<td>X</td>
<td>Need actual data</td>
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</tr>
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<td></td>
<td>Length and radii of horizontal curves</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lane width</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Left and right shoulder width</td>
<td>X</td>
<td>Need actual data</td>
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<td></td>
</tr>
<tr>
<td>14—Ramps</td>
<td>Length of (and offset to) right side barrier</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Length of (and offset to) left side barrier</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presence of lane add or drop</td>
<td>X</td>
<td>Assume not present</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presence of speed-change lane</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>For C-D roads only:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presence and length of weaving section</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>INTERSECTIONS</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td><strong>For freeway speed-change lanes:</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Area type (rural or urban)</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number of through lanes</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Segment length</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Length and radii of horizontal curves</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lane width</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13—Freeways</td>
<td>Inside shoulder width</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median width</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presence of rumble strips on inside shoulder</td>
<td>X</td>
<td>Base default on agency policy</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Length of (and offset to) median barrier</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AADT of ramp in speed-change lane</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presence and length of Type B weaving sections</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proportion of AADT that occurs during hours</td>
<td>X</td>
<td>Equation for computing default is in Chapter 13, Section 13.4</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>where lane volume exceeds 1,000 veh/h/ln</td>
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<td></td>
<td></td>
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<td>AADT of freeway adjacent to speed-change lane</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
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</tr>
</tbody>
</table>
Table A-2. Data Needs for Calibration of Part C Predictive Models *continued* [addendum]

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Data Element</th>
<th>Data Need</th>
<th>Required</th>
<th>Desirable</th>
<th>Default Assumption</th>
</tr>
</thead>
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<tr>
<td>INTERSECTIONS</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>For all crossroad ramp terminals:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area type (rural or urban)</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramp terminal configuration</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of traffic control</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control for exit ramp right-turn movement</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AADT for inside and outside crossroad legs</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AADT for each ramp leg</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of through lanes on each crossroad approach</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of lanes on the exit ramp</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nbr. of crossroad approaches with left-turn lanes</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nbr. of crossroad approaches with right-turn lanes</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of unsignalized public street approaches to the crossroad leg outside of the interchange</td>
<td>X</td>
<td>Assume no public street approaches present</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to next public street intersection</td>
<td>X</td>
<td>Assume 0.15 mi for urban areas, assume 0.20 mi for rural areas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to adjacent crossroad ramp terminal</td>
<td>X</td>
<td>Based default on terminal configuration and area typea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossroad median width and left-turn lane width</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For signal-controlled crossroad ramp terminals only:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of unsignalized driveways on the crossroad leg outside of the interchange</td>
<td>X</td>
<td>Assume no driveways present</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of crossroad approaches with protected-only left-turn operation</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of crossroad approaches with right-turn channelization</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence of exit ramp right-turn channelization</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence of a non-ramp public street leg</td>
<td>X</td>
<td>Assume leg not present</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>For one-way stop-controlled crossroad ramp terminals only:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skew angle</td>
<td>X</td>
<td>Need actual data</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note:

a Default values by crossroad ramp terminal configuration and area type. Urban areas: A2 = 0.17 mi, A4 = 0.17 mi, B2 = 0.19 mi, B4 = 0.19 mi, D3 = 0.13 mi, D4 = 0.11 mi. Rural areas: A2 = 0.20 mi, A4 = 0.20 mi, B2 = 0.22 mi, B4 = 0.22 mi, D3 = 0.16 mi, D4 = 0.17 mi. Crossroad ramp terminal configurations are shown in Chapter 14, Figure 14-1.
If data for some required elements are not readily available, it may be possible to select sites in Step 2 for which these data are available. For example, in calibrating the predictive models for freeway segments, if data on the radii of horizontal curves are not readily available, the calibration data set could be limited to tangent freeways. Decisions of this type should be made, as needed, to keep the effort required to assemble the calibration data set within reasonable bounds.

A.1.1.4. Step 4—Apply the applicable Part C predictive method to estimate the predicted average crash frequency for each site during the calibration period as a whole.

This step is repeated for each predictive model identified in Step 1 and its associated set of calibration sites assembled in Step 2. The site characteristics data assembled in Step 3 are used to apply the applicable Part C predictive method to each site in the set of calibration sites. For this application, the predictive model should be applied without using the EB Method and without employing a calibration factor (i.e., a calibration factor of 1.00 is assumed). Through this process, the predicted average crash frequency is obtained for each site in the set of calibration sites and for each year in the calibration period.

A.1.1.5. Step 5—Compute calibration factors for use in Part C predictive models.

The final step is to compute the calibration factor using the following equation. The appropriate subscripts for this equation are identified in Table A-1 for each predictive model.

\[
C_{w,x,y,z} = \frac{\sum_{i=1}^{n_c} \sum_{j=1}^{n_j} N_{o,w(i),x(i),y,z,j}}{\sum_{i=1}^{n_c} \sum_{j=1}^{n_j} N_{p,w(i),x(i),y,z,j}}
\]

Where:

- \( C_{w,x,y,z} \) = calibration factor to adjust SPF for local conditions for site type \( w \), cross section or control type \( x \), crash type \( y \), and severity \( z \);
- \( N_{o,w(i),x(i),y,z,j} \) = observed crash frequency for year \( j \) at site \( i \) with site type \( w(i) \) and cross section or control type \( x(i) \) for crash type \( y \), and severity \( z \) (crashes/yr);
- \( N_{p,w(i),x(i),y,z,j} \) = predicted average crash frequency for year \( j \) at site \( i \) with site type \( w(i) \) and cross section or control type \( x(i) \) for crash type \( y \), and severity \( z \) (crashes/yr); and
- \( n_c \) = number of years in the crash period (yr).

The computation is performed separately for each predictive model identified in Step 1. The computed calibration factor is rounded to two decimal places for application in the appropriate predictive model.

A.1.2. Development of Jurisdiction-Specific Safety Performance Functions for Use in the Part C Predictive Method

[All cases where “Chapters 10, 11, and 12” is written need to be replaced with “Chapters 10 to 14”.

A.1.3. Replacement of Selected Default Values in the Part C Predictive Methods

[No changes to the paragraphs in this section.]

[Only that portion of Table A-3 that is applicable to Chapters 13 and 14 is shown]
Table A-3. Crash Distributions in Part C Predictive Models That May Be Calibrated to Local Conditions
[addendum]

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A.1.3.1. Replacement of Default Values for Rural Two-Lane, Two-way Roads
[No changes to this section.]

A.1.3.2. Replacement of Default Values for Rural Multilane Highways
[No changes to this section.]

A.1.3.3. Replacement of Default Values for Urban and Suburban Arterials
[No changes to this section.]

A.1.3.4. Replacement of Default Values for Freeways
Four default distributions for freeways may be updated with locally-derived replacement values. Procedures to develop each of these replacement values are described in the following subsections.

Crash Type for Multiple-Vehicle Crashes
Table 13-6 presents the distribution of multiple-vehicle crashes by crash type for freeway segments. The distribution is categorized by two crash severity levels and two area types. If sufficient data are available, the values in Table 13-6 may be updated. This table represents a joint distribution of two variables for each area type. Therefore, for a given area type, sufficient data for calibrating the distribution requires a set of freeway segments that have collectively experienced at least 200 multiple-vehicle crashes during a recent one- to three-year period.

Crash Type for Single-Vehicle Crashes
Table 13-8 presents the distribution of single-vehicle crashes by crash type for freeway segments. The distribution is categorized by two crash severity levels and two area types. If sufficient data are available, the values in Table 13-8 may be updated. This table represents a joint distribution of two variables for each area type. Therefore, for a given area type, sufficient data for calibrating the distribution requires a set of freeway
segments that have collectively experienced at least 200 single-vehicle crashes during a recent one- to three-year period.

**Crash Type for Ramp-Entrance-Related Crashes**
Table 13-10 presents the distribution of ramp-entrance-related crashes by crash type for freeway ramp entrances (and adjacent freeway lanes). The distribution is based on ramp-entrance speed-change lane crashes. It does not include crashes associated with a ramp entrance that adds a lane to the cross section. The distribution is categorized by two crash severity levels and two area types. If sufficient data are available, the values in Table 13-10 may be updated. This table represents a joint distribution of two variables for each area type. Therefore, for a given area type, sufficient data for calibrating the distribution requires a set of ramp entrances (and adjacent freeway lanes) that have collectively experienced at least 200 crashes during a recent one- to three-year period.

**Crash Type for Ramp-Exit-Related Crashes**
Table 13-12 presents the distribution of ramp-exit-related crashes by crash type for freeway ramp exits (and adjacent freeway lanes). The distribution is based on ramp-exit speed-change lane crashes. It does not include crashes associated with a ramp exit that drops a lane from the cross section. The distribution is categorized by two crash severity levels and two area types. If sufficient data are available, the values in Table 13-12 may be updated. This table represents a joint distribution of two variables for each area type. Therefore, for a given area type, sufficient data for calibrating the distribution requires a set of ramp exits (and adjacent freeway lanes) that have collectively experienced at least 200 crashes during a recent one- to three-year period.

**A.1.3.5. Replacement of Default Values for Ramps**
Five default distributions for ramps may be updated with locally-derived replacement values. Procedures to develop each of these replacement values are described in the following subsections.

**Crash Type for Multiple-Vehicle Crashes**
Table 14-6 presents the distribution of multiple-vehicle crashes by crash type for ramp and C-D road segments. The distribution is categorized by two crash severity levels. If sufficient data are available, the values in Table 14-6 may be updated. Sufficient data for calibrating the distribution requires a set of ramp and C-D road segments that have collectively experienced at least 200 multiple-vehicle crashes during a recent one- to three-year period.

**Crash Type for Single-Vehicle Crashes**
Table 14-9 presents the distribution of single-vehicle crashes by crash type for ramp and C-D road segments. The distribution is categorized by two crash severity levels and two area types. If sufficient data are available, the values in Table 14-9 may be updated. This table represents a joint distribution of two variables for each area type. Therefore, for a given area type, sufficient data for calibrating the distribution requires a set of ramp and C-D road segments that have collectively experienced at least 200 single-vehicle crashes during a recent one- to three-year period.

**Crash Type for Signal-Controlled Ramp Terminal Crashes**
Table 14-16 presents the distribution of intersection-related crashes by crash type for signal-controlled crossroad ramp terminals. The distribution is categorized by two crash severity levels and two area types. If sufficient data are available, the values in Table 14-16 may be updated. This table represents a joint distribution of two variables for each area type. Therefore, for a given area type, sufficient data for calibrating the distribution requires a set of signal-controlled ramp terminals that have collectively experienced at least 200 intersection-related crashes during a recent one- to three-year period.
Crash Type for One-Way Stop-Controlled Ramp Terminal Crashes
Table 14-21 presents the distribution of intersection-related crashes by crash type for one-way stop-controlled crossroad ramp terminals. The distribution is categorized by two crash severity levels and two area types. If sufficient data are available, the values in Table 14-21 may be updated. This table represents a joint distribution of two variables for each area type. Therefore, for a given area type, sufficient data for calibrating the distribution requires a set of one-way stop-controlled ramp terminals that have collectively experienced at least 200 intersection-related crashes during a recent one- to three-year period.

Crash Type for All-Way Stop-Controlled Ramp Terminal Crashes
Table 14-45 presents the distribution of intersection-related crashes by crash type for all-way stop-controlled crossroad ramp terminals. The distribution is categorized by two crash severity levels and two area types. If sufficient data are available, the values in Table 14-45 may be updated. This table represents a joint distribution of two variables for each area type. Therefore, for a given area type, sufficient data for calibrating the distribution requires a set of all-way stop-controlled ramp terminals that have collectively experienced at least 200 intersection-related crashes during a recent one- to three-year period.

A.1.4. Calibration of Part C Severity Distribution Functions
The SDFs used in the predictive methods of Chapters 13 and 14 were developed from the most complete and consistent databases available. Satisfactory results can be obtained with these SDFs, as they stand, when the predictive model for each facility type is calibrated with the procedure given in Section A.1.1. Therefore, calibration of the SDFs in Chapters 13 and 14 is optional. However, more reliable results may be obtained by calibrating the SDFs. Each SDF that is calibrated with locally-derived values should provide a small improvement in the reliability of the estimates of expected average crash frequency by severity level.

The procedure described in this section is used to quantify the calibration factor for an SDF. The procedure consists of five steps. It requires data for a set of sites (i.e., freeway segments, speed-change lanes, ramp segments, or crossroad ramp terminals) that are located in the jurisdiction of interest.

The SDF calibration factors will have values greater than 1.0 for sites that, on average, experience more severe crashes than those used in the development of the SDFs. Similarly, the calibration factors for sites that experience fewer severe crashes on average than those used in the development of the SDFs will have values less than 1.0.

The procedures presented in this subsection should be used after the predictive models have been calibrated using the procedure described in a previous subsection. The calibrated predictive models are used to determine the calibration factor for an SDF.

A.1.4.1. Step 1—Identify the site types for which the SDFs are to be calibrated.
Calibration is performed separately for each SDF provided in Chapters 13 and 14. Chapter 13 provides an SDF for freeway segments and speed-change lanes. Chapter 14 provides an SDF for ramp and C-D road segments. It also provides an SDF for one-way stop-controlled crossroad ramp terminals and an SDF for signal-controlled ramp terminals. The site types needed to calibrate a given SDF are identified in this step.

