Enhanced Interchange Safety Analysis Tool: User Manual

by

James A. Bonneson,
Michael P. Pratt, and
Srinivas Geedipally
Texas Transportation Institute
College Station, Texas

Dominique Lord
Texas A&M University
College Station, Texas

Tim Neuman and
Jason A. Moller
CH2M-Hill
Chicago, Illinois

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DISCLAIMER

This is an uncorrected draft as submitted by the research agency. The opinions and conclusions expressed or implied in the report are those of the research agency. They are not necessarily those of the Transportation Research Board, the National Academies, or the program sponsors.

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Dr. Srinivas Geedipally	Texas Transportation Institute
Dr. Dominique Lord	Texas A&M University
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Mr. Michael P. Pratt	Texas Transportation Institute

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Dr. John C. Milton (chair)	Washington State DOT
Mr. James P. Allen	FHWA, Region 2
Ms. Geni Bahar	NAVIGATS Inc.
Dr. Joe Bared	FHWA Liaison Representative
Dr. Shyuan-Ren "Clayton" Chen	FHWA Liaison Representative
Mr. Michael Matzke	FHWA, Office of Infrastructure
Mr. Johnson Owusu-Amoako	Maryland State Highway Administration
Dr. Richard Pain	TRB Liaison Representative
Dr. Daniel S. Turner	University of Alabama - Tuscaloosa

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ENHANCED INTERCHANGE SAFETY ANALYSIS TOOL:
USER MANUAL

Chapter 1. Introduction

This user manual provides guidance for the use of the Enhanced Interchange Safety Analysis Tool (ISATe). This tool can be used to evaluate freeway and interchange safety. The algorithms and equations used in ISATe are implemented in a Microsoft ® Excel ® workbook as software (using the Visual-Basic-for-Applications programming language).

The user manual consists of three chapters. The first chapter provides an introduction to ISATe and describes basic interactions with the ISATe software. The second chapter describes the information needed for an ISATe evaluation. It also reviews the performance measures predicted by ISATe. The last chapter describes some typical applications of ISATe. The manual also contains three appendices that provide supplemental information and sample applications.

OVERVIEW

ISATe provides information about the relationship between roadway geometric design features and safety. It is based on research that quantified the relationship between various design elements (e.g., lane width) or design components (e.g., left-turn bay) and expected average crash frequency. The information provided in ISATe is intended to help designers make informed judgments about the safety performance of design alternatives. ISATe automates a safety prediction method that consists of various algorithms and equations. The predictive method is documented by Bonneson et al. (1). It was developed for inclusion as a Part C predictive method for a future edition of the *Highway Safety Manual* (2).

Evaluation Scope

ISATe is intended to be used to evaluate the safety of freeway facilities, including freeway main lanes and interchanges. The interchange may connect a freeway and a crossroad (service interchange) or two freeways (system interchange). It may include ramps, collector-distributor (C-D) roads, or both.

ISATe incorporates the disaggregate safety evaluation approach recommended by the *Highway Safety Manual* for its Part C predictive methods. In this regard, the freeway facility is disaggregated into one or more freeway sections and interchanges. The interchange is disaggregated into one or more ramps, C-D roads, and crossroad ramp terminals. Thus, a freeway facility consists of the following basic facility components.

- Freeway sections (with or without speed-change lanes).
- Ramps or C-D roads.
- Crossroad ramp terminals (i.e., the intersection between one or more ramps and the crossroad).

Each component is further disaggregated into a set of individual sites (i.e., segments and intersections). Safety performance measures are then calculated for each site. The measures are aggregated as needed to describe the performance of a freeway section, an interchange, or the facility as a whole.

ISATe can also be used to evaluate combinations of components, as may exist along a freeway section or in the vicinity of an interchange. Examples include:

- A freeway section comprised of several consecutive freeway segments.
- A freeway section within an interchange area with one or more freeway speed-change lanes.
- An interchange ramp comprised of one or more segments.
- An interchange consisting of one or more ramps and related ramp terminals.

ISATe can be used to evaluate freeways and interchanges in urban and rural areas.

ISATe cannot be used to evaluate crossroad segments at an interchange. If the crossroad needs to be evaluated, then one of the following Part C methods in the *Highway Safety Manual* should be used for this purpose (as determined by the area type and crossroad cross section).

- Chapter 10 - Predictive Method for Rural Two-Lane Roads.
- Chapter 11 - Predictive Method for Rural Multilane Highways.
- Chapter 12 - Predictive Method for Urban and Suburban Arterials.

If either the Chapter 10 or Chapter 12 method is used to evaluate crossroad segments, then driveways on the crossroad that are within 250 ft of the crossroad ramp terminal should not be counted (or included) in the application of that method. This approach provides consistency with the crossroad ramp terminal predictive method in ISATe (which explicitly addresses the presence of driveways within 250 ft of the ramp terminal).

ISATe combines the evaluation of freeway segments and speed-change lanes by using one input worksheet for both site types. This approach reduces the data entry effort by using the same input data for both the freeway segment and the adjacent speed-change lane (whenever a speed-change lane is present). If the speed-change lane geometry is not the same as (or reasonably similar to) the adjacent freeway segment, then the freeway segment and speed-change lane should be separately evaluated using the predictive methods documented in Reference (1).

Limitations of the Predictive Methods

ISATe incorporates two predictive methods that were developed for a future edition of the *Highway Safety Manual* (1). One predictive method is for freeways and the other method is for ramps. As a result, it shares the stated limitations of both methods.

Neither predictive method distinguishes between barrier types (i.e., cable barrier, concrete barrier, guardrail, and bridge rail) in terms of their possible different influence on crash severity.

Freeway Predictive Method

The predictive method for freeways includes models for freeway segments and speed-change lanes. The range of annual average daily traffic (AADT) volume for which the models are applicable is shown in

Table 1. Application of the models to sites with AADT volumes substantially outside these ranges may not provide reliable results.

Table 1. Applicable AADT Volume Ranges for Predictive Models for Freeways

Area Type	Cross Section (Through Lanes) (*x*)	Applicable AADT Volume Range (veh/day)
Rural	4	0 to 73,000
	5	0 to 102,000
	6	0 to 130,000
	7	0 to 160,000
	8	0 to 190,000
Urban	4	0 to 110,000
	5	0 to 145,000
	6	0 to 180,000
	7	0 to 225,000
	8	0 to 270,000
	9	0 to 290,000
	10	0 to 310,000

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

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

Predictive Method for Ramps

The predictive method for ramps includes models for ramp segments, C-D road segments, and crossroad ramp terminals. The range of AADT volume for which the segment models are applicable is shown in Table 2. Similarly, the range of AADT volume for which the crossroad ramp terminal models are applicable is shown in Table 3. Application of the models to sites with AADT volumes substantially outside these ranges may not provide reliable results.

Table 2. Applicable AADT Volume Ranges for Predictive Models for Ramps and C-D Roads

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

Table 3. Applicable AADT Volume Ranges for Predictive Models for Crossroad Ramp Terminals

Site Type (*w*)	Control Type (*x*)	Applicable AADT Volume Range (veh/day)	
		Crossroad	Total All Ramps
Three-leg terminals with diagonal exit ramp (*D3ex*)	Stop control (*ST*)	0 to 22,000	0 to 8,000
	Signal control (*SG*)	0 to 34,000	0 to 16,000
Three-leg terminals with diagonal entrance ramp (*D3en*)	Stop control (*ST*)	0 to 22,000	0 to 15,000
	Signal control (*SG*)	0 to 29,000	0 to 21,000
Four-leg terminals with diagonal ramps (*D4*)	Stop control (*ST*)	0 to 18,000	0 to 10,000
	Signal control (*SG*)	0 to 47,000	0 to 31,000
Four-leg terminals at four-quadrant parclo A (*A4*)	Stop control (*ST*)	0 to 21,000	0 to 12,000
	Signal control (*SG*)	0 to 71,000	0 to 30,000
Four-leg terminals at four-quadrant parclo B (*B4*)	Stop control (*ST*)	0 to 20,000	0 to 12,000
	Signal control (*SG*)	0 to 45,000	0 to 29,000
Three-leg terminals at two-quadrant parclo A (*A2*)	Stop control (*ST*)	0 to 17,000	0 to 12,000
	Signal control (*SG*)	0 to 46,000	0 to 25,000
Three-leg terminals at two-quadrant parclo B (*B2*)	Stop control (*ST*)	0 to 26,000	0 to 14,000
	Signal control (*SG*)	0 to 44,000	0 to 22,000

The predictive method for ramps 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.

Software Limits

ISATe can accommodate data for 20 freeway segments, 40 ramp or C-D road segments, and 6 crossroad ramp terminals. If a given project exceeds one or more of these limits, the analyst will need to subdivide the project into two or more parts such that each part does not exceed the workbook limits. If desired, the workbook can be electronically duplicated (i.e., copied and renamed) to evaluate each separate project part.

The aforementioned limits were established to facilitate the combined evaluation of one interchange and its associated freeway section using the ISATe workbook. Freeway facilities with two or more interchanges can be evaluated by disaggregating the facility into separate parts that have no more than one interchange per part.

ISATe can accommodate a crash period that is 1 to 5 years in duration. It can accommodate an evaluation period that is 1 to 24 years in duration. The terms crash period and evaluation period are defined in the next section.

TERMINOLOGY

This section defines the terms used in this manual.

Area Type

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. 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 term "suburban" is used herein to refer to outlying portions of an urban area. The area type designation in ISATe does not distinguish between urban and suburban portions of a developed area.

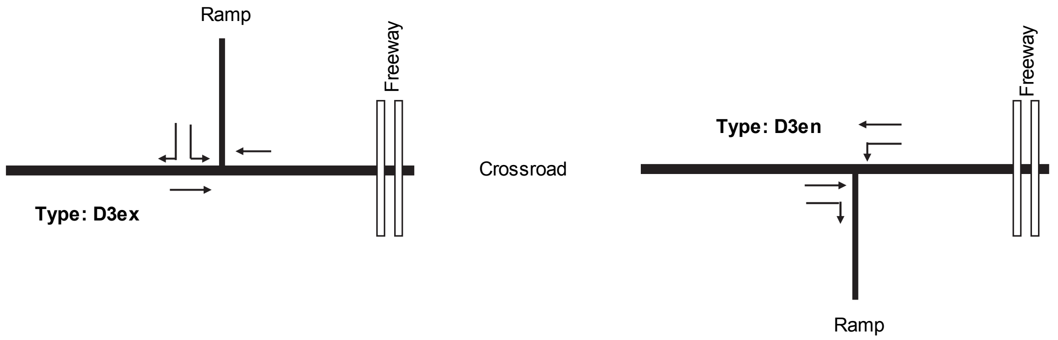
Crossroad Ramp Terminal

A crossroad ramp terminal is a controlled terminal between a ramp and a crossroad.

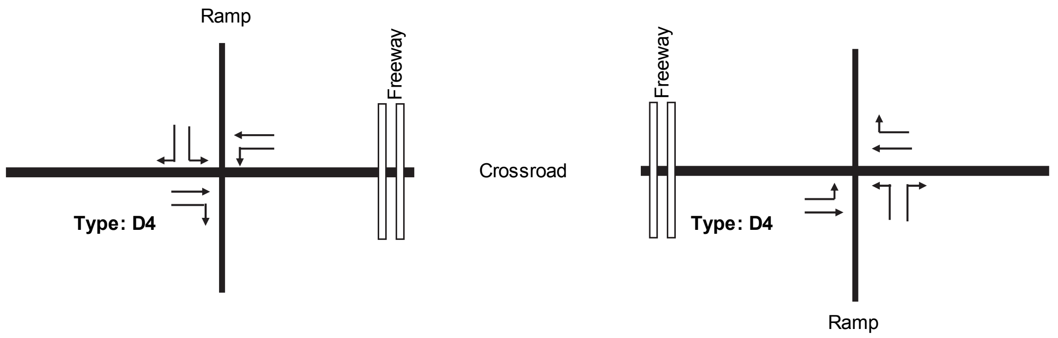
Crossroad Ramp Terminal Configurations

There are many different configurations of crossroad ramp terminals used at interchanges. The more common configurations are identified in Figure 1. Each of these configurations is addressed in ISATe.

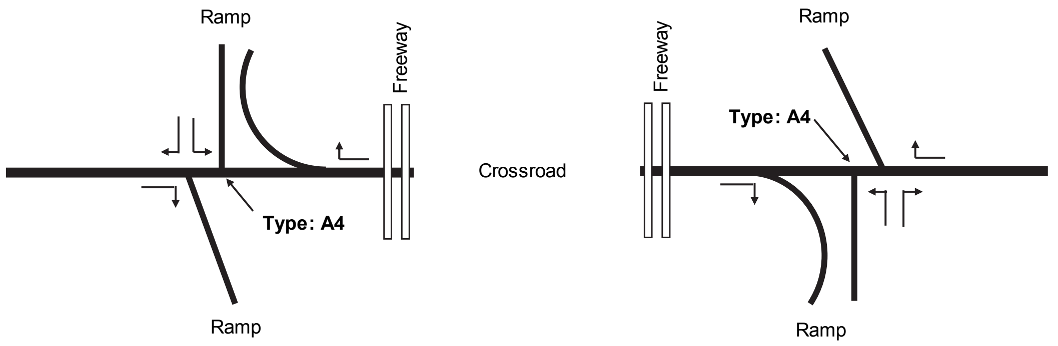
Differences among the terminal configurations in Figure 1 are shown to reflect the number of ramp legs, number of left-turn movements, and location of crossroad left-turn storage (i.e., inside or outside of the interchange). Although not shown, control type (i.e., signalized or stop controlled) is also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



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

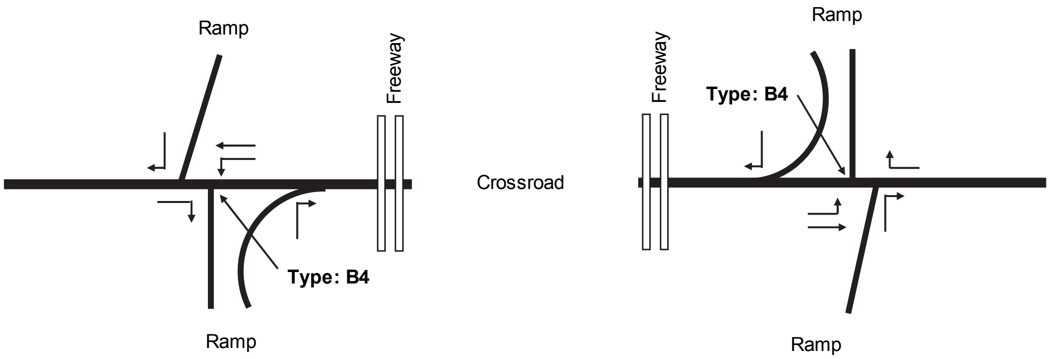


b. Four-Leg Ramp Terminal With Diagonal Ramps (*D4*)

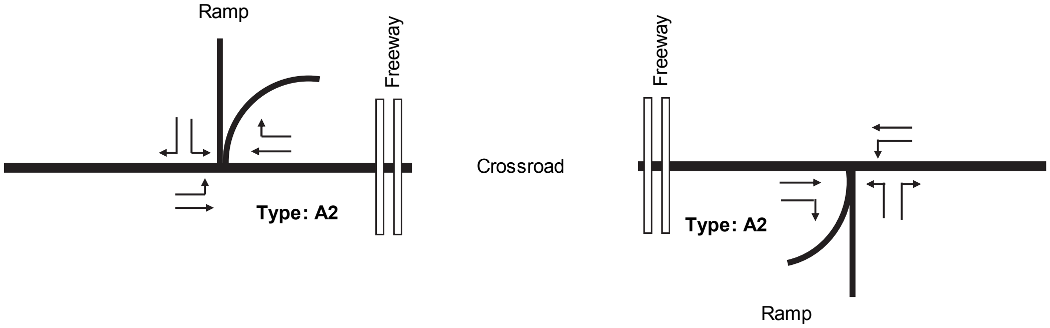


c. Four-Leg Ramp Terminal at Four-Quadrant Parclo A (*A4*)

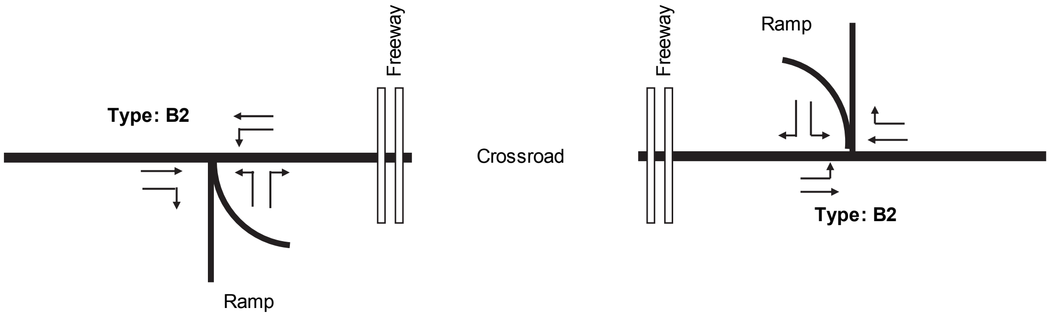
Figure 1. Ramp Terminal Configurations



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



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



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

Figure 1. Ramp Terminal Configurations *continued*

Empirical Bayes Method

The predictive methods in ISATe include models that are used to estimate the predicted average crash frequency for a site. If crash data are available and the analyst desires to use these data, the model prediction can be combined with crash data for the site to obtain a more reliable estimate of the expected average crash frequency. The empirical Bayes (EB) Method is used as the basis for combining the model prediction and the observed crash data. Criteria are provided in Appendix B for determining the applicability of the EB Method. The development of the EB Method is documented by Hauer (3).

Freeway Segment

A freeway segment is a length of freeway consisting of several through lanes with a constant cross section providing two directions of travel in which the opposing travel lanes are physically separated by a median. It is considered a homogenous segment if it has a relatively constant cross section, constant traffic volume, and similar geometric design features along its length. A freeway segment can include no more than one ramp entrance and one ramp exit in each travel direction.

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 gore point and the taper point of the speed-change lane.

Predictive Method

A predictive method consists of one or more predictive models, guidance for acquiring the model input data, and a step-by-step procedure for using the models to quantify the performance of a facility component.

Predictive Model

A predictive model consists of a safety performance function (SPF), crash modification factors (CMFs), and a calibration factor. It is used to compute the predicted average crash frequency for a site. The predicted quantity can describe crash frequency in total, or by crash type or severity.

Project Limits

The project limits define the physical extent of the entity being evaluated. They typically encircle two or more sites that are physically connected to form a functioning roadway. Thus, the limits can include a freeway facility, a freeway section, an interchange, or an entire ramp. In the extreme, the project limits can include just one site. Specification of the project limits depends upon the purpose of the study.

Ramp Segment and C-D Road Segment

A ramp or C-D road segment is a length of ramp or C-D roadway consisting of one or more through lanes with a constant cross section providing one direction of travel. It is considered a homogenous segment if it has a relatively constant cross section, constant traffic volume, and similar geometric design features along its length. A ramp or C-D road segment can include no more than one ramp entrance and one ramp exit with a second ramp.

Site

A site is a segment or intersection that is explicitly evaluated using a predictive method. When a freeway or interchange is being evaluated, it is disaggregated into a set of contiguous sites that are separately evaluated. For freeway facilities, a site is a freeway segment, ramp segment, C-D road segment, or crossroad ramp terminal.

Time Periods

Three time periods are defined to describe the safety evaluation. 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.

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.

GETTING STARTED

This section describes the basic interactions needed to complete an evaluation using the ISATe software. It consists of the following five subsections.

- **Enabling Macros:** guidance for setting spreadsheet security to enable macros.
- **Navigation:** guidance for selecting and using the worksheets.
- **Entering Data:** guidance for entering data in a worksheet.
- **Reviewing Results:** guidance for reviewing, saving, and printing results.
- **Modifying Calibration Factors and Distributions:** guidance for calibrating ISATe to local conditions.

Enabling Macros

The ISATe software contains computer code written in the Visual Basic for Applications programming language is referred to as “macro” code in Excel ®. This macro code must be enabled when first loading ISATe into Excel. This subsection describes a technique for enabling macros. The technique varies depending on whether Excel 2003 or Excel 2007 is used.

Enabling Macros in Excel 2003

The following instruction sequence enables macros for Excel 2003. Open the Excel software. From the main screen, click on Tools and then Options. In the Options panel, click on Security, and then click Macro Security. In the Security panel, click on Security Level, and then click the radio button adjacent to Medium (the button will show a black circle). Finally, click Ok to exit the Security Level panel and click Ok to exit the Options panel. This setting should only need to be set once. It will remain effective until this process is repeated and a new security level is selected.

Every time ISATe is opened in Excel, the pop-up box shown to the right will be displayed. The analyst should click on Enable Macros. ISATe will finish loading and will function as intended.

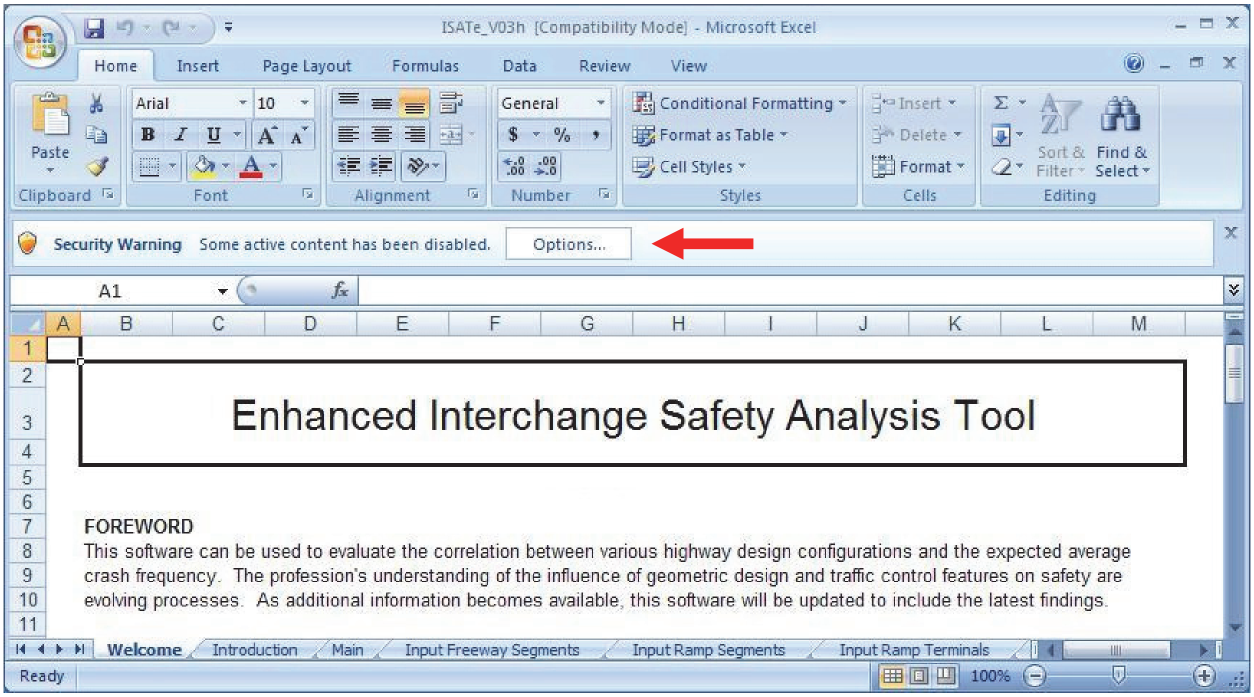
"C:\Documents and Settings\My Documents\user\NCHRP_17-45\ISATe\ISATe_V03g.xls" contains macros.

Macros may contain viruses. It is usually safe to disable macros, but if the macros are legitimate, you might lose some functionality.

Enabling Macros in Excel 2007

The following instruction sequence enables macros for Excel 2007. Open the Excel software. From the main screen, click on the Office Button and a panel will be displayed. In this panel, click the Excel Options button to bring up the Excel Options panel. In this panel, click on Trust Center, and then click on Trust Center Settings to bring up the Trust Center panel. In this panel, click on Macro Settings and then click the radio button adjacent to “Disable all macros with notification” (the button will show a black circle). Finally, click Ok to exit the Trust Center panel and click Ok to exit the Excel Options panel. This setting should only need to be set once. It will remain effective until this process is repeated and a new security level is selected.

Every time ISATe is opened in Excel, a security warning is displayed. It is shown about half way down from the top in the graphic below (just to the left of the large arrow). The analyst should click on the Options button, click on “Enable this content,” and then click Ok.



Security Warning Some active content has been disabled.

Enhanced Interchange Safety Analysis Tool

FOREWORD

This software can be used to evaluate the correlation between various highway design configurations and the expected average crash frequency. The profession's understanding of the influence of geometric design and traffic control features on safety are evolving processes. As additional information becomes available, this software will be updated to include the latest findings.

Navigation

The ISATe workbook contains 11 worksheets. To navigate among worksheets, click on the worksheet tabs at the bottom of the workbook window. ISATe includes the following worksheets.

- **Welcome:** includes a foreword, acknowledgments, and disclaimer.
- **Introduction:** brief overview of ISATe and this user manual.
- **Main:** input data to describe evaluation and start calculations.
- **Input Freeway Segments:** input data describing freeway segments and speed-change lanes.
- **Input Ramp Segments:** input data describing ramp and C-D road segments.
- **Input Ramp Terminals:** input data describing crossroad ramp terminals.
- **Output Summary:** summary of analysis results.
- **Output Freeway Segments:** detailed listing of analysis results for freeway segments.
- **Output Ramp Segments:** detailed listing of analysis results for ramp segments.
- **Output Ramp Terminals:** detailed listing of analysis results for crossroad ramp terminals.
- **Calibration Factors:** calibration factors for predictive models and crash type distributions.

The worksheets used for any specific evaluation will depend on a variety of factors. For the first evaluation conducted by the analyst, the Welcome and the Introduction worksheets should be selected and their respective content reviewed. For all subsequent evaluations, the analyst should proceed directly to the Main worksheet.

If the project limits represent a freeway section, then the following worksheets will be used in the sequence listed.

1. **Main:** input basic project data.
2. **Input Freeway Segments:** input site data.
3. **Main:** execute software to complete all calculations.
4. **Output Summary:** review results of safety evaluation.

Optionally, the Output Freeway Segments worksheet could be used to examine the detailed results on a site-by-site basis or to interpret the safety effect of specific geometric design or traffic control features.

If the project limits represent an interchange (i.e., its ramps and crossroad ramp terminals), then the following worksheets will be used in the sequence listed.

1. **Main:** input basic project data.
2. **Input Ramp Segments:** input site data.
3. **Input Ramp Terminals:** input site data.
4. **Main:** execute software to complete all calculations.
5. **Output Summary:** review results of safety evaluation.

Optionally, the Output Ramp Segments and Output Ramp Terminals worksheets could also be consulted.

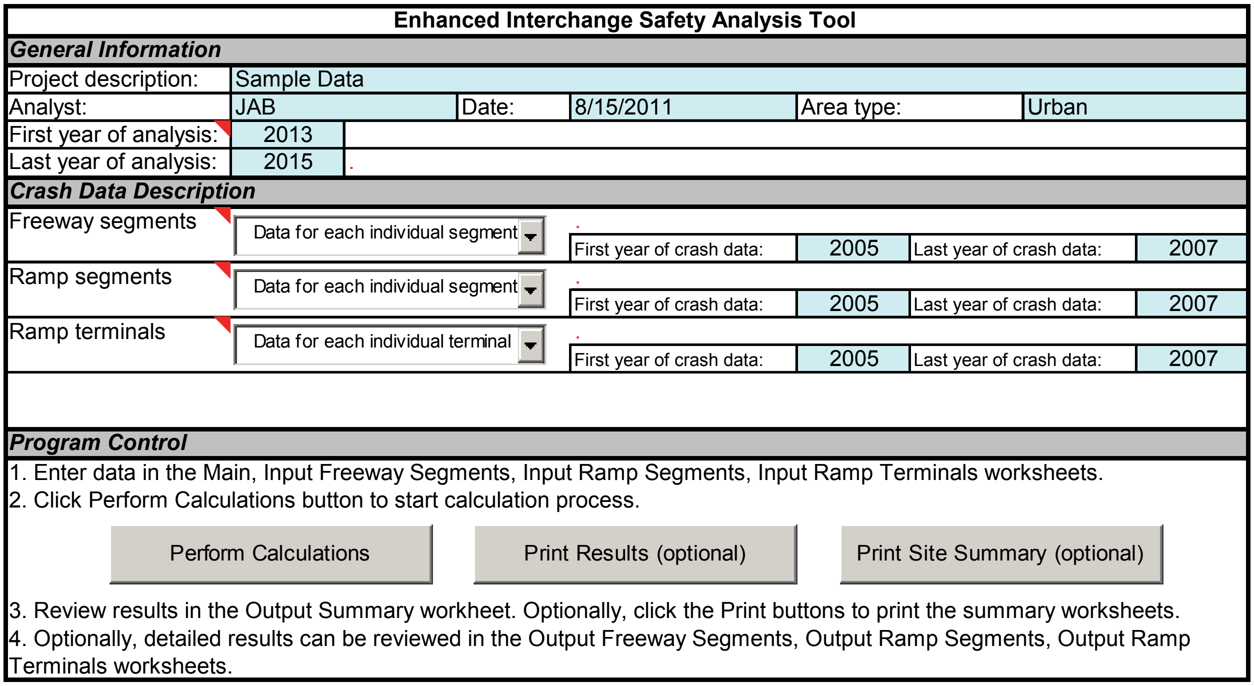
Entering Data

Each data entry worksheet is designed in a consistent manner and their use is similar. A sample portion of the Main worksheet is shown in Figure 2 to illustrate basic data input considerations.

In general, the cells with a light blue background are for user input. White cells and grey cells are locked to prevent inadvertent changes to cell content.

The red triangles in the upper right corner of some cells are linked to supplemental information balloons. Four red triangles are shown in cells on the right side of Figure 2. By positioning the mouse pointer over a red triangle, a balloon will appear. In it will be information relevant to the adjacent cell. It will typically explain more precisely what input data are needed.

A drop-down list is provided for some cells with a light-blue background. When one of these cells is selected, a grey button will appear on the right side of the cell. Position the mouse pointer over the button and click the left mouse button. After clicking on this button, a list of input choices will appear. Use the mouse pointer to select the desired choice, and then click the left mouse button.