Also established in this step is the calibration period. Because crash severity is likely to change over time, a calibration period longer than three years is not recommended. The calibration period should have a duration that is a multiple of 12 months to avoid seasonal effects. It is recommended to use the same calibration period for all sites, but exceptions may be made where necessary.

A.1.4.2. Step 2—Select sites for calibration of the SDF.
Calibration sites are selected during this step. One set of calibration sites is assembled for each SDF identified in Step 1. Each calibration site must be located in the agency’s jurisdiction. It is desirable that
these sites be reasonably representative of the range of site characteristics to which the predictive model will be applied. However, no formal stratification by traffic volume or other site characteristics is needed in selecting the calibration sites. As such, the sites can be selected in a manner to make the data collection needed for Step 3 as efficient as practical.

Each calibration site should be selected without regard to its reported number or severity of crashes during the calibration period. In other words, calibration sites should not be selected to intentionally limit the calibration database to include only sites with either high or low crash frequencies. Also, they should not be selected to intentionally limit the database to include sites with more (or less) severe crashes. Where practical, this may be accomplished by selecting calibration sites randomly from a larger set of candidate sites.

The desirable minimum sample size for the calibration database for one site type is 30 to 50 sites. For segments, each site should be between 0.1 and 1.0 mi in length. Lengths in this range should be long enough to have statistical validity and short enough to be realistically homogenous.

For large jurisdictions, such as entire states, with a variety of topographical and climate conditions, it may be desirable to assemble a separate set of calibration sites representing two or three different conditions. In this manner, separate calibration factors are developed for each specific terrain type or geographical region for a given site type. For example, a state with distinct plains and mountain regions (or with distinct dry and wet regions), might choose to develop separate calibration factors for those regions. Where separate calibration factors are developed by terrain type or region, this needs to be done consistently for all site types applicable to those regions.

A.1.4.3. Step 3—Obtain data for each set of calibration sites for the calibration period.

This step is repeated for each SDF identified in Step 1 and its associated set of calibration sites assembled in Step 2. For this step, a calibration database is assembled for each set of calibration sites. The calibration data are assembled for a common calibration period for all sites. The calibration database should include the following information for each site represented in the database:

- All fatal or injury crashes that are reported during the calibration period.
- Site characteristics data needed to apply the predictive method for the same calibration period.

Only fatal or injury crashes should be included in calibration database. Each observation in the database represents one site. It includes the site characteristics as well as the separate count of fatal, incapacitating injury, nonincapacitating injury, and possible injury crashes reported during the calibration period.

For a given site type, the calibration database should include at least 300 fatal or injury crashes per calibration period. If this minimum is not realized then (a) additional sites should be added to the database following the guidelines in Step 2 or (b) the calibration period should be expanded to include additional years of crash data.

The crash data used for calibration should include all fatal or injury crashes related to each site selected for the calibration database. Crashes should be assigned to specific sites based on the guidelines presented in Section A.2.3.

Table A-2 identifies the site characteristics data that are needed to apply the Part C predictive method. The table classifies each data element as either required or desirable for the calibration procedure. Data for each of the required elements are needed for calibration. For the desirable data elements, it is recommended that actual data be used if available. Assumptions are offered in the table when these data are not available.
A.1.1.4. Step 4—Apply the applicable predictive method to estimate the predicted average crash frequency by severity for each site during the calibration period.

This step is repeated for each SDF identified in Step 1 and its associated set of calibration sites assembled in Step 2. The site characteristics data assembled in Step 3 are used to apply the applicable Part C predictive method to each site in the set of calibration sites. For this application, the predictive model should be applied without using the EB Method. The SDF calibration factor is set to 1.00. Through this process, the predicted average crash frequency for each severity level is obtained for each site in the set of calibration sites and for each year in the calibration period.

A.1.1.5. Step 5—Compute the calibration factors for use in the Part C SDFs.

This step is repeated for each SDF identified in Step 1 and its associated set of calibration sites assembled in Step 2. It consists of three tasks.

During the first task, the reported crash data are used to calculate the observed probability of a severe crash (i.e., fatal $K$, incapacitating injury $A$, or nonincapacitating injury $B$), given that a fatal or injury crash has occurred. Equation A-2 is used for this purpose. In this manner, one overall average value is obtained for all sites represented in the database.

\[
P_{o, aS, ac, at, KAB} = \frac{\sum_{i} \sum_{j=1}^{n_{c}} (N_{o, w(i), x(i), at, K, j} + N_{o, w(i), x(i), at, A, j} + N_{o, w(i), x(i), at, B, j})}{\sum_{i} \sum_{j=1}^{n_{c}} (N_{a, w(i), x(i), at, K, j} + N_{a, w(i), x(i), at, A, j} + N_{a, w(i), x(i), at, B, j} + N_{a, w(i), x(i), at, C, j})}
\]

Where:

\[P_{o, aS, ac, at, KAB}\] = observed probability of a severe crash (i.e., $K$, $A$, or $B$) for all crash types $at$ at all sites $aS$ and all cross sections or control types $ac$;

\[N_{o, w(i), x(i), at, m, j}\] = reported crash frequency for year $j$ for site $i$ with site type $w(i)$ and cross section or control type $x(i)$ for all crash types $at$ and severity level $m$ ($m = K, A, B, C$) (crashes/yr);

\[n_{sites}\] = number of sites; and

\[n_{c}\] = number of years in the crash period (yr).

In the second task, the predicted average crash frequency by severity from Step 4 is used to calculate the predicted probability of occurrence of a severe crash, given that a fatal or injury crash has occurred. Equation A-3 is used for this purpose. In this manner, one overall average value is obtained for all sites represented in the database.

\[
P_{p, aS, ac, at, KAB} = \frac{\sum_{i} \sum_{j=1}^{n_{c}} (N_{p, w(i), x(i), at, K, j} + N_{p, w(i), x(i), at, A, j} + N_{p, w(i), x(i), at, B, j})}{\sum_{i} \sum_{j=1}^{n_{c}} (N_{p, w(i), x(i), at, K, j} + N_{p, w(i), x(i), at, A, j} + N_{p, w(i), x(i), at, B, j} + N_{p, w(i), x(i), at, C, j})}
\]

Where:
\[ P_{p, aS, ac, at, KAB} = \text{predicted probability a severe crash (i.e., } K, A, \text{ or } B \text{) for all crash types } at \text{ at all sites } aS \text{ and all cross sections or control types } ac; \text{ and} \]

\[ N_{p, w(i), x(i), at, m, j} = \text{predicted crash frequency for year } j \text{ for site } i \text{ with site type } w(i) \text{ and cross section or control type } x(i) \text{ for all crash types } at \text{ and severity level } m (m = K, A, B, C) \text{ (crashes/yr).} \]

The final step is to compute the calibration factor using the following equation. The appropriate site-type subscript in this equation is uniquely defined for each SDF identified in Step 1.

\[
C_{sdf, w} = \frac{P_{o, aS, ac, at, KAB}}{1.0 - P_{o, aS, ac, at, KAB}} \times \frac{1.0 - P_{p, aS, ac, at, KAB}}{P_{p, aS, ac, at, KAB}}
\]

Equation A-4

Where:

\[ C_{sdf, w} = \text{calibration factor to adjust SDF for local conditions for site type } w. \]

The computation is performed separately for each SDF identified in Step 1. The computed calibration factor is rounded to two decimal places for application in the appropriate SDF.

A.2. THE EMPIRICAL BAYES METHOD

The EB Method is used to combine the estimate from a Part C predictive model with observed crash data to obtain a more reliable estimate of the expected average crash frequency. The development of the EB Method described in this appendix is documented by Hauer (1).

The EB Method improves the reliability of the estimate of expected average crash frequency by pooling the predicted value from a regression model with the subject site’s observed crash data. The predicted value describes the safety of the typical site with attributes matching those of the subject site. However, it has some level of statistical uncertainty due to unexplained differences among the set of similar sites used to calibrate the regression model. Similarly, an average crash frequency computed from crash data has uncertainty because of the random variability inherent to crash data. The EB Method produces an estimate of the expected average crash frequency that combines the model prediction and the site-specific crash data in proportion to the level of certainty that can be attached to each.

The EB Method’s pooling process is also helpful when evaluating before-after data from an observational study. The estimate of treatment effectiveness from this study design is susceptible to potential bias because the sites selected for treatment tend to have a recent history of above-average crash frequency. Crash counts vary naturally from one time period to the next. If a site’s crash count during one time period is higher than the average count during other periods of similar duration, then the site is likely to have lower crash count in a subsequent time period. This tendency is called “regression to the mean” (RTM). Statistical methods can minimize the effect of RTM such that an observed change in crash frequency is not mistakenly attributed to a change in the site’s features or traffic characteristics.

Each of the Part C chapters presents a four-step process for applying the EB Method. Before the EB Method can be applied, the appropriate Part C predictive model must be used to determine the predicted average crash frequency for each site of interest. Each site’s predicted average crash frequency is estimated for each year in a specified crash period. The steps in applying the EB Method are:

- Determine whether the EB Method is applicable, as explained in Section A.2.1.
- Determine whether observed crash data are available for the project or facility for a desired crash period. Acquire the crash data for this crash period, as explained in Section A.2.2.
Apply the EB Method to estimate the expected average crash frequency by combining the predicted average crash frequency and observed crash data for the crash period.

Adjust the estimated value of expected average crash frequency to a future time period, if appropriate, as explained in Section A.2.6.

A.2.1. Determine whether the EB Method is Applicable
The applicability of the EB Method to a particular project depends on the type of analysis being performed and the type of future project work that is anticipated. If the analysis is being performed to evaluate the safety of an existing project, then the EB Method should be applied.

If a future project is being planned, then the nature of that future project should be considered in deciding whether to apply the EB Method. Specifically, the EB Method should be applied for the analyses involving the following future project types.

- Sites at which the roadway geometrics and traffic control are not being changed (e.g., the “do-nothing” alternative).
- Projects in which the roadway cross section is modified but the basic number of through lanes remains the same. This could include projects for which lanes or shoulders were widened or the roadside was improved, but the roadway remained a rural two-lane highway.
- Projects in which minor changes in alignment are made, such as flattening individual horizontal curves while leaving most of the alignment intact.
- Projects in which a passing lane or a short four-lane section is added to a rural two-lane highway to increase passing opportunities.
- Projects in which a weaving section is added to a freeway.
- Any combination of the above improvements.

The EB Method is not applicable to the following types of improvements.

- Projects in which a new alignment is developed for a substantial proportion of the project length.
- Intersections at which the basic number of intersection legs or type of traffic control is changed as part of a project.

The reason that the EB Method is not used for the two improvement types in the previous list is that the observed crash data for a previous time period is not necessarily indicative of the crash experience that is likely to occur, after such a major geometric improvement. In other words, the observed crash frequency for the existing design is not relevant to the estimation of the future crash frequencies for the improved site or project. If the EB Method is applied to individual sites and some sites within the project limits will not be affected by the major geometric improvement, it is acceptable to apply the EB Method to those unaffected sites.

Because the EB Method requires an overdispersion parameter, it cannot be applied to predictive models that do not have an overdispersion parameter. For example, in the Chapter 12 predictive method, vehicle-
pedestrian and vehicle-bicycle collisions are estimated from adjustment factors rather than from predictive models and should, therefore, be excluded from the computations with the EB Method.

A.2.2. Determine whether Observed Crash Data are Available for the Project and, if so, Obtain those Data

If the EB Method is determined to be applicable to a given project, then it should be determined whether observed crash data are available directly from the jurisdiction’s crash record system, or indirectly from another source. At least two years of observed crash data are desirable to apply the EB Method.

Two variations of the EB Method are available. They are the site-specific EB Method and the project-level EB Method. The appropriate variation to use for a given project depends on the level of detail provided in the crash record system, the site types to which the method is applied, and the crash types associated with the predictive model that will be used. In general, the best results will be obtained if the site-specific EB Method is used. Figure A-1 provides a flow chart to assist in the determination of whether the site-specific or project-level variation of the EB Method is applicable for a given project.

A.2.2.1. Projects with One Site

Two considerations are discussed in this section. The first consideration relates to crash type. It is included in Figure A-1. The second consideration relates to crash severity. It is not included in the figure, and may only apply in rare instances.

Crash Type Considerations

For projects that consist of one site, Figure A-1 indicates that the first consideration is whether the applicable predictive model is specific to one crash type (i.e., multiple-vehicle crashes or single-vehicle crashes). In fact, the predictive methods in Chapters 12, 13, and 14 use models that are specific to crash type and consequently, have different overdispersion parameters for each crash type.

If the crash record system provides sufficient information to determine crash type for each site, then the site-specific EB Method is applicable. This method is described in Section A.2.4.

If the crash record system does not provide sufficient information to determine crash type, then the observed crash data cannot be associated with the model prediction, and the site-specific EB Method cannot be used. In this situation, the equations described in Section A.2.5 for the project-level EB Method should be used with the total observed crash data to compute the total expected average crash frequency for each site.
Figure A-1. Determination of the Appropriate Variation of the EB Method

Crash Severity Considerations
Although not shown in Figure A-1, another consideration is whether the applicable predictive model is specific to one crash severity (i.e., fatal-and-injury crashes or property-damage-only crashes). The predictive methods in Chapters 11, 12, 13, and 14 include some models that are specific to crash severity and consequently, have different overdispersion parameters for each severity level.

If the crash record system provides sufficient information to determine crash severity for each site, then the site-specific EB Method is applicable. This method is described in Section A.2.4.

If the crash record system does not provide sufficient information to determine crash severity for each site and a model with this sensitivity from Chapter 13 or 14 is being used, then the equations described in Section A.2.5 for the project-level EB Method should be used with the total observed crash data to compute the total expected average crash frequency for each site.

If the crash record system does not provide sufficient information to determine crash severity for each site and a model with this sensitivity from Chapter 11 or 12 is being used, then just the predictive model for total crashes should be used with the site-specific EB Method to estimate the total expected average crash frequency for each site.
Once the total expected average crash frequency is obtained, the estimate of expected average crash frequency for fatal-and-injury crashes is calculated by applying the proportion of predicted average crash frequency for fatal-and-injury crashes (i.e., \( N_{p, w, x, y, fi} / N_{p, w, x, y, as} \)) to the total expected average crash frequency. Similarly, the estimate of expected average crash frequency for property-damage-only crashes is calculated by applying the proportion of predicted average crash frequency for property-damage-only crashes (i.e., \( N_{p, w, x, y, pdo} / N_{p, w, x, y, as} \)) to the total expected average crash frequency.

A.2.2.2. Projects with Two or More Sites
For projects that consist of two or more sites, Figure A-1 indicates that there are several considerations when determining the appropriate EB Method variation. The first consideration relates to the site types and cross sections or control types represented within the project limits. In general, a project will consist of many sites that collectively represent different site types, cross sections, and control types. Occasionally, a project may consist of several sites that have the same site type and cross section or control type (e.g., a succession of segments along a specific highway).

Projects with Different Types of Sites
If a project consists of many sites that collectively have different site types, cross sections or control types, then the next consideration is whether the crash record system provides sufficient information to assign reported crashes to the individual sites. If the crashes can be assigned to individual sites, then the evaluation proceeds on a site-by-site basis. In this situation, the discussion in Section A.2.2.1 applies and the guidance therein is followed to determine the appropriate EB Method variation. Criteria for assigning crashes to individual sites are presented in Section A.2.3.

If the crashes cannot be assigned to individual sites, then the project-level EB Method is applicable. This method is described in Section A.2.5.

Projects with the Same Site Types
If a project consists of several sites that have the same site type and cross section or control type, then the next consideration is whether the crash record system provides sufficient information to assign reported crashes to the individual sites. If the crashes can be assigned to individual sites, then the evaluation proceeds on a site-by-site basis. In this situation, the discussion in Section A.2.2.1 applies and the guidance therein is followed to determine the appropriate EB Method variation. Criteria for assigning crashes to individual sites are presented in Section A.2.3.

If the crashes cannot be assigned to individual sites, then the next consideration is whether the overdispersion parameter is the same for all the sites. The overdispersion parameter is constant for some Part C predictive models; for others it is a function of segment length. For those models in which it is a function of segment length, the length of each site would have to be the same to produce an overdispersion factor that is the same for all sites.

If the overdispersion parameter is the same for all sites, then the site-specific EB Method can be used. In this application, the predicted average crash frequency for each site is combined into a single estimate for the group of sites. Similarly, the observed crash count for each site is combined into a single estimate for the group of sites.

If the overdispersion parameter is not the same for all sites, then the project-level EB Method is applicable. This method is described in Section A.2.5.

A.2.3. Assign Crashes to Individual Sites for Use in the EB Method
[No changes to this section. Add the following content to the end of the section.]
Guidance for Assigning Crashes to Freeway Segments and Speed-Change Lanes
Speed-change lane crashes include (a) crashes that occur in the speed-change lane and (b) crashes that occur on the same side of the freeway as the speed-change lane and between the taper point and gore point of the speed-change lane. All freeway crashes that are not classified as speed-change-related crashes are considered to be freeway segment crashes.

Figure A-2 illustrates the method used to assign crashes to freeway segments or speed-change lanes. All crashes that occur in Region A are assigned to the speed-change lane. Crashes that occur outside of Region A (i.e., in Region B) are assigned to the freeway segment.

Guidance for Assigning Crashes to Ramp Segments and Crossroad Ramp Terminals
The guidance for assigning crashes to intersections (described previously in this section) also applies to assigning crashes to crossroad ramp terminals. Exceptions to this guidance are described in the following paragraphs. Crashes that are not assigned to the crossroad ramp terminal are assigned to the crossroad or intersecting ramp segments.

The predictive models for crossroad ramp terminals include consideration of crashes on the crossroad that are associated with an unsignalized driveway or public street approach located within 250 ft of the crossroad ramp terminal. The interaction between driveway traffic and ramp terminal traffic is complex. As a result, it is often difficult to determine whether crashes between the two traffic streams are related to the driveway or the ramp terminal geometry and traffic control features. Consideration of these crashes in the crossroad ramp terminal predictive models facilitates an examination of the safety implications of these interactions. Therefore, driveway- and public-street-related crashes on the crossroad within 250 ft of the crossroad ramp terminal should be assigned to the crossroad ramp terminal (they should not be assigned to the crossroad segment).

Rear-end crashes on exit ramps should be carefully scrutinized for their relationship to the downstream crossroad ramp terminal. Lengthy queues of stopped vehicles can exist on some ramps during peak traffic demand periods. If the crash is related to the presence of queue created by the operation of the downstream ramp terminal, then the crash should be assigned to the ramp terminal regardless of the distance between the crash location and the ramp terminal.
In general, a ramp is defined to begin at a gore point and end at (a) another gore point (when ending at another ramp) or (b) the near edge of traveled way of the crossroad (when ending at a crossroad ramp terminal). Exit ramp and entrance ramp crashes represent crashes that occur on a ramp, between the near edge of traveled way of the crossroad and the freeway speed-change lane gore point (this point is shown in Figure A-2). Connector ramp crashes represent all crashes that occur on a ramp, between the freeway speed-change lane gore point and the crossroad speed-change lane gore point.

Any crashes that occur in a ramp speed-change lane associated with a ramp-to-ramp junction are assigned to the originating ramp (i.e., they are not assigned to the merging or diverging ramp). The merging ramp ends at the gore point of the ramp speed-change lane. The diverging ramp begins at the gore point of the ramp speed-change lane.

C-D road crashes represent crashes that occur on a C-D road, between the freeway exit gore point and the freeway entrance gore point.

### A.2.4. Apply the Site-Specific EB Method

This section describes the EB Method that is used when reported crash data are available for each site of interest. It is used to estimate the expected average crash frequency (in total, or by crash type or severity) for a specific site by combining the predictive model estimate with observed crash data.

The expected average crash frequency for reference year \( r \) at a site \( i \) with site type \( w(i) \) and cross section or control type \( x(i) \) for a specified crash type \( y \), and severity \( z \) is computed using the following equation.

\[
N_{e, w(i), x(i), y, z, r} = w_{w(i), x(i), y, z, r} \times N_{p, w(i), x(i), y, z, r} \times \left( 1.0 - w_{w(i), x(i), y, z, r} \right) \times \frac{N_{o, w(i), x(i), y, z, r}}{C_{b, w(i), x(i), y, z, r}}
\]

Equation A-5

with,

\[
w_{w(i), x(i), y, z, r} = \frac{1.0}{1.0 + \left( k_{w(i), x(i), y, z, r} \sum_{j=1}^{n_j} N_{p, w(i), x(i), y, z, j} \right)}
\]

Equation A-6

\[
C_{b, w(i), x(i), y, z, r} = \frac{1.0}{N_{p, w(i), x(i), y, z, r}} \times \sum_{j=1}^{n_j} N_{p, w(i), x(i), y, z, j}
\]

Equation A-7

Where:

- \( N_{e, w(i), x(i), y, z, r} \) = expected average crash frequency for reference year \( r \) at site \( i \) with site type \( w(i) \) and cross section or control type \( x(i) \) for crash type \( y \), and severity \( z \) (crashes/yr);
- \( N_{e, w(i), x(i), y, z, j} \) = expected average crash frequency for year \( j \) at site \( i \) with site type \( w(i) \) and cross section or control type \( x(i) \) for crash type \( y \), and severity \( z \) (crashes/yr);
- \( N_{p, w(i), x(i), y, z, r} \) = predicted average crash frequency for reference year \( r \) at site \( i \) with site type \( w(i) \) and cross section or control type \( x(i) \) for crash type \( y \), and severity \( z \) (crashes/yr);
- \( N_{p, w(i), x(i), y, z, j} \) = predicted average crash frequency for year \( j \) at site \( i \) with site type \( w(i) \) and cross section or control type \( x(i) \) for crash type \( y \), and severity \( z \) (crashes/yr);
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\( N^*_{o, w(i), x(i), y, z} \) = observed number of crashes for all years in the crash period for site \( i \) with site type \( w(i) \) and cross section or control type \( x(i) \) for crash type \( y \), and severity \( z \) (crashes);

\( C_b, w(i), x(i), y, z, r \) = equivalent years in the crash period relative to reference year \( r \) at site \( i \) with site type \( w(i) \) and cross section or control type \( x(i) \) for crash type \( y \), and severity \( z \) (yr);

\( k_{w, x(i), y(i), z} \) = overdispersion parameter for site \( i \) with site type \( w(i) \), cross section or control type \( x(i) \), crash type \( y \), and severity \( z \);

\( n_c \) = number of years in the crash period (yr); and

\( w_{w(i), x(i), y(i), z} \) = weighted adjustment factor for site \( i \) with site type \( w(i) \) and cross section or control type \( x(i) \) for crash type \( y \), and severity \( z \).

The following equation is an alternative form of Equation A-5 that is useful when the expected number of crashes for the crash period is desired.

\[
N^*_e, w(i), x(i), y, z = w_{w(i), x(i), y, z} \left( \sum_{j=1}^{n} N_{p, w(i), x(i), y, z, f} \right) + \left( 1.0 - w_{w(i), x(i), y, z} \right) \times N^*_{o, w(i), x(i), y, z}
\]

Equation A-8

Where:

\( N^*_e, w(i), x(i), y, z \) = expected number of crashes for all years in the crash period for site \( i \) with site type \( w(i) \) and cross section or control type \( x(i) \) for crash type \( y \), and severity \( z \) (crashes).

The expected average crash frequency is specific to a given site type \( w \), cross section or control type \( x \), crash type \( y \), and severity \( z \). As a result, the variables used in these equations must all be consistent in their representation of site type, cross section or control type, crash type, and severity. Also, the reference year \( r \) must be one of the years represented in the crash period. The crash period is defined as the consecutive years for which observed crash data are available.

The predicted average crash frequencies used in Equation A-5 to Equation A-7 are obtained from the appropriate predictive model described in Part C. Similarly, the overdispersion parameter used in Equation A-6 is obtained from the same predictive model as used to estimate the predicted average crash frequencies.

The overdispersion parameter is shown to be specific to site \( i \). This situation will apply whenever it is computed as a function of segment length, which is the case for Chapters 11, 13, and 14. When it is not a function of segment length, the subscript components referencing site \( i \) are removed.

Equation A-6 shows an inverse relationship between the overdispersion parameter and the weight \( w \). This implies that when a model with little overdispersion is available, more reliance will be placed on the predictive model estimate \( N_p \) and less reliance on the observed crash count \( N^*_{o} \). The opposite is also the case; when a model with substantial overdispersion is available, less reliance will be placed on the predictive model estimate and more reliance on the observed crash count.

It is important to note in Equation A-6 that, as \( N_p \) increases, there is less weight placed on it and more on \( N^*_{o} \). This might seem counterintuitive at first. However, this implies that for longer sites and for longer study periods, there are more opportunities for crashes to occur. Thus, the observed crash history is likely to be more meaningful and the model prediction less important. So, as \( N_p \) increases, the EB Method places more weight on the number of crashes that actually occur. When few crashes are predicted, the observed crash
count is not likely to be meaningful, in statistical terms, so greater reliance is placed on the predicted crash frequency.

Chapters 10, 11, 12, 13, and 14 each present worksheets that can be used to apply the site-specific EB Method as presented in this section.

Section A.2.6 explains how to use Equation A-5 to estimate the expected average crash frequency for a time period other than the crash period, such as the time period when a proposed future project will be implemented.

A.2.5. Apply the Project-Level EB Method
This section describes an alternative EB Method that is used when reported crash data are aggregated across several sites (e.g., for an entire facility or project). The development of this variation of the EB Method is documented by Hauer et al. (2).

In general, the EB Method described in this section is used when the predictive model and its overdispersion parameter are not uniquely defined for the combined set of sites being evaluated. It is also needed when the predictive model is specific to crash type (or severity) but the information in the crash database is insufficient to make crash type determinations.

When the crash data cannot be disaggregated to the level of the predictive model, the estimates from each of the predictive models for the various sites have different weights. These estimates cannot be directly combined to compute an overall weighted adjustment factor \( w \) because they are likely correlated to some degree (e.g., all sites in a given project may be consistently safer [or less safe] than the similar sites used to calibrate the predictive model). Because the degree of correlation is unknown, an approximate method is used to estimate the expected average crash frequency for each of two extreme conditions of correlation. The first condition assumes that the estimates among sites are independent. The second condition assumes that the estimates among sites are perfectly correlated. The best estimate of expected average crash frequency is rationalized to be the average of these two extreme conditions.

The following procedure describes the sequence of calculations necessary to implement the project-level EB Method. To facilitate the presentation of this procedure, the equations shown in this section have subscripts denoting fatal-and-injury \( fi \) crashes of all crash types (i.e., multiple-vehicle and single-vehicle fatal-and-injury crashes combined). The conversion of these equations so that they are applicable to property-damage-only crashes (or crashes of a specific crash type) requires only the substitution of the appropriate subscripts.