Enhanced Interchange Safety Analysis Tool

General Information

Project description:	Sample Data				
Analyst:	JAB	Date:	8/15/2011	Area type:	Urban
First year of analysis:	2013				
Last year of analysis:	2015				

Crash Data Description

Freeway segments	Data for each individual segment	First year of crash data:	2005	Last year of crash data:	2007
Ramp segments	Data for each individual segment	First year of crash data:	2005	Last year of crash data:	2007
Ramp terminals	Data for each individual terminal	First year of crash data:	2005	Last year of crash data:	2007

Program Control

1. Enter data in the Main, Input Freeway Segments, Input Ramp Segments, Input Ramp Terminals worksheets.
2. Click Perform Calculations button to start calculation process.

3. Review results in the Output Summary workheet. Optionally, click the Print buttons to print the summary worksheets.
4. Optionally, detailed results can be reviewed in the Output Freeway Segments, Output Ramp Segments, Output Ramp Terminals worksheets.

Figure 2. Main Worksheet

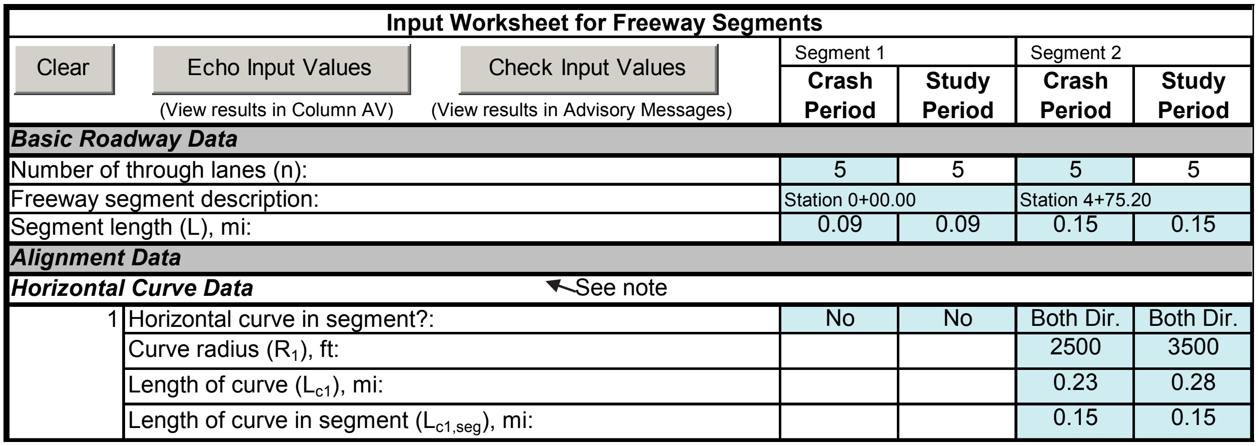
The section of Figure 2 titled Crash Data Description shows three drop-down windows. On the right side of each list there is a grey button. Position the mouse pointer over the button and click the left mouse button. After clicking on this button, a list of input choices will appear. Use the mouse pointer to select the desired choice. Then click the left mouse button.

The section of Figure 2 titled Program Control shows three grey buttons. Clicking on a button will initiate a sequence of software instructions. Similar buttons exist in the upper right corner of each input worksheet.

If crash data are provided, then two data entry columns will be provided for each site in each input worksheet. The first column corresponds to input data for the crash period. The second column corresponds to input data for the study period. If crash data are not provided, then one column will be provided for each site in each input worksheet. It will correspond to data for the study period. Figure 3 illustrates the case where two columns are provided for each site.

If two columns are shown for each site, then the input cells in the columns headed Study Period will have an equation that sets the study period value equal to the crash period value, for a common row. This equation is provided as a convenience to the analyst because it is likely that the site’s geometric design and traffic control features have not changed between the crash period and the study period. Thus, the analyst can enter the value for the crash period and it will be repeated for the study period. If a feature has changed in the time that has elapsed from the crash period to the study period, then the appropriate value should be entered in each column (thus, eliminating the equation in the study period column).

As discussed in Appendix B, the EB Method requires that the segment has not undergone major changes in character between the crash period and study period. Those variables considered to be fundamental to a segment’s character have an input cell with a white background in the study period column (indicating that the cell is locked to prevent a change in value between the two periods).



Input Worksheet for Freeway Segments

	Segment 1		Segment 2	
	Crash Period	**Study Period**	**Crash Period**	**Study Period**
Basic Roadway Data				
Number of through lanes (n):	5	5	5	5
Freeway segment description:	Station 0+00.00		Station 4+75.20	
Segment length (L), mi:	0.09	0.09	0.15	0.15
Alignment Data				
Horizontal Curve Data				
1 Horizontal curve in segment?:	No	No	Both Dir.	Both Dir.
Curve radius (R_1), ft:			2500	3500
Length of curve (L_{c1}), mi:			0.23	0.28
Length of curve in segment ($L_{c1,seg}$), mi:			0.15	0.15

Figure 3. Input Worksheet for Freeway Segments

If there is a change in one or more features at a specific site between the crash period and the study period, then the analyst should enter the appropriate data in the row corresponding to that feature and in the two columns corresponding to the site. For example, Segment 1 is shown in Figure 3 to have no curves in the segment. A "No" is entered in the cell associated with the row titled "Horizontal curve in segment?" and the column headed Crash Period. The default equation in the Study Period column replicates the "No" entry automatically.

Continuing the example, Segment 2 is shown to have a curve during the crash period. However, different curve geometry is present during the study period. In this instance, the curve radius and length are unique to each time period and must be separately entered in the corresponding columns. The default equation is deleted and the correct values entered directly in each cell.

Each input worksheet has a software routine that will clear all existing data in that worksheet. This routine is initiated by clicking on the Clear button in the upper left corner of the worksheet. This button is shown in Figure 3. After the button is activated, a message box appears to confirm the request to clear all data. If No is clicked, then control is returned to the input worksheet. If Yes is clicked, then the data in all input cells are cleared.

Continue?

Reviewing Results

This subsection provides guidance for reviewing, saving, and printing results in ISATe. The results of an evaluation are available in the output worksheets. The detailed output for each site type is available in the corresponding worksheet (i.e., Output Freeway Segments, Output Ramp Segments, and Output Ramp Terminals). These results are aggregated and summarized in the Output Summary worksheet.

The data entered into the ISATe worksheet can be saved by saving the entire workbook. The File, Save As menu sequence should be selected and a new file name entered when prompted (i.e., avoid overwriting the original ISATe workbook).

The Print Results button in the Main worksheet is shown in Figure 2. Clicking on this button enables a software routine that prints the evaluation results in the Output Summary worksheet. After clicking this button, a print review screen is presented. The screen will show a one-page printout of the results. If the information shown is acceptable, then press the Print button at the top of the window to submit the image to the printer. Note that the printer must be turned on prior to clicking the Print button.

If the information shown in the one-page printout is not acceptable, then click on the Close button at the top of the window to return to the Main worksheet.

Modifying Calibration Factors and Distributions

The predictive models in ISATe 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 sites being evaluated. It ensures that the evaluation results are meaningful and accurate for the jurisdiction.

A calibration factor is applied to each predictive model. It is important that each model be calibrated for application in the jurisdiction in which the sites being evaluated are located. A procedure for calibrating these models is described in Appendix A.

ISATe includes functions to estimate the crash severity distribution. These functions are used to estimate the expected average crash frequency for each severity level. Each severity distribution function has a calibration factor that can be used to calibrate it to local conditions.

The crash severity distribution can vary from jurisdiction to jurisdiction for the same reasons noted previously for predictive models. However, satisfactory results can be obtained with the functions provided with ISATe. Calibration of these functions is encouraged, but considered to be optional. A procedure for calibrating these functions is described in Appendix A.

ISATe includes a distribution of crash type (e.g., head on, fixed object, etc.). This distribution is used to estimate the expected average crash frequency for each crash type. Separate distributions are provided for each type of site addressed by ISATe.

The crash type distribution can vary from jurisdiction to jurisdiction for the same reasons noted previously for predictive models. However, satisfactory results can be obtained with the distributions provided with ISATe. Providing locally-derived values for these distributions is encouraged, but considered to be optional. Guidance for replacing the distribution values with local values is described in Appendix A.

Chapter 2. Evaluation Process

This chapter describes the activities undertaken during the safety evaluation of a freeway facility or site. The first section describes the sequence of activities in the order they are conducted. These activities are outlined as a series of analysis steps. The other sections provide the detailed procedures and information needed to implement one of the analysis steps in ISATe.

At the conclusion of the evaluation process, an estimate of the expected average crash frequency is obtained for the project and for each site within the project limits. The estimate is provided as a total that includes all severities and crash types. An estimate is also provided for each severity level and crash type.

Through repetition of this process for different design alternatives, information is obtained about the safety implications of the alternatives.

ANALYSIS STEPS

This section outlines the steps involved in a safety evaluation using ISATe. The steps are considered to be the routine steps that are used each time a safety evaluation is undertaken. It is assumed that the models and distributions have been calibrated for application to sites in the local jurisdiction.

The analysis steps are identified in the following list.

1. Define Project Limits.
2. Define Study Period.
3. Acquire Traffic Volume and Observed Crash Data.
4. Acquire Geometric Design and Traffic Control Data.
5. Divide Project into Individual Sites.
6. Assign Observed Crashes.
7. Initiate Calculations and Review Results.

Detailed information about each step is provided in the following subsections.

Step 1—Define Project Limits

The project limits are defined in this step. They define the physical extent of the entity being evaluated and typically encircle two or more sites that are physically connected to form a functioning roadway.

The selection of project limits will depend on the purpose of the study. The study may be limited to one specific site, a group of contiguous sites, or an entire facility (and its associated sites). If comparing design alternatives, the project limits should be the same for all alternatives.

Step 2—Define Study Period

The study period is defined in this step. It defines the period of years for which the results of the safety evaluation will apply. If observed crash data are available for the project, then the most recent years for which they are available define the crash period. The evaluation period includes the years represented in the study period and the crash period.

The study period depends upon the purpose of the study. The study period may be:

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

Step 3—Acquire Traffic Volume and Observed Crash Data

Traffic volume data are acquired in this step. Also, a decision is made whether the EB Method will be applied. If it will be applied, then it must also be decided whether the site-specific or project-level EB Method will be applied. If the EB Method will be applied, then the observed crash data are also acquired in this step.

Acquiring Traffic Volume Data

The traffic volume data is primarily represented by AADT data. The AADT volumes are needed for each year of the evaluation period.

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 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.

In many cases, it is expected that AADT data will not be available for all years of the evaluation period. In that case, an estimate of AADT volume for each missing year is computed in ISATe using the following rules.

- 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.

Acquiring 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 Appendix B.

The EB Method can be applied at the site-specific level or at the project level. At the site-specific level, crash data are assigned to specific sites in Step 6. At the project level, crash data are assigned to a freeway section as a whole because they cannot be assigned to individual freeway segments. Similarly, they are assigned to a group of ramp segments or crossroad ramp terminals, because they cannot be assigned to individual ramp segments or terminals. In general, the best results will be obtained if the site-specific EB Method is used. Guidance is provided in Appendix B for determining whether to choose the site-specific or project-level EB Method.

Step 4—Acquire Geometric Design and Traffic Control Data

The data needed to apply the predictive models are acquired in this step. 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 in the project limits. They are needed for the study period and, if applicable, the crash period.

The specific data elements needed are described in the section titled Input Data Requirements. The means by which they are entered into ISATe is described in the section titled Site Data Entry.

Step 5—Divide Project into Individual Sites

Using the information from Step 1 and Step 4, the project is divided into individual sites, consisting of individual homogeneous freeway segments, ramp segments, C-D road segments, or crossroad ramp terminals. The procedure for dividing a freeway, ramp, or C-D road into individual segments is described in the section titled Segmentation Process.

Step 6—Assign Observed Crashes

If it was decided in Step 3 to use the EB Method, then the crash data acquired in Step 3 are assigned to either the individual sites or the project in this step. If crashes are assigned to individual sites, then the crash-assignment criteria presented in Appendix B are used. If the project-level EB Method is used, then the crashes are assigned to the collection of freeway segments as a whole, ramp or C-D roads as a whole, and crossroad ramp terminals as a whole. If the EB Method is not used, then proceed to Step 7.

Step 7—Initiate Calculations and Review Results

The Perform Calculations button in the Main worksheet is selected to initiate the calculation sequence. This button is shown in Figure 2.

The calculations proceed on a site-by-site and year-by-year basis. Each year in the evaluation period is evaluated for a given site. Then, the process is repeated for the next site. A predictive model is used to compute the predicted average crash frequency for each site and year. A different model is used for each unique site type and cross section or control type represented by the project.

If observed crash data are not available, then the EB Method is not used. In this case, the estimate of expected average crash frequency is limited to the estimate of predicted average crash frequency from a predictive model. If the EB Method is used, then the expected average crash frequency is equal to the estimate obtained from the EB Method.

A severity distribution function (SDF) is used to compute the severity distribution for each site. This distribution is used to obtain an estimate of the expected average crash frequency by severity level.

A crash type distribution is used to obtain an estimate of the expected average crash frequency by crash type category (e.g., head on, fixed object, etc.).

The estimates of expected average crash frequency are summed for all years to obtain an estimate of the expected number of crashes for each site during the study period.

The expected number of crashes for each site is summed for all sites to obtain an estimate of the expected number of crashes for the project during the study period.

Additional information about the performance measures predicted by ISATe is provided in the section titled Results Review and Interpretation.

INPUT DATA REQUIREMENTS

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 in the project limits. Criteria for defining site boundaries are described in the next section.

The input data are described in three subsections. The first subsection describes the input data for freeway segments. The second subsection describes the input data for ramp and C-D road segments. The third subsection describes the input data for crossroad ramp terminals. In all subsections, the data are described in terms of the values or descriptors needed by the predictive model variables.

Freeway Segments

The input data needed for freeway segments is described in this subsection. There are several data identified in this subsection that describe a length along the roadway (e.g., segment length, curve length, weaving section length, etc.). All of these lengths are measured along the inside edge of traveled way in the direction of increasing milepost.

- Number of through lanes. The total number of through lanes in the segment (in both directions 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) taper is considered to have the same number of through lanes as the roadway just downstream of the lane-add (or lane-drop) taper. This guidance is shown in Figure 25.
    - Do not include any high-occupancy vehicle (HOV) lanes or managed lanes.
    - Do not include any auxiliary lanes that are associated with a weaving section, unless the weaving section length exceeds 0.85 mi (4,500 ft). If this length is exceeded, then the auxiliary lane is counted as a through lane that starts as a lane-add ramp entrance and ends as a lane-drop ramp exit.
    - Do not include the speed-change lane that is associated with a ramp that merges with (or diverges from) the freeway, unless its length exceeds 0.30 mi (1,600 ft). If this length is exceeded, then the speed-change lane is counted as a through lane that starts as a lane-add ramp entrance and ends as a lane drop by taper (or starts as a lane add by taper and ends as a lane-drop ramp exit).
- Length of freeway segment, and length of speed-change lane (if present). Speed-change lane length is measured from the gore point to the taper point. Figure 4 illustrates these measurement points for a ramp entrance and a ramp exit speed-change lane with the parallel and taper design, respectively.

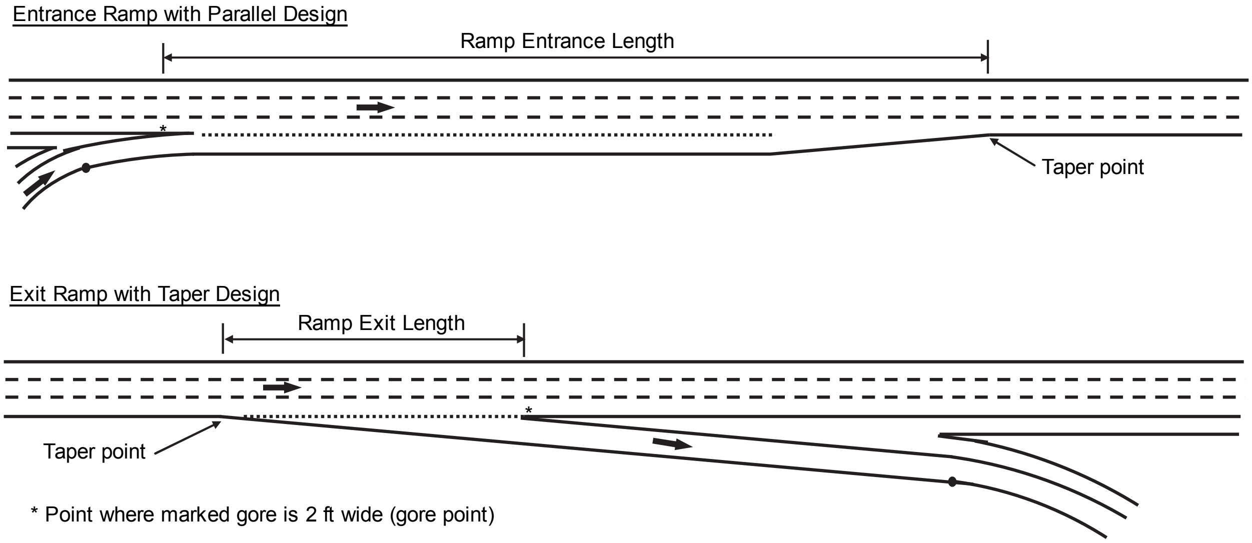
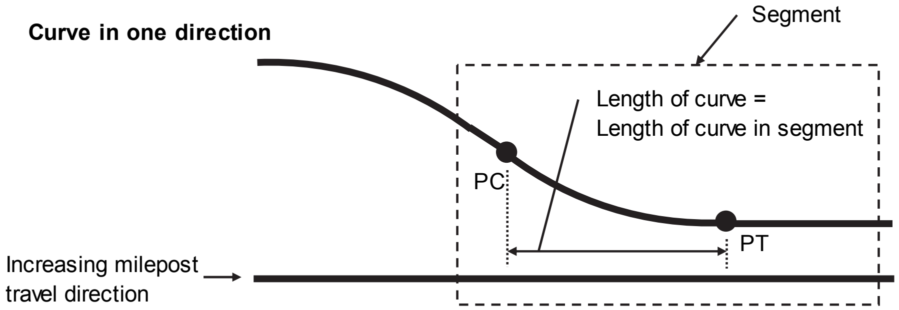


Figure 4. Freeway Speed-Change Lane Length

- Presence of a horizontal curve on one or both roadbeds. If a curve is present, then the three data elements in the following list are needed. Guidelines for obtaining these data are provided in Figure 5.
    - Length of curve.
        - 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 use 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 curve.
        - Both Directions. Measure radius for each curve. For a given curve, measure to the inside edge of the traveled way of the roadbed associated with 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.

Curve in one direction

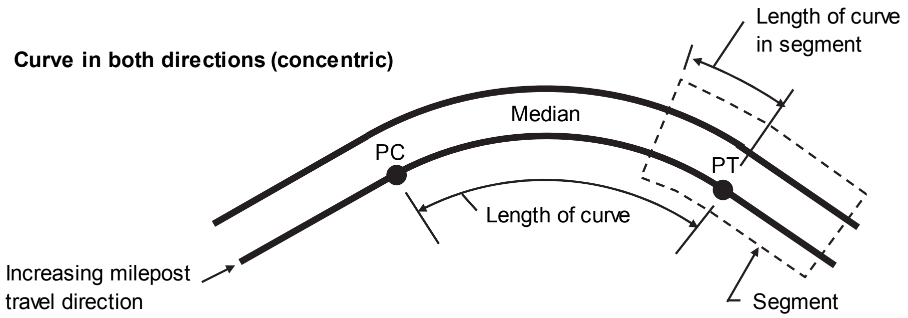


Rules

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

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

Curve in both directions (concentric)

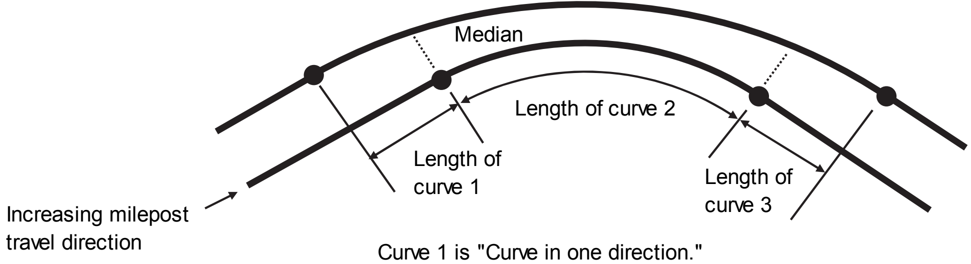


Rules

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

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

Curve in both directions (not concentric)



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

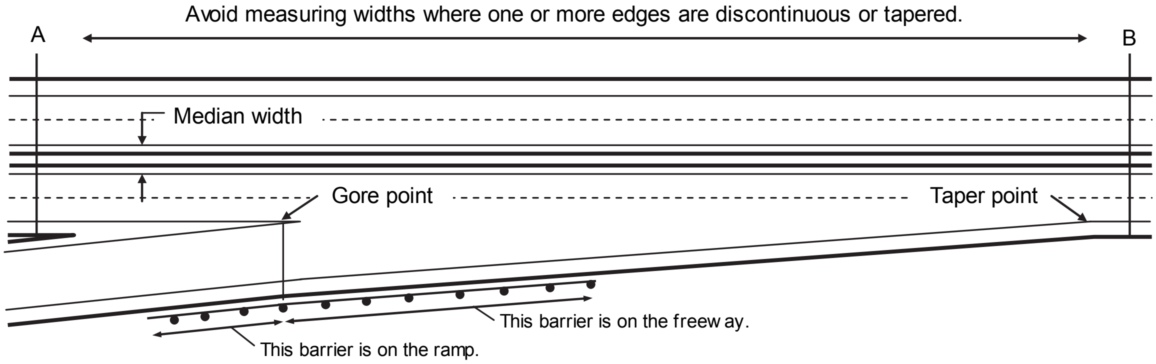
Rules

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

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

Figure 5. Curve Length and Radius Measurements

- Widths of lanes, outside shoulders, inside shoulders, and median. The first three elements represent an average for both roadbeds. These widths should be measured where the cross section is constant, such as along line A or B shown in Figure 6. They should not be measured where one or more edges are discontinuous or tapered. If a width varies along the segment (but not enough to justify beginning a new segment), then compute the length-weighted average width.
    - Lane width is an average for all through lanes (as defined at the start of this section).
    - Shoulder width represents the paved width.
    - Median width is measured between the edges of the traveled way for the two roadways in the opposite direction of travel, including the width of the inside shoulders, if they are present.



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

Figure 6. 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.
    - Figure 7 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 7. 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 6.

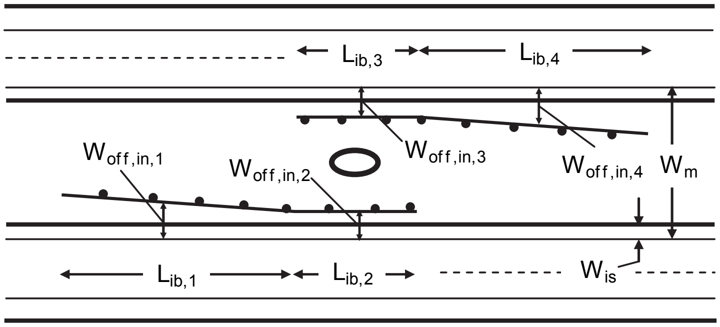


Figure 7. Barrier Variables

- 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 8.
    - Weaving section length. This length is measured along the edge of the freeway traveled way from the gore point of the ramp entrance to the gore point of the next ramp exit, as shown in Figure 8. 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."

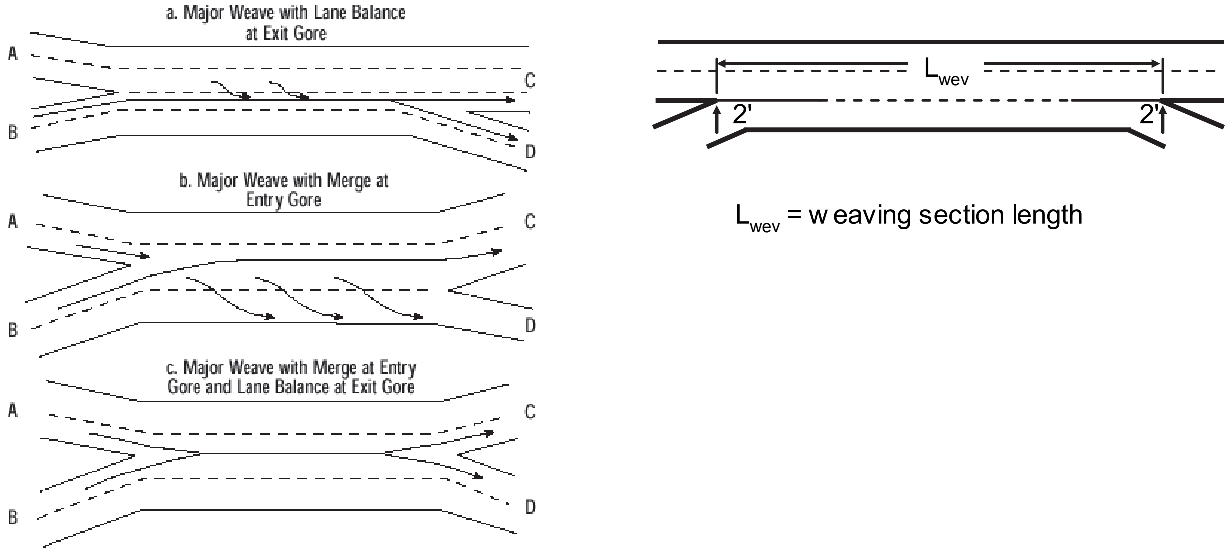
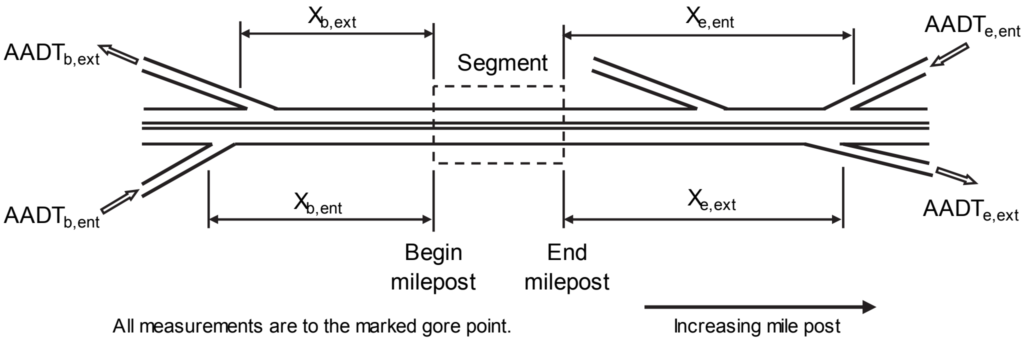
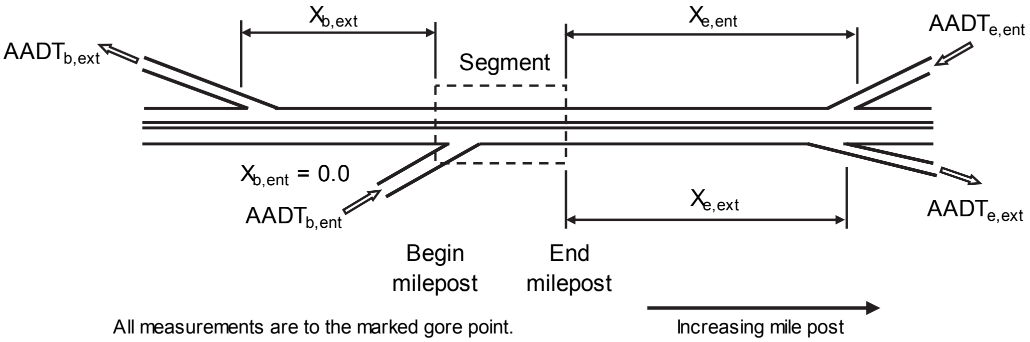


Figure 8. Type B Weaving Section and Length

- 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 9 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 ISATe 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 9a 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.



a. All Ramps External to the Segment



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

Figure 9. Distance to Nearest Ramp

- 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 9 using the two variables $X_{b,\ ext}$ and $X_{e,\ ext}$. Downstream *entrance* ramps are not of direct interest, and their data are not needed.

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

  This guidance is illustrated in Figure 10 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.

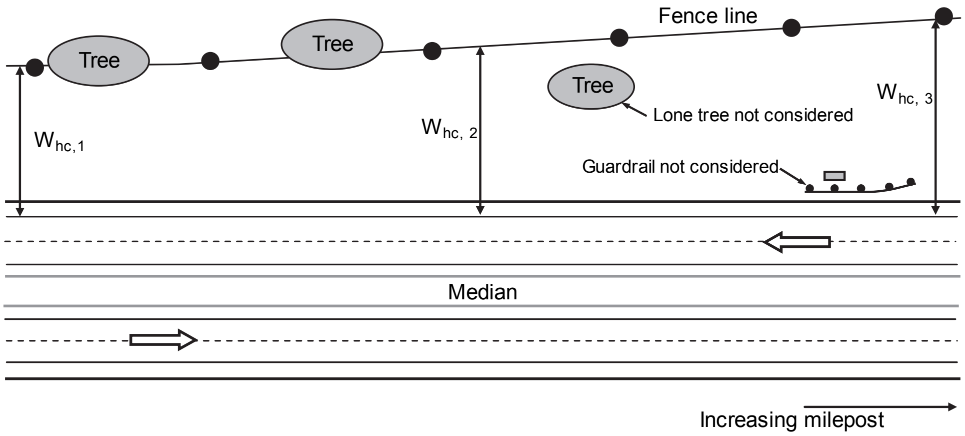


Figure 10. Clear Zone Width Considerations

- Proportion of freeway AADT volume that occurs during hours where the lane volume exceeds 1,000 vehicles per hour per lane (veh/h/ln). The lane volume for hour i LV_i is computed as $LV_i = HV_i/n$ where HV_i is the volume during hour i (i = 1, 2, 3, ..., 24) and n is the number of through lanes. The desired proportion P_{hv} is computed as $P_{hv} = (\Sigma\ HV_i^*)/AADT$ where $\Sigma\ HV_i^*$ is the sum of the volume during each hour where the lane volume exceeds 1,000 veh/h/ln. The *AADT*, *HV*, and *n* variables include both freeway travel directions. These data will typically be obtained from the continuous traffic counting station that (1) is nearest to the subject freeway and (2) has similar traffic demand and peaking characteristics. If this value is unknown, then leave the associated data entry cell in ISATe blank and a default value will be computed.
- Freeway AADT volume, upstream entrance ramp AADT volume, downstream exit ramp AADT volume.