**Step 1—Sum the predicted average crash frequency and observed crash counts.**
The desired crash type \( w \) and crash severity \( z \) are specified during this step. The crash type chosen must have an associated predictive model. For example, if an estimate of the expected average multiple-vehicle crash frequency is desired, then an SPF that predicts multiple-vehicle crash frequency must be available in the predictive model. Similarly, if an estimate of the expected average fatal-and-injury crash frequency is desired, then an SPF that predicts fatal-and-injury crash frequency is required.

The predicted average crash frequency is summed for each site and year represented in the crash period to obtain the predicted number of crashes for all sites and all years in the crash period. Each site \( i \) will have a specific site type \( w(i) \) and cross section or control type \( x(i) \). Similarly, the observed crash counts are summed for each site and year represented in the crash period to obtain the observed number of crashes for all sites and all years in the crash period. The following equations are used to compute the desired sums for fatal-and-injury crashes of all crash types.
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\[ N^*_p, aS, ac, at, fi = \sum_{i} \sum_{k} \sum_{j=1}^{n_c} N_{p, w(i), x(i), y(k), fi, j} \]

\[ N^*_o, aS, ac, at, fi = \sum_{i} \sum_{k} \sum_{j=1}^{n_c} N_{o, w(i), x(i), y(k), fi, j} \]

Where:

- \( N^*_p, aS, ac, at, fi \) = predicted number of crashes for all sites \( aS \) and all years in the crash period, fatal-and-injury crashes of all crash types \( at \) (crashes);
- \( N_{p, w(i), x(i), y(k), fi, j} \) = predicted average crash frequency for year \( j \) at site \( i \) with site type \( w(i) \) and cross section or control type \( x(i) \) for fatal-and-injury crashes of crash type \( y(k) \) (crashes/yr);
- \( N^*_o, aS, ac, at, fi \) = observed number of crashes for all sites \( aS \) and all years in the crash period, fatal-and-injury crashes of all crash types \( at \) (crashes);
- \( N_{o, w(i), x(i), y(k), z, j} \) = observed crash frequency for year \( j \) at site \( i \) with site type \( w(i) \) and cross section or control type \( x(i) \) for fatal-and-injury crashes of crash type \( y(k) \) (crashes/yr); and
- \( n_c \) = number of years in the crash period (yr).

The predicted average crash frequencies used in Equation A-9 are obtained from the appropriate predictive model described in Part C. Because the EB Method is applied at the project level, it is likely that observed crashes cannot be associated with specific sites and Equation A-10 cannot be directly used. In this situation, the analyst should use the equation as guidance when consulting crash records to identify crashes of all types that are associated with one of the sites in the project limits and that occur during the crash period.

**Step 2—Compute the variance of the predicted average crash frequency.**

Two variance estimates are computed in this step. One estimate is based on the assumption that the sites are independent and the other estimate is based on the assumption that the sites are perfectly correlated. The following equations are used for these computations.

\[ V_{0, aS, ac, at, fi} = \sum_{i} \sum_{k} \left[ N_{p, w(i), x(i), y(k), fi, j} \right]^2 \left[ N_{p, w(i), x(i), y(k), fi, j} \right]^{-2} \]

\[ V_{1, aS, ac, at, fi} = \left( \sum_{i} \sum_{k} \left[ N_{p, w(i), x(i), y(k), fi, j} \right]^2 \right)^2 \]

Where:
\[ V_{0,\text{aS, ac, at, } \text{fi}} = \text{variance of the predicted average crash frequency assuming independence for all sites aS and all years in the crash period, fatal-and-injury crashes of all crash types at} \text{ (crashes}^2/\text{yr}^2) \];

\[ V_{1,\text{aS, ac, at, } \text{fi}} = \text{variance of the predicted average crash frequency assuming perfect correlation for all sites aS and all years in the crash period, fatal-and-injury crashes of all crash types at} \text{ (crashes}^2/\text{yr}^2) \]; and

\[ k_{w(i), x(i), y(k), \text{fi}} = \text{overdispersion parameter for site } i \text{ with site type } w(i) \text{ and cross section or control type } x(i) \text{ for fatal-and-injury crashes of crash type } y(k). \]

The overdispersion parameters used in Equation A-11 and Equation A-12 are obtained from the same predictive model that was used to estimate the predicted average crash frequencies.

**Step 3—Compute the weighted adjustment factor.**

Two weighted adjustment factors are computed in this step. One factor is based on the assumption that the sites are independent and the other factor is based on the assumption that the sites are perfectly correlated. The following equations are used for these computations.

\[
\begin{align*}
  w_{0,\text{aS, ac, at, } \text{fi}} &= \frac{1.0}{1.0 + \frac{V_{0,\text{aS, ac, at, } \text{fi}}}{N_{p,\text{aS, ac, at, } \text{fi}}}} \quad \text{Equation A-13} \\
  w_{1,\text{aS, ac, at, } \text{fi}} &= \frac{1.0}{1.0 + \frac{V_{1,\text{aS, ac, at, } \text{fi}}}{N_{p,\text{aS, ac, at, } \text{fi}}}} \quad \text{Equation A-14}
\end{align*}
\]

Where:

\[ w_{0, \text{aS, ac, at, } \text{fi}} = \text{weighted adjustment factor assuming independence for all sites aS and all years in the crash period, fatal-and-injury crashes of all crash types at;} \] and

\[ w_{1, \text{aS, ac, at, } \text{fi}} = \text{weighted adjustment factor assuming perfect correlation for all sites aS and all years in the crash period, fatal-and-injury crashes of all crash types at}. \]

**Step 4—Compute the equivalent years in the crash period.**

The equivalent number of years in the crash period reflects changes in traffic volume and other factors during the crash period. The changes are relative to a specified reference year \( r \). Any year in the crash period can be designated as the reference year. It is the year for which the expected average crash frequency will be estimated in Step 5. The equivalent number of years is computed using the following equation.

\[
C_{k,\text{aS, ac, at, } \text{fi, } r} = \frac{N_{p, \text{aS, ac, at, } \text{fi}}^r}{N_{p, \text{aS, ac, at, } \text{fi, } r}} \quad \text{Equation A-15}
\]

with,
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\[ \sum_{i} \sum_{k} N_{p, w(i), x(i), y(k), f, r} \]

Where:

- \( C_{b, aS, ac, at, fi, r} \) = equivalent years in the crash period relative to reference year \( r \) for all sites \( aS \) and fatal-and-injury crashes of all crash types \( at \) \( (yr) \); and
- \( N_{p, aS, ac, at, fi, r} \) = predicted average crash frequency for reference year \( r \) for all sites \( aS \) and fatal-and-injury crashes of all crash types \( at \) \( \text{(crashes/yr)} \).

**Step 5—Compute the expected average crash frequency.**

The expected average crash frequency for the reference year \( r \) is computed in this step. Steps 4 and 5 are repeated for other reference years of interest. The expected average crash frequency is computed as the average of the expected values for the two assumed conditions (i.e., sites are independent and sites are perfectly correlated). The following equation is used for this calculation.

\[
N_{e, aS, ac, at, fi, r} = \frac{N_{0, aS, ac, at, fi, r} + N_{1, aS, ac, at, fi, r}}{2}
\]

Equation A-17

with,

\[
N_{0, aS, ac, at, fi, r} = w_{0, aS, ac, at, fi} \times N_{p, aS, ac, at, fi, r} + \left(1 - w_{0, aS, ac, at, fi}\right) \times \frac{N_{0, aS, ac, at, fi}}{C_{b, aS, ac, at, fi, r}}
\]

Equation A-18

\[
N_{1, aS, ac, at, fi, r} = w_{1, aS, ac, at, fi} \times N_{p, aS, ac, at, fi, r} + \left(1 - w_{1, aS, ac, at, fi}\right) \times \frac{N_{0, aS, ac, at, fi}}{C_{b, aS, ac, at, fi, r}}
\]

Equation A-19

Where:

- \( N_{e, aS, ac, at, fi, r} \) = expected average crash frequency for reference year \( r \) for all sites \( aS \) and fatal-and-injury crashes of all crash types \( at \) \( \text{(crashes/yr)} \);
- \( N_{0, aS, ac, at, fi, r} \) = expected average crash frequency for reference year \( r \) assuming independence for all sites \( aS \) and fatal-and-injury crashes of all crash types \( at \) \( \text{(crashes/yr)} \); and
- \( N_{1, aS, ac, at, fi, r} \) = expected average crash frequency for reference year \( r \) assuming perfect correlation for all sites \( aS \) and fatal-and-injury crashes of all crash types \( at \) \( \text{(crashes/yr)} \).

The following equation is an alternative form of Equation A-17 that is useful when the expected number of crashes for the crash period is desired.

\[
N_{e, aS, ac, at, fi}^* = \frac{N_{0, aS, ac, at, fi}^* + N_{1, aS, ac, at, fi}^*}{2}
\]

Equation A-20

with,
Where:

\[ N^{*}_{e, aS, ac, at, fi} = w_{0, aS, ac, at, fi} \times N^{*}_{p, aS, ac, at, fi} + (1.0 - w_{0, aS, ac, at, fi}) \times N^{*}_{o, aS, ac, at, fi} \]  

Equation A-21

\[ N^{*}_{0, aS, ac, at, fi} = w_{1, aS, ac, at, fi} \times N^{*}_{p, aS, ac, at, fi} + (1.0 - w_{1, aS, ac, at, fi}) \times N^{*}_{o, aS, ac, at, fi} \]  

Equation A-22

Chapters 10, 11, 12, 13, and 14 each present worksheets that can be used to apply the project-level EB Method as presented in this section.

Section A.2.6 explains how to use Equation A-17 to estimate the expected average crash frequency for a time period other than the crash period, such as the time period when a proposed future project will be implemented.

**A.2.6. Estimate the Expected Average Crash Frequency for a Future Time Period**

The estimate obtained from Equation A-5 or Equation A-17 represents the expected average crash frequency for a given site or project, respectively, during the crash period.

This section describes a procedure that is used to obtain an estimate of the expected average crash frequency during the study period. The study period is defined as the consecutive years for which an estimate of the expected average crash frequency is desired. This procedure is used when the study period includes years that are not represented in the crash period. Typically, the study period includes one or more future years that are coincident with a proposed or anticipated change in some feature or characteristic of the project.

The procedure yields an estimate of the expected average crash frequency for a specified study year \( j \). This estimate is corrected for (a) any growth or decline in AADTs between the crash period and the study period and (b) any change in geometric design or traffic control features between the crash period and the study period (as represented by the values of the associated CMFs). The estimates for each study year \( j \) are added to obtain the expected number of crashes for the study period.

**Site-Specific EB Method**

The expected average crash frequency for a site for year \( j \) can be estimated using the following equation. In this application, the year of interest is year \( j \) and the reference year \( r \) is any one year in the crash period (by convention, the reference year is typically selected to be the first year in the crash period).

\[ N_{e, w(i), x(i), y, z, j} = N_{e, w(i), x(i), y, z, r} \times \frac{N_{p, w(i), x(i), y, z, j}}{N_{p, w(i), x(i), y, z, r}} \]  

Equation A-23

Where:

\[ N_{e, w(i), x(i), y, z, j} = \text{expected average crash frequency for year } j \text{ at site } i \text{ with site type } w(i) \text{ and cross section or control type } x(i) \text{ for crash type } y, \text{ and severity } z \text{ (crashes/yr);} \]
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$N_{e, w(i), x(i), y, z, r} = \text{expected average crash frequency for reference year } r \text{ at site } i \text{ with site type } w(i) \text{ and cross section or control type } x(i) \text{ for crash type } y \text{, and severity } z \text{ (crashes/yr);}$

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

$N_{p, w(i), x(i), y, z, r} = \text{predicted average crash frequency for reference year } r \text{ at site } i \text{ with site type } w(i) \text{ and cross section or control type } x(i) \text{ for crash type } y \text{, and severity } z \text{ (crashes/yr).}$

The expected average crash frequency is specific to a given site type $w$, cross section or control type $x$, crash type $y$, and severity $z$. As a result, the variables used in this equation must all be consistent in their representation of site type, cross section or control type, crash type, and severity.

The predicted average crash frequencies used in Equation A-23 are obtained from the appropriate predictive model described in Part C. The expected average crash frequency is obtained from Equation A-5.