Ramp and C-D Road Segments

The input data needed for ramp and C-D road segments is described in this subsection. There are several data identified in this subsection that describe a length along the roadway (e.g., segment length, curve length, weaving section length, etc.). All of these lengths are measured along the right edge of traveled way, in relation to the direction of travel.

- Number of through lanes. The total number of through lanes in the segment. Rural ramp segments are limited to one lane. Urban ramp segments are limited to two lanes. A segment with a lane-add (or lane-drop) taper is considered to have the same number of through lanes as the roadway just downstream of the lane-add (or lane-drop) taper.
    - Do not include any high-occupancy vehicle (HOV) bypass lanes.
    - Do not include any auxiliary lanes that are associated with a C-D road weaving section, unless the weaving section length exceeds 0.30 mi (1,600 ft). If this length is exceeded, then the auxiliary lane is counted as a through lane that starts as a lane-add ramp entrance and ends as a lane-drop ramp exit.
    - Do not include any auxiliary lanes that are developed as a turn bay (for queued vehicle storage) at the crossroad ramp terminal.
    - Do not include the speed-change lane that is associated with a second ramp that merges with (or diverges from) the subject ramp, unless its length exceeds 0.19 mi (1,000 ft). If this length is exceeded, then the speed-change lane is counted as a through lane that starts as a lane-add ramp entrance and ends as a lane drop by taper (or starts as a lane add by taper and ends as a lane-drop ramp exit).

This guidance is illustrated in Figure 11 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.

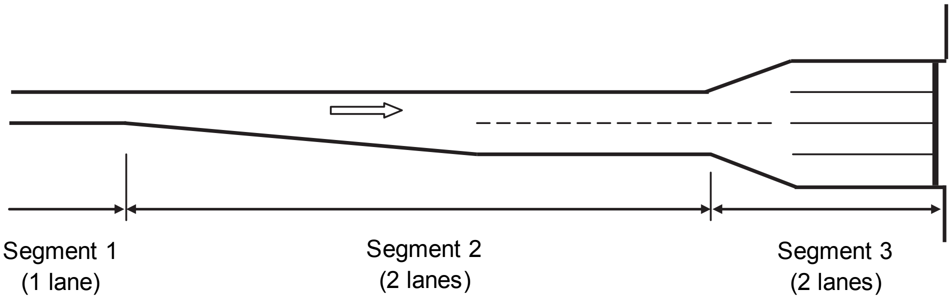
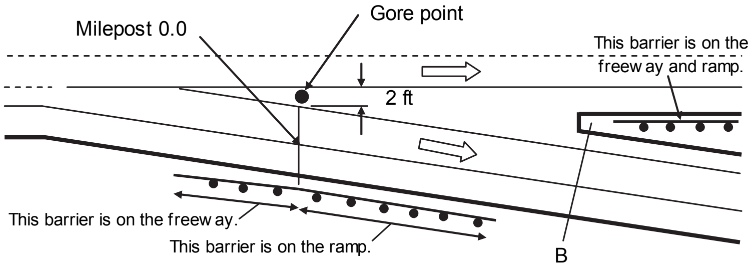


Figure 11. Number-of-Lanes Determination for Ramp Segments

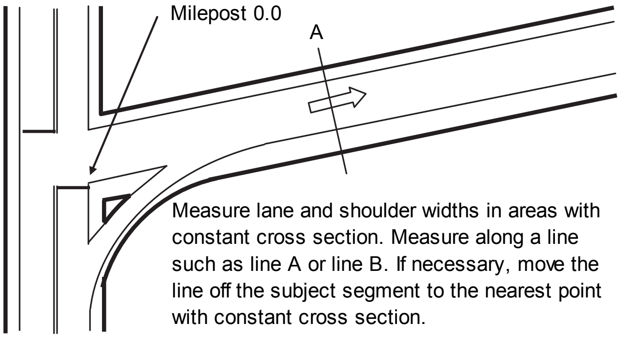
- Length of ramp or C-D road segment.
- Average traffic speed on the freeway during off-peak periods of the typical day. This speed is used to compute the speed for each curve (if any) that is present on the ramp. If better information is not available, then this speed can be estimated as the freeway 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.
    - 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.
    - If the curve is continued from a curve on an intersecting alignment, then consider only the curve length on the subject alignment. For example, if the subject ramp diverges from another ramp and the curvature from the originating ramp continues into the subject ramp, then the curve on the subject ramp is considered to start at the beginning of the subject ramp (i.e., at the gore point).
- Radius of curve. The radius is measured to the right edge of traveled way. If the curve has spiral transitions, then use the radius of the central circular portion of the curve.
- Length of curve in segment. The length of the curve within the boundaries of the segment. This length cannot exceed the segment length or the curve length.
- 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 12.
    - 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 12.
    - 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



Measure lane and shoulder 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 12. 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 12. They should not be measured where one or more edges are discontinuous or tapered. If a width varies along the segment (but not enough to justify beginning a new segment), then compute the length-weighted average width.
    - Lane width is an average for all through lanes (as defined at the start of this section).
    - 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.
    - Figure 13 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 13. 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 the 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 12.

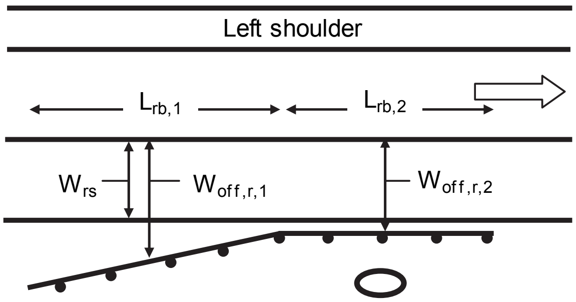


Figure 13. Barrier Variables

- Presence of an entrance speed-change lane (due to a second merging ramp). If a speed-change lane is present, then the length of the speed-change lane *in the segment* is needed. Guidance for measuring this length is provided in the following list:
    - Speed-change lane length in the segment is measured between the segment's 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 4 for freeway segments and is defined the same way for ramp segments.
    - 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 4 for freeway segments and is defined the same way for ramp segments.
- 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 8. The gore point is located where the pair of solid white pavement edge markings that separate the ramp from the C-D road are 2.0 ft apart. If the markings do not extend to a point where they are 2.0 ft apart, then the gore point is found by extrapolating both markings until the extrapolated portion is 2.0 ft apart. If the measured gore-to-gore distance exceeds 0.30 mi (1,600 ft), then a weaving section is not considered to exist. Rather, the entrance ramp is a "lane add" and the exit ramp is a "lane drop."
  - 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.

Crossroad Ramp Terminals

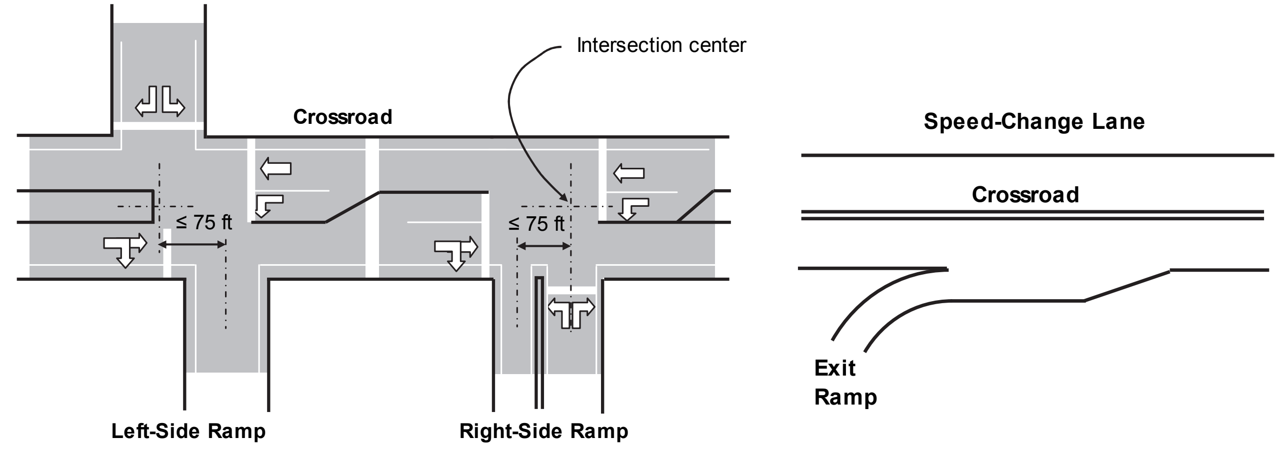
The input data that describe a crossroad ramp terminal are described in this subsection. The phrase "crossroad ramp terminal" refers to a controlled terminal between the ramp and crossroad. This type of terminal is addressed by the predictive method. A terminal where the ramp merges with (or diverges from) the crossroad as a speed-change lane is not addressed by the predictive method. Figure 14a and Figure 14b illustrate these two terminal types.

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.

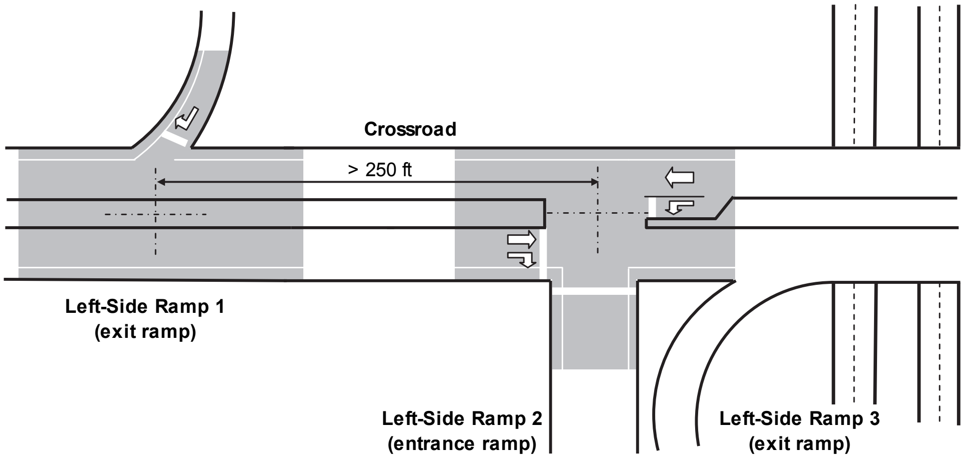
If the centerlines of the two ramps are offset by 75 ft or less, and they are configured to function as one intersection, then both ramps are considered to be part of the same intersection. This point is illustrated in Figure 14a for the left-side ramp and the right-side ramp at an interchange. Two intersections 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 14c 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 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. Four-Leg Intersection and Three-Leg Intersection b. Speed-Change Lane



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

Figure 14. Illustrative Ramp Terminals

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 1.
- Ramp terminal control type (signal, one-way stop control, all-way stop control). The predictive models are calibrated to address signal control, one-way stop control, and 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 15. 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 just behind the stop line. If vehicles can exit the ramp as left- or right-turn movements, then use a left-turning vehicle as the vehicle of reference. This information is needed only for terminals with one-way stop control. At a *B4* terminal configuration, the skew angle represents that for the diagonal exit ramp (not the loop exit ramp).

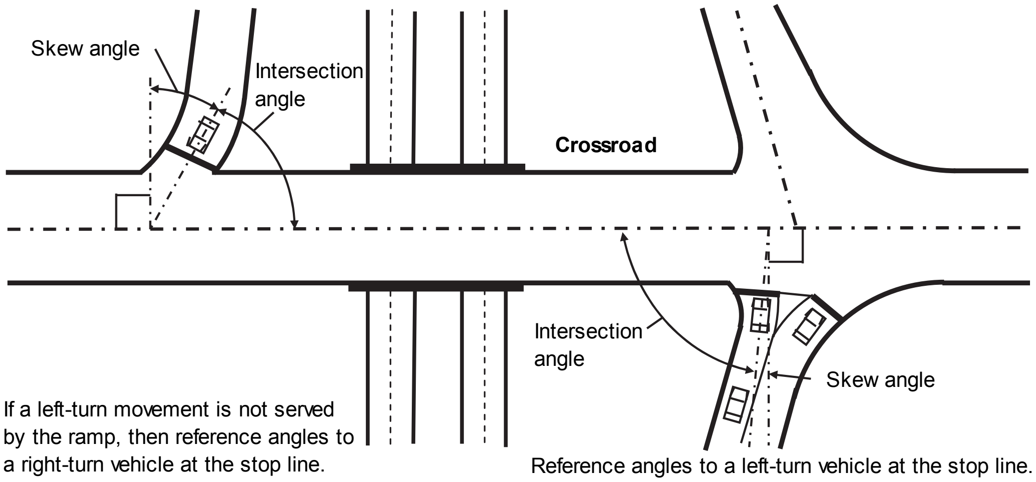


Figure 15. Exit Ramp Skew Angle

- Distance to the next public street intersection on the outside crossroad leg. This data element represents the distance between the subject ramp terminal and the nearest public street intersection located in a direction away from the freeway (measured along the crossroad from subject terminal center to intersection center).
- Distance to the adjacent ramp terminal. This data element represents the distance between the subject ramp terminal and the adjacent ramp terminal (measured along the crossroad from terminal center to terminal center). If there is no adjacent ramp terminal, then use the distance to the next public street intersection (located on the crossroad in the direction opposite to the intersection described in the previous bullet).
- Presence of protected left-turn operation (signal control). This information is needed for each crossroad left-turn movement that exists at the terminal. An affirmative response is indicated if the left-turn operates as protected only. If it operates as permissive or protected-permissive, then the response is negative. This information is needed only for signalized terminals.
- Exit ramp right-turn control type. This information is needed only for the exit ramp (at terminals with an exit ramp). It is focused on the right-turn movement, which may have a different control type than the left-turn movement. Control types considered include: free flow, merge, yield, stop, and signal (where free-flow and merge operation are recognized to represent “no control”). The free-flow type is associated with an accepting (or auxiliary) lane on the crossroad for the right-turn movement. The merge type is associated with a speed-change lane for the right-turn movement.
- Crossroad median width. This width is measured along a line perpendicular to the centerline of the crossroad in the vicinity of the intersection. If no median exists, then a width of 0.0 ft is used in the predictive model. If a raised curb is present, then the width is measured from face-of-curb to face-of-curb. If a raised curb is not present, then the width is measured between the near edge of traveled way for the two opposing travel directions. If a left-turn bay is present, then the

median width includes the width of the left-turn bay. It is measured from the lane line delineating the bay to the face-of-curb adjacent to (or the near edge of traveled way for) the opposing travel direction. If the median width is different on the two crossroad legs, then use an average of the two widths.

- Number of through lanes on the inside crossroad approach. Number of lanes (shared or exclusive) serving through traffic on the crossroad approach that is nearest to the freeway (i.e., the inside approach). 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.
- Presence of a left-turn lane (or bay) on the outside crossroad approach. The guidance provided in the previous bullet also applies to this variable.
- Width of left-turn lane (or bay) on the inside crossroad approach. This variable represents the total width of all lanes that exclusively serve turning vehicles on the subject approach. It is measured from the near edge of traveled way of the adjacent through lane to the near lane marking (or curb face) that delineates the median.

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

SEGMENTATION PROCESS

This section consists of two subsections. The first subsection describes the various sites that comprise the freeway facility. The second subsection describes the criteria for disaggregating roadway sections into homogenous segments that are suitable for evaluation as a study site using a predictive model.

Study Sites

When using the predictive method, the freeways, ramps, and C-D roads within the defined project limits are divided into individual sites. A site is a homogeneous freeway segment, homogenous ramp segment, homogeneous C-D road segment, or crossroad ramp terminal. The focus of the discussion in this subsection is on the sites located in the vicinity of an interchange due to the complexity of interchange roadways.

Four ramps and one C-D road are shown in Figure 16. This figure represents one side of an interchange. Each ramp is shown to consist of one segment. The C-D road is divided into five segments. The ramp segments are labeled R_{en1}, R_{en2}, R_{ex3}, and R_{ex4}. The C-D road segments are labeled CD_1 to CD_5. Two of the C-D road segments include a speed-change lane with a ramp. A third C-D road segment includes two speed-change lanes associated with the two loop ramps. The C-D road is not shown to have a weaving section; however, the predictive models can address C-D roads with or without a weaving section.

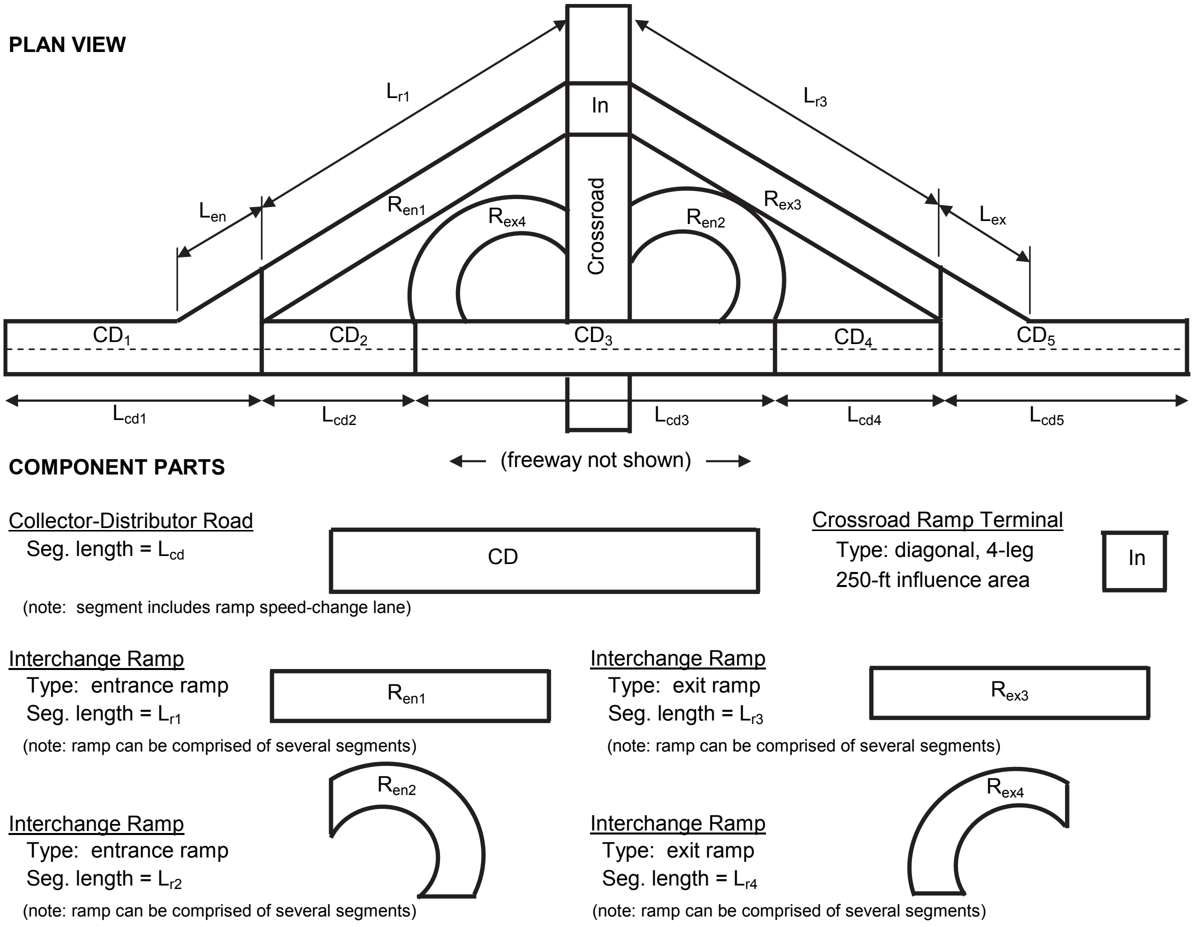


Figure 16. Illustrative Ramp Segments and Ramp Terminals

One crossroad ramp terminal is shown in Figure 16. 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.

Segmentation Criteria

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. The amount of change in feature dimension or presence that dictates the start of a new segment is described in this section.

Freeway Segments

A new homogeneous segment begins where there is a change in at least one of the following characteristics of the freeway:

- Number of through lanes. Begin segment at the gore point if the lane is added or dropped at a ramp or C-D road. Begin segment at the upstream start of taper if the lane is added or dropped by taper. This guidance is shown in Figure 25.
- Lane width. Measure the lane width at successive points along the roadway. Compute an average lane width for each point and round this average to the nearest 0.5 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 11.5 to 12.0 ft).
- Outside shoulder width. Measure the outside shoulder width at successive points along the roadway. Compute an average shoulder width for each point and round this average to the nearest 1.0 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 6 to 7 ft).
- Inside shoulder width. Measure the inside shoulder width at successive points along the roadway. Compute an average shoulder width for each point and round this average to the nearest 1.0 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 6 to 5 ft).
- Median width. Measure the median width at successive points along the roadway. Round the measured median width at each point to the nearest 10 ft. If the rounded value exceeds 90 ft, then set it to 90 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 30 to 20 ft)..
- Ramp presence. Begin segment at the ramp gore point.
- Clear zone width. Measure the clear zone width at successive points along the roadway. Compute an average clear zone width for each point and round this average to the nearest 5 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 25 to 30 ft).

The presence of a horizontal curve does not necessarily define segment boundaries. A ramp entrance or exit is evaluated with the adjacent freeway roadbed in the other travel direction. A freeway segment can include no more than one ramp entrance and one ramp exit in each travel direction.

Application of the “median width” segmentation criterion is shown in Figure 17. The freeway section in this figure is shown to consist of five segments. Segment 1 has a rounded median width of 70 ft. Segment 2 starts where the rounded median width first changes to 80 ft. Segment 3 begins at the point where the rounded median width first changes to 90 ft. Segment 4 begins where the rounded median width first changes to 80 ft. Segment 5 begins where the rounded median width first changes to 70 ft.

Guidance regarding the location of the lane, shoulder, median, and clear zone width measurement points is provided in Figure 6. The rounded lane, shoulder, median, and clear zone width values are used solely to determine segment boundaries. Once these boundaries are determined, the guidance in the text associated with Figure 6 is used to determine the average lane, shoulder, median, and clear zone width for the segment. The unrounded average for the segment is then used for all subsequent calculations in the predictive method.

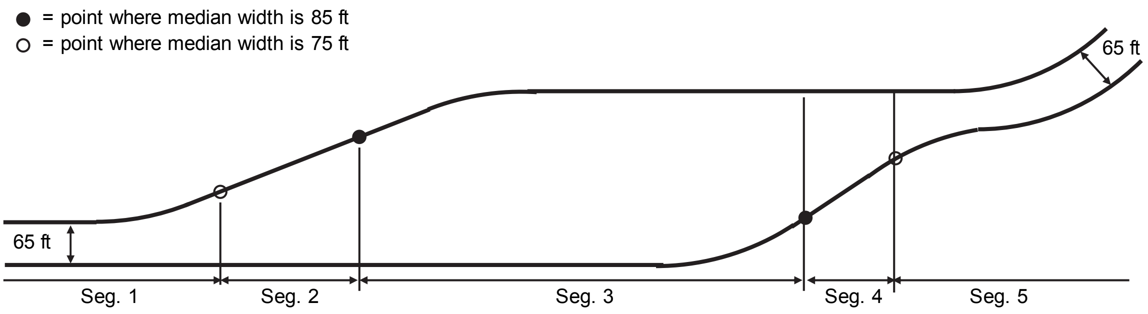


Figure 17. Segmentation for Varying Median Width

Ramp and C-D Road Segments

A new homogeneous ramp or C-D road segment begins where there is a change in at least one of the following characteristics of the roadway:

- Number of through lanes. Begin segment at the gore point if the lane is added or dropped at a ramp or C-D road. Begin segment at the upstream start of taper if the lane is added or dropped by taper.
- Lane width. Measure the lane width at successive points along the roadway. Compute an average lane width for each point and round this average to the nearest 0.5 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 12.5 to 13.0 ft).
- Right shoulder width. Measure the right shoulder width at successive points along the roadway. Round the measured shoulder width at each point to the nearest 1.0 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 4 to 5 ft).
- Left shoulder width. Measure the left shoulder width at successive points along the roadway. Round the measured shoulder width at each point to the nearest 1.0 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 4 to 3 ft).
- Merging ramp or C-D road presence. Begin segment at the gore point.
- Diverging ramp or C-D road presence. Begin segment at the gore point.

The presence of a horizontal curve does not necessarily define ramp or C-D road segment boundaries. Application of the “number of through lanes” criterion is shown in Figure 11.

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 12). When a segment begins or ends at a terminal formed by a merging or diverging ramp, then the length of the segment is measured from the gore point, as shown in Figure 12. A ramp or C-D road segment can include no more than one ramp entrance with a second ramp and one ramp exit with a second ramp.

Guidance regarding the location of the lane and shoulder width measurement points is provided in Figure 12. The rounded lane and shoulder width values are used solely to determine segment boundaries. Once these boundaries are determined, the guidance in the text associated with Figure 12 is used to determine the average lane and shoulder width for the segment. The unrounded average for the segment is then used for all subsequent calculations in the predictive method.

SITE DATA ENTRY

This section describes the data entry process for ISATe. ISATe provides four worksheets to facilitate data entry. They are identified in the following list.

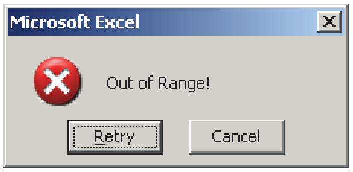
- **Main:** input data to describe evaluation and start calculations.
- **Input Freeway Segments:** input data describing freeway segments.
- **Input Ramp Segments:** input data describing ramp and C-D road segments.
- **Input Ramp Terminals:** input data describing crossroad ramp terminals.

Data Entry Basics

In each worksheet, the analyst enters information that describes the geometric design features, traffic control features, or traffic volume characteristics for each site in the project limits. These data are entered for the study period and, if applicable, the crash period.

The worksheet cells are used for data entry. Some cells accept numeric data, which can be typed in directly using the keyboard. Some cells provide a drop-down list of text choices. In this case, the analyst should use the mouse pointer to select the applicable choice.

If a numeric entry is not within an allowed range, or if it does not match one of the drop-down list of text choices, then a message box is displayed indicating “Out of Range!” The analyst can click Retry and re-enter the data, or click Cancel and return to the cell’s previous content.


Microsoft Excel

Out of Range!

With a couple of noted exceptions, data must be entered in every cell highlighted with a light blue background. One exception is AADT data. ISATe highlights one cell with a light blue background for every year in the evaluation period. AADT volume is required for one of these highlighted cells (i.e., for one year in the evaluation period), but it is optional for the other years. If the volume for a year is missing, then ISATe will estimate it using the rules described in the section titled Step 3—Acquire Traffic Volume and Observed Crash Data.

A second exception is the data describing short barrier pieces. Specifically, light-blue cells are provided for describing up to five pieces of barrier on each side of the segment. Only those cells needed to describe the barrier found along a segment are used. If there are fewer than five barrier pieces on a particular side of the segment, then the corresponding highlighted cells should be left blank.

Some data elements apply only when used with other data elements. ISATe monitors each data element that is entered and highlights all other applicable data entry cells using a light blue background. Similarly, it changes the cell background to white for any data elements that are not applicable. For example, if the Traffic Control Type for a crossroad ramp terminal is entered as “Signal”, then the cell associated with Exit Ramp Skew Angle for that terminal is changed to a white background. This change is made by ISATe because skew angle is not applicable to the predictive model for signalized terminals.

Any data that is entered in a cell that subsequently is changed to a white background (due to changes in other cells) will be ignored by ISATe.

Data entry in the input worksheets should proceed from top to bottom to take full advantage of ISATe's ability to highlight applicable data entry cells. That is, data entry should proceed in the direction of increasing row number. Entry in the top-down direction is not a requirement. The only consequence of entering data in a different order is that some data may be entered that is ultimately not needed for a specific site.

Main Worksheet

The information and data entered in the Main worksheet is universal to the project (and all sites in the project limits). This worksheet is shown in Figure 2. The input data elements are described in the following paragraphs.

General Information

The Project Description data entry field is used to describe the project being evaluated. This entry is not used by the predictive method. It is repeated in the Output Summary. It is an optional data entry field that will accept any desired combination of numeric and character data.

The Analyst data entry field is used to identify the person conducting the evaluation. This entry is not used by the predictive method. It is repeated in the Output Summary. It is an optional data entry field that will accept any desired combination of numeric and character data.

The Date data entry field is used to indicate the date of the evaluation (or any other date meaningful to the analyst). An equation in the cell will display the current date. It can be deleted or overwritten by the analyst. This entry is not used by the predictive method. It is repeated in the Output Summary. It is an optional data entry field that will accept any desired combination of numeric and character data.

The Area Type data entry field is used to indicate whether the project is in an urban or rural area. Only two entries will be accepted: "Urban" and "Rural." This entry is used by several SPFs and CMFs in the predictive method. It is repeated in the Output Summary. It is a required data entry field.

The First Year of Analysis and Last Year of Analysis data entry fields are used to define the first year and last year of the study period (inclusive). These data are used by several SPFs and CMFs in the predictive method. They are repeated in the Output Summary. They are required data entry fields. A common study period is used for all freeway segments, ramp segments, and crossroad ramp terminals.

Crash Data Description

The data entry fields in the Crash Data Description section are repeated for freeway segments, ramp (and C-D road) segments, and crossroad ramp terminals. The drop-down box indicates whether the EB Method will be used in the evaluation and, if used, whether it will be at the site-specific level or project level. This decision is made in Step 3, as described in the section titled Analysis Steps. The following three choices are offered in the drop-down box to facilitate this entry.

- No Crash Data.
- Data for All Segments Combined.
- Data for Each Individual Segment.

The first choice is selected if the EB Method will not be applied. The second choice is selected if the project-level EB Method will be applied. The third choice is selected if the site-specific EB Method will be applied. The choice made for one facility component can be different from that for the other two components.

If either the second or third choice is selected, then the First Year of Crash Data and the Last Year of Crash Data fields are highlighted with a light blue background and must be provided. These data define the first year and last year of the crash period (inclusive). These data are used with the EB Method in the predictive method. They are repeated in the Output Summary. They are required data entry cells.

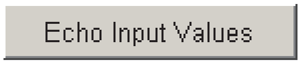
If the EB Method is used for two or more components, then the crash period can vary among these components. Desirably, a common crash period would be maintained for all facility components for which the EB Method is used.

Input Worksheets

The presentation in this section focuses on the Input Freeway Segments worksheet. However, each input worksheet is configured in a similar format and operates in a similar manner. For this reason, the guidance provided in this section is equally applicable to all three input worksheets, unless specifically noted otherwise.

Specific details related to each data element in each input worksheet are provided in a pop-up comment balloon. One comment is located on the worksheet row associated with the data element. It is identified by a red triangle (as shown in Figure 2).

Each input worksheet is organized to list the data elements from top to bottom along the left side of the worksheet. The adjacent columns are used to represent individual sites (i.e., a segment or crossroad ramp terminal). This arrangement is shown in Figure 3.



Each input worksheet has a button titled Echo Input Values. This button is located in the upper left corner of the worksheet. Its use is optional. If used, it initiates a software routine that reads the entered data and writes it to an unused area of the worksheet. The location of the “echoed” data is identified by the text just below the button. This routine allows the analyst to confirm that ISATe is correctly reading the entered data.

Each input worksheet has a button titled Check Input Values. This button is located in the upper left corner of the worksheet. Its use is encouraged. When used, it initiates a software routine that reads the entered data and checks it for consistency with other entered data for a common site. If any discrepancies are found, a brief message is written in an unused area of the worksheet. When the routine is finished, the active window is relocated to this area so the analyst can determine if any errors exist and their possible cause. The location of these messages is also identified by the text just below the button. This routine allows the analyst to confirm that the entered data is correct before performing any calculations.

Each input worksheet organizes the data elements in similar categories and lists them in the same order. A blank row is used to identify category headings in ISATe. This row has a light grey background. All related data elements are listed under the heading. These categories are identified in the following list. The specific titles may vary slightly among the three input worksheets.

- Basic Roadway Data.
- Alignment Data.
- Cross Section Data.

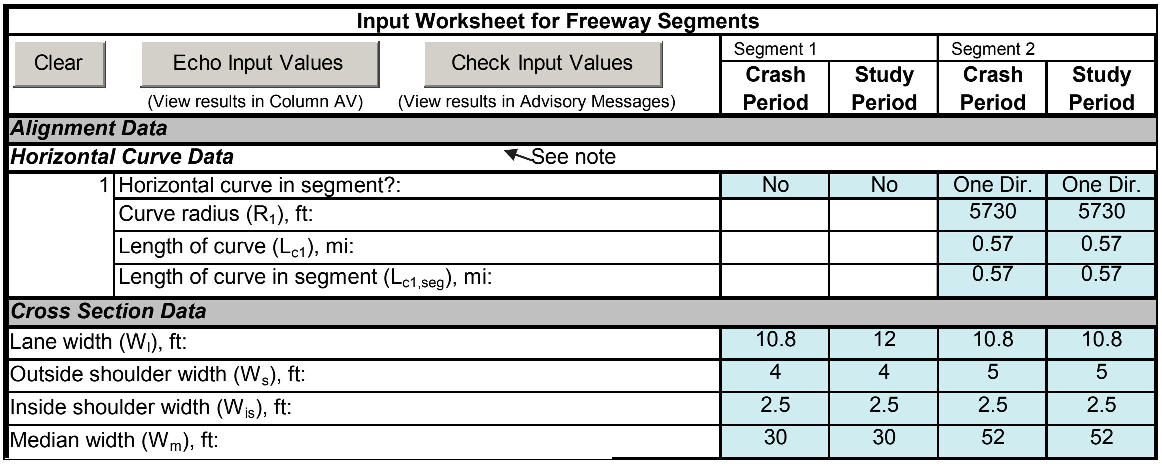
- Roadside Data.
- Access Data.
- Traffic Data.
- Crash Data.

Data elements in each category of the preceding list are described in the section titled Input Data Requirements. Data entry considerations for several of these categories are described in the following subsections.

Alignment Data

The Alignment Data section of the Input Freeway Segments worksheet is shown in Figure 18. Data describing the horizontal curves in a segment are described in this section. Data entry cells are provided for three curves in ISATe; however, theses cells are only shown for one curve in the figure. If a curve is in a segment, then its radius and length are required input data. The length of the curve in the segment is also a required input. This latter input recognizes that a curve may be in several consecutive segments.

Figure 18 illustrates the case where segment 1 has no curve and segment 2 has a curve on one roadbed (the roadbed serving the other travel direction is straight). If both roadbeds are curved, then "Both Dir." is input in the row titled "Horizontal curve in segment?"

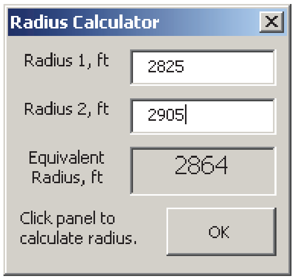


Input Worksheet for Freeway Segments

	Segment 1		Segment 2	
(View results in Column AV) (View results in Advisory Messages)	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**
Alignment Data				
Horizontal Curve Data ↖See note				
1 Horizontal curve in segment?:	No	No	One Dir.	One Dir.
Curve radius (R_1), ft:			5730	5730
Length of curve (L_{c1}), mi:			0.57	0.57
Length of curve in segment ($L_{c1,seg}$), mi:			0.57	0.57
Cross Section Data				
Lane width (W_l), ft:	10.8	12	10.8	10.8
Outside shoulder width (W_s), ft:	4	4	5	5
Inside shoulder width (W_{is}), ft:	2.5	2.5	2.5	2.5
Median width (W_m), ft:	30	30	52	52

Figure 18. Input Freeway Segments Worksheet–Alignment Data

If "Both Dir." is entered, then the Radius Calculator will pop up to assist in computing an equivalent radius for the combined curvature. The two radius measurements are entered in the respective fields (the order does not matter). The computed radius will accurately reflect the influence of both curves on segment crash frequency.



Radius Calculator

Radius 1, ft: 2825

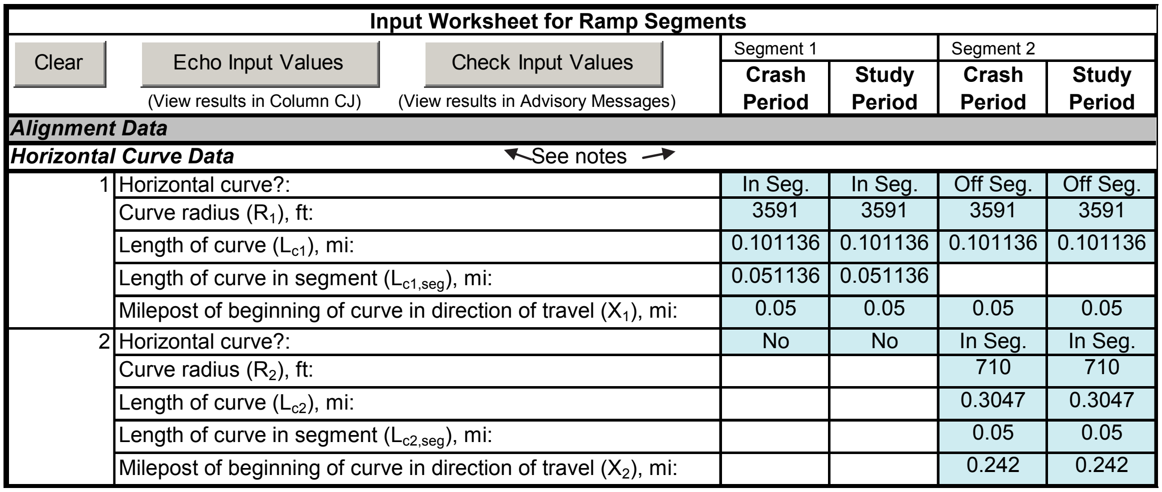
Radius 2, ft: 2905

Equivalent Radius, ft: 2864

Click panel to calculate radius.

The Alignment Data section of the Input Ramp Segments worksheet is shown in Figure 19. The curve data for each ramp segment are entered in this section. For a given segment, data are entered for all curves in the segment as well as those located prior to the subject segment. Information about the curves located prior to the segment is used to estimate the speed at each curve in the segment.

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 12 for simple situations. It is shown in Figure 20 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.

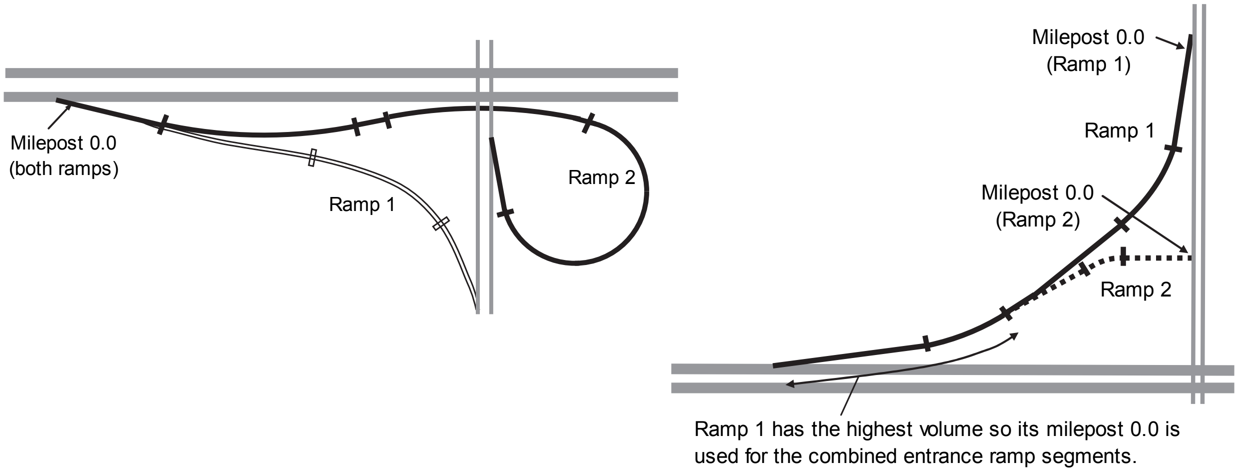


Input Worksheet for Ramp Segments

(View results in Column CJ) (View results in Advisory Messages)

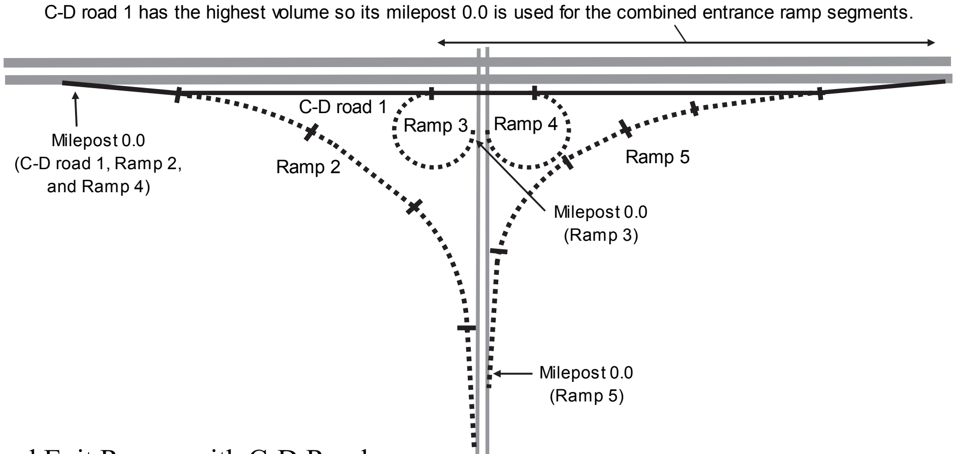
		Segment 1		Segment 2	
		Crash Period	**Study Period**	**Crash Period**	**Study Period**
Alignment Data					
Horizontal Curve Data	See notes				
1	Horizontal curve?:	In Seg.	In Seg.	Off Seg.	Off Seg.
	Curve radius (R_1), ft:	3591	3591	3591	3591
	Length of curve (L_{c1}), mi:	0.101136	0.101136	0.101136	0.101136
	Length of curve in segment ($L_{c1,seg}$), mi:	0.051136	0.051136		
	Milepost of beginning of curve in direction of travel (X_1), mi:	0.05	0.05	0.05	0.05
2	Horizontal curve?:	No	No	In Seg.	In Seg.
	Curve radius (R_2), ft:			710	710
	Length of curve (L_{c2}), mi:			0.3047	0.3047
	Length of curve in segment ($L_{c2,seg}$), mi:			0.05	0.05
	Milepost of beginning of curve in direction of travel (X_2), mi:			0.242	0.242

Figure 19. Input Ramp Segments Worksheet–Alignment Data



a. Exit Ramp b. Entrance Ramp

Figure 20. Starting Milepost Location for Ramp and C-D Road Combinations



c. Entrance and Exit Ramps with C-D Road

Figure 20. Starting Milepost Location for Ramp and C-D Road Combinations *continued*

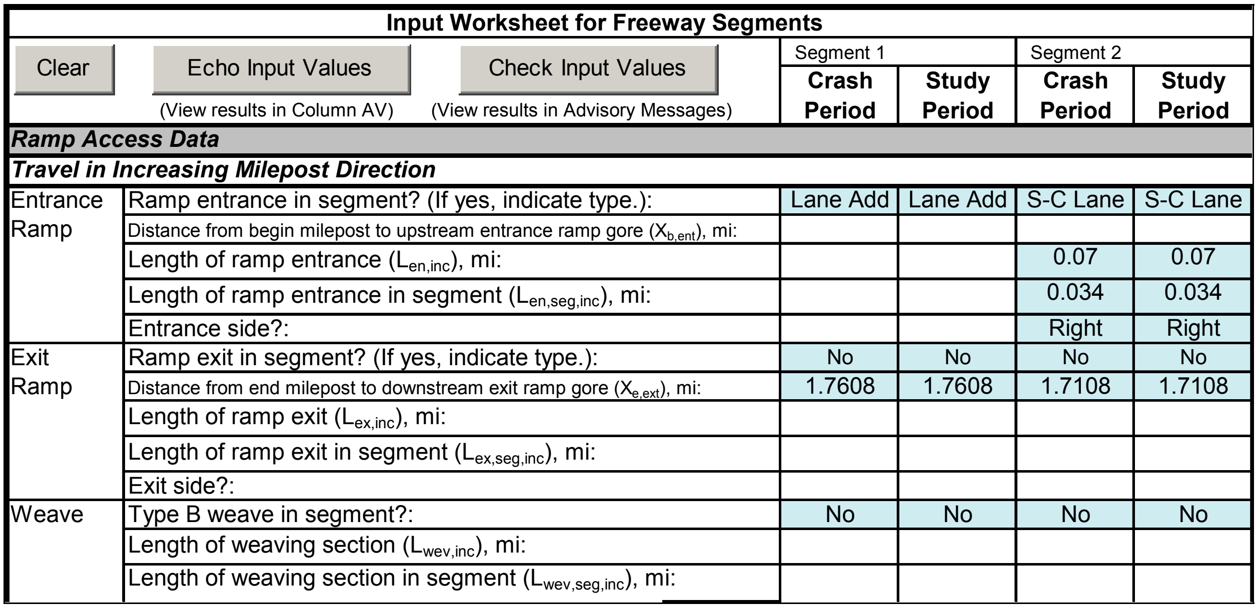
Cross Section Data

A portion of the Cross Section Data section of the Input Freeway Segments worksheet is shown in the bottom half of Figure 18. This figure is used to illustrate the input data for the first two segments shown in Figure 17. The freeway section in this figure is shown to consist of seven segments. Segment 1 has a length-weighted average median width of 67 ft. It has one curved roadbed and one that is straight. Segment 2 is defined to begin at the point where the rounded median width changes from 70 to 80 ft. It has a length-weighted average median width of 80 ft. Segment 3 begins at the point where the rounded median width changes from 80 to 90 ft. It has a length-weighted average median width in excess of 90 ft so, "90" is entered for the median width.

Access Data

The Ramp Access Data section of the Input Freeway Segments worksheet is shown in Figure 21. These data entry cells are used to describe the ramp entrances and exits located near or in the subject segment. If the ramp is not in the segment, then the distance between this ramp and the segment is entered. For a given segment, information about four ramps is requested. Two of these ramps are located on the roadbed serving travel in the increasing milepost direction and two ramps are located on the other roadbed. The ramps of interest are shown in Figure 9.

The data entry cells in Figure 21 are used to describe all types of weaving sections. The last three rows in the figure represent data entry cells used to describe weaving sections with the Type B configuration, as described in Figure 8.



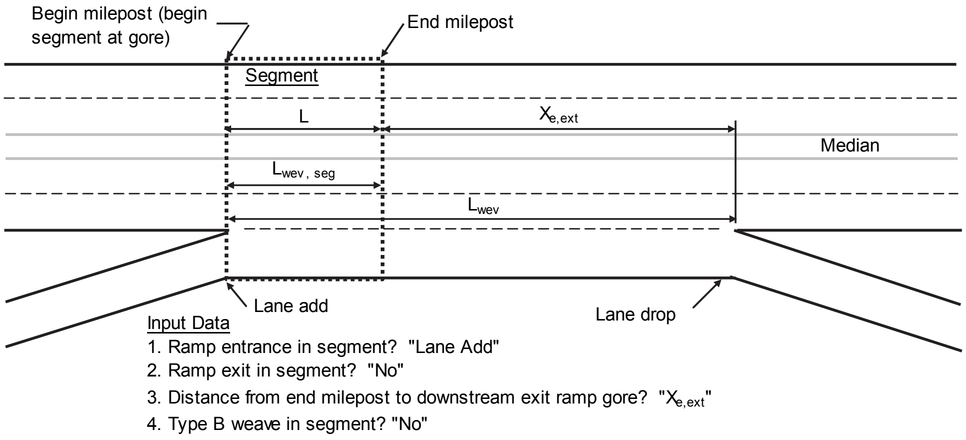
Input Worksheet for Freeway Segments

		Segment 1		Segment 2	
		Crash Period	**Study Period**	**Crash Period**	**Study Period**
Ramp Access Data					
Travel in Increasing Milepost Direction					
Entrance Ramp	Ramp entrance in segment? (If yes, indicate type.):	Lane Add	Lane Add	S-C Lane	S-C Lane
	Distance from begin milepost to upstream entrance ramp gore ($X_{b,ent}$), mi:				
	Length of ramp entrance ($L_{en,inc}$), mi:			0.07	0.07
	Length of ramp entrance in segment ($L_{en,seg,inc}$), mi:			0.034	0.034
	Entrance side?:			Right	Right
Exit Ramp	Ramp exit in segment? (If yes, indicate type.):	No	No	No	No
	Distance from end milepost to downstream exit ramp gore ($X_{e,ext}$), mi:	1.7608	1.7608	1.7108	1.7108
	Length of ramp exit ($L_{ex,inc}$), mi:				
	Length of ramp exit in segment ($L_{ex,seg,inc}$), mi:				
	Exit side?:				
Weave	Type B weave in segment?:	No	No	No	No
	Length of weaving section ($L_{wev,inc}$), mi:				
	Length of weaving section in segment ($L_{wev,seg,inc}$), mi:				

Figure 21. Input Freeway Segments Worksheet–Ramp Access Data

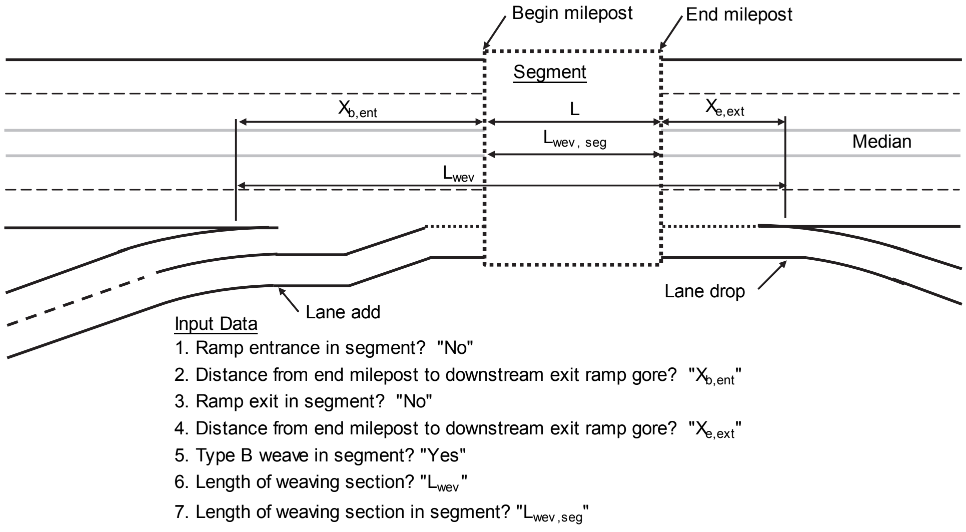
The input data appropriate for two weaving sections are shown in Figure 22. A basic weaving section is shown in Figure 22a. The segment is located such that the ramp entrance is located in the segment. This weaving section is not categorized as a Type B configuration, so the last three rows in Figure 21 are not used. However, data are used to describe the entrance and exit ramps associated with the weaving section. Specifically, the ramp entrance is described as “Lane Add” and the ramp exit is indicated to be off the segment. In this case, the distance to the ramp exit is entered.

A Type B weaving section is shown in Figure 22b. The segment is located near the middle of the weaving section. It does not include either the ramp entrance or exit, so the distance to both ramps is entered. The overall length of the weaving section is entered as well as the length of the weaving section that is in the segment. In this case, the length of the weaving section in the segment is equal to the segment length.



Input Data
1. Ramp entrance in segment? "Lane Add"
2. Ramp exit in segment? "No"
3. Distance from end milepost to downstream exit ramp gore? "$X_{e,ext}$"
4. Type B weave in segment? "No"

a. Basic Weaving Section

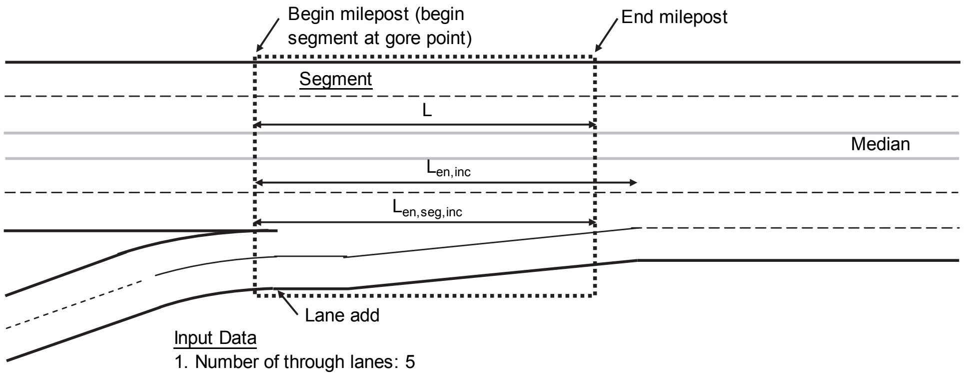


Input Data
1. Ramp entrance in segment? "No"
2. Distance from end milepost to downstream exit ramp gore? "$X_{b,ent}$"
3. Ramp exit in segment? "No"
4. Distance from end milepost to downstream exit ramp gore? "$X_{e,ext}$"
5. Type B weave in segment? "Yes"
6. Length of weaving section? "L_{wev}"
7. Length of weaving section in segment? "$L_{wev,seg}$"

b. Type B Weaving Section

Figure 22. Input Data Used to Describe a Weaving Section

The input data appropriate for a two-lane entrance ramp are shown in Figure 23. This geometry is shown to have a speed-change lane and a lane add associated with the entrance ramp. The added lane is *not* an auxiliary lane associated with a weaving section, so the lane addition is represented by entering five lanes for the segment. The speed-change lane is represented in the Ramp Access Data section. The segment is started at the gore point and extends to a point downstream (the segment was ended due to a change in lane width).

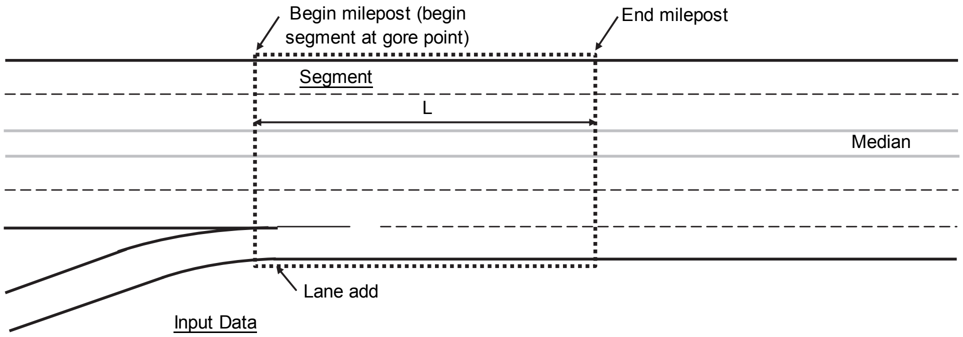


Input Data

1. Number of through lanes: 5
2. Ramp entrance in segment? "S-C Lane"
3. Length of ramp entrance: "$L_{en,inc}$"
4. Length of ramp entrance in segment: "$L_{en,seg,inc}$"
5. Entrance side? "Right"
6. Ramp exit in segment? "No"
7. Type B weave in segment? "No"

Figure 23. Input Data Used to Describe a Two-Lane Entrance Ramp

The input data for a lane-add entrance ramp are shown in Figure 24. The added lane is *not* an auxiliary lane associated with a weaving section, so the lane addition is represented by entering five lanes for the segment and entering "Lane Add" in the Ramp Access Data section. The segment is started at the gore point and extends to a point downstream (the segment was ended due to a change in lane width).

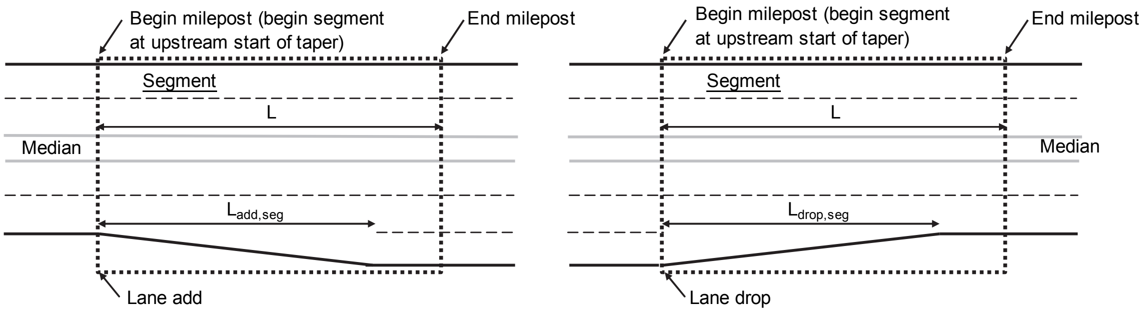


Input Data

1. Number of through lanes: 5
2. Ramp entrance in segment? "Lane Add"
3. Ramp exit in segment? "No"
4. Type B weave in segment? "No"

Figure 24. Input Data Used to Describe a Lane-Add Entrance Ramp

The input data for a segment with a lane addition and a segment with a lane drop are shown in Figure 25. Both changes in cross section are accomplished using a taper, as opposed to a ramp. There is no ramp access on either segment.



Input Data
1. Number of through lanes: 5 (= downstream lane count)
2. Ramp entrance in segment? "No"
3. Ramp exit in segment? "No"
4. Type B weave in segment? "No"

Input Data
1. Number of through lanes: 4 (= downstream lane count)
2. Ramp entrance in segment? "No"
3. Ramp exit in segment? "No"
4. Type B weave in segment? "No"

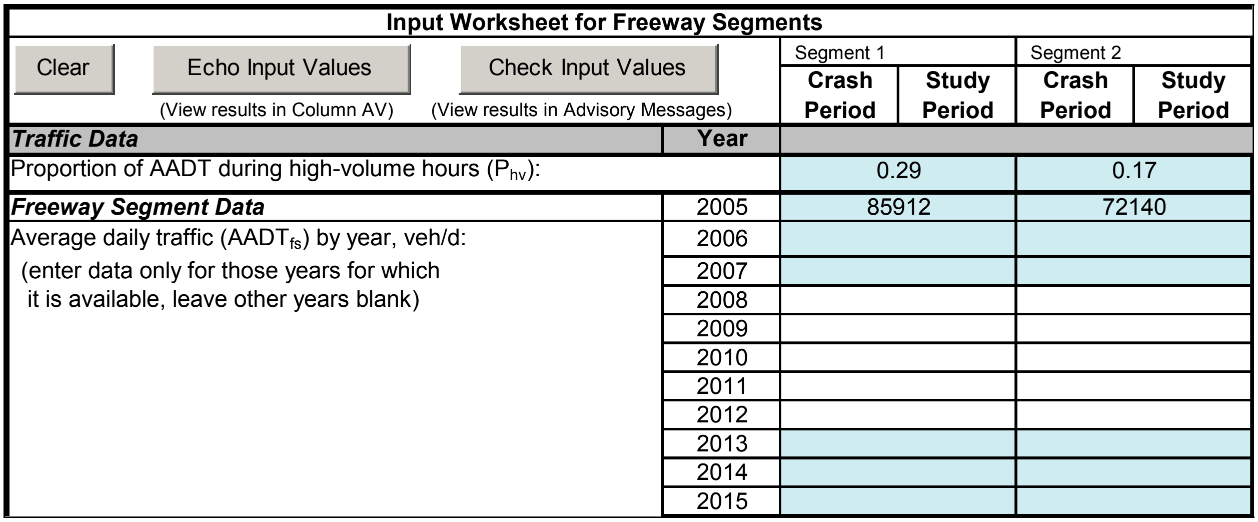
Figure 25. Input Data for Lane-Add and Lane-Drop Segments

Traffic Data

The Traffic Data section of the Input Freeway Segments worksheet is shown in Figure 26. The AADT data are entered in this section. As noted previously, the AADT data entry cells are one of two data elements for which some of the cells with light-blue background can be left blank (barrier data represents the other data element for which the light-blue cells can be left blank when barrier is not present).

AADT data must be provided for at least one cell with a light-blue background for each site. If the AADT volume for a year is missing, then ISATe will estimate it using the rules described in the section titled Step 3—Acquire Traffic Volume and Observed Crash Data.

In Figure 26, the cells with light-blue background coincide with the years 2005 to 2007 and 2013 to 2015. The first set of blue cells represent the crash period. The second set of cells represent the study period. These years were specified in the Main worksheet, as shown in Figure 2.