The expected number of crashes for a site for a specified study period is computed using the following equation.

$$N^*_{e, w(i), x(i), y, z} = \sum_{j=1}^{n_s} N_{e, w(i), x(i), y, z, j}$$

Where:

$N^*_{e, w(i), x(i), y, z} = \text{expected number of crashes for all years in the study period for site } i \text{ with site type } w(i) \text{ and cross section or control type } x(i) \text{ for crash type } y \text{, and severity } z \text{ (crashes); and}$

$n_s = \text{number of years in the study period (yr).}$

The expected number of crashes for all sites for a specified study period is computed using the following equation.

$$N^*_{e, aS, ac, at, as} = \sum_{r} \sum_{l} \sum_{k} N^*_{e, w(i), x(i), y(k), z(l)}$$

Where:

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

**Project-Level EB Method**

The following procedure describes the sequence of calculations necessary to adjust the estimate of expected average crash frequency to a future year (or years). To facilitate the presentation of this procedure, the equations shown in this subsection have subscripts denoting fatal-and-injury $fi$ crashes of all crash types (i.e., multiple-vehicle and single-vehicle fatal-and-injury crashes combined). The conversion of these equations so that they are applicable to property-damage-only crashes (or crashes of a specific crash type) requires only the substitution of the appropriate subscripts.
The expected average crash frequency for all sites for year $j$ can be estimated using the following equation. In this application, the year of interest is year $j$ and the reference year $r$ is any one year in the crash period (by convention, the reference year is typically selected to be the first year in the crash period).

$$N_{e,aS,ac,at,fi,j} = N_{e,aS,ac,at,fi,r} \times \frac{N_{p,aS,ac,at,fi,j}}{N_{p,aS,ac,at,fi,r}}$$

**Equation A-26**

Where:

- $N_{e,aS,ac,at,fi,j}$ = expected average crash frequency for year $j$ for all sites $aS$ and fatal-and-injury crashes of all crash types $at$ (crashes/yr);
- $N_{e,aS,ac,at,fi,r}$ = expected average crash frequency for reference year $r$ for all sites $aS$ and fatal-and-injury crashes of all crash types $at$ (crashes/yr);
- $N_{p,aS,ac,at,fi,r}$ = predicted average crash frequency for year $j$ for all sites $aS$ and fatal-and-injury crashes of all crash types $at$ (crashes/yr); and
- $N_{p,aS,ac,at,fi,r}$ = predicted average crash frequency for reference year $r$ for all sites $aS$ and fatal-and-injury crashes of all crash types $at$ (crashes/yr).

The predicted average crash frequencies used in Equation A-26 are computed using Equation A-16. The expected average crash frequency is obtained from Equation A-17.

The expected number of crashes for all sites for a specified study period is computed using the following equation.

$$N^*_{e,aS,ac,at,fi} = \sum_{j=1}^{n_s} N_{e,aS,ac,at,fi,j}$$

**Equation A-27**

Where:

- $N^*_{e,aS,ac,at,fi}$ = expected number of crashes for all years in the study period for all sites $aS$ and fatal-and-injury crashes of all crash types $at$ (crashes); and
- $n_s$ = number of years in the study period (yr).

### A.2.7. EB Method for Segments with an Odd Number of Lanes

Most roadway cross sections have an even number of through traffic lanes. As a result, researchers can typically acquire data for segments with even numbers of lanes in sufficient number to permit the development of statistically valid predictive models. On the other hand, some roadways do exist with an odd number of through lanes. The development of statistically valid models for these cross sections is sometimes not possible due to inadequate sample size.

This section describes a procedure for evaluating a segment of interest that has a cross section with an odd number of through lanes. This procedure can be used when a predictive model is not available for the specified cross section. It is described in the form of supplemental equations that are used in the steps of the predictive method. The step numbers of the procedure match those of the predictive method to which they apply. The procedure is viable if the following checks are satisfied.
The segment has $X$ total lanes that represent $Y$ lanes in one direction and $Z$ lanes in the opposite direction (i.e., $X = Y + Z$) and $Y$ is not equal to $Z$.

The predictive model for segments includes an SPF for $2\times Y$ lanes.

The predictive model for segments includes an SPF for $2\times Z$ lanes.

If these checks are satisfied, then the procedure can be applied.

**Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site type and features.**

The applicable predictive model is identified from the appropriate Part C chapter. The site of interest is determined to have a site type $w$ with an $X$-lane cross section, and the analysis is focused on crash type $y$ and severity $z$.

Select an SPF for the subject site based on it being applicable to a cross section of $2\times Y$ lanes. Select a second SPF for the subject site based on it being applicable to a cross section of $2\times Z$ lanes. The best estimate of the predicted average crash frequency for base conditions is computed as the average of the estimates from the two SPFs. This calculation is shown using the following equation.

$$N_{spf, w, X, y, z, j} = \frac{N_{spf, w, 2Y, y, z, j} + N_{spf, w, 2Z, y, z, j}}{2}$$

**Equation A-28**

Where:

- $N_{spf, w, n, y, z, j} = \text{predicted average crash frequency for year } j \text{ determined for base conditions of the SPF developed for site type } w, n\text{-lane cross section } (n = X, 2Y, 2Z), \text{ crash type } y, \text{ and severity } z \text{ (crashes/yr).}$

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

The predictive model is used to compute the predicted average crash frequency for the subject site. The general form of this model is shown in the equation below. The specific CMFs and calibration factor are obtained from the appropriate Part C chapter.

$$N_{p, w, X, y, z, j} = N_{spf, w, X, y, z, j} \times (CMF_{1, w, X, y, z} \times CMF_{2, w, X, y, z} \times \ldots \times CMF_{m, w, X, y, z}) \times C_{w, X, y, z}$$

**Equation A-29**

Where:

- $N_{p, w, X, y, z, j} = \text{predicted average crash frequency for year } j \text{ for site type } w, X\text{-lane cross section, crash type } y, \text{ and severity } z \text{ (crashes/yr);}$
- $CMF_{m, w, X, y, z} = \text{crash modification factors specific to site type } w, X\text{-lane cross section, crash type } y, \text{ and severity } z \text{ for specific geometric design and traffic control features } m; \text{ and}$
- $C_{w, X, y, z} = \text{calibration factor to adjust SPF for local conditions for site type } w, X\text{-lane cross section, crash type } y, \text{ and severity } z.$

**Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.**

If the EB Method is used in the predictive method, then the variance of the predicted average crash frequency is computed in this step using the following equation.
\[ V_{p,w,X,y,z} = \left( k_{w,2Y,y,z} \times \left( \sum_{j=1}^{n_j} \left( 0.5 \times N_{p,w,2Y,y,z,j} \right) \right)^2 + k_{w,2Z,y,z} \times \left( \sum_{j=1}^{n_j} \left( 0.5 \times N_{p,w,2Z,y,z,j} \right) \right)^2 \right)^2 \] 

Equation A-30

with,

\[ N_{p,w,2Y,y,z,j} = N_{wpf,w,2Y,y,z,j} \times \left( CMF_{1,w,X,y,z} \times CMF_{2,w,X,y,z} \times \ldots \times CMF_{m,w,X,y,z} \right) \times C_{w,X,y,z} \] 

Equation A-31

\[ N_{p,w,2Z,y,z,j} = N_{wpf,w,2Z,y,z,j} \times \left( CMF_{1,w,X,y,z} \times CMF_{2,w,X,y,z} \times \ldots \times CMF_{m,w,X,y,z} \right) \times C_{w,X,y,z} \] 

Equation A-32

Where:

\[ k_{w,n,y,z} \] = overdispersion parameter for site type \( w \), \( n \)-lane cross section, crash type \( y \), and severity \( z \); 

\[ N_{p,w,Y,y,z,j} \] = predicted average crash frequency for a year \( j \) for site type \( w \), \( n \)-lane cross section \( (n = X, 2Y, 2Z) \), crash type \( y \), and severity \( z \); and 

\[ n_c \] = number of years in the crash period (yr).

The overdispersion parameters used in Equation A-30 are obtained from the same predictive model as used to estimate the predicted average crash frequencies.

An overdispersion parameter is needed to apply the EB Method. An equivalent overdispersion parameter that is associated with the predicted average crash frequency from Equation A-29 is computed using the following equation.

\[ k^*_{p,w,X,y,z} = \frac{V_{p,w,X,y,z}}{\left( \sum_{j=1}^{n_c} N_{p,w,X,y,z,j} \right)^2} \] 

Equation A-33

Where:

\[ k^*_{w,X,y,z} \] = effective overdispersion parameter for site type \( w \), \( X \)-lane cross section, crash type \( y \), and severity \( z \).

The effective overdispersion parameter computed using Equation A-33 is used in Equation A-5 of the site-specific EB Method described in Section A.2.4.

**Step 15—Apply the project-level EB Method (if applicable).**

The effective overdispersion parameter computed using Equation A-33 is used in Step 2 of the project-level EB Method described in Section A.2.5.
A.3. REFERENCES


APPENDIX F

ALGORITHM DESCRIPTION
ALGORITHM DESCRIPTION

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This document provides a description of the algorithms used in the predictive methods for evaluating freeways and ramps. These methods have been implemented in software in the Enhanced Interchange Safety Analysis Tool (ISATe). They are documented in the Draft HSM Freeways chapter (Appendix C), Draft HSM Ramps chapter (Appendix D), and Draft HSM Appendix A for Part C (Appendix E).

The objective of this document is to identify the information needed to implement the predictive methods in software products other than ISATe, such as the Interactive Highway Safety Design Model (IHSDM). This objective is achieved by identifying the input data needed, and predictive models used, when implementing the predictive methods. Extensive reference is made to the content of the draft documents identified in the previous paragraph, as opposed to repeating that material in this document.

This document consists of five parts. Each part provides the information needed to implement the predictive method for one of the following freeway facility site types.

- Freeway segments.
- Freeway speed-change lanes.
- Ramp or C-D road segments.
- Crossroad ramp terminals.

The fifth part of this document provides a series of flow charts that describe the logic flow used in the ISATe software implementation.

**ALGORITHM DESCRIPTION FOR FREEWAY SEGMENTS**

This part of the appendix provides information needed to implement the predictive method for freeway segments in software. This method is described in the Draft HSM Freeways chapter.

The remainder of this part consists of four sections. The first section identifies the input data needed by the predictive method. The second section presents the crash prediction models. The third section describes the sequence of steps that comprise the predictive method. The last section describes the output data that are available from an application of the predictive method.

**Input Data**

This section describes the input data for the predictive method. These data are identified using the following categories.

- Evaluation period.
- Evaluation type.
- Crash data.
- Geometric design, traffic control, and traffic volume data.
**Evaluation Period**

The evaluation period is the set of years in the combined study period and crash period. Every calendar year in the evaluation period is separately evaluated using the methodology.

Specific details about this input are provided in Section 13.4.1, Step 2 of the Draft *HSM* Freeways chapter.

**Evaluation Type**

The predictive method can be used to evaluate one site, or a contiguous group of sites. The evaluation is described as one of several types, as determined by the analyst. When one site is being evaluated, the evaluation types are:

A. Evaluation based on using the predictive model only.

B. Evaluation based on using the predictive model and crash data.

When a group of sites are being evaluated, the evaluation types are:

A. Evaluation based on using the predictive model only for each site.

B. Evaluation based on using the predictive model and crash data for each site.

C. Evaluation based on using the predictive model for each site and crash data for the group of sites.

When crash data are used, the empirical Bayes (EB) Method is used to combine the crash data with the predictive model estimate to obtain a more reliable estimate of the expected crash frequency. The three evaluation types are referred to herein as types A, B, and C. In the HSM, type B evaluation is referred to as the “site-specific” EB Method and type C is referred to as “project-level” EB Method.

There are several factors to be considered when determining whether the EB Method is appropriate for a given project. These criteria are described in Sections A.2.1 and A.2.2 of the Draft *HSM* Appendix A for Part C.

**Crash Counts**

If evaluation type B is input by the analyst, then the crash data for each site are necessary input data. The criteria for assigning crashes to individual freeway segment sites are described in Section A.2.3 of the Draft *HSM* Appendix A for Part C. If evaluation type C is input, then the crash data for the group of sites is needed.

The crash counts must correspond to the crash period. The crash period can be site-specific; however, for coding convenience, the crash period should be the same for all sites. If the crash period includes multiple years, then the crash data do not have to be separately tabulated for each year at each site. Rather, it is sufficient for the analyst to input the total number of crashes for the crash period.

**Geometric Design, Traffic Control, and Traffic Volume Data**

The input data describing the geometric design and traffic volume data for freeway segments are identified in the following list.

**General**

- Area type (urban or rural).
Geometric Design

- Number of through lanes.
- Segment length.
- Length and radius of horizontal curve.
- Lane width.
- Inside and outside shoulder width.
- Median width.
- Length of rumble strips on inside and outside shoulders.
- Length of (and offset to) median barrier.
- Length of (and offset to) outside barrier.
- Clear zone width.
- Presence and length of Type B weaving section.

Traffic Characteristics

- AADT volume of (and distance to) nearest upstream and downstream entrance ramp.
- AADT volume of (and distance to) nearest upstream and downstream exit ramp.
- AADT volume of freeway segment.
- Proportion of AADT that occurs during hours where the lane volume exceeds 1,000 veh/h/ln.

Specific details about these input data are provided in Section 13.4.2 of the Draft HSM Freeways chapter. These details include the method of measurement and the value limits for each variable. The AADT volume ranges for the predictive models are listed in Table 13-4 of the Draft HSM Freeways chapter.

The units of measurement for all input data are U.S. customary. If input data are provided in metric units, then they should undergo soft conversion to U.S. customary units before their use in the predictive method.

Predictive Models

The general structure of the predictive model is described by Equation 13-1 of the Draft HSM Freeways chapter. A more specific structure is described by Equation 13-2.

Safety Performance Functions

Separate safety performance functions (SPFs) are provided for the following conditions:

- Area type (rural or urban).
- Through lanes (4, 6, 8, 10 in urban areas).
- Crash type (multiple-vehicle, single-vehicle).
- Crash severity (fatal-and-injury, property-damage-only).
All total, there are 28 SPFs represented by unique combinations of the four conditions identified in the preceding list. Specific details about the SPF regression coefficients are provided in Section 13.6.1 of the Draft *HSM* Freeways chapter.

Section 13.6.1 of the Draft *HSM* Freeways chapter describes a procedure for extending the SPFs to segments with an odd number of lanes. Section A.2.7 of the Draft *HSM* Appendix A for Part C describes a procedure for applying the EB Method to segments with an odd number of lanes.