Input Worksheet for Freeway Segments

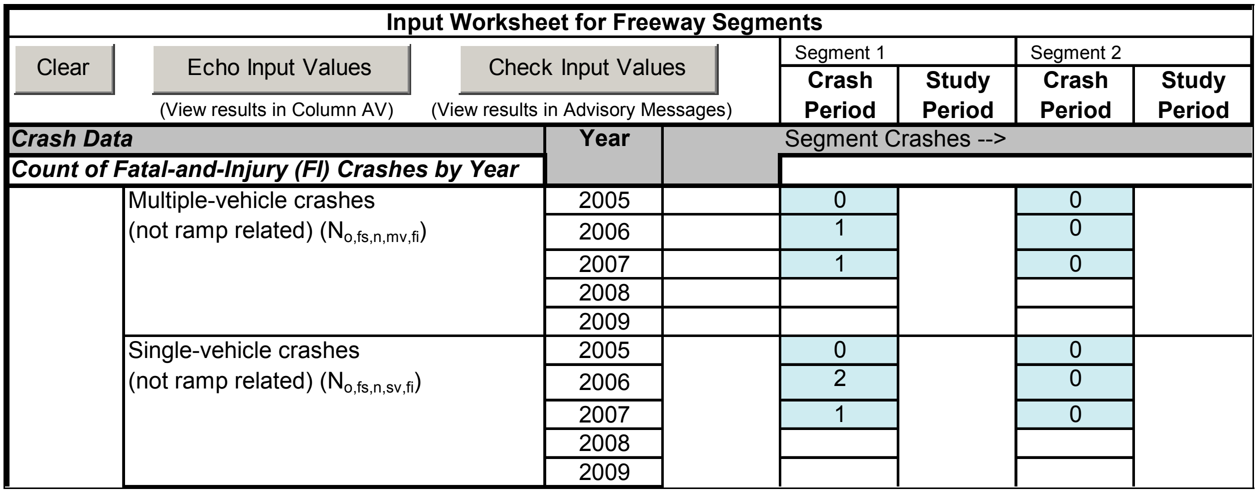
		Segment 1		Segment 2	
		Crash Period	**Study Period**	**Crash Period**	**Study Period**
Traffic Data	**Year**				
Proportion of AADT during high-volume hours (P_{hv}):		0.29		0.17	
Freeway Segment Data	2005	85912		72140	
Average daily traffic ($AADT_{fs}$) by year, veh/d:	2006				
(enter data only for those years for which it is available, leave other years blank)	2007				
	2008				
	2009				
	2010				
	2011				
	2012				
	2013				
	2014				
	2015				

Figure 26. Input Freeway Segments Worksheet–Traffic Data

Figure 26 shows that the data entry cells for both the crash period and the study period are in a common (i.e., merged) column. These data entry cells apply to *both* periods. This approach to AADT data entry is intended to simplify the entry of AADT data because the study period and crash periods often overlap.

Crash Data

The Crash Data section of the Input Freeway Segments worksheet is shown in Figure 27. This section is used if crash data are available and the analyst desires to use the EB Method to obtain a more reliable estimate of the expected average crash frequency. The observed crash counts are entered in this section. Data are entered for all data entry cells with a light-blue background. These cells are in the column headed Crash Period and represent data that correspond to the crash period.



				Segment 1		Segment 2	
				Crash Period	**Study Period**	**Crash Period**	**Study Period**
Crash Data		**Year**		Segment Crashes -->			
Count of Fatal-and-Injury (FI) Crashes by Year							
	Multiple-vehicle crashes (not ramp related) ($N_{o,fs,n,mv,fi}$)	2005		0		0	
		2006		1		0	
		2007		1		0	
		2008					
		2009					
	Single-vehicle crashes (not ramp related) ($N_{o,fs,n,sv,fi}$)	2005		0		0	
		2006		2		0	
		2007		1		0	
		2008					
		2009					

Figure 27. Input Freeway Segments Worksheet–Crash Data

The data entry cells shown in Figure 27 correspond to the site-specific EB Method. The values entered in this section must represent the crash counts for each site reported during the calendar year indicated. The crashes are categorized by crash severity (i.e., fatal-and-injury crash and property-damage-only crash) and by crash type (i.e., multiple-vehicle crash and single-vehicle crash).

If the project-level EB Method is used, then the cells with light-blue background in Figure 27 will have their background changed to white. The white cells just to the right of the Year column will have their background changed to light blue. The values entered in these cells must represent the number of crashes aggregated over all sites reported during the calendar year indicated. The crashes are categorized by crash severity.

RESULTS REVIEW AND INTERPRETATION

This section describes the output data provided by ISATe. These data are provided in four worksheets in ISATe. These worksheets are identified in the following list.

- Output Summary.
- Output Freeway Segments.
- Output Ramp Segments.
- Output Ramp Terminals.

The output data provided in the Output Summary worksheet will provide the information needed for many applications. Optionally, the analyst can review the detailed results of the analysis in the three worksheets specific to a given facility component (i.e., freeway segment, ramp segment, or ramp terminal). The information in these worksheets is described in the following subsections.

Output Summary

The Perform Calculations button in the Main worksheet is used to initiate the calculations associated with the predictive methods in ISATe. The calculations will take a few seconds to complete. When they are completed, the analyst can view the results in the Output Summary worksheet. An example of this worksheet is shown in Figure 28.

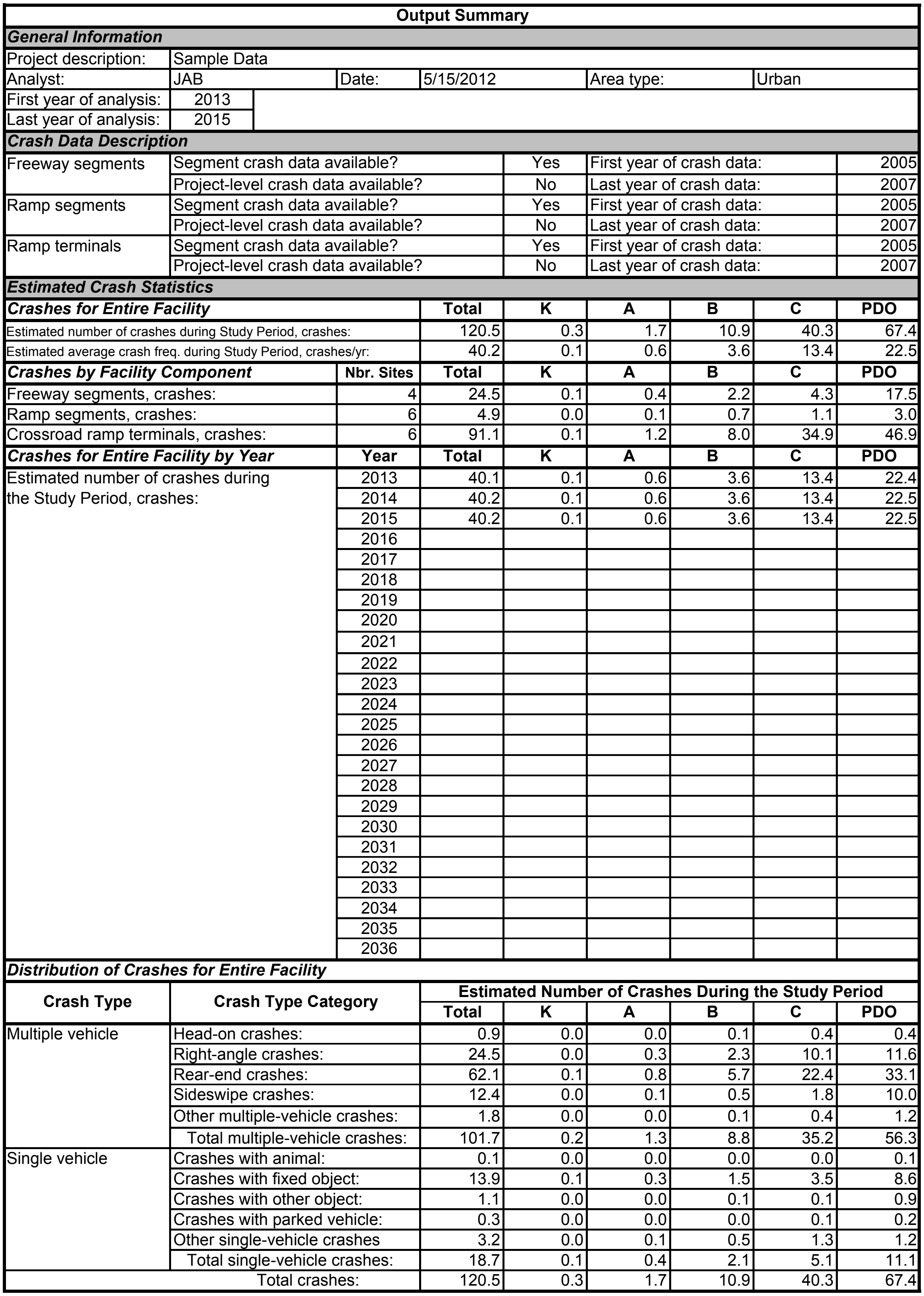
The results of the analysis are shown in four sections in the output summary. The data in each section correspond to the study period. Estimates associated with the crash period are not shown unless the crash period is within the study period.

The first section is titled Crashes for the Entire Facility. This section lists the estimated number of crashes for all sites in the project limits and a distribution of this total by crash severity. This section also lists the estimated average crash frequency for the project. This estimate is equal to the estimated number of crashes divided by the number of years in the study period.

The second section is titled Crashes by Facility Component. This section lists the estimated number of crashes (in total and by severity) for all sites associated with a given facility component. The number of sites by component is also indicated.

The third section is titled Crashes for Entire Facility by Year. This section lists the estimated number of crashes (in total and by severity) for all sites in the project limits by year. ISATe can evaluate up to 24 consecutive years. The three years for which data are shown in Figure 28 correspond to the study period.

The forth section is titled Distribution of Crashes for Entire Facility. This section lists the estimated number of crashes (in total, and by crash type and severity) for all sites in the project limits. Five crash type categories are associated with multiple-vehicle crashes and five categories are associated with single-vehicle crashes.



Output Summary

General Information

Project description:	Sample Data				
Analyst:	JAB	Date:	5/15/2012	Area type:	Urban
First year of analysis:	2013				
Last year of analysis:	2015				

Crash Data Description

Freeway segments	Segment crash data available?	Yes	First year of crash data:	2005
	Project-level crash data available?	No	Last year of crash data:	2007
Ramp segments	Segment crash data available?	Yes	First year of crash data:	2005
	Project-level crash data available?	No	Last year of crash data:	2007
Ramp terminals	Segment crash data available?	Yes	First year of crash data:	2005
	Project-level crash data available?	No	Last year of crash data:	2007

Estimated Crash Statistics

Crashes for Entire Facility	**Total**	**K**	**A**	**B**	**C**	**PDO**
Estimated number of crashes during Study Period, crashes:	120.5	0.3	1.7	10.9	40.3	67.4
Estimated average crash freq. during Study Period, crashes/yr:	40.2	0.1	0.6	3.6	13.4	22.5

Crashes by Facility Component	**Nbr. Sites**	**Total**	**K**	**A**	**B**	**C**	**PDO**
Freeway segments, crashes:	4	24.5	0.1	0.4	2.2	4.3	17.5
Ramp segments, crashes:	6	4.9	0.0	0.1	0.7	1.1	3.0
Crossroad ramp terminals, crashes:	6	91.1	0.1	1.2	8.0	34.9	46.9

Crashes for Entire Facility by Year	**Year**	**Total**	**K**	**A**	**B**	**C**	**PDO**
Estimated number of crashes during the Study Period, crashes:	2013	40.1	0.1	0.6	3.6	13.4	22.4
	2014	40.2	0.1	0.6	3.6	13.4	22.5
	2015	40.2	0.1	0.6	3.6	13.4	22.5
	2016						
	2017						
	2018						
	2019						
	2020						
	2021						
	2022						
	2023						
	2024						
	2025						
	2026						
	2027						
	2028						
	2029						
	2030						
	2031						
	2032						
	2033						
	2034						
	2035						
	2036						

Distribution of Crashes for Entire Facility

Crash Type	**Crash Type Category**	**Estimated Number of Crashes During the Study Period**					
		Total	**K**	**A**	**B**	**C**	**PDO**
Multiple vehicle	Head-on crashes:	0.9	0.0	0.0	0.1	0.4	0.4
	Right-angle crashes:	24.5	0.0	0.3	2.3	10.1	11.6
	Rear-end crashes:	62.1	0.1	0.8	5.7	22.4	33.1
	Sideswipe crashes:	12.4	0.0	0.1	0.5	1.8	10.0
	Other multiple-vehicle crashes:	1.8	0.0	0.0	0.1	0.4	1.2
	Total multiple-vehicle crashes:	101.7	0.2	1.3	8.8	35.2	56.3
Single vehicle	Crashes with animal:	0.1	0.0	0.0	0.0	0.0	0.1
	Crashes with fixed object:	13.9	0.1	0.3	1.5	3.5	8.6
	Crashes with other object:	1.1	0.0	0.0	0.1	0.1	0.9
	Crashes with parked vehicle:	0.3	0.0	0.0	0.0	0.1	0.2
	Other single-vehicle crashes	3.2	0.0	0.1	0.5	1.3	1.2
	Total single-vehicle crashes:	18.7	0.1	0.4	2.1	5.1	11.1
	Total crashes:	120.5	0.3	1.7	10.9	40.3	67.4

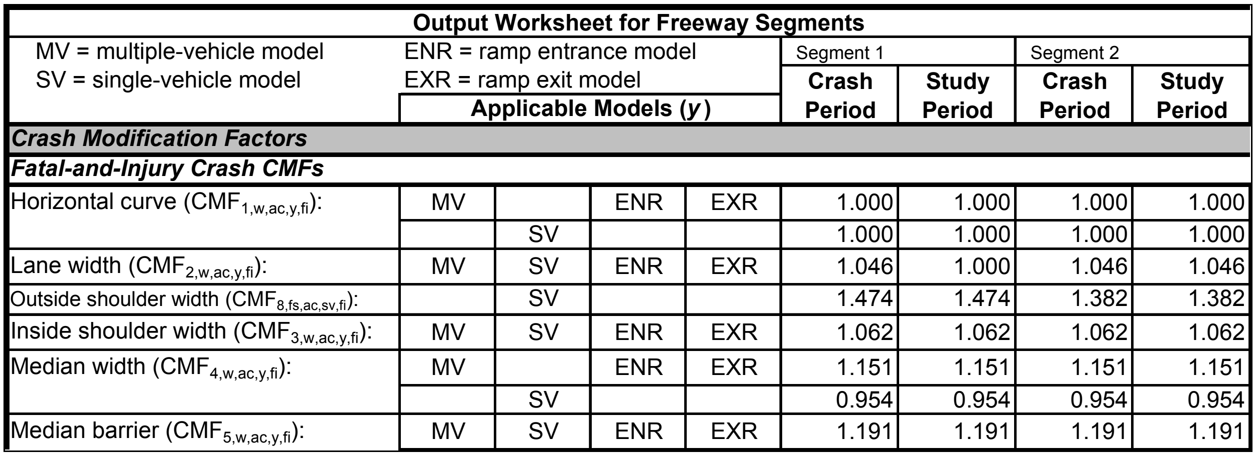
Figure 28. Output Summary Worksheet

Output Worksheets

The data in the output worksheets are divided into the following sections.

- Crash Modification Factors.
- Expected Average Crash Frequency.
    - Fatal-and-Injury (FI) Crash Frequency.
    - Property-Damage-Only (PDO) Crash Frequency.
    - Crash Severity Distribution.
- Intermediate Results.
- Traffic Data.

A portion of the Crash Modification Factors section is shown in Figure 29. Listed first are the CMFs that are used with the model that predicts FI crash frequency. Thereafter, the CMFs that are used with the model that predicts PDO crash frequency are listed.



Output Worksheet for Freeway Segments

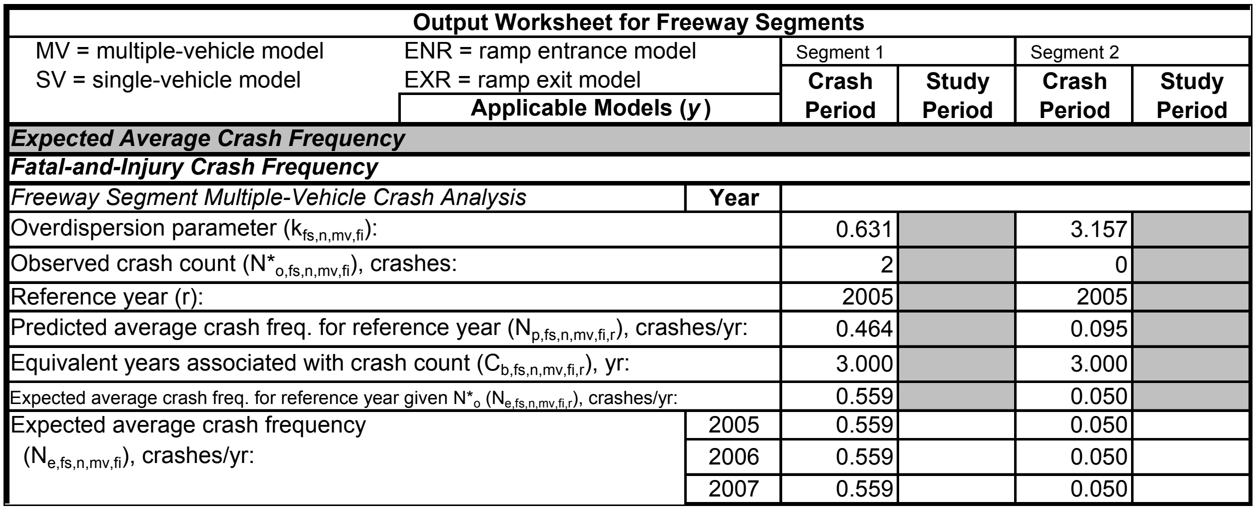
					Segment 1		Segment 2	
MV = multiple-vehicle model SV = single-vehicle model	ENR = ramp entrance model EXR = ramp exit model				**Crash Period**	**Study Period**	**Crash Period**	**Study Period**
	Applicable Models (y)							
Crash Modification Factors								
Fatal-and-Injury Crash CMFs								
Horizontal curve ($CMF_{1,w,ac,y,fi}$):	MV		ENR	EXR	1.000	1.000	1.000	1.000
		SV			1.000	1.000	1.000	1.000
Lane width ($CMF_{2,w,ac,y,fi}$):	MV	SV	ENR	EXR	1.046	1.000	1.046	1.046
Outside shoulder width ($CMF_{8,fs,ac,sv,fi}$):		SV			1.474	1.474	1.382	1.382
Inside shoulder width ($CMF_{3,w,ac,y,fi}$):	MV	SV	ENR	EXR	1.062	1.062	1.062	1.062
Median width ($CMF_{4,w,ac,y,fi}$):	MV		ENR	EXR	1.151	1.151	1.151	1.151
		SV			0.954	0.954	0.954	0.954
Median barrier ($CMF_{5,w,ac,y,fi}$):	MV	SV	ENR	EXR	1.191	1.191	1.191	1.191

Figure 29. Output Freeway Segments Worksheet–Crash Modification Factors

This section provides a summary of the computed CMF values. These CMFs are included in the predictive method. The CMF equations are described in the final report by Bonneson et al. (1).

Each CMF is associated with one geometric design or traffic control feature. Its value is 1.0 when the feature's characteristics are the same as those used to define the base condition for the predictive model. The CMF value will be less than 1.0 if (a) the characteristics of the associated feature are different from those of the base condition and (b) the sites that have this variation of the feature experience fewer crashes than otherwise similar sites but with feature characteristics consistent with base conditions. The *Highway Safety Manual* provides additional discussion of CMFs (2).

A portion of the Expected Average Crash Frequency section is shown in Figure 30. This section has separate subsections that summarize the estimates of expected average FI crash frequency, expected average PDO crash frequency, and expected average crash frequency by severity level. Within subsections, the estimates are further categorized by crash type. Figure 30 shows the summary for multiple-vehicle FI crashes on freeway segments that do not include a speed-change lane.



Output Worksheet for Freeway Segments					
MV = multiple-vehicle model SV = single-vehicle model	ENR = ramp entrance model EXR = ramp exit model	Segment 1		Segment 2	
	Applicable Models (*y*)	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**
Expected Average Crash Frequency					
Fatal-and-Injury Crash Frequency					
Freeway Segment Multiple-Vehicle Crash Analysis	**Year**				
Overdispersion parameter ($k_{fs,n,mv,fi}$):		0.631		3.157	
Observed crash count ($N^*_{o,fs,n,mv,fi}$), crashes:		2		0	
Reference year (r):		2005		2005	
Predicted average crash freq. for reference year ($N_{p,fs,n,mv,fi,r}$), crashes/yr:		0.464		0.095	
Equivalent years associated with crash count ($C_{b,fs,n,mv,fi,r}$), yr:		3.000		3.000	
Expected average crash freq. for reference year given N^*_o ($N_{e,fs,n,mv,fi,r}$), crashes/yr:		0.559		0.050	
Expected average crash frequency ($N_{e,fs,n,mv,fi}$), crashes/yr:	2005	0.559		0.050	
	2006	0.559		0.050	
	2007	0.559		0.050	

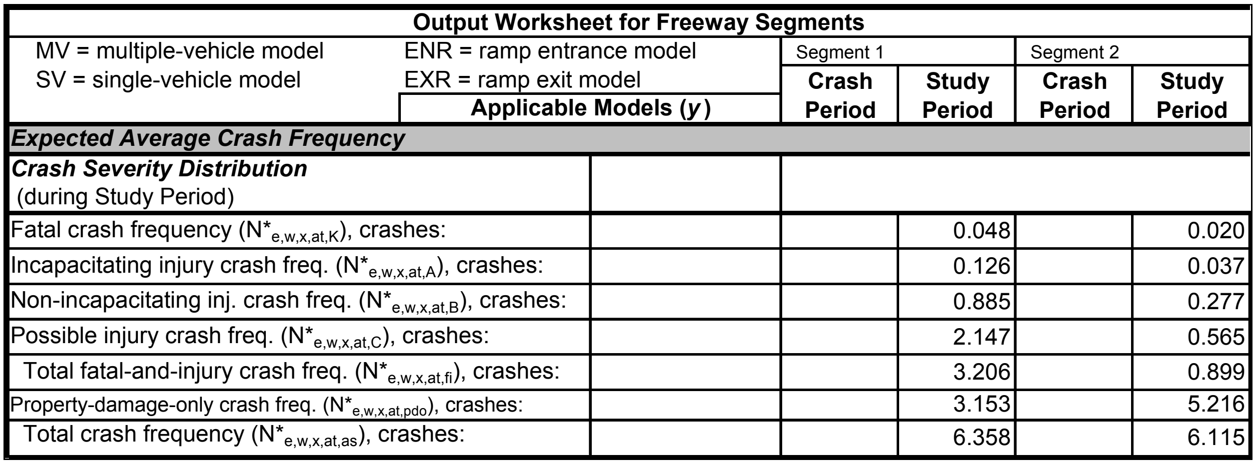
Figure 30. Output Freeway Segments Worksheet–Expected Average Crash Frequency

In Figure 30, the row titled Overdispersion Parameter and all rows below it to (and including) the row titled “Expected average crash freq. for...” have numbers displayed for Segments 1 and 2. These numbers are present because the site-specific EB Method was applied to the sample data shown. These rows are blank if the EB Method is not used.

The last three rows in Figure 30 show the expected average crash frequency for each site and year if the EB Method is used. They show the predicted average crash frequency for each site and year if the EB Method is not used.

Only three years are shown in the figure; however, rows are provided in the worksheet to report estimates for twenty-one additional years. The three years for which estimates are shown in the figure correspond to the crash period. Estimates for the study period (i.e., 2013, to 2015) are not shown in the figure but were computed and shown in the worksheet (under the column headed Study Period).

A portion of the Crash Severity Distribution is shown in Figure 31. It is at the end of the Expected Average Crash Frequency section. The distribution lists the expected average crash frequency by severity level for each site. The estimates shown represent the sum for all years in the study period. They were computed using the severity distribution functions that are part of the predictive method. These functions predict the proportion of crashes associated with each severity level, as a function of the subject site’s geometric design and traffic control features.

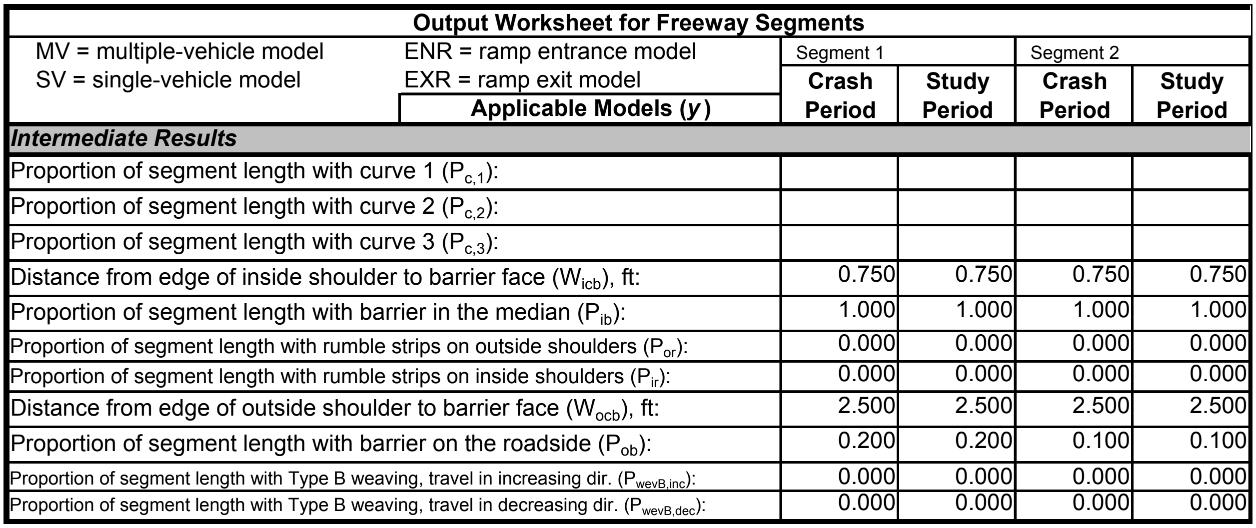


Output Worksheet for Freeway Segments

MV = multiple-vehicle model SV = single-vehicle model	ENR = ramp entrance model EXR = ramp exit model Applicable Models (*y*)	Segment 1		Segment 2	
		Crash Period	**Study Period**	**Crash Period**	**Study Period**
Expected Average Crash Frequency					
Crash Severity Distribution (during Study Period)					
Fatal crash frequency ($N^*_{e,w,x,at,K}$), crashes:			0.048		0.020
Incapacitating injury crash freq. ($N^*_{e,w,x,at,A}$), crashes:			0.126		0.037
Non-incapacitating inj. crash freq. ($N^*_{e,w,x,at,B}$), crashes:			0.885		0.277
Possible injury crash freq. ($N^*_{e,w,x,at,C}$), crashes:			2.147		0.565
Total fatal-and-injury crash freq. ($N^*_{e,w,x,at,fi}$), crashes:			3.206		0.899
Property-damage-only crash freq. ($N^*_{e,w,x,at,pdo}$), crashes:			3.153		5.216
Total crash frequency ($N^*_{e,w,x,at,as}$), crashes:			6.358		6.115

Figure 31. Output Freeway Segments Worksheet–Crash Severity Distribution

A portion of the Intermediate Results section is shown in Figure 32. It lists the variables that were computed and used in one or more of the CMFs in a predictive model. The CMF equations and related variables are described in the final report by Bonneson et al. (1). The values shown in Figure 32 can be used to more fully understand and interpret the CMF values shown in the Crash Modification Factors section.

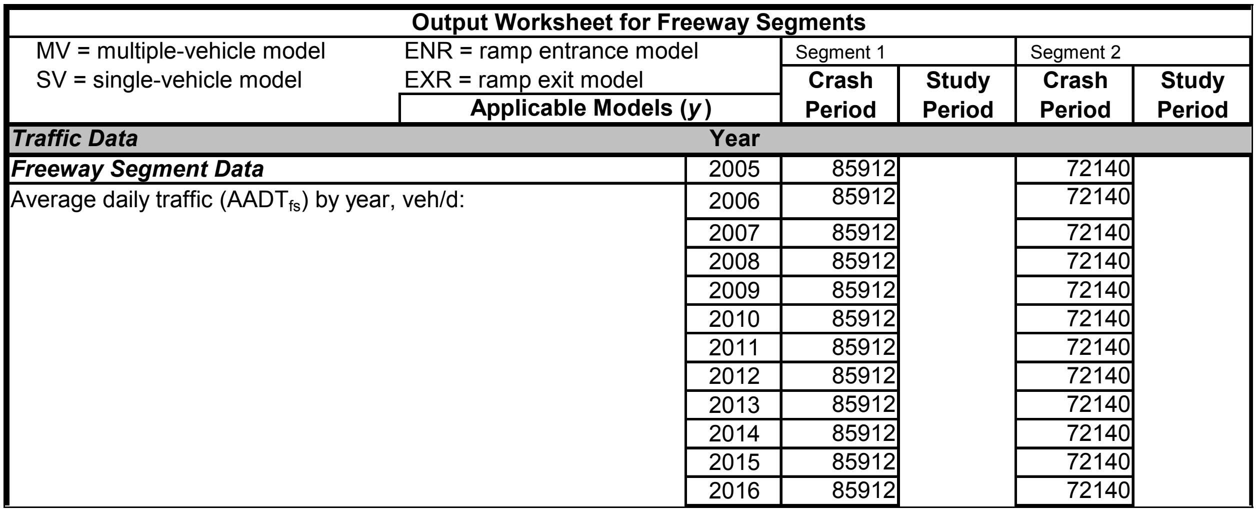


Output Worksheet for Freeway Segments

MV = multiple-vehicle model SV = single-vehicle model	ENR = ramp entrance model EXR = ramp exit model Applicable Models (*y*)	Segment 1		Segment 2	
		Crash Period	**Study Period**	**Crash Period**	**Study Period**
Intermediate Results					
Proportion of segment length with curve 1 ($P_{c,1}$):					
Proportion of segment length with curve 2 ($P_{c,2}$):					
Proportion of segment length with curve 3 ($P_{c,3}$):					
Distance from edge of inside shoulder to barrier face (W_{icb}), ft:		0.750	0.750	0.750	0.750
Proportion of segment length with barrier in the median (P_{ib}):		1.000	1.000	1.000	1.000
Proportion of segment length with rumble strips on outside shoulders (P_{or}):		0.000	0.000	0.000	0.000
Proportion of segment length with rumble strips on inside shoulders (P_{ir}):		0.000	0.000	0.000	0.000
Distance from edge of outside shoulder to barrier face (W_{ocb}), ft:		2.500	2.500	2.500	2.500
Proportion of segment length with barrier on the roadside (P_{ob}):		0.200	0.200	0.100	0.100
Proportion of segment length with Type B weaving, travel in increasing dir. ($P_{wevB,inc}$):		0.000	0.000	0.000	0.000
Proportion of segment length with Type B weaving, travel in decreasing dir. ($P_{wevB,dec}$):		0.000	0.000	0.000	0.000

Figure 32. Output Freeway Segments Worksheet–Intermediate Results

A portion of the Traffic Data section is shown in Figure 33. It indicates the AADT value used in the computations for each year of the evaluation period. If an AADT value is entered (in the Input Freeway Segments worksheet) for every year, then the values shown in this section will match those entered. However, if values are entered for only some of the years, then values for the other years will be estimated using the rules described in the section titled Step 3—Acquire Traffic Volume and Observed Crash Data. In this case, the values shown in this section will be those that were calculated using the stated rules.



Output Worksheet for Freeway Segments

MV = multiple-vehicle model — ENR = ramp entrance model
SV = single-vehicle model — EXR = ramp exit model

		Segment 1		Segment 2	
Applicable Models (*y*)		**Crash Period**	**Study Period**	**Crash Period**	**Study Period**
Traffic Data	**Year**				
Freeway Segment Data	2005	85912		72140	
Average daily traffic ($AADT_{fs}$) by year, veh/d:	2006	85912		72140	
	2007	85912		72140	
	2008	85912		72140	
	2009	85912		72140	
	2010	85912		72140	
	2011	85912		72140	
	2012	85912		72140	
	2013	85912		72140	
	2014	85912		72140	
	2015	85912		72140	
	2016	85912		72140	

Figure 33. Output Freeway Segments Worksheet–Traffic Data

In Figure 26, it was shown that one AADT value was entered for year 2005 for each site. The values shown in Figure 33 repeat the entered value for every other year. These values were estimated based on the aforementioned rules.

Chapter 3. Applications

This chapter provides information to assist in the application of ISATe for a safety evaluation. It consists of two sections. The first section provides some default values that can be used when local data are not available. The second section describes some typical types of analyses that can be undertaken using ISATe. Several sample applications are provided in Appendix C.

DEFAULT VALUES

This section describes default values for two variables used in ISATe. One variable is the "Proportion of AADT during high-volume hours." The other variable is "ramp AADT volume."

Proportion of AADT during High-Volume Hours

The proportion of AADT during high-volume hours is entered in the Input Freeway Segments worksheet, and is shown in Figure 26. It is described in the section titled Input Data Requirements of Chapter 2.

This variable indicates the proportion of freeway AADT volume that occurs during hours where the lane volume exceeds 1,000 vehicles per hour per lane. It is used in the predictive model 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. Such conditions have an influence on crash frequency, crash type, and crash severity.

Default values of this variable are provided in Table 4. Their development is documented by Bonneson et al. (1). They represent typical hourly volume variations for the typical 24-hour period. If the volume is more (or less) varied at the subject freeway, then local data should be used to compute this proportion. If the data entry cell associated with this variable is blank in ISATe, then a default value will be computed from the values in this table.

Ramp AADT Volume

Ramp AADT volume is an input variable in all three input worksheets. For this reason, it is of fundamental importance to the predictive models and the reliability of the estimates produced by these models. Analysts are encouraged to obtain accurate estimates of ramp AADT volume whenever possible.

It is recognized that some agencies do not routinely collect ramp AADT data or have access to this data. In situations where ramp AADT volumes are not available, the default data in Table 5 can be substituted to obtain acceptable results. The use of these default values should be limited to the Input Freeway Segments worksheet. The actual AADT volume for a given ramp can vary by up to ±50 percent from the value shown in the table. The amount of variation will depend on other factors (e.g., crossroad AADT volume, interchange spacing, alternative routes in the corridor, etc.).

Table 4. Default Values for the Proportion of AADT During High-Volume Hours

Freeway AADT Volume (veh/day)	Proportion of AADT During High-Volume Hours by Number of Freeway Lanes			
	4	6	8	10
0 to 40,000	0.00	0.00	0.00	0.00
50,000	0.10	0.00	0.00	0.00
60,000	0.34	0.00	0.00	0.00
70,000	0.51	0.00	0.00	0.00
80,000	0.64	0.18	0.00	0.00
90,000	0.74	0.34	0.00	0.00
100,000	0.81	0.46	0.10	0.00
120,000	0.90	0.64	0.34	0.04
140,000		0.76	0.51	0.25
160,000		0.84	0.64	0.41
180,000		0.90	0.74	0.54
200,000			0.81	0.64
220,000			0.86	0.72
240,000			0.90	0.78
260,000				0.83
280,000				0.87
300,000				0.90

Table 5. Default Values for Ramp AADT Volume

Freeway AADT Volume (veh/day)	Ramp AADT Volume by Area Type and Number of Ramp Lanes (veh/day)		
	Rural, 1 Lane	Urban, 1 Lane	Urban, 2 Lanes
20,000	1,600	3,200	7,700
40,000	2,200	4,400	10,500
60,000	2,600	5,200	12,500
80,000	3,000	5,900	14,200
100,000	3,300	6,500	15,600
120,000	3,600	7,100	16,900
140,000	3,800	7,600	18,100
160,000	4,000	8,000	19,200
180,000	4,200	8,500	20,200
200,000	4,400	8,900	21,200
220,000		9,200	22,100
240,000		9,600	22,900
260,000		9,900	23,700
280,000		10,300	24,500
300,000		10,600	25,300

ALTERNATIVE ANALYSIS

ISATe, and the predictive methods within it, is able to address a wide range of freeway and interchange conditions. Some of these conditions are identified in the following list.

- Freeway-freeway (i.e., system) and freeway-crossroad (i.e., service) interchanges.
- Freeway facilities in urban and rural areas.
- Crossroad ramp terminals that are signalized or two-way stop controlled.

The predictive methods include procedures for evaluating the safety of a site for a single year or a specified evaluation period consisting of several consecutive years. The methods support the following types of design decisions.

- Interchange spacing.
- Interchange and ramp configuration (e.g., ramp type, location, radius, over or underpass, etc.).
- Arrangement of ramps (e.g., successive entrance ramps, weaving section versus C-D road, etc.).

This section describes basic techniques for using ISATe in various safety evaluations, with an emphasis on alternatives analysis.

Analysis Types

ISATe can be used to evaluate the safety of freeway facilities, including freeway main lanes and interchanges. It requires the application of all seven analysis steps described in Chapter 2 and the use of all three input worksheets. A key result of this evaluation is the estimate of the facility's expected average crash frequency for one or more recent years. This estimate is a measure of the facility's safety performance.

Reconstruction Project Prioritization

Estimating a facility's safety performance can be useful for determining its priority for reconstruction. ISATe is particularly useful for this application when observed crash data are not readily available for some or all of the sites that make up the facility. Of course, if these data are available, then using the EB Method to combine the model predictions with the crash data yields a more reliable estimate of the facility's expected average crash frequency.

System Safety Management

Safety performance information can be useful to highway agencies responsible for the safety management of freeway facilities. By evaluating the safety performance of several facilities, the agency can identify those facilities that tend to experience a relatively high crash frequency. This information provides an opportunity for safety improvement and can be used as a basis for prioritizing these improvements.

Economic Analysis

The estimates of expected average crash frequency (by crash type and severity) obtained from ISATe can be used to compute a road-user cost. These costs can then be used to compute a road-user benefit associated with an alternative design that improves road safety. This benefit could then be combined with the change in road-user operation costs and related to construction cost to obtain a cost-effectiveness measure (e.g., benefit-cost ratio) for each alternative. Ultimately, these measures could be used as a basis for alternative selection.

Evaluating an Interchange

ISATe can be used to evaluate the safety performance of a proposed new interchange design. Specifically, it can be used to evaluate almost any interchange form and its associated freeway speed-change lanes. This application requires all seven analysis steps described in Chapter 2 and the use of the Input Ramp Segments and Input Ramp Terminals worksheets.

To use ISATe to evaluate an interchange, the ramps, C-D roads, and crossroad ramp terminals in the vicinity of the interchange are initially disaggregated into individual sites. The disaggregation of two diagonal ramps at a diamond interchange is shown in Figure 34. The segments were established using the criteria provided in the section titled Segmentation Process in Chapter 2. The exit ramp is shown to be disaggregated into three tangent segments and two curve segments. The entrance ramp is also disaggregated into three tangent segments and two curve segments. There is one crossroad ramp terminal.

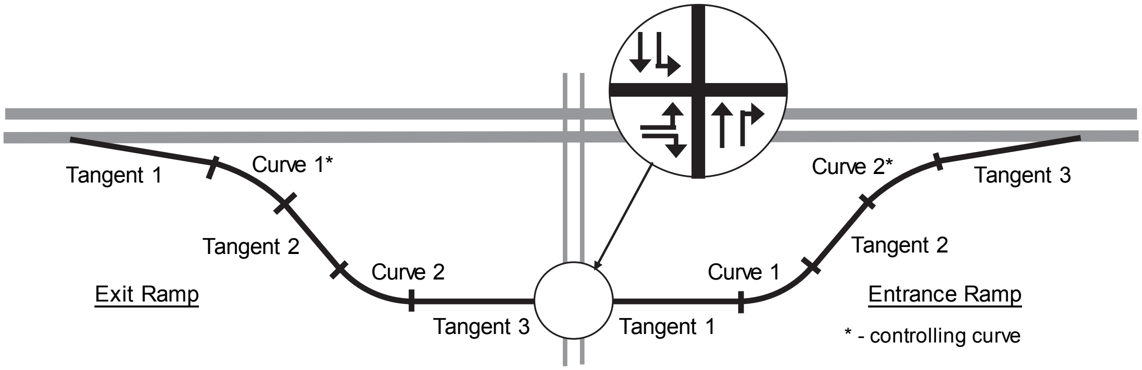


Figure 34. Disaggregated Alignment for a Diagonal Ramp

The disaggregate approach to ramp and C-D road evaluation provides the flexibility needed to evaluate any proposed ramp configuration. It also provides an important sensitivity to the unique roadway features that influence safety. Individual segments can be used to focus the evaluation on a ramp curve, a ramp speed-change lane, a lane added to a ramp, or a weaving section on a C-D road. The range of ramp and C-D road configurations that can be evaluated using this approach is shown in Figure 35.

A wide variety of common crossroad ramp terminal configurations can be evaluated with ISATe. These configurations are shown in Figure 1. In addition, the safety influence of a variety of ramp terminal geometric design and traffic control features can be evaluated with ISATe. These features include the use of signal or stop control, the provision of turn bays, the provision of protected left-turn operation, or the provision of right-turn channelization. Changes in crossroad median width or exit ramp skew angle can also be evaluated.

Interchange alternatives can be evaluated by entering the data for each site that represents the "base" interchange (i.e., the existing interchange or a proposed new interchange). Once the base interchange has been entered into ISATe, the evaluation of a design alternative requires only that changes be made to the variables associated with the alternative (all unchanged input variables are retained in the worksheets). In some instances, an alternative can be defined by changing one input variable (i.e., add a turn bay, widen the ramp shoulder). Evaluation results for each alternative can be compared and the differences attributed directly to the changes made (because all unchanged variables were maintained as common to both alternatives).

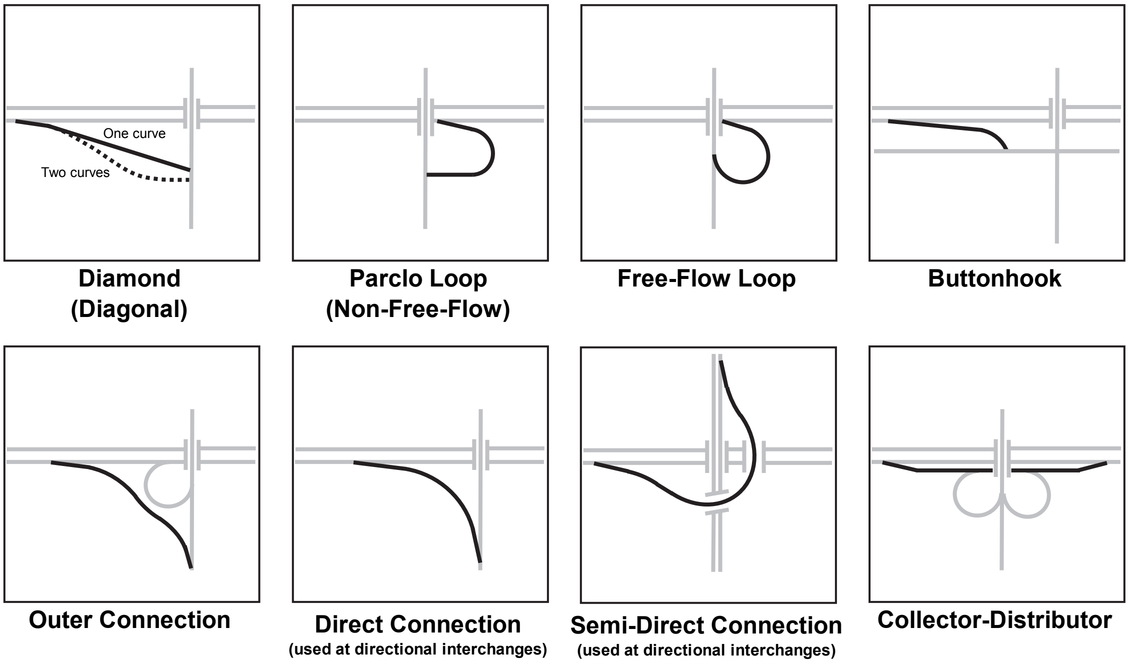
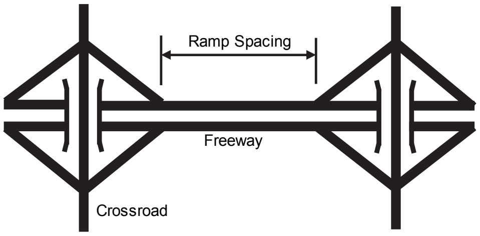


Figure 35. Typical Ramp and C-D Road Configurations

Evaluating a Freeway

ISATe can be used to evaluate the safety performance of an existing or proposed freeway. One common issue related to freeway design and operation is ramp spacing. The freeway predictive model in ISATe can be used to evaluate the influence of ramp-related lane changes and freeway safety. This model replicates the frequency of lane change activity as a function of the distance to (or from) the ramp and the ramp AADT volume. It is also sensitive to weaving section geometry. As a result, it can be used to evaluate the safety of interchange spacing, with or without a weaving section.



ISATe can be used to evaluate speed-change lane design for a proposed freeway. The predictive model for speed-change lanes is sensitive to speed-change lane type (i.e., ramp entrance or ramp exit), length, and location on the left- or right-hand side of the freeway through lanes.

ISATe can be used to evaluate freeway segments with and without a horizontal curve. It can be used to explore the potential safety benefit of flattening a curve. The two roadbeds that serve opposing directions of travel may occasionally diverge, where a horizontal curve is used on one roadbed while the other roadbed maintains a straight alignment. ISATe can be used to evaluate the condition where only one roadbed has a horizontal curve.

ISATe can be used to evaluate the presence of barrier in the median or along the roadside. The barrier can be represented as continuous for the segment, individual barrier pieces, or both. Individual barrier pieces are typically used to protect point hazards (e.g., gantry support) on the roadside. This capability can be used to evaluate the safety implications of roadside hazard relocation, removal, or barrier protection. The influence of barrier presence on crash severity is explicitly addressed in the ISATe predictive model. ISATe does not quantify the influence of barrier *type* (e.g., cable, rigid) on crash frequency or severity.

Evaluating a Freeway with Barrier-Separated Managed Lanes

ISATe 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.

Chapter 4. References

(1) Bonneson, J., S. Geedipally, M. Pratt, and D. Lord. *National Cooperative Highway Research Program Document XXX, Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges.* (Web-Only). NCHRP, Transportation Research Board, Washington, D.C., 2012.

(2) *Highway Safety Manual*, 1st Edition. American Association of State Highway and Transportation Officials, Washington, D.C., 2010.

(3) Hauer, E. *Observational Before-After Studies in Road Safety*. Pergamon Press, Elsevier Ltd., Oxford, United Kingdom, 1997.

Appendix A. Model Coefficients, Distributions, and Calibration Factors

This appendix presents the default model coefficients, distributions, and calibration factors used in the predictive methods represented in ISATe. The model coefficients presented are those in the safety performance functions (SPFs) used in the predictive models.

The appendix consists of three sections. The first section provides a summary of the coefficients used in the SPFs and the default calibration factors used in the predictive models. The second section provides a summary of the default crash type distribution values used in each predictive method. The last section describes procedures for calibrating the predictive models and distributions.

PREDICTIVE MODELS

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

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

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* (*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);

$N_{spf,\,w,\,x,\,y,\,z}$ = 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. The models predict FI crash frequency and PDO 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. Additional information about these models is documented by Bonneson et al. (1).

When using a predictive method, the appropriate 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 SPF, like all regression models, estimates the value of the dependent variable as a function of a set of independent variables. The independent variables include area type (i.e., rural or urban), AADT volume, and segment length.

The range of AADT volumes for which the SPFs are applicable is shown in Table 1 to Table 3. Application of the SPFs to sites with AADT volumes substantially outside these ranges may not provide reliable results.

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

$$N_{spf,w,x,y,z} = L \times \exp(a + b \times \ln[c \times AADT_{fs}]) \qquad \text{Equation 2}$$

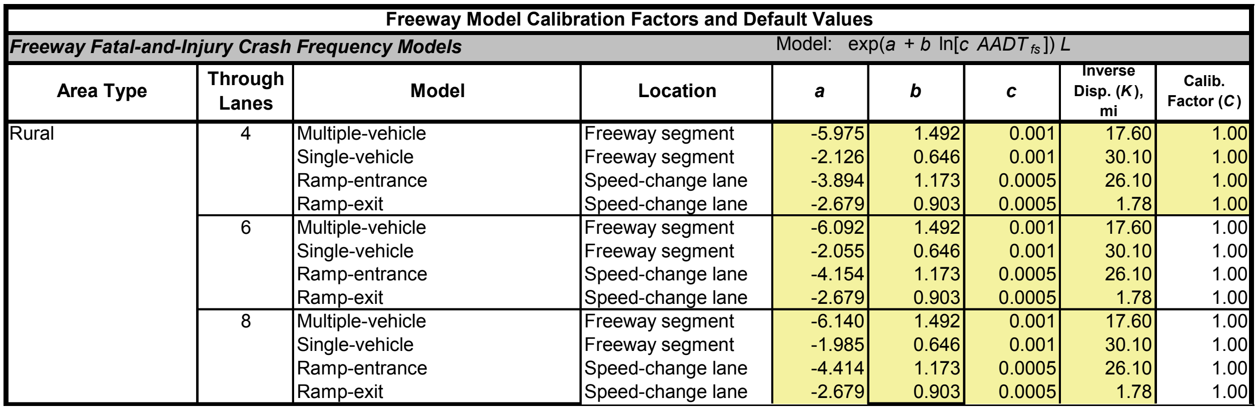
Where:

L = length of freeway segment (mi);

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

a, b, c = regression coefficients.

The regression coefficients for each SPF are listed in the Calibration Factors worksheet. A portion of this worksheet is shown in Figure 36. The coefficients for 12 SPFs are shown. They apply to the SPFs for freeway FI crashes in rural areas. Equation 2 is replicated in the heading of this figure to confirm the SPF model structure and the representation of each regression coefficient in the SPF.



Freeway Model Calibration Factors and Default Values

Freeway Fatal-and-Injury Crash Frequency Models Model: exp(a + b ln[c $AADT_{fs}$]) L

Area Type	Through Lanes	Model	Location	*a*	*b*	*c*	Inverse Disp. (*K*), mi	Calib. Factor (*C*)
Rural	4	Multiple-vehicle	Freeway segment	-5.975	1.492	0.001	17.60	1.00
		Single-vehicle	Freeway segment	-2.126	0.646	0.001	30.10	1.00
		Ramp-entrance	Speed-change lane	-3.894	1.173	0.0005	26.10	1.00
		Ramp-exit	Speed-change lane	-2.679	0.903	0.0005	1.78	1.00
	6	Multiple-vehicle	Freeway segment	-6.092	1.492	0.001	17.60	1.00
		Single-vehicle	Freeway segment	-2.055	0.646	0.001	30.10	1.00
		Ramp-entrance	Speed-change lane	-4.154	1.173	0.0005	26.10	1.00
		Ramp-exit	Speed-change lane	-2.679	0.903	0.0005	1.78	1.00
	8	Multiple-vehicle	Freeway segment	-6.140	1.492	0.001	17.60	1.00
		Single-vehicle	Freeway segment	-1.985	0.646	0.001	30.10	1.00
		Ramp-entrance	Speed-change lane	-4.414	1.173	0.0005	26.10	1.00
		Ramp-exit	Speed-change lane	-2.679	0.903	0.0005	1.78	1.00

Figure 36. Freeway SPF Regression Coefficients and Calibration Factors

Figure 36 shows only a few of the SPF coefficients identified in the Calibration Factors worksheet. The following list identifies all of the SPF combinations for freeway sites included in this worksheet. A total of 56 SPFs are represented by these combinations.

- Site types: freeway segment, ramp-entrance speed-change lane, ramp-exit speed-change lane.

- Severity: fatal and injury, property damage only.
- Area type: rural, urban.
- Freeway through lanes: 4, 6, 8, 10 (urban areas only).
- Crash type: multiple vehicle (freeway segments only), single vehicle (freeway segments only).

The SPFs for crashes on ramp and C-D road segments is represented using the following equation.

$$N_{spf\,,\,w,x,\,y,\,z} = L \times \exp\left(a + b \times \ln[c \times AADT\ ] + d\,[c \times AADT]\right) \qquad \text{Equation 3}$$

Where:

L = length of ramp or C-D road segment (mi);

$AADT$ = AADT volume of ramp or C-D road segment (veh/day); and

a, b, c, d = regression coefficients.

The following list identifies all of the SPF combinations for ramp and C-D road segments included in the Calibration Factors worksheet. A total of 36 SPFs are represented by these combinations.

- Site types: entrance ramp, exit ramp, C-D road.
- Severity: fatal-and-injury (FI), property-damage-only (PDO).
- Area type: rural, urban.
- Ramp through lanes: 1, 2 (urban areas only).
- Crash type: multiple vehicle, single vehicle.

The SPFs for crashes at crossroad ramp terminals are presented using the following equation.

$$N_{spf\,,\,w,x,\,y,\,z} = \exp\left(a + b \times \ln[c \times AADT_{xrd}\,] + d \times \ln[c \times AADT_{ex} + c \times AADT_{en}\,]\right) \qquad \text{Equation 4}$$

with

$$AADT_{xrd} = 0.5 \times (AADT_{in} + AADT_{out}) \qquad \text{Equation 5}$$

Where:

$AADT_{xrd}$ = AADT volume for the crossroad (veh/day);

$AADT_{in}$ = AADT volume for the crossroad leg between ramps (veh/day);

$AADT_{out}$ = AADT volume for the crossroad leg outside of interchange (veh/day);

$AADT_{ex}$ = AADT volume for the exit ramp (veh/day); and

$AADT_{en}$ = AADT volume for the entrance ramp (veh/day).

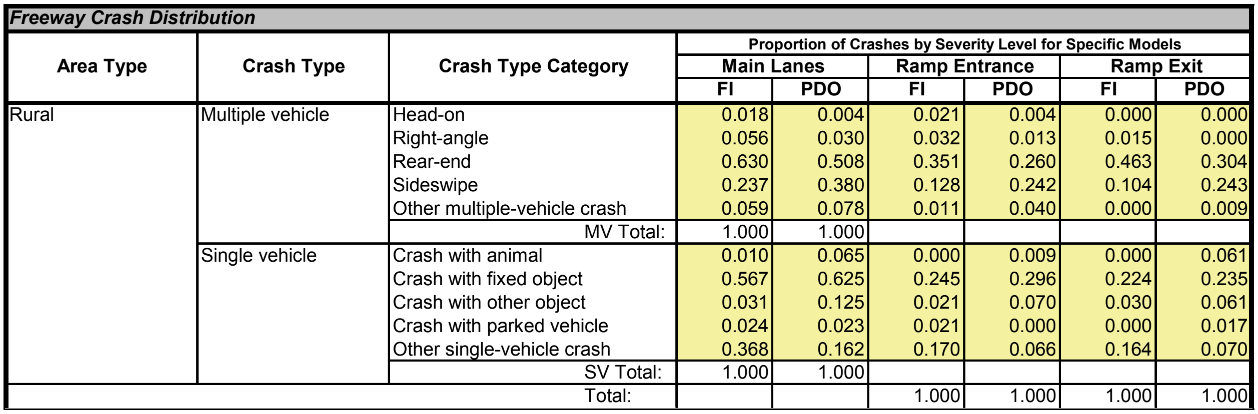
The following list identifies all of the SPF combinations for crossroad ramp terminals included in the Calibration Factors worksheet. A total of 196 SPFs are represented by these combinations.

- Site type (ramp terminal configuration, see Figure 1): D3ex, D3en, D4, A4, B4, A2, B2
- Severity: FI, PDO.
- Area type: rural, urban.
- Control type: one-way stop, signalized.
- Crossroad through lanes: 2, 3, 4, 5 (urban areas only), 6 (urban areas only).

CRASH TYPE DISTRIBUTIONS

Default distributions of crash type are included in the predictive methods in ISATe. One distribution is used with each predictive method to estimate the expected average crash frequency for each of ten crash types.

The crash type distributions are listed in the Calibration Factors worksheet. A portion of this worksheet is shown in Figure 37. The distribution of crashes on the freeway segments (i.e., main lanes), ramp entrances, and ramp exits are separately tabulated. Separate distributions are provided for rural and urban sites; however, the figure only shows those values for rural areas.



Freeway Crash Distribution

Area Type	Crash Type	Crash Type Category	Proportion of Crashes by Severity Level for Specific Models					
			Main Lanes		Ramp Entrance		Ramp Exit	
			FI	PDO	FI	PDO	FI	PDO
Rural	Multiple vehicle	Head-on	0.018	0.004	0.021	0.004	0.000	0.000
		Right-angle	0.056	0.030	0.032	0.013	0.015	0.000
		Rear-end	0.630	0.508	0.351	0.260	0.463	0.304
		Sideswipe	0.237	0.380	0.128	0.242	0.104	0.243
		Other multiple-vehicle crash	0.059	0.078	0.011	0.040	0.000	0.009
		MV Total:	1.000	1.000				
	Single vehicle	Crash with animal	0.010	0.065	0.000	0.009	0.000	0.061
		Crash with fixed object	0.567	0.625	0.245	0.296	0.224	0.235
		Crash with other object	0.031	0.125	0.021	0.070	0.030	0.061
		Crash with parked vehicle	0.024	0.023	0.021	0.000	0.000	0.017
		Other single-vehicle crash	0.368	0.162	0.170	0.066	0.164	0.070
		SV Total:	1.000	1.000				
		Total:			1.000	1.000	1.000	1.000

Figure 37. Freeway Crash Type Distribution

The following list characterizes the crash type distributions for freeways.

- Site types: freeway segment, ramp-entrance speed-change lane, ramp-exit speed-change lane.
- Area type: rural, urban.

The following list characterizes the crash type distributions for ramps and C-D roads. The crash type categories shown in Figure 37 are also represented for ramps and C-D roads.

- Site types: entrance ramp, exit ramp, C-D road.
- Area type: rural, urban.

The following list characterizes the crash type distributions for crossroad ramp terminals. The crash type categories shown in Figure 37 are also represented for crossroad ramp terminals.

- Area type: rural, urban.
- Control type: one-way stop, signalized, all-way stop

CALIBRATION FACTORS

The predictive models in ISATe 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 the next subsection.

The predictive methods in ISATe consist of a set of predictive models, default crash type distributions and severity distribution functions (SDFs). Most of the regression coefficients and distribution values used in the predictive methods have been determined through research. Therefore, modification of the regression coefficients is not recommended. However, analysts may replace the default distribution values with locally derived values. A procedure for deriving jurisdiction-specific distribution values is presented in the second subsection. A procedure for calibrating the SDFs is described in the third subsection.

Predictive Model Calibration Procedure

The calibration procedure is used to derive the value of the calibration factor that is included in each predictive model. A calibration factor represents the ratio of the total observed number of crashes for a selected set of sites to the total predicted number of crashes for the same sites, during the same time period, using the applicable predictive model. Thus, the nominal value of the calibration factor is 1.00 when the observed and predicted number of crashes happen 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 analysts 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 the procedure described in the next subsection is used to calibrate default distribution, then the locally-calibrated values should be used in the calibration process described in this subsection.

Step 1—Identify the predictive models to be calibrated.

Calibration is performed separately for each predictive model ISATe. Table 6 identifies the models for which calibration factors can be derived. The models of interest are identified by the analyst in this step.

Table 6. Predictive Models that Need Calibration

Site Type (*w*)	Cross Section or Control Type (*x*)	Crash Type (*y*)	Crash Severity (*z*)
Freeway segment (*fs*)	*n* lanes (*n*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)
			Property damage only (*pdo*)
		Single vehicle (*sv*)	Fatal and injury (*fi*)
			Property damage only (*pdo*)
Ramp segment (*rps*)	Entrance ramp (*EN*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)
			Property damage only (*pdo*)
		Single vehicle (*sv*)	Fatal and injury (*fi*)
			Property damage only (*pdo*)
	Exit ramp (*EX*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)
			Property damage only (*pdo*)
		Single vehicle (*sv*)	Fatal and injury (*fi*)
			Property damage only (*pdo*)
C-D road segment (*cds*)	*n* lanes (*n*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)
			Property damage only (*pdo*)
		Single vehicle (*sv*)	Fatal and injury (*fi*)
			Property damage only (*pdo*)
Freeway speed-change lane (*sc*)	Ramp entrance speed-change lane (*EN*)	All types (*at*)	Fatal and injury (*fi*)
			Property damage only (*pdo*)
	Ramp exit speed-change lane (*EX*)	All types (*at*)	Fatal and injury (*fi*)
			Property damage only (*pdo*)
Crossroad ramp terminal (all configurations) (*aS*)	One-way stop control (*ST*)	All types (*at*)	Fatal and injury (*fi*)
			Property damage only (*pdo*)
	Signal control (*SG*)	All types (*at*)	Fatal and injury (*fi*)
			Property damage only (*pdo*)

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.

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 6). 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 the number of crashes reported 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.

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 FI crashes on freeway segments, then the target crashes are multiple-vehicle FI 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 the section titled Crash Assignment to Sites in Appendix B.

Table 7 identifies the site characteristics data that are needed to apply the 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.