The overdispersion parameter is computed as a function of segment length. The equation for this calculation is provided in Section 13.6.1 of the Draft *HSM* Freeways chapter.

A procedure for calibrating the predictive models is described in Section A.1.1 of the Draft *HSM* Appendix A for Part C.

**Crash Modification Factors**

Eleven crash modification factors (CMFs) are provided in the predictive method. The geometric design features and traffic conditions that they address are identified in the following list.

- Horizontal curvature.
- Lane width.
- Inside shoulder width.
- Median width.
- Median barrier.
- High-volume (congested) conditions.
- Lane change activity related to ramp entrances and ramp exits.
- Outside shoulder width.
- Shoulder rumble strip presence.
- Outside clearance.
- Outside barrier.

Specific details about the CMF formulation and regression coefficients are provided in Section 13.7.1 of the Draft *HSM* Freeways chapter. This section also identifies conditions where a CMF is not applicable.

Supplemental calculations for using the barrier-related CMFs are described in Section 13.7.3 of the Draft *HSM* Freeways chapter.

**Crash Type Distribution**

The predicted crash frequency from a predictive model can be disaggregated into estimates of crash frequency by crash type. The crash type categories for multiple-vehicle crashes include head-on, right-angle, rear-end, and sideswipe. The crash type categories for multiple-vehicle crashes include animal, fixed object, other object, and parked vehicle.
Distribution percentages for these crash types are provided in Section 13.6.1 of the Draft *HSM* Freeways chapter. Application of these percentages is described in Sample Problem 1 in Section 13.13.1 of the Draft *HSM* Freeways chapter.

**Crash Severity Distribution**

The predicted crash frequency from a predictive model can be disaggregated into estimates of crash severity. Specifically, the predicted fatal-and-injury crash frequency can be disaggregated into estimates of fatal (K), incapacitating injury (A), non-incapacitating injury (B), and possible injury (C) crash frequency. A severity distribution function is used for this purpose. The function is an equation that includes some of the same variables used in the predictive model.

The equations that comprise the severity distribution function are described in Section 13.8 of the Draft *HSM* Freeways chapter. Application of these equations is described in Sample Problem 1 in Section 13.13.1 of the Draft *HSM* Freeways chapter.

A procedure for calibrating the severity distribution functions is described in Section A.1.4 of the Draft *HSM* Appendix A for Part C.

**Predictive Method**

The predictive method for freeway segments is described as a flow chart in Figure 13-1 of the Draft *HSM* Freeways chapter. The flow chart indicates that the method includes 18 steps that are completed in sequence when evaluating one or more sites. The method is described in sufficient generality that it can be applied to one or more sites, for one or more years, with or without the use of crash data.

The steps that comprise the predictive method are described in detail in Section 13.4.1 of the Draft *HSM* Freeways chapter. If the EB Method is used in the method, the related calculations are described in Section A.2 of the Draft *HSM* Appendix A for Part C.

A key step of the predictive method is to divide the facility being evaluated into individual sites (i.e., segments and speed-change lanes). The procedure for dividing the freeway into individual sites is described in Section 13.5 of the Draft *HSM* Freeways chapter.

Application of the predictive method is described in the sample problems in Section 13.13 of the Draft *HSM* Freeways chapter.

Limitations of the predictive method are identified in Section 13.10 of the Draft *HSM* Freeways chapter.

**Output**

The output data computed using the predictive method consists primarily of the expected crash frequency for each site and year in the evaluation period. Only the output data computed for the study period should be summarized given that it is most relevant to the analyst. Data for the crash period (available when the EB Method is used) may be of nominal interest, but its primary purpose to support the calculation of the expected average crash frequency for the study period.

The estimated crash frequency for a site can be reported in terms of the following performance measures:

- Total estimated number of crashes for the study period.
- Estimated crash frequency for each year during the study period
Either of these two measures can be further disaggregated in terms of crash severity or crash type. For example, the “total estimated number of crashes for the study period” can be disaggregated into the following measures.

- Total estimated number of crashes for each severity level
- Total estimated number of crashes for each crash type (e.g., head on, fixed object, etc.)

Other combinations of study year, severity level, and crash type can be devised, if desired.

If there are multiple sites, then the aforementioned measures should be computed for all sites combined. This type of project-wide aggregation will provide meaningful summary measures that facilitate the comparison of competing projects or alternatives for a given project.

Detailed output data can also be made available on a site-by-site basis. Of particular note are the crash modification factors. The value of a factor can be used as an indicator of relative crash risk. Collectively, these factors provide insight into geometric design and traffic control features that have potential for safety improvement.

If the input AADT volume data were incomplete (i.e., some years missing) and values were estimated (within the software) for the missing years, then the AADT volume history should be reported so that the analyst can review and confirm the suitability of the estimated volumes. Step 3 in Section 13.4.1 of the Draft HSM Freeways chapter provides some rules for estimating missing AADT volumes. These rules are implemented in ISATe.

ALGORITHM DESCRIPTION FOR FREEWAY SPEED-CHANGE LANES

This part of the appendix provides information needed to implement the predictive method for freeway speed-change lanes in software. This method is described in the Draft HSM Freeways chapter.

The remainder of this part consists of four sections. The first section identifies the input data needed by the predictive method. The second section presents the crash prediction models. The third section describes the sequence of steps that comprise the predictive method. The last section describes the output data that are available from an application of the predictive method.

Input Data

This section describes the input data for the predictive method. These data are identified using the following categories.

- Evaluation period.
- Evaluation type.
- Crash data.
- Geometric design, traffic control, and traffic volume data.

Evaluation Period

The evaluation period is the set of years in the combined study period and crash period. Every calendar year in the evaluation period is separately evaluated using the methodology.
Specific details about this input are provided in Section 13.4.1, Step 2 of the Draft HSM Freeways chapter.

**Evaluation Type**
The predictive method can be used to evaluate one site, or a contiguous group of sites. The evaluation is described as one of several types, as determined by the analyst. When one site is being evaluated, the evaluation types are:

A. Evaluation based on using the predictive model only.

B. Evaluation based on using the predictive model and crash data.

When a group of sites are being evaluated, the evaluation types are:

A. Evaluation based on using the predictive model only for each site.

B. Evaluation based on using the predictive model and crash data for each site.

C. Evaluation based on using the predictive model for each site and crash data for the group of sites.

When crash data are used, the empirical Bayes (EB) Method is used to combine the crash data with the predictive model estimate to obtain a more reliable estimate of the expected crash frequency. The three evaluation types are referred to herein as types A, B, and C. In the HSM, type B evaluation is referred to as the “site-specific” EB Method and type C is referred to as “project-level” EB Method.

There are several factors to be considered when determining whether the EB Method is appropriate for a given project. These criteria are described in Sections A.2.1 and A.2.2 of the Draft HSM Appendix A for Part C.

**Crash Counts**
If evaluation type B is input by the analyst, then the crash data for each site are necessary input data. The criteria for assigning crashes to individual freeway speed-change lane sites are described in Section A.2.3 of the Draft HSM Appendix A for Part C. If evaluation type C is input, then the crash data for the group of sites is needed.

The crash counts must correspond to the crash period. The crash period can be site-specific; however, for coding convenience, the crash period should be the same for all sites. If the crash period includes multiple years, then the crash data do not have to be separately tabulated for each year at each site. Rather, it is sufficient for the analyst to input the total number of crashes for the crash period.

**Geometric Design, Traffic Control, and Traffic Volume Data**
The input data describing the geometric design and traffic volume data for freeway speed-change lanes are identified in the following list.

**General**

- Area type (urban or rural).
Algorithm Description

Geometric Design

- Number of through lanes.
- Segment length.
- Length and radius of horizontal curve.
- Lane width.
- Inside shoulder width.
- Median width.
- Length of rumble strips on inside shoulders.
- Length of (and offset to) median barrier.
- Presence and length of Type B weaving section.

Traffic Characteristics

- AADT volume of ramp associated with speed-change lane.
- AADT volume of freeway segment.
- Proportion of AADT that occurs during hours where the lane volume exceeds 1,000 veh/h/ln.

Specific details about these input data are provided in Section 13.4.2 of the Draft HSM Freeways chapter. These details include the method of measurement and the value limits for each variable. The AADT volume ranges for the predictive models are listed in Table 13-4 of the Draft HSM Freeways chapter.

The units of measurement for all input data are U.S. customary. If input data are provided in metric units, then they should undergo soft conversion to U.S. customary units before their use in the predictive method.

Predictive Models

The general structure of the predictive model is described by Equation 13-1 of the Draft HSM Freeways chapter. A more specific structure is described by Equation 13-7 and Equation 13-10.

Safety Performance Functions

Separate safety performance functions (SPFs) are provided for the following conditions:

- Area type (rural or urban).
- Through lanes (4, 6, 8, 10 in urban areas).
- Crash type (multiple-vehicle, single-vehicle).
- Crash severity (fatal-and-injury, property-damage-only).

All total, there are 28 SPFs represented by unique combinations of the four conditions identified in the preceding list. Specific details about the SPF regression coefficients are provided in Section 13.6.2 of the Draft HSM Freeways chapter.
Section 13.6.1 of the Draft *HSM* Freeways chapter describes a procedure for extending the SPFs to freeways with an odd number of lanes. Section A.2.7 of the Draft *HSM* Appendix A for Part C describes a procedure for applying the EB Method to freeways with an odd number of lanes.

The overdispersion parameter for ramp entrance speed-change lanes is computed as a function of speed-change lane length. The equation for this calculation is provided in Section 13.6.2 of the Draft *HSM* Freeways chapter. The factor for ramp exit speed-change lanes is a constant (i.e., it is not a function of speed-change lane length).

A procedure for calibrating the predictive models is described in Section A.1.1 of the Draft *HSM* Appendix A for Part C.

**Crash Modification Factors**

Eight crash modification factors (CMFs) are provided in the predictive method. The geometric design features and traffic conditions that they address are identified in the following list.

- Horizontal curvature.
- Lane width.
- Inside shoulder width.
- Median width.
- Median barrier.
- High-volume (congested) conditions.
- Ramp entrance length and side of freeway.
- Ramp exit length and side of freeway.

Specific details about the CMF formulation and regression coefficients are provided in Section 13.7.2 of the Draft *HSM* Freeways chapter. This section also identifies conditions where a CMF is not applicable.

Supplemental calculations for using the barrier-related CMFs are described in Section 13.7.3 of the Draft *HSM* Freeways chapter.

**Crash Type Distribution**

The predicted crash frequency from a predictive model can be disaggregated into estimates of crash frequency by crash type. The crash type categories for multiple-vehicle crashes include head-on, right-angle, rear-end, and sideswipe. The crash type categories for multiple-vehicle crashes include animal, fixed object, other object, and parked vehicle.

Distribution percentages for these crash types are provided in Section 13.6.2 of the Draft *HSM* Freeways chapter. Application of these percentages is described in Sample Problem 3 in Section 13.13.3 of the Draft *HSM* Freeways chapter.

**Crash Severity Distribution**

The predicted crash frequency from a predictive model can be disaggregated into estimates of crash severity. Specifically, the predicted fatal-and-injury crash frequency can be disaggregated into estimates of fatal (K), incapacitating injury (A), non-incapacitating injury (B), and possible injury (C) crash
frequency. A severity distribution function is used for this purpose. The function is an equation that includes some of the same variables used in the predictive model.

The equations that comprise the severity distribution function are described in Section 13.8 of the Draft HSM Freeways chapter. Application of these equations is described in Sample Problem 3 in Section 13.13.3 of the Draft HSM Freeways chapter.

A procedure for calibrating the severity distribution functions is described in Section A.1.4 of the Draft HSM Appendix A for Part C.

**Predictive Method**

The predictive method for freeway speed-change lanes is described as a flow chart in Figure 13-1 of the Draft HSM Freeways chapter. The flow chart indicates that the method includes 18 steps that are completed in sequence when evaluating one or more sites. The method is described in sufficient generality that it can be applied to one or more sites, for one or more years, with or without the use of crash data.

The steps that comprise the predictive method are described in detail in Section 13.4.1 of the Draft HSM Freeways chapter. If the EB Method is used in the method, the related calculations are described in Section A.2 of the Draft HSM Appendix A for Part C.

A key step of the predictive method is to divide the facility being evaluated into individual sites (i.e., segments and speed-change lanes). The procedure for dividing the freeway into individual sites is described in Section 13.5 of the Draft HSM Freeways chapter.

Application of the predictive method is described in the sample problems in Section 13.13 of the Draft HSM Freeways chapter.

Limitations of the predictive method are identified in Section 13.10 of the Draft HSM Freeways chapter.

**Output**

The output data computed using the predictive method consists primarily of the expected crash frequency for each site and year in the evaluation period. Useful performance measures and techniques for presenting this output are presented in the Output section in the previous part of this document.

**ALGORITHM DESCRIPTION FOR RAMP SEGMENTS**

This part of the appendix provides information needed to implement the predictive method for ramp segments in software. This method is described in the Draft HSM Ramps chapter.

The remainder of this part consists of four sections. The first section identifies the input data needed by the predictive method. The second section presents the crash prediction models. The third section describes the sequence of steps that comprise the predictive method. The last section describes the output data that are available from an application of the predictive method.

**Input Data**

This section describes the input data for the predictive method. These data are identified using the following categories.

- Evaluation period.
• Evaluation type.
• Crash data.
• Geometric design, traffic control, and traffic volume data.

**Evaluation Period**
The evaluation period is the set of years in the combined study period and crash period. Every calendar year in the evaluation period is separately evaluated using the methodology.