Table 7. Data Needs for Calibration of Predictive Models

Predictive Method	Data Element	Data Need		Default Assumption
		Required	Desirable	
ROADWAY SEGMENTS				
Freeways	Area type (rural or urban)	X		Need actual data
	Number of through lanes	X		Need actual data
	Segment length	X		Need actual data
	Length and radii of horizontal curves	X		Need actual data
	Lane width	X		Need actual data
	Inside and outside shoulder width	X		Need actual data
	Median width	X		Need actual data
	Length of rumble strips on inside and outside shoulders		X	Base default on agency policy
	Length of (and offset to) median barrier	X		Need actual data
	Length of (and offset to) outside barrier	X		Need actual data
	Clear zone width		X	Base default on agency policy
	AADT volume of (and distance to) nearest upstream entrance ramp	X	X	Need actual data
	AADT volume of (and distance to) nearest downstream exit ramp	X	X	Need actual data
	Presence of speed-change lane	X		Need actual data
	Presence and length of Type B weaving sections	X		Need actual data
	Proportion of AADT that occurs during hours where lane volume exceeds 1,000 veh/h/ln		X	Use values in Table 4
	Average annual daily traffic (AADT) volume	X		Need actual data

Table 7. Data Needs for Calibration of Predictive Models *continued*

Predictive Method	Data Element	Data Need		Default Assumption
		Required	Desirable	
ROADWAY SEGMENTS				
Ramps	***For ramps and collector-distributor (C-D) roads:***			
	Area type (rural or urban)	X		Need actual data
	Number of through lanes	X		Need actual data
	Segment length	X		Need actual data
	Average annual daily traffic (AADT) volume	X		Need actual data
	Length and radii of horizontal curves	X		Need actual data
	Lane width	X		Need actual data
	Left and right shoulder width	X		Need actual data
	Length of (and offset to) right side barrier	X		Need actual data
	Length of (and offset to) left side barrier	X		Need actual data
	Presence of lane add or drop		X	Assume not present
	Presence of speed-change lane	X		Need actual data
	For C-D roads only:			
	Presence and length of weaving section	X		Need actual data
INTERSECTIONS				
Freeways	***For freeway speed-change lanes:***			
	Area type (rural or urban)	X		Need actual data
	Number of through lanes	X		Need actual data
	Segment length	X		Need actual data
	Length and radii of horizontal curves	X		Need actual data
	Lane width	X		Need actual data
	Inside shoulder width	X		Need actual data
	Median width	X		Need actual data
	Presence of rumble strips on inside shoulder		X	Base default on agency policy
	Length of (and offset to) median barrier	X		Need actual data
	AADT volume of ramp in speed-change lane		X	Need actual data
	Presence and length of Type B weaving sections	X		Need actual data
	Proportion of AADT that occurs during hours where lane volume exceeds 1,000 veh/h/ln		X	Use values in Table 4
	AADT of freeway adjacent to speed-change lane	X		Need actual data

Table 7. Data Needs for Calibration of Predictive Models *continued*

Predict. Method	Data Element	Data Need Required	Data Need Desirable	Default Assumption
INTERSECTIONS				
	For all crossroad ramp terminals:			
	Area type (rural or urban)	X		Need actual data
	Ramp terminal configuration	X		Need actual data
	Type of traffic control	X		Need actual data
	Control for exit ramp right-turn movement	X		Need actual data
	AADT for inside and outside crossroad legs	X		Need actual data
	AADT volume for each ramp leg	X		Need actual data
	Number of through lanes on each crossroad approach	X		Need actual data
	Number of lanes on the exit ramp	X		Need actual data
	Nbr. of crossroad approaches with left-turn lanes	X		Need actual data
	Nbr. of crossroad approaches with right-turn lanes	X		Need actual data
	Number of unsignalized public street approaches to the crossroad leg outside of the interchange		X	Assume no public street approaches present
Ramps	Distance to next public street intersection		X	Assume 0.15 mi for urban areas, assume 0.20 mi for rural areas
	Distance to adjacent crossroad ramp terminal		X	Based default on terminal configuration and area type[a]
	Crossroad median width and left-turn lane width	X		Need actual data
	For signal-controlled crossroad ramp terminals only:			
	Number of unsignalized driveways on the crossroad leg outside of the interchange		X	Assume no driveways present
	Number of crossroad approaches with protected-only left-turn operation	X		Need actual data
	Number of crossroad approaches with right-turn channelization	X		Need actual data
	Presence of exit ramp right-turn channelization	X		Need actual data
	Presence of a non-ramp public street leg		X	Assume leg not present
	For one-way stop-controlled crossroad ramp terminals only:			
	Skew angle	X		Need actual data

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 Figure 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.

Step 4—Apply the applicable 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 ISATe to each site in the set of calibration sites. For this application, ISATe should be applied without using the EB Method and with a calibration factor of 1.00. 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.

Step 5—Compute calibration factors for use in the 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 6 for each predictive model.

Equation 6

$$C_{w,x,y,z} = \frac{\sum_{i=1}^{\substack{all \\ sites}} \sum_{j=1}^{n_c} N_{o,w(i),x(i),y,z,j}}{\sum_{i=1}^{\substack{all \\ sites}} \sum_{j=1}^{n_c} N_{p,w(i),x(i),y,z,j}}$$

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 site i with site type $w(i)$ and year j (includes 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 site i with site type $w(i)$ and year j (includes 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 ISATe.

Distribution Value Replacement Procedure

Table 8 identifies the specific distributions used in ISATe. The default distribution values provided in these tables were developed from the most complete and consistent databases available. If desired, these default values may be replaced with locally-derived values. This replacement is optional, but it may yield more reliable results.

Any replacement values derived with the procedures presented in this section should be incorporated in the predictive models before the calibration described in the previous section is performed.

Table 8. Crash Distributions That May Be Calibrated to Local Conditions

Predictive Method	Site Type		Distribution That May Be Calibrated to Local Conditions
	Roadway Segments	Intersections	
Freeways	X		Crash type for multiple-vehicle crashes
	X		Crash type for single-vehicle crashes
		X	Crash type for ramp-entrance-related crashes
		X	Crash type for ramp-exit-related crashes
Ramps	X		Crash type for multiple-vehicle crashes
	X		Crash type for single-vehicle crashes
		X	Crash type for signal-controlled ramp terminal crashes
		X	Crash type for one-way stop-controlled ramp terminal crashes
		X	Crash type for all-way stop-controlled ramp terminal crashes

Replacement of Default Values for Freeways

Four default distributions for freeways may be updated with locally-derived replacement values. These distributions are located in the Calibration Factors worksheet.

Each of the four distributions is categorized by two crash severity levels (i.e., fatal-and-injury, property-damage-only) and two area types (i.e., rural, urban). As a result, any one distribution represents a joint distribution of two variables for each area type. Therefore, for a given area type, sufficient data for calibrating one distribution requires a set of freeway sites that have collectively experienced at least 200 crashes during a recent one- to three-year period.

The 200 crashes represented in the distribution must match the description of the distribution, as identified in the last column of Table 8. For example, if the crash type distribution for multiple-vehicles crashes is being calibrated, then 200 *multiple-vehicle* crashes must be represented in the calibration data.

Replacement of Default Values for Ramps

Five default distributions for ramps may be updated with locally-derived replacement values. These distributions are located in the Calibration Factors worksheet. Procedures to develop each of these replacement values are described in the following subsections.

Each of the five distributions is categorized by two crash severity levels and two area types. As a result, any one distribution represents a joint distribution of two variables for each area type. Therefore, for a given area type, sufficient data for calibrating one distribution requires a set of ramp sites that have collectively experienced at least 200 crashes during a recent one- to three-year period.

The 200 crashes represented in the distribution must match the description of the distribution, as identified in the last column of Table 8. For example, if the crash type distribution for signal-controlled ramp terminal crashes is being calibrated, then 200 crashes that are related to signal-controlled ramp terminals must be represented in the calibration data.

SDF Calibration Procedure

The SDFs used in ISATe were developed from the most complete and consistent databases available. If desired, these SDFs may be calibrated to local conditions. This calibration is optional, but it may yield more reliable 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 procedures described in the two previous subsections. The calibrated predictive models are used to determine the calibration factor for an SDF.

Step 1—Identify the site types for which the SDFs are to be calibrated.

Calibration is performed separately for each SDF provided in ISATe. SDFs are provided for the following site type combinations. The site types needed to calibrate a given SDF are identified in this step.

- Freeway segments and speed-change lanes.
- Ramp and C-D road segments.
- One-way stop-controlled crossroad ramp terminals.
- Signal-controlled crossroad ramp terminals.

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.

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. 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 the number or severity of crashes reported 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 either more severe 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.

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 ISATe for the same calibration period.

Only fatal or injury crashes should be included in the 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, non-incapacitating 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 the section titled Crash Assignment to Sites in Appendix B.

Table 7 identifies the site characteristics data that are needed to apply ISATe. 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.

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 ISAT to each site in the set of calibration sites. For this application, ISATe 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.

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 observed crash data are used to calculate the observed probability of a severe crash (i.e., fatal *K*, incapacitating injury *A*, or non-incapacitating injury *B*), given that an injury or fatal crash has occurred. Equation 7 is used for this purpose. In this manner, one overall average value is obtained for all sites represented in the database.

Equation 7

$$P_{o,aS,ac,at,KAB} = \frac{\sum_{i}^{\substack{all \\ sites}} \sum_{j=1}^{n_c} \left(N_{o,w(i),x(i),at,K,j} + N_{o,w(i),x(i),at,A,j} + N_{o,w(i),x(i),at,B,j} \right)}{\sum_{i}^{\substack{all \\ sites}} \sum_{j=1}^{n_c} \left(N_{o,w(i),x(i),at,K,j} + N_{o,w(i),x(i),at,A,j} + N_{o,w(i),x(i),at,B,j} + N_{o,w(i),x(i),at,C,j} \right)}$$

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*;

$N_{o,\ w(i),\ x(i),\ at,\ m,\ j}$ = observed crash frequency for site *i* with site type *w(i)* and year *j* (includes cross section or control type *x(i)* for all crash types *at* and severity level *m*, with *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 a severe crash, given that a fatal or injury crash has occurred. Equation 8 is used for this purpose. In this manner, one overall average value is obtained for all sites represented in the database.

Equation 8

$$P_{p,aS,ac,at,KAB} = \frac{\sum_{i}^{\substack{all \\ sites}} \sum_{j=1}^{n_c} \left(N_{p,w(i),x(i),at,K,j} + N_{p,w(i),x(i),at,A,j} + N_{p,w(i),x(i),at,B,j} \right)}{\sum_{i}^{\substack{all \\ sites}} \sum_{j=1}^{n_c} \left(N_{p,w(i),x(i),at,K,j} + N_{p,w(i),x(i),at,A,j} + N_{p,w(i),x(i),at,B,j} + N_{p,w(i),x(i),at,C,j} \right)}$$

Where:

$P_{p,\ aS,\ ac,\ at,\ KAB}$ = predicted 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*; and

$N_{p,\ w(i),\ x(i),\ at,\ m,\ j}$ = predicted crash frequency for site *i* with site type *w(i)* and year *j* (includes cross section or control type *x(i)* for all crash types *at* and severity level *m*, with *m* = *K*, *A*, *B*, *C*) (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 9

Where:

$C_{sdf,w}$ = 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.

Appendix B. Empirical Bayes Method

The empirical Bayes (EB) Method is used to combine the estimate from a 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 (3). It is implemented in ISATe when the analyst provides the necessary crash data and indicates its availability in the Main worksheet.

The EB Method improves the reliability of the estimate of expected average crash frequency by pooling the estimate from a predictive model with the subject site's observed crash data. The model estimate 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 predictive 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.

This appendix consists of three sections. The first section describes criteria for determining whether the analyst should apply the EB Method to evaluate a particular project or site. The second section describes two variations of the EB Method. The method used for a particular evaluation is dependent on a variety of considerations, one of which is whether the crash reports include sufficient information to accurately assign crashes to individual sites within the project limits. The third section describes a procedure for assigning crashes to individual sites.

EB METHOD APPLICATION CRITERIA

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.

- 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 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.
- Crossroad ramp terminals 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 a major geometric improvement.

If alternative improvements are being evaluated for a given project and the EB Method is being considered, then the EB Method will need to be consistently applied to all alternatives being evaluated. If the EB Method cannot be consistently applied to all alternatives, then it should not be used for any alternatives (i.e., the predictive method should be used without EB adjustment). This approach recognizes that there is typically a small difference in the results obtained from the predictive method when it is used with and without the EB Method. If the EB Method is not applied consistently, such differences will likely introduce a small bias in the comparison of expected crash frequency among alternatives.

In addition to the above criteria, ISATe requires that the crash record system include information that can be used to categorize crashes as fatal-or-injury or as PDO. If this requirement is met, then the EB Method can be used.

VARIATIONS OF THE EB METHOD

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.

If the following conditions are satisfied, the site-specific EB Method should be used. This variation of the EB Method is implemented in the Main worksheet by selecting “Data for each individual segment” in the appropriate drop-down box.

- If the project includes one or more freeway, ramp, or C-D road segments, then the crash record system will need to include information that can be used to categorize crashes as multiple vehicle or single vehicle.

- The information in the crash record system must be sufficient to assign observed crashes to the individual sites within the project limits.

If one (or both) of these conditions is not satisfied, then the project-level EB Method should be used. This variation of the EB Method is implemented in the Main worksheet by selecting “Data for all segments combined” in the appropriate drop-down box.

CRASH ASSIGNMENT TO SITES

The predictive methods in ISATe have been developed to estimate the expected average crash frequency for intersections and for segments. To be consistent with this model basis, observed crashes must be differentiated and assigned as either intersection-related crashes or segment-related crashes.

General Guidance for Assigning Crashes to Segments and Intersections

Intersection crashes include crashes that occur at an intersection (i.e., within the curb limits) and crashes that occur on the intersection legs and are intersection related. All crashes that are not classified as intersection or intersection-related crashes are considered to be segment-related crashes.

Figure 38 illustrates the method used to assign crashes to segments or intersections. As shown, all crashes that occur within the curb line limits of an intersection (i.e., Region A) are assigned to that intersection.

Crashes that occur outside the curb line limits of an intersection (i.e., Region B) are assigned to either the segment on which they occur or an intersection, depending on their characteristics. Crashes that are classified on the crash report as intersection-related or have characteristics consistent with an intersection-related crash are assigned to the intersection to which they are related; such crashes would include rear-end crashes related to queues on an intersection approach. Crashes that occur between intersections and are not related to an intersection are assigned to the roadway segment on which they occur.

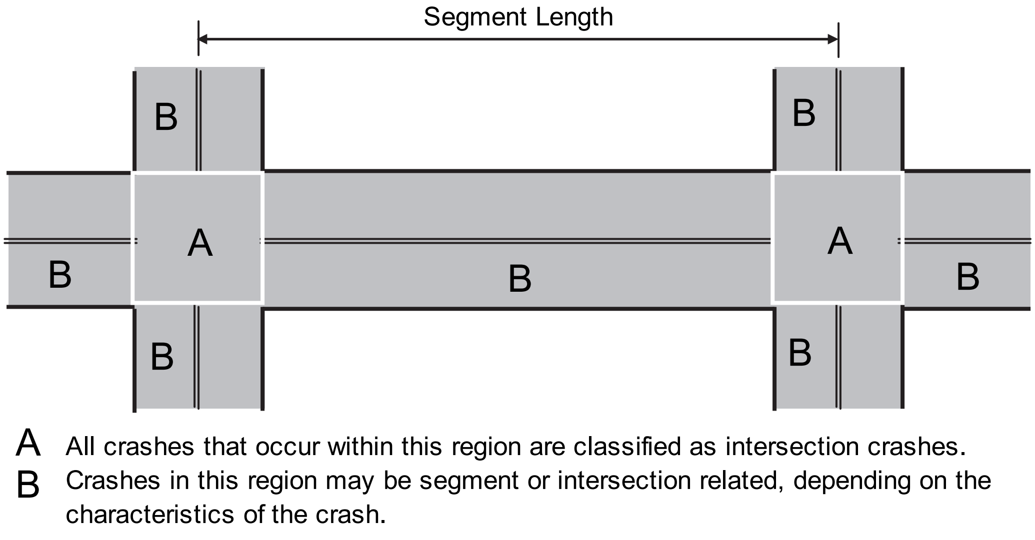


Figure 38. Definition of Roadway Segments and Intersections

In some jurisdictions, crash reports include a field that allows the reporting officer to designate the crash as intersection related. When this field is available on the crash reports, crashes should be assigned to the intersection or the segment based on the way the officer marked the field on the report.

In jurisdictions where there is not a field on the crash report that allows the officer to designate crashes as intersection related, the characteristics of the crash may be considered to make a judgment as to whether the crash should be assigned to the intersection or the segment. Other fields on the report, such as crash type, number of vehicles involved, contributing circumstances, weather condition, pavement condition, traffic control malfunction, and sequence of events can provide helpful information in making this determination. If the officer's narrative and a crash diagram are available, they can also assist in making the determination of a crash's intersection relationship.

The following crash characteristics are indicative of an intersection-related crash.

- A rear-end crash in which both vehicles were going straight approaching an intersection or in which one vehicle was going straight and struck a stopped vehicle.
- A crash in which the report indicates a signal malfunction or improper traffic control at the intersection contributed to the crash.

Guidance for Assigning Crashes to Freeway Segments and Speed-Change Lanes

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. All freeway crashes that are not classified as speed-change-related crashes are considered to be freeway segment crashes.

Figure 39 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.

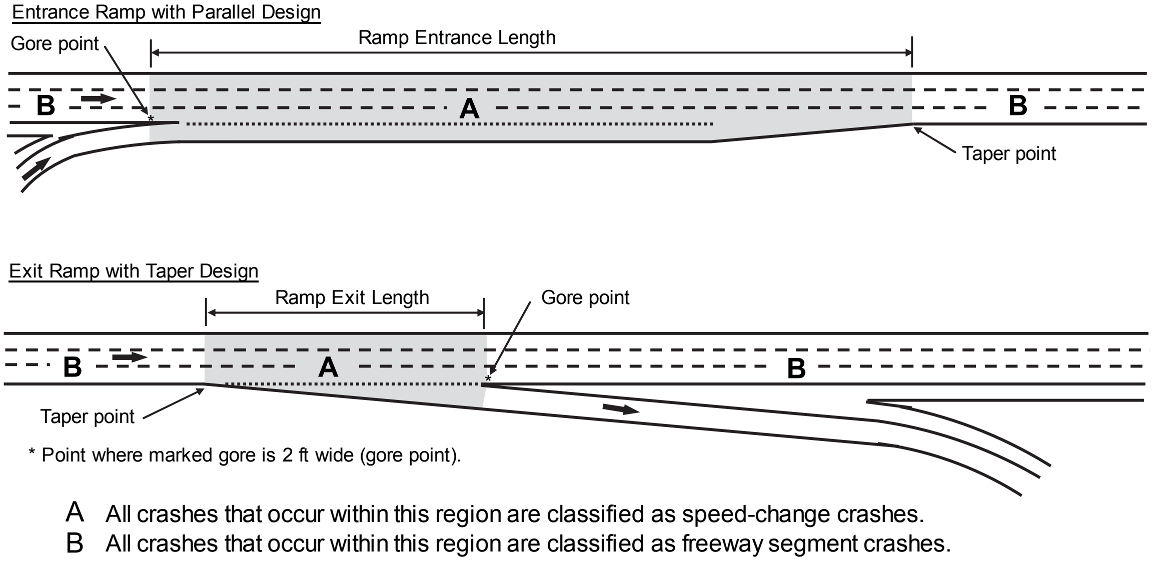


Figure 39. Definition of Freeway Segments and Speed-Change Lanes

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 39). 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.

Appendix C. Sample Applications

ISATe can be applied to various types of freeway facilities, including freeway main lanes and interchanges. This appendix provides sample applications for the following four facility types:

- Application 1. Basic freeway section.
- Application 2. Combined freeway and interchange.
- Application 3. Partial cloverleaf interchange.
- Application 4. Full cloverleaf interchange.

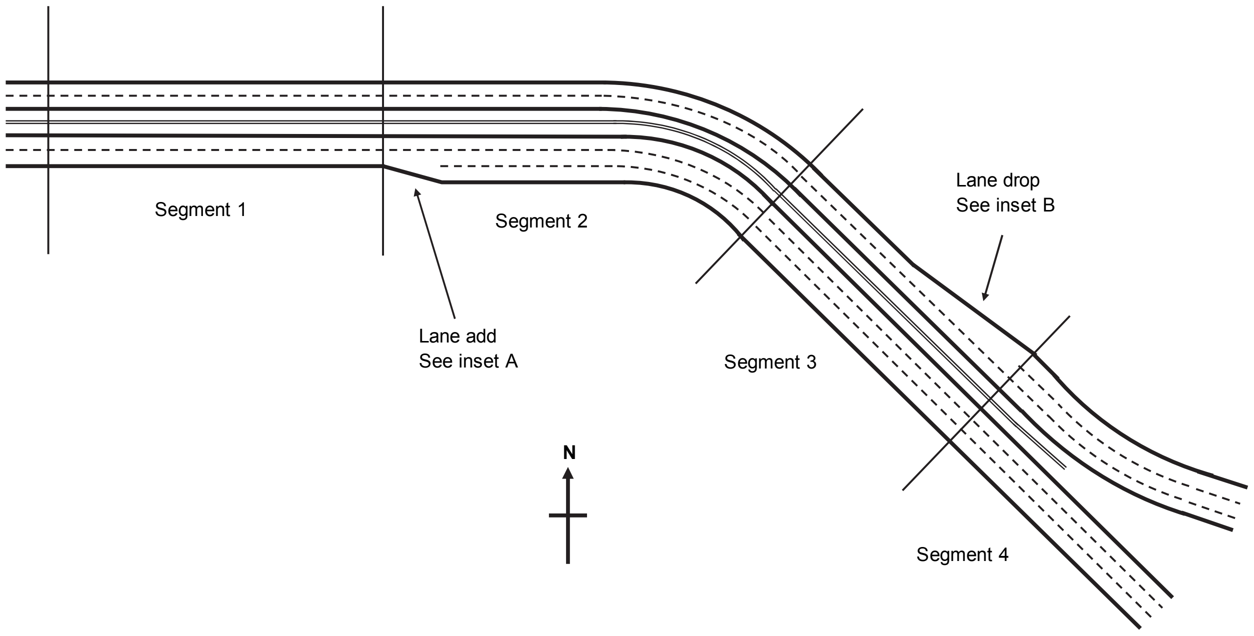
The sample applications are intended to illustrate how to use ISATe to evaluate several typical freeway and interchanges. They include some features commonly considered in the design process. These features include freeway weaving sections, ramps with multiple segments, and ramps with significant curvature.

APPLICATION 1. BASIC FREEWAY SECTION

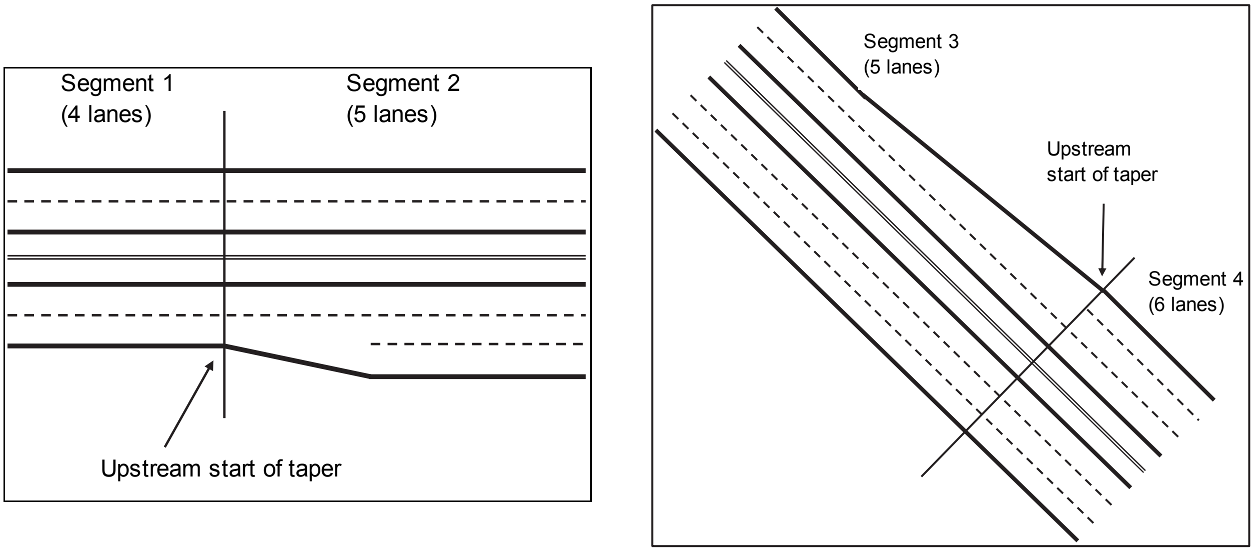
The freeway section is a rural freeway that ranges from four to six lanes in width. The traffic volume is 25,000 vehicles per day. The median is 20 ft in width for most of its length, but widens considerably at its eastern end. It has continuous median barrier where the median is 20 ft wide. The freeway section is of interest because of its narrow median, horizontal curves, and changes in lane count. The objective of this sample application is to evaluate the safety of the section, with a focus on the median and curvature.

The freeway section is split into four segments for analysis. The segments are shown in Figure 40a. The segment boundaries are determined by changes in geometry and the presence of lane drops and adds. The insets in this figure show the details of the lane add between segments 1 and 2 and the lane drop between segments 3 and 4.

The division between segments 1 and 2 occurs at the upstream start of taper of the lane add that occurs on the eastbound roadbed. The division between segments 2 and 3 occurs at the location of a change in inside shoulder width. The division between segments 3 and 4 occurs at the upstream start of taper of the lane drop that occurs on the westbound roadbed. The median width also begins to change at this location, as the two roadbeds begin to diverge due to terrain constraints.



a. Freeway Section Plan View



b. Inset A—Lane Add Start of Taper

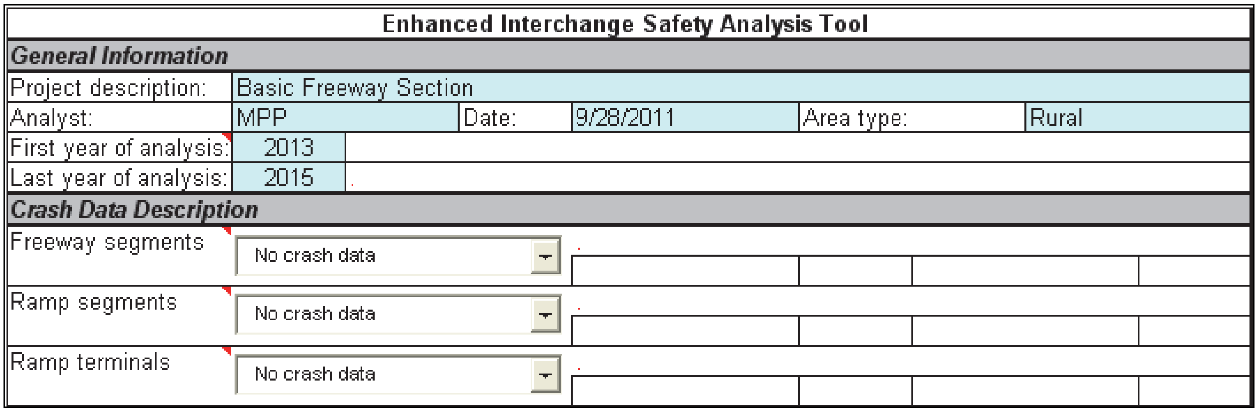
c. Inset B—Lane Drop Start of Taper

Figure 40. Application 1: Basic Freeway Section

Input Data

The data entry cells in the sections titled General Information and Crash Data Description are shown in Figure 41. As indicated in this figure, the area type is rural, the analysis period includes the years 2013 to 2015, and no crash data are available.

The data entry cells in the sections titled Basic Roadway Data and Alignment Data are shown in Figure 42. The data entry cells in the section titled Alignment Data indicate that segment 2 has a horizontal curve in both directions of travel, and that segment 4 has a horizontal curve in only one direction of travel. The curvature in segment 4 is a consequence of the divergence of the two roadbeds.