Specific details about this input are provided in Section 14.4.1, Step 2 of the Draft HSM Ramps chapter.

**Evaluation Type**
The predictive method can be used to evaluate one site, or a contiguous group of sites. The evaluation is described as one of several types, as determined by the analyst. When one site is being evaluated, the evaluation types are:

A. Evaluation based on using the predictive model only.

B. Evaluation based on using the predictive model and crash data.

When a group of sites are being evaluated, the evaluation types are:

A. Evaluation based on using the predictive model only for each site.

B. Evaluation based on using the predictive model and crash data for each site.

C. Evaluation based on using the predictive model for each site and crash data for the group of sites.

When crash data are used, the empirical Bayes (EB) Method is used to combine the crash data with the predictive model estimate to obtain a more reliable estimate of the expected crash frequency. The three evaluation types are referred to herein as types A, B, and C. In the HSM, type B evaluation is referred to as the “site-specific” EB Method and type C is referred to as “project-level” EB Method.

There are several factors to be considered when determining whether the EB Method is appropriate for a given project. These criteria are described in Sections A.2.1 and A.2.2 of the Draft HSM Appendix A for Part C.

**Crash Counts**
If evaluation type B is input by the analyst, then the crash data for each site are necessary input data. The criteria for assigning crashes to individual ramp segment sites are described in Section A.2.3 of the Draft HSM Appendix A for Part C. If evaluation type C is input, then the crash data for the group of sites is needed.

The crash counts must correspond to the crash period. The crash period can be site-specific; however, for coding convenience, the crash period should be the same for all sites. If the crash period includes multiple years, then the crash data do not have to be separately tabulated for each year at each site. Rather, it is sufficient for the analyst to input the total number of crashes for the crash period.
**Geometric Design, Traffic Control, and Traffic Volume Data**

The input data describing the geometric design and traffic volume data for ramp segments are identified in the following list.

**General**
- Area type (urban or rural).

**Geometric Design**
- Number of through lanes.
- Segment length.
- Length and radius of horizontal curve.
- Lane width.
- Left and right shoulder width.
- Length of (and offset to) right side barrier.
- Length of (and offset to) left side barrier.
- Presence of lane add or drop.
- Presence of speed-change lane (associated with a ramp-to-ramp merge or diverge).
- Presence and length of weaving section (only applicable to C-D roads).

**Traffic Characteristics**
- AADT volume of ramp segment.

Specific details about these input data are provided in Section 14.4.2 of the Draft *HSM Ramps* chapter. These details include the method of measurement and the value limits for each variable. The AADT volume ranges for the predictive models are listed in Table 14-4 of the Draft *HSM Ramps* chapter.

The units of measurement for all input data are U.S. customary. If input data are provided in metric units, then they should undergo soft conversion to U.S. customary units before their use in the predictive method.

**Predictive Models**
The general structure of the predictive model is described by Equation 14-1 of the Draft *HSM Ramps* chapter. A more specific structure is described by Equation 14-2 and Equation 14-7.

**Safety Performance Functions**
Separate safety performance functions (SPFs) are provided for the following conditions:
- Area type (rural or urban).
- Ramp type (entrance ramp, exit ramp, C-D road)
• Through lanes (1, 2 in urban areas).
• Crash type (multiple-vehicle, single-vehicle).
• Crash severity (fatal-and-injury, property-damage-only).

All total, there are 36 SPFs represented by unique combinations of the five conditions identified in the preceding list. Specific details about the SPF regression coefficients are provided in Section 14.6.1 of the Draft HSM Ramps chapter.

The overdispersion parameter is computed as a function of segment length. The equation for this calculation is provided in Section 14.6.1 of the Draft HSM Ramps chapter.

A procedure for calibrating the predictive models is described in Section A.1.1 of the Draft HSM Appendix A for Part C.

**Crash Modification Factors**

Nine crash modification factors (CMFs) are provided in the predictive method. The geometric design features and traffic conditions that they address are identified in the following list.

• Horizontal curvature.
• Lane width.
• Right shoulder width.
• Left shoulder width.
• Right side barrier.
• Left side barrier.
• Lane add or drop.
• Ramp speed-change lane.
• Weaving section.

Specific details about the CMF formulation and regression coefficients are provided in Section 14.7.1 of the Draft HSM Ramps chapter. This section also identifies conditions where a CMF is not applicable.

Supplemental calculations for using the barrier-related CMFs and the Horizontal Curve CMF are described in Section 14.7.3 of the Draft HSM Ramps chapter.

**Crash Type Distribution**

The predicted crash frequency from a predictive model can be disaggregated into estimates of crash frequency by crash type. The crash type categories for multiple-vehicle crashes include head-on, right-angle, rear-end, and sideswipe. The crash type categories for multiple-vehicle crashes include animal, fixed object, other object, and parked vehicle.

Distribution percentages for these crash types are provided in Section 14.6.1 of the Draft HSM Ramps chapter. Application of these percentages is described in Sample Problem 1 in Section 14.14.1 of the Draft HSM Ramps chapter.
**Crash Severity Distribution**
The predicted crash frequency from a predictive model can be disaggregated into estimates of crash severity. Specifically, the predicted fatal-and-injury crash frequency can be disaggregated into estimates of fatal (K), incapacitating injury (A), non-incapacitating injury (B), and possible injury (C) crash frequency. A severity distribution function is used for this purpose. The function is an equation that includes some of the same variables used in the predictive model.

The equations that comprise the severity distribution function for ramp segments are described in Section 14.8.1 of the Draft HSM Ramps chapter. Application of these equations is described in Sample Problem 1 in Section 14.14.1 of the Draft HSM Ramps chapter.

A procedure for calibrating the severity distribution functions is described in Section A.1.4 of the Draft HSM Appendix A for Part C.

**Predictive Method**
The predictive method for ramp segments is described as a flow chart in Figure 14-2 of the Draft HSM Ramps chapter. The flow chart indicates that the method includes 18 steps that are completed in sequence when evaluating one or more sites. The method is described in sufficient generality that it can be applied to one or more sites, for one or more years, with or without the use of crash data.

The steps that comprise the predictive method are described in detail in Section 14.4.1 of the Draft HSM Ramps chapter. If the EB Method is used in the method, the related calculations are described in Section A.2 of the Draft HSM Appendix A for Part C.

A key step of the predictive method is to divide the facility being evaluated into individual sites (i.e., ramp segments and crossroad ramp terminals). The procedure for dividing the ramps into individual sites is described in Section 14.5 of the Draft HSM Ramps chapter.

Application of the predictive method is described in the sample problems in Section 14.14 of the Draft HSM Ramps chapter.

Limitations of the predictive method are identified in Section 14.11 of the Draft HSM Ramps chapter.

**Output**
The output data computed using the predictive method consists primarily of the expected crash frequency for each site and year in the evaluation period. Useful performance measures and techniques for presenting this output are presented in the Output section in the part titled Algorithm Description for Freeway Segments.

**ALGORITHM DESCRIPTION FOR CROSSROAD RAMP TERMINALS**
This part of the appendix provides information needed to implement the predictive method for crossroad ramp terminals in software. This method is described in the Draft HSM Ramps chapter.

The remainder of this part consists of four sections. The first section identifies the input data needed by the predictive method. The second section presents the crash prediction models. The third section describes the sequence of steps that comprise the predictive method. The last section describes the output data that are available from an application of the predictive method.
Input Data
This section describes the input data for the predictive method. These data are identified using the following categories.

- Evaluation period.
- Evaluation type.
- Crash data.
- Geometric design, traffic control, and traffic volume data.

Evaluation Period
The evaluation period is the set of years in the combined study period and crash period. Every calendar year in the evaluation period is separately evaluated using the methodology.

Specific details about this input are provided in Section 14.4.1, Step 2 of the Draft HSM Ramps chapter.

Evaluation Type
The predictive method can be used to evaluate one site, or a contiguous group of sites. The evaluation is described as one of several types, as determined by the analyst. When one site is being evaluated, the evaluation types are:

A. Evaluation based on using the predictive model only.

B. Evaluation based on using the predictive model and crash data.

When a group of sites are being evaluated, the evaluation types are:

A. Evaluation based on using the predictive model only for each site.

B. Evaluation based on using the predictive model and crash data for each site.

C. Evaluation based on using the predictive model for each site and crash data for the group of sites.

When crash data are used, the empirical Bayes (EB) Method is used to combine the crash data with the predictive model estimate to obtain a more reliable estimate of the expected crash frequency. The three evaluation types are referred to herein as types A, B, and C. In the HSM, type B evaluation is referred to as the “site-specific” EB Method and type C is referred to as “project-level” EB Method.

There are several factors to be considered when determining whether the EB Method is appropriate for a given project. These criteria are described in Sections A.2.1 and A.2.2 of the Draft HSM Appendix A for Part C.

Crash Counts
If evaluation type B is input by the analyst, then the crash data for each site are necessary input data. The criteria for assigning crashes to individual crossroad ramp terminal sites are described in Section A.2.3 of the Draft HSM Appendix A for Part C. If evaluation type C is input, then the crash data for the group of sites is needed.
The crash counts must correspond to the crash period. The crash period can be site-specific; however, for coding convenience, the crash period should be the same for all sites. If the crash period includes multiple years, then the crash data do not have to be separately tabulated for each year at each site. Rather, it is sufficient for the analyst to input the total number of crashes for the crash period.

**Geometric Design, Traffic Control, and Traffic Volume Data**
The input data describing the geometric design and traffic volume data for crossroad ramp terminals are identified in the following list.

**General**
- Area type (urban or rural).
- Ramp terminal configuration.

**Geometric Design Data for All Terminals**
- Number of through lanes on each crossroad approach.
- Number of lanes on the exit ramp.
- Number of crossroad approaches with left-turn lanes.
- Number of crossroad approaches with right-turn lanes.
- Number of unsignalized public street approaches to the crossroad leg outside of the interchange.
- Distance to the next public street intersection
- Distance to the adjacent crossroad ramp terminal.
- Crossroad median width and left-turn lane width.

**Geometric Design Data for Signalized Terminals Only**
- Number of unsignalized driveways on the crossroad leg outside of the interchange.
- Number of crossroad approaches with protected-only left-turn operation.
- Number of crossroad approaches with right-turn channelization.
- Presence of exit ramp right-turn channelization.
- Presence of a non-ramp public street leg at the terminal.

**Geometric Design Data for Unsignalized Terminals Only**
- Skew angle.

**Traffic Control**
- Type of traffic control (signal, one-way stop, all-way stop).
- Type of control for the exit ramp right-turn movement.
Traffic Characteristics

- AADT volume for the inside and outside crossroad legs
- AADT volume for each ramp leg.

Specific details about these input data are provided in Section 14.4.2 of the Draft HSM Ramps chapter. These details include the method of measurement and the value limits for each variable. The AADT volume ranges for the predictive models are listed in Table 14-11 of the Draft HSM Ramps chapter.

The units of measurement for all input data are U.S. customary. If input data are provided in metric units, then they should undergo soft conversion to U.S. customary units before their use in the predictive method.

Predictive Models

The general structure of the predictive model is described by Equation 14-1 of the Draft HSM Ramps chapter. A more specific structure is described by Equation 14-12 and Equation 14-15.

Safety Performance Functions

Separate safety performance functions (SPFs) are provided for the following conditions:

- Area type (rural or urban).
- Terminal configuration (D3ex, D3en, D4, A4, B4, A2, B2)
- Control mode (signal, one-way stop)
- Crossroad through lanes (2, 3, 4, 5 signalized in urban areas, 6 signalized in urban areas).
- Crash severity (fatal-and-injury, property-damage-only).

All total, there are 196 SPFs represented by unique combinations of the five conditions identified in the preceding list. Specific details about the SPF regression coefficients are provided in Section 14.6.2 of the Draft HSM Ramps chapter.

The overdispersion parameter is constant. It is provided in Section 14.6.2 of the Draft HSM Ramps chapter.

A procedure for calibrating the predictive models is described in Section A.1.1 of the Draft HSM Appendix A for Part C.

Crash Modification Factors

Eleven crash modification factors (CMFs) are provided in the predictive method. The geometric design features, traffic control features, and traffic conditions that they address are identified in the following list.

- Exit ramp capacity.
- Crossroad left-turn lane.
- Crossroad right-turn lane.
- Access point frequency.
• Segment length.
• Median width.
• Protected left-turn operation (signalized terminals only).
• Channelized right turn on crossroad (signalized terminals only).
• Channelized right turn on exit ramp (signalized terminals only).
• Non-ramp public street leg (signalized terminals only).
• Skew angle (unsignalized terminals only).

Specific details about the CMF formulation and regression coefficients are provided in Section 14.7.2 of the Draft HSM Ramps chapter. This section also identifies conditions where a CMF is not applicable.

A CMF for all-way stop control is also provided with the predictive model for one-way stop controlled terminals. A procedure for using it is described in Section 14.10 of the Draft HSM Ramps chapter. It is an interim procedure to be used to evaluate all-way stop controlled terminals until a better procedure can be developed through research.

**Crash Type Distribution**
The predicted crash frequency from a predictive model can be disaggregated into estimates of crash frequency by crash type. The crash type categories for multiple-vehicle crashes include head-on, right-angle, rear-end, and sideswipe. The crash type categories for multiple-vehicle crashes include animal, fixed object, other object, and parked vehicle.

Distribution percentages for these crash types are provided in Section 14.6.2 of the Draft HSM Ramps chapter. Application of these percentages is described in Sample Problem 4 in Section 14.14.4 of the Draft HSM Ramps chapter.

**Crash Severity Distribution**
The predicted crash frequency from a predictive model can be disaggregated into estimates of crash severity. Specifically, the predicted fatal-and-injury crash frequency can be disaggregated into estimates of fatal (K), incapacitating injury (A), non-incapacitating injury (B), and possible injury (C) crash frequency. A severity distribution function is used for this purpose. The function is an equation that includes some of the same variables used in the predictive model.

The equations that comprise the severity distribution function for crossroad ramp terminals are described in Section 14.8.2 of the Draft HSM Ramps chapter. Application of these equations is described in Sample Problem 4 in Section 14.14.4 of the Draft HSM Ramps chapter.

A procedure for calibrating the severity distribution functions is described in Section A.1.4 of the Draft HSM Appendix A for Part C.

**Predictive Method**
The predictive method for crossroad ramp terminals is described as a flow chart in Figure 14-2 of the Draft HSM Ramps chapter. The flow chart indicates that the method includes 18 steps that are completed in sequence when evaluating one or more sites. The method is described in sufficient generality that it can be applied to one or more sites, for one or more years, with or without the use of crash data.
The steps that comprise the predictive method are described in detail in Section 14.4.1 of the Draft HSM Ramps chapter. If the EB Method is used in the method, the related calculations are described in Section A.2 of the Draft HSM Appendix A for Part C.

A key step of the predictive method is to divide the facility being evaluated into individual sites (i.e., ramp segments and crossroad ramp terminals). The procedure for dividing the ramps into individual sites is described in Section 14.5 of the Draft HSM Ramps chapter.

Application of the predictive method is described in the sample problems in Section 14.14 of the Draft HSM Ramps chapter.

Limitations of the predictive method are identified in Section 14.11 of the Draft HSM Ramps chapter.

**Output**
The output data computed using the predictive method consists primarily of the expected crash frequency for each site and year in the evaluation period. Useful performance measures and techniques for presenting this output are presented in the Output section in the part titled Algorithm Description for Freeway Segments.

**SOFTWARE DOCUMENTATION**
This part of the document uses a series of flow charts and linkage lists to document the logic flow for the ISATe software.

**Flowcharts**
The calculation sequence is controlled by the subroutine titled Main_PerformanceCalculations. It calls other subroutines in the sequence needed to complete the calculations. This subroutine is shown in Figure 1. The subroutines called by this main subroutine are identified by name in parentheses in the flowchart boxes.

![Diagram](image-url)

**Figure 1.** Main Subroutine

When the main subroutine is invoked, it initially clears any data in the output worksheets that is left from a prior evaluation. It also sets all variable values to zero. Next, the main subroutine calls a subroutine that
reads the regression coefficients and local calibration factors from the Calibration Factors worksheet. Then, it calls the performance measures subroutine. This subroutine implements the calculations associated with the predictive methods described in the draft *HSM* chapters. When the calculations are complete, a subroutine is called to write the performance measures to the output worksheets. More information about these subroutines is provided in the section titled Linkage Lists.

The calculation sequence for the performance measures subroutine (i.e., ComputePerformance) is shown in Figure 2. Initially, it checks the input AADT volume data to determine if there are any missing data. If one or more volumes are missing, then a subroutine is called that implements the rules for estimating missing volume. These rules are described in Step 3 in Section 13.4.1 of the Draft *HSM* Freeways chapter.

![Figure 2. Performance Measures Subroutine](image)

Once the AADT data are determined to be complete, the predictive method is initiated. This method has three variations, depending on whether crash data are available and, if available, whether it can be correctly associated with individual sites. One of three evaluation types is identified based on these three considerations. The choice of evaluation type dictates the subsequent sequence of calculations.

**Predictive Model Only**

If the evaluation is determined to be based on the predictive model only, then the calculation sequence is shown in Figure 3. Two variations are shown in the figure. One variation applies to freeway segments. The other variation applies to ramp segments. This latter variation includes a subroutine to calculate ramp curve speed. The chart shown in Figure 3b can be applied to crossroad ramp terminals if the subroutine for computing curve speed is removed and the references to “ramp segment” are changed to “ramp terminal.”
Algorithm Description

**Figure 3.** Evaluation based on Predictive Model Only

The subroutine sequence in Figure 3 is shown to be repeated for each site. The first subroutine called in Figure 3a is used to calculate the CMFs for each year at the subject site. These CMFs are then used in the second subroutine to calculate the predicted average crash frequency using the predictive model. Finally, the third subroutine computes the crash severity distribution and combines it with the predicted average crash frequency from the previous subroutine to estimate the crash frequency by severity level. The sequence is repeated until all sites are evaluated.

**Site-Specific EB Method**

If the evaluation is determined to be based on the site-specific EB Method, then the calculation sequence is shown in Figure 4. Two variations are shown in the figure. One variation applies to freeway segments. It includes a subroutine to calculate an equivalent overdispersion parameter for odd-lane cross sections based on the parameters provided for even-lane SPFfs. The other variation applies to ramp segments. This variation includes a subroutine to calculate ramp curve speed. The chart shown in Figure 4b can be applied to crossroad ramp terminals if the subroutine for computing curve speed is removed and the references to “ramp segment” are changed to “ramp terminal.”

The subroutine sequence in Figure 4 is shown to have two looping sequences. In the first loop, the sequence is repeated for each site. Each site is evaluated once for the crash period and once for the study period. The first subroutine called in Figure 4a is used to calculate the CMFs for each year at the subject site. These CMFs are then used in the second subroutine to calculate the predicted average crash frequency using the predictive model. Finally, the third subroutine computes the equivalent overdispersion parameter, as described in the previous paragraph. The sequence is repeated until all sites are evaluated.

In the second loop shown in Figure 4, the sequence is again repeated for each site but only for the study period. The first subroutine implements the EB Method to combine the predicted crash frequency with the crash data to obtain an estimate of the expected average crash frequency. The second subroutine computes the crash severity distribution and combines it with the expected average crash frequency from the previous subroutine to estimate the crash frequency by severity level.
Algorithm Description

**Freeway Segments**

Figure 4. Evaluation based on the Site-Specific EB Method

**Project-Level EB Method**

If the evaluation is determined to be based on the project-level EB Method, then the calculation sequence is shown in Figure 5. Two variations are shown in the figure. One variation applies to freeway segments. It includes a subroutine to calculate an equivalent overdispersion parameter for odd-lane cross sections based on the parameters provided for even-lane SPFs. The other variation applies to ramp segments. This variation includes a subroutine to calculate ramp curve speed. The chart shown in Figure 5b can be applied to crossroad ramp terminals if the subroutine for computing curve speed is removed and the references to “ramp segment” are changed to “ramp terminal.”

The subroutine sequence in Figure 5 is shown to have two looping sequences. In the first loop, the sequence is repeated for each site. Each site is evaluated once for the crash period and once for the study period. This sequence of calculations is described in the discussion associated with Figure 4. When the loop is completed, the project-level EB Method calculations are completed for the collective set of sites to produce an estimate of the total expected average crash frequency.

In the second loop shown in Figure 5, the sequence is again repeated for each site but only for the study period. The subroutine in this loop computes the crash severity distribution and combines it with the predicted average crash frequency from a previous subroutine to estimate the crash frequency by severity...
level for each site. After the loop is complete, the last subroutine uses the site estimates of predicted average crash frequency by severity level to compute a total by severity level for the project. The proportion of predicted crashes in each severity level is then multiplied by the total expected average crash frequency to compute the distribution of expected average crash frequency by severity level for the project.

**Figure 5.** Evaluation based on the Project-Level EB Method

**Linkage Lists**

This section uses linkage lists to describe the main subroutines that comprise the ISATe software. Each list is provided in a table that identifies the main subroutine and the subroutines that it calls. A brief description is provided for each called subroutine.

A linkage list is provided in Table 1 for the subroutines identified in Figure 1. The subroutine naming convention includes a prefix for many subroutines to denote their application to one of the three freeway facility components (i.e., freeway segments, ramp segments, and crossroad ramp terminals). In each case, the subroutine includes the same basic calculations but it is tailored to address some unique elements of the associated facility component. The prefix is not shown in the table because the description offered is sufficiently general as to be applicable to all components.
Table 1. Linkage List for Key Subroutines

<table>
<thead>
<tr>
<th>Main Subroutine <em>a</em></th>
<th>Called Subroutine <em>a</em></th>
<th>Called Subroutine Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main_PerformCalculations</td>
<td>CheckLaneCounts</td>
<td>Check lanes entered for sites and report a warning message for any sites with a lane count that is not consistent with the limits of the predictive model for the input area type.</td>
</tr>
<tr>
<td></td>
<td>ClearOutput</td>
<td>Clear all cells in the output worksheets. Cells are blank (empty) after this subroutine is called.</td>
</tr>
<tr>
<td></td>
<td>ClearVariables</td>
<td>Set all variables and arrays to zero.</td>
</tr>
<tr>
<td></td>
<td>ReadCalibData</td>
<td>Read all regression coefficients, distribution values, and calibration factors in the Calibration Factors worksheet.</td>
</tr>
<tr>
<td></td>
<td>ReadInputData</td>
<td>Read input data from the input worksheets.</td>
</tr>
<tr>
<td></td>
<td>ComputePerformance</td>
<td>Compute performance measures for each year in the evaluation period for each site in the project.</td>
</tr>
<tr>
<td></td>
<td>Sum_ReportData</td>
<td>Combines the freeway, ramp, and ramp terminal performance measures and reports the results at the project level, as total crashes by severity and crash type. Reports results in the Output Summary worksheet.</td>
</tr>
<tr>
<td>ReadInputData</td>
<td>GetData</td>
<td>Reads a cell with a blue background. If the background is not blue, then a zero or blank is returned.</td>
</tr>
<tr>
<td>Sum_ReportData</td>
<td>Report</td>
<td>Combines site performance measures for a specified freeway component (i.e., freeway, ramp, or ramp terminal) as total crashes by severity and crash type.</td>
</tr>
<tr>
<td>Report</td>
<td>ClearMOCDistribution</td>
<td>Clears the manner-of-collision-by-severity array. Sets all a values to zero.</td>
</tr>
<tr>
<td></td>
<td>ComputeMOCDistribution</td>
<td>Computes the manner-of-collision-by-severity array for all years and sites combined.</td>
</tr>
</tbody>
</table>

Note:  

a. Underlined subroutine names actually represent three subroutines and have a prefix of “Frwy_,” “Ramp_,” or “Term.” Each subroutine variation is minor variations to address one of the three freeway components: freeway, ramp, or crossroad ramp terminal.

The linkage list provided in Table 2 is specific to the subroutines called by the performance measures subroutine. These subroutines are identified in Figure 2 to Figure 5.
<table>
<thead>
<tr>
<th>Main Subroutine a</th>
<th>Called Subroutine a</th>
<th>Called Subroutine Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ComputePerformance</td>
<td>ComputeMissinAADT</td>
<td>Scans the AADT input cells for each year at each site. If an AADT value for a given year is missing, then it is estimated using the rules described in Step 3 of the predictive method.</td>
</tr>
<tr>
<td></td>
<td>ComputeCMFs</td>
<td>Computes the value of each applicable CMF for each year at each site.</td>
</tr>
<tr>
<td></td>
<td>ComputeNpredicted</td>
<td>Combines the CMFs with the SPFs and the calibration factor to compute the predicted average crash frequency for each year at each site.</td>
</tr>
<tr>
<td>Frwy_ComputeKfactors</td>
<td></td>
<td>Used only in the Freeways module when the EB Method is applied. This subroutine computes an effective overdispersion parameter when the segment has an odd number of lanes. It is generalized such that it is called regardless of whether the lane count is even or odd. However, the computed overdispersion parameter is equal to the input factor value when the segment has an even number of lanes.</td>
</tr>
<tr>
<td></td>
<td>ComputeNadjusted</td>
<td>Used when the site-specific EB Method is applied. This subroutine combines the predictive model estimate with the crash count to determine the expected average crash frequency for each year at each site.</td>
</tr>
<tr>
<td></td>
<td>ComputeSeverityDistribution</td>
<td>Uses a severity distribution function to estimate the crash severity distribution. Combines this distribution with the estimated crash frequency to estimate the crash frequency by severity level for each site.</td>
</tr>
<tr>
<td></td>
<td>ComputeProjectSeverity</td>
<td>Uses the predicted crash frequency by severity level for each site from ComputeSeverityDistribution with the total expected number of crashes from ComputeProjectNadusted to estimate the total crash frequency by severity level for the project.</td>
</tr>
<tr>
<td></td>
<td>ComputeProjectNpredicted</td>
<td>Used when the project-level EB Method is applied. This subroutine combines the predictive model estimates for each year at each site to produce a total estimated number of crashes for the project.</td>
</tr>
<tr>
<td></td>
<td>ComputeProjectNadjusted</td>
<td>Used when the project-level EB Method is applied. This subroutine combines the predictive model estimate with the crash count to determine the total expected number of crashes for the project.</td>
</tr>
<tr>
<td>Ramp_ComputeSpeed</td>
<td></td>
<td>Used only in the Ramps module. This subroutine computes the curve entry speed for each ramp curve.</td>
</tr>
</tbody>
</table>

Note:

a. Underlined subroutine names actually represent three subroutines and have a prefix of “Frwy_,” “Ramp_,” or “Term_.” Each subroutine variation is minor variations to address one of the three freeway components: freeway, ramp, or crossroad ramp terminal.