Enhanced Interchange Safety Analysis Tool

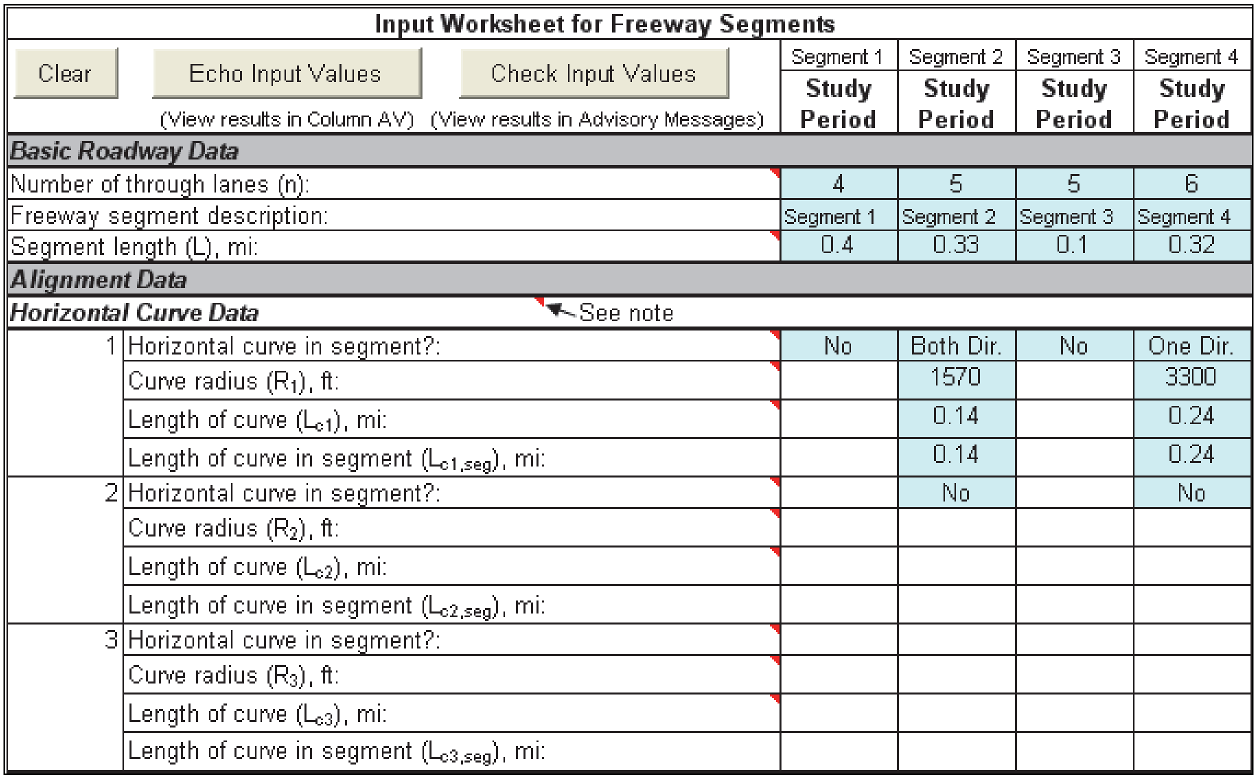
General Information

Project description:	Basic Freeway Section				
Analyst:	MPP	Date:	9/28/2011	Area type:	Rural
First year of analysis:	2013				
Last year of analysis:	2015				

Crash Data Description

Freeway segments	No crash data
Ramp segments	No crash data
Ramp terminals	No crash data

Figure 41. A1: Main Worksheet—General Information and Crash Data Description



Input Worksheet for Freeway Segments

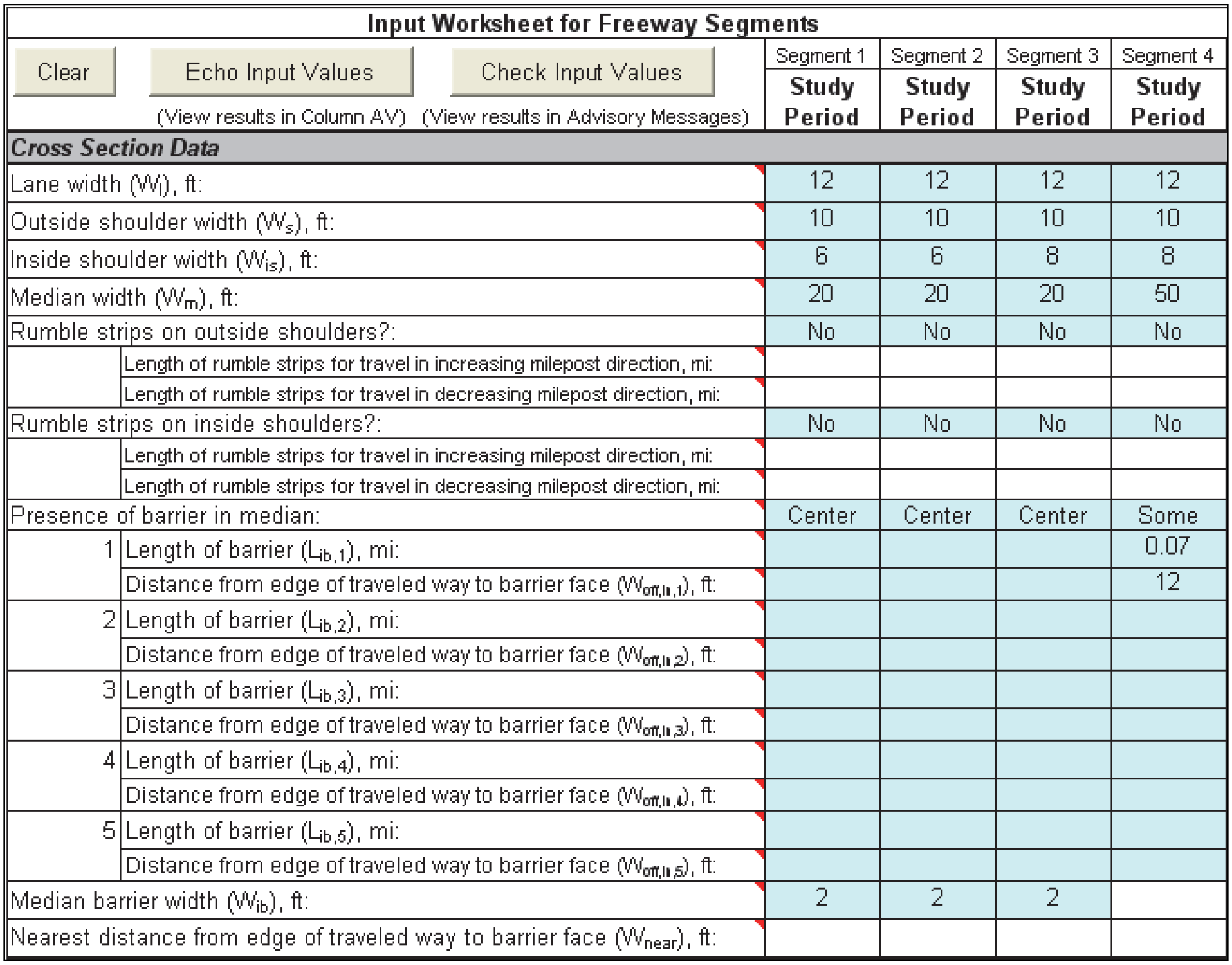
		Segment 1 Study Period	Segment 2 Study Period	Segment 3 Study Period	Segment 4 Study Period
Basic Roadway Data					
Number of through lanes (n):		4	5	5	6
Freeway segment description:		Segment 1	Segment 2	Segment 3	Segment 4
Segment length (L), mi:		0.4	0.33	0.1	0.32
Alignment Data					
Horizontal Curve Data ← See note					
1	Horizontal curve in segment?:	No	Both Dir.	No	One Dir.
	Curve radius (R_1), ft:		1570		3300
	Length of curve (L_{c1}), mi:		0.14		0.24
	Length of curve in segment ($L_{c1,seg}$), mi:		0.14		0.24
2	Horizontal curve in segment?:		No		No
	Curve radius (R_2), ft:				
	Length of curve (L_{c2}), mi:				
	Length of curve in segment ($L_{c2,seg}$), mi:				
3	Horizontal curve in segment?:				
	Curve radius (R_3), ft:				
	Length of curve (L_{c3}), mi:				
	Length of curve in segment ($L_{c3,seg}$), mi:				

Figure 42. A1: Input Freeway Segments Worksheet—Roadway and Alignment Data

The data entry cells in the section titled Cross Section Data are shown in Figure 43. All segments have 12-ft lanes and 10-ft outside shoulders. The inside shoulder width for segments 2 and 3 is shown to differ by 2.0 ft, which is a condition for starting a new segment.

Segments 1 to 3 have the narrow 20-ft median width, while segment 4 has a wider median. For this latter segment, the input median width of 50 ft represents an average value because the roadbeds are diverging.

The median barrier is described as continuous through segments 1 to 3. However, the barrier only continues for a distance of 0.07 mi beyond the beginning of segment 4.

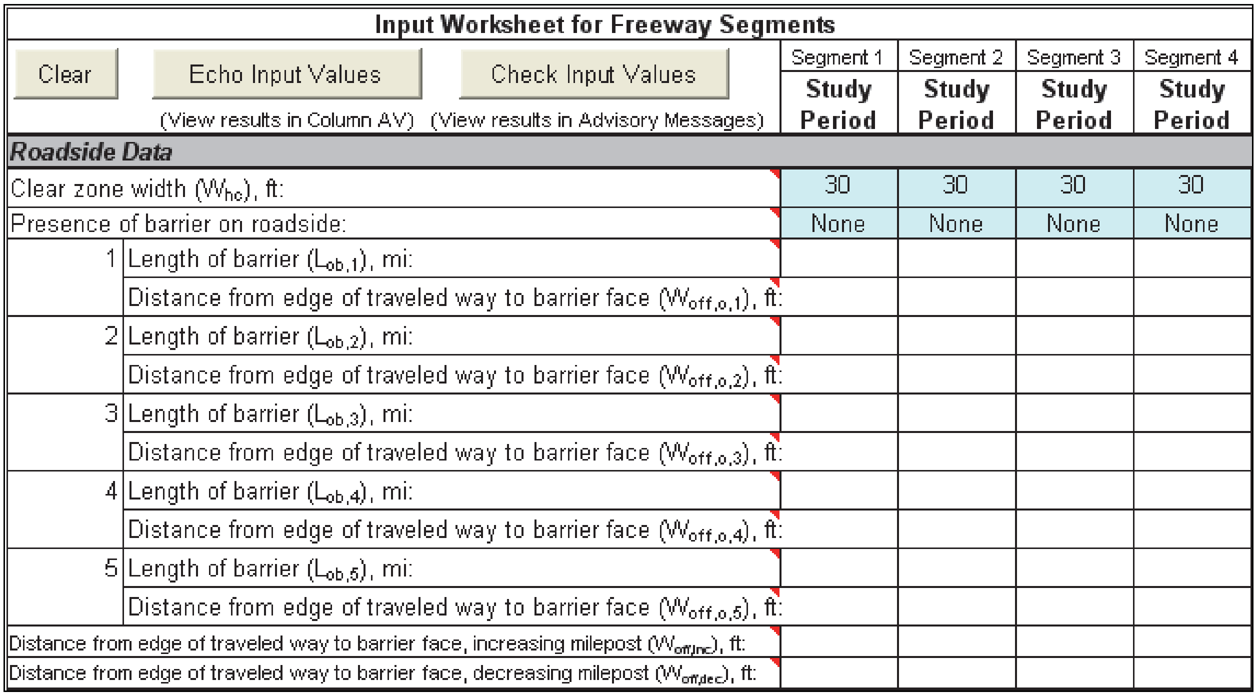


Input Worksheet for Freeway Segments

		Segment 1 Study Period	Segment 2 Study Period	Segment 3 Study Period	Segment 4 Study Period
Cross Section Data					
Lane width (W_l), ft:		12	12	12	12
Outside shoulder width (W_s), ft:		10	10	10	10
Inside shoulder width (W_{is}), ft:		6	6	8	8
Median width (W_m), ft:		20	20	20	50
Rumble strips on outside shoulders?:		No	No	No	No
	Length of rumble strips for travel in increasing milepost direction, mi:				
	Length of rumble strips for travel in decreasing milepost direction, mi:				
Rumble strips on inside shoulders?:		No	No	No	No
	Length of rumble strips for travel in increasing milepost direction, mi:				
	Length of rumble strips for travel in decreasing milepost direction, mi:				
Presence of barrier in median:		Center	Center	Center	Some
1	Length of barrier ($L_{ib,1}$), mi:				0.07
	Distance from edge of traveled way to barrier face ($W_{off,ll,1}$), ft:				12
2	Length of barrier ($L_{ib,2}$), mi:				
	Distance from edge of traveled way to barrier face ($W_{off,ll,2}$), ft:				
3	Length of barrier ($L_{ib,3}$), mi:				
	Distance from edge of traveled way to barrier face ($W_{off,ll,3}$), ft:				
4	Length of barrier ($L_{ib,4}$), mi:				
	Distance from edge of traveled way to barrier face ($W_{off,ll,4}$), ft:				
5	Length of barrier ($L_{ib,5}$), mi:				
	Distance from edge of traveled way to barrier face ($W_{off,ll,5}$), ft:				
Median barrier width (W_{ib}), ft:		2	2	2	
Nearest distance from edge of traveled way to barrier face (W_{near}), ft:					

Figure 43. A1: Input Freeway Segments Worksheet—Cross Section Data

The data entry cells in the section titled Roadside Data are shown in Figure 44. Most of these cells are unused because the segments do not have roadside barrier. The clear zone width is specified as 30 ft for all segments.

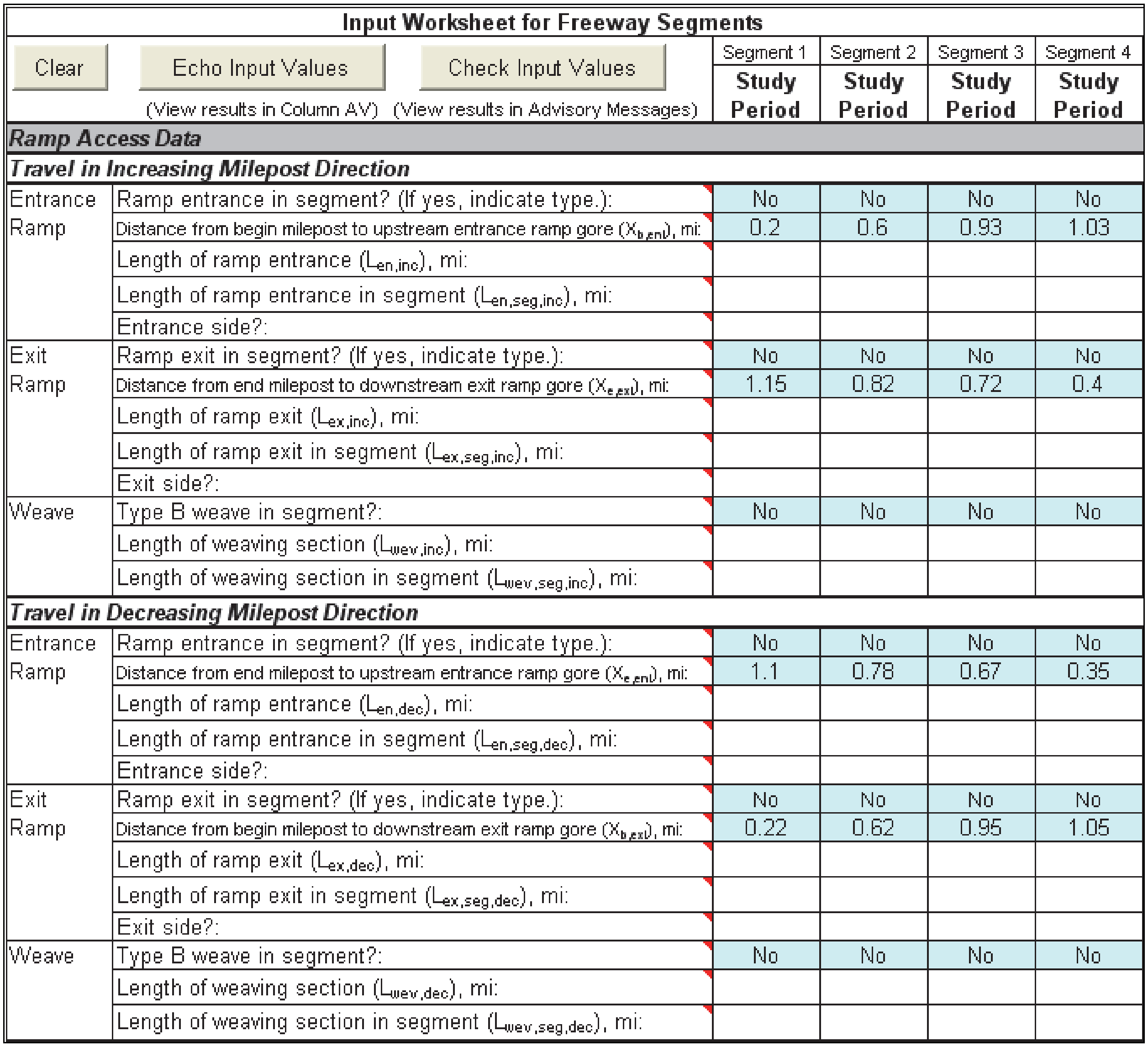


Input Worksheet for Freeway Segments

		Segment 1	Segment 2	Segment 3	Segment 4
		Study Period	**Study Period**	**Study Period**	**Study Period**
Roadside Data					
Clear zone width (W_{hc}), ft:		30	30	30	30
Presence of barrier on roadside:		None	None	None	None
1	Length of barrier ($L_{ob,1}$), mi:				
	Distance from edge of traveled way to barrier face ($W_{off,o,1}$), ft:				
2	Length of barrier ($L_{ob,2}$), mi:				
	Distance from edge of traveled way to barrier face ($W_{off,o,2}$), ft:				
3	Length of barrier ($L_{ob,3}$), mi:				
	Distance from edge of traveled way to barrier face ($W_{off,o,3}$), ft:				
4	Length of barrier ($L_{ob,4}$), mi:				
	Distance from edge of traveled way to barrier face ($W_{off,o,4}$), ft:				
5	Length of barrier ($L_{ob,5}$), mi:				
	Distance from edge of traveled way to barrier face ($W_{off,o,5}$), ft:				
Distance from edge of traveled way to barrier face, increasing milepost ($W_{off,inc}$), ft:					
Distance from edge of traveled way to barrier face, decreasing milepost ($W_{off,dec}$), ft:					

Figure 44. A1: Input Freeway Segments Worksheet—Roadside Data

The data entry cells in the section titled Ramp Access Data are shown in Figure 45. No ramp entrances or exits are located on the freeway segments. Similarly, there is no weaving section in any of the segments. The distances in the cells represent the measurements, in miles, to the nearest ramp entrance and exit to each segment in each direction of travel. The method for measuring these distances is described in the text associated with Figure 9.

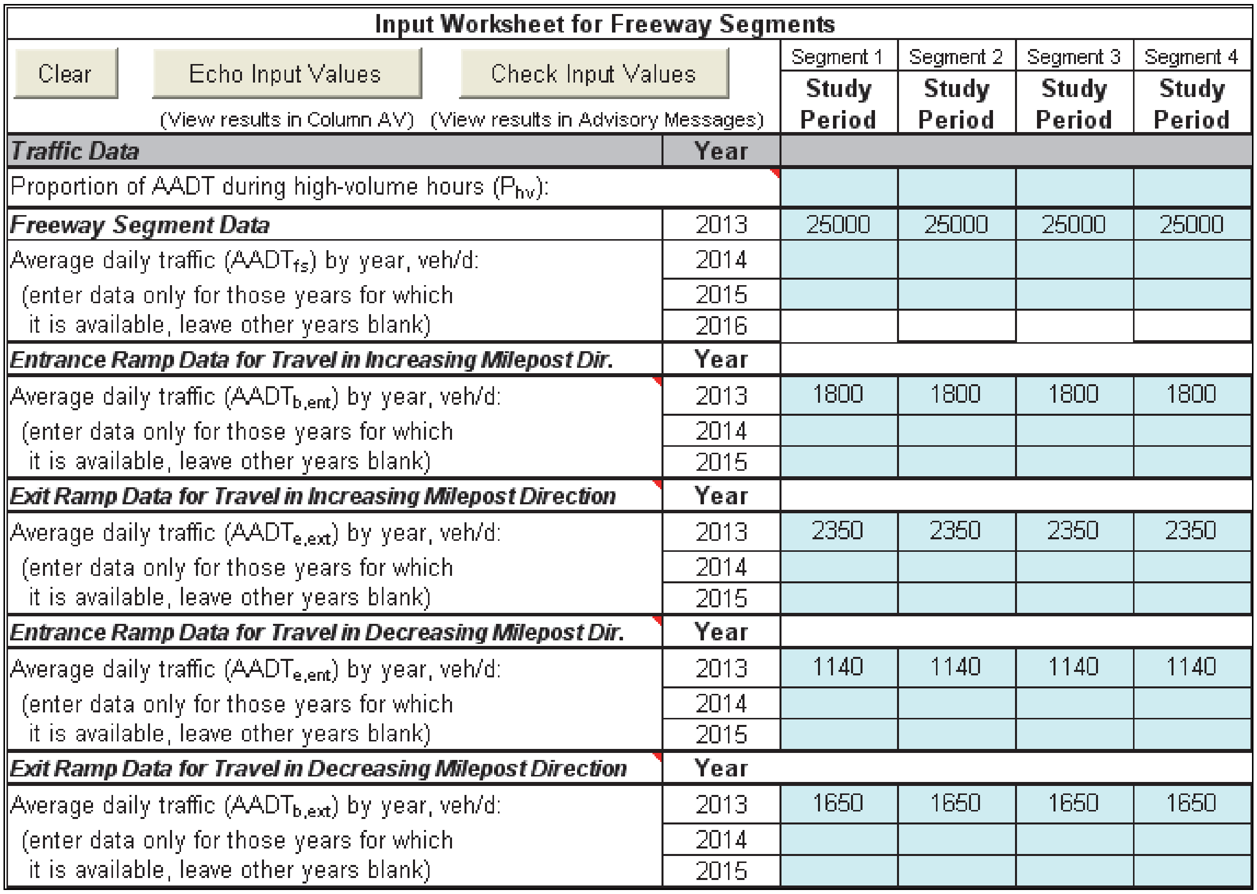


Input Worksheet for Freeway Segments

		Segment 1 Study Period	Segment 2 Study Period	Segment 3 Study Period	Segment 4 Study Period
Ramp Access Data					
Travel in Increasing Milepost Direction					
Entrance Ramp	Ramp entrance in segment? (If yes, indicate type.):	No	No	No	No
	Distance from begin milepost to upstream entrance ramp gore ($X_{b,ent}$), mi:	0.2	0.6	0.93	1.03
	Length of ramp entrance ($L_{en,inc}$), mi:				
	Length of ramp entrance in segment ($L_{en,seg,inc}$), mi:				
	Entrance side?:				
Exit Ramp	Ramp exit in segment? (If yes, indicate type.):	No	No	No	No
	Distance from end milepost to downstream exit ramp gore ($X_{e,ext}$), mi:	1.15	0.82	0.72	0.4
	Length of ramp exit ($L_{ex,inc}$), mi:				
	Length of ramp exit in segment ($L_{ex,seg,inc}$), mi:				
	Exit side?:				
Weave	Type B weave in segment?:	No	No	No	No
	Length of weaving section ($L_{wev,inc}$), mi:				
	Length of weaving section in segment ($L_{wev,seg,inc}$), mi:				
Travel in Decreasing Milepost Direction					
Entrance Ramp	Ramp entrance in segment? (If yes, indicate type.):	No	No	No	No
	Distance from end milepost to upstream entrance ramp gore ($X_{e,ent}$), mi:	1.1	0.78	0.67	0.35
	Length of ramp entrance ($L_{en,dec}$), mi:				
	Length of ramp entrance in segment ($L_{en,seg,dec}$), mi:				
	Entrance side?:				
Exit Ramp	Ramp exit in segment? (If yes, indicate type.):	No	No	No	No
	Distance from begin milepost to downstream exit ramp gore ($X_{b,ext}$), mi:	0.22	0.62	0.95	1.05
	Length of ramp exit ($L_{ex,dec}$), mi:				
	Length of ramp exit in segment ($L_{ex,seg,dec}$), mi:				
	Exit side?:				
Weave	Type B weave in segment?:	No	No	No	No
	Length of weaving section ($L_{wev,dec}$), mi:				
	Length of weaving section in segment ($L_{wev,seg,dec}$), mi:				

Figure 45. A1: Input Freeway Segments Worksheet—Ramp Access Data

The data entry cells in the section titled Traffic Data are shown in Figure 46. The volumes for the blank blue cells for the years 2014 and 2015 were estimated as equal to that for the year 2013 (based on the rules described in the section titled Analysis Steps). Volumes are entered for each of the four ramps (denoted by subscripts *b, ent*; *e, ext*; *e, ent*; and *b, ext*), that had distances coded in Figure 45. The proportion of AADT occurring during high-volume hours (P_{hv}) is not entered; as a result, the default value for this quantity was computed by the program (based on the values shown in Table 4).



Input Worksheet for Freeway Segments

		Segment 1 Study Period	Segment 2 Study Period	Segment 3 Study Period	Segment 4 Study Period
Traffic Data	**Year**				
Proportion of AADT during high-volume hours (P_{hv}):					
Freeway Segment Data	2013	25000	25000	25000	25000
Average daily traffic ($AADT_{fs}$) by year, veh/d:	2014				
(enter data only for those years for which	2015				
it is available, leave other years blank)	2016				
Entrance Ramp Data for Travel in Increasing Milepost Dir.	**Year**				
Average daily traffic ($AADT_{b,ent}$) by year, veh/d:	2013	1800	1800	1800	1800
(enter data only for those years for which	2014				
it is available, leave other years blank)	2015				
Exit Ramp Data for Travel in Increasing Milepost Direction	**Year**				
Average daily traffic ($AADT_{e,ext}$) by year, veh/d:	2013	2350	2350	2350	2350
(enter data only for those years for which	2014				
it is available, leave other years blank)	2015				
Entrance Ramp Data for Travel in Decreasing Milepost Dir.	**Year**				
Average daily traffic ($AADT_{e,ent}$) by year, veh/d:	2013	1140	1140	1140	1140
(enter data only for those years for which	2014				
it is available, leave other years blank)	2015				
Exit Ramp Data for Travel in Decreasing Milepost Direction	**Year**				
Average daily traffic ($AADT_{b,ext}$) by year, veh/d:	2013	1650	1650	1650	1650
(enter data only for those years for which	2014				
it is available, leave other years blank)	2015				

Figure 46. A1: Input Freeway Segments Worksheet—Traffic Data

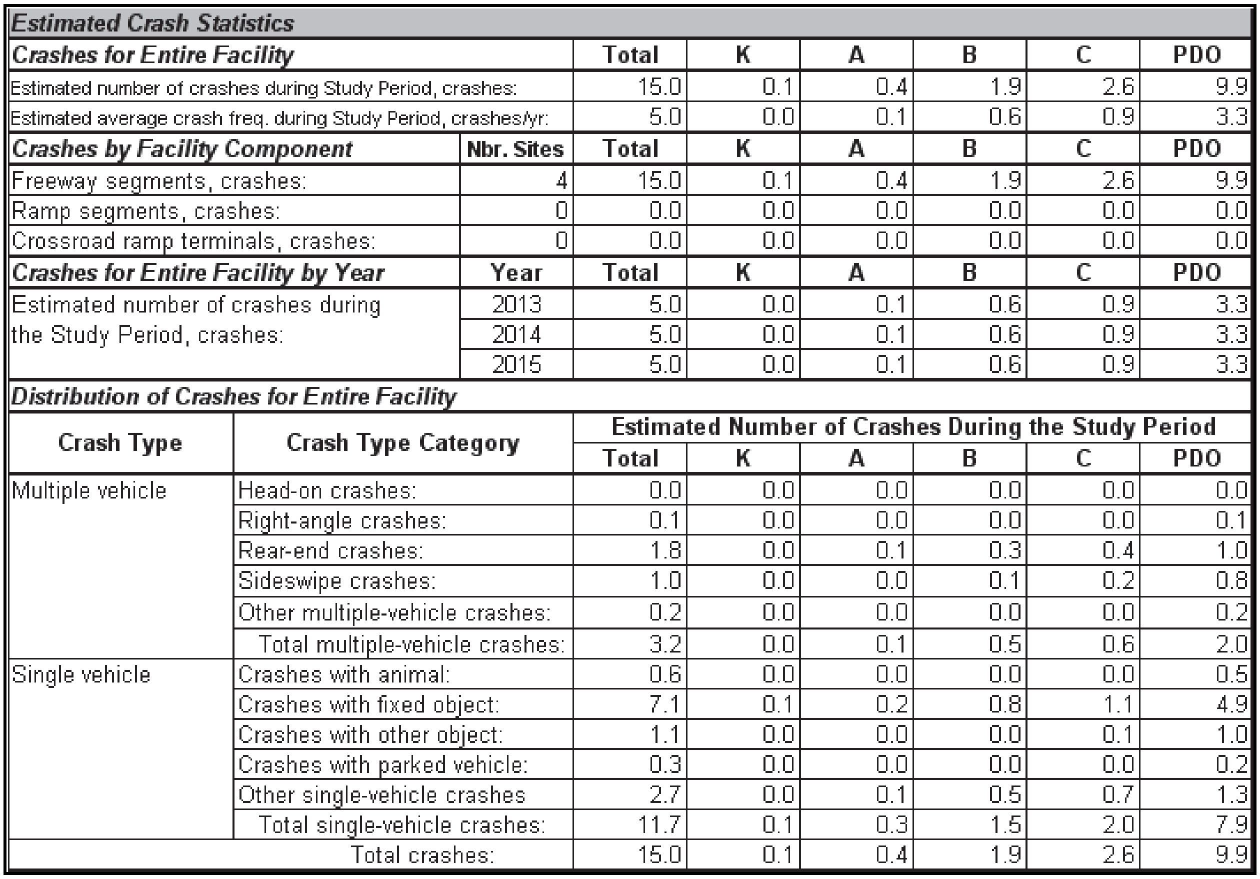
Output Summary

The Estimated Crash Statistics output cells are shown in Figure 47. Note that the unused rows are omitted from the figure. The two rows under the heading Crashes for Entire Facility provide the estimated number of crashes and crash frequency for the study period.

The three rows under the heading Crashes by Facility Component provide the estimated number of crashes for the three component types (freeway segment, ramp segment, and crossroad ramp terminal) modeled by ISATe. In this sample application, only freeway segments exist, so the rows for ramp segments and crossroad ramp terminals indicate zero crashes.

The three rows under the heading Crashes for Entire Facility by Year provide the estimated number of crashes for each of the three years included in the study period. In this sample application, the estimates are the same for all three years in the study period because the same volumes were used for each of the three years.

The rows under the heading Distribution of Crashes for Entire Facility provide the estimated number of crashes by severity and crash type. This distribution represents crashes at all sites for the entire study period.



Estimated Crash Statistics

Crashes for Entire Facility	Total	K	A	B	C	PDO
Estimated number of crashes during Study Period, crashes:	15.0	0.1	0.4	1.9	2.6	9.9
Estimated average crash freq. during Study Period, crashes/yr:	5.0	0.0	0.1	0.6	0.9	3.3

Crashes by Facility Component	Nbr. Sites	Total	K	A	B	C	PDO
Freeway segments, crashes:	4	15.0	0.1	0.4	1.9	2.6	9.9
Ramp segments, crashes:	0	0.0	0.0	0.0	0.0	0.0	0.0
Crossroad ramp terminals, crashes:	0	0.0	0.0	0.0	0.0	0.0	0.0

Crashes for Entire Facility by Year	Year	Total	K	A	B	C	PDO
Estimated number of crashes during the Study Period, crashes:	2013	5.0	0.0	0.1	0.6	0.9	3.3
	2014	5.0	0.0	0.1	0.6	0.9	3.3
	2015	5.0	0.0	0.1	0.6	0.9	3.3

Distribution of Crashes for Entire Facility

Crash Type	Crash Type Category	Estimated Number of Crashes During the Study Period					
		Total	K	A	B	C	PDO
Multiple vehicle	Head-on crashes:	0.0	0.0	0.0	0.0	0.0	0.0
	Right-angle crashes:	0.1	0.0	0.0	0.0	0.0	0.1
	Rear-end crashes:	1.8	0.0	0.1	0.3	0.4	1.0
	Sideswipe crashes:	1.0	0.0	0.0	0.1	0.2	0.8
	Other multiple-vehicle crashes:	0.2	0.0	0.0	0.0	0.0	0.2
	Total multiple-vehicle crashes:	3.2	0.0	0.1	0.5	0.6	2.0
Single vehicle	Crashes with animal:	0.6	0.0	0.0	0.0	0.0	0.5
	Crashes with fixed object:	7.1	0.1	0.2	0.8	1.1	4.9
	Crashes with other object:	1.1	0.0	0.0	0.0	0.1	1.0
	Crashes with parked vehicle:	0.3	0.0	0.0	0.0	0.0	0.2
	Other single-vehicle crashes	2.7	0.0	0.1	0.5	0.7	1.3
	Total single-vehicle crashes:	11.7	0.1	0.3	1.5	2.0	7.9
Total crashes:		15.0	0.1	0.4	1.9	2.6	9.9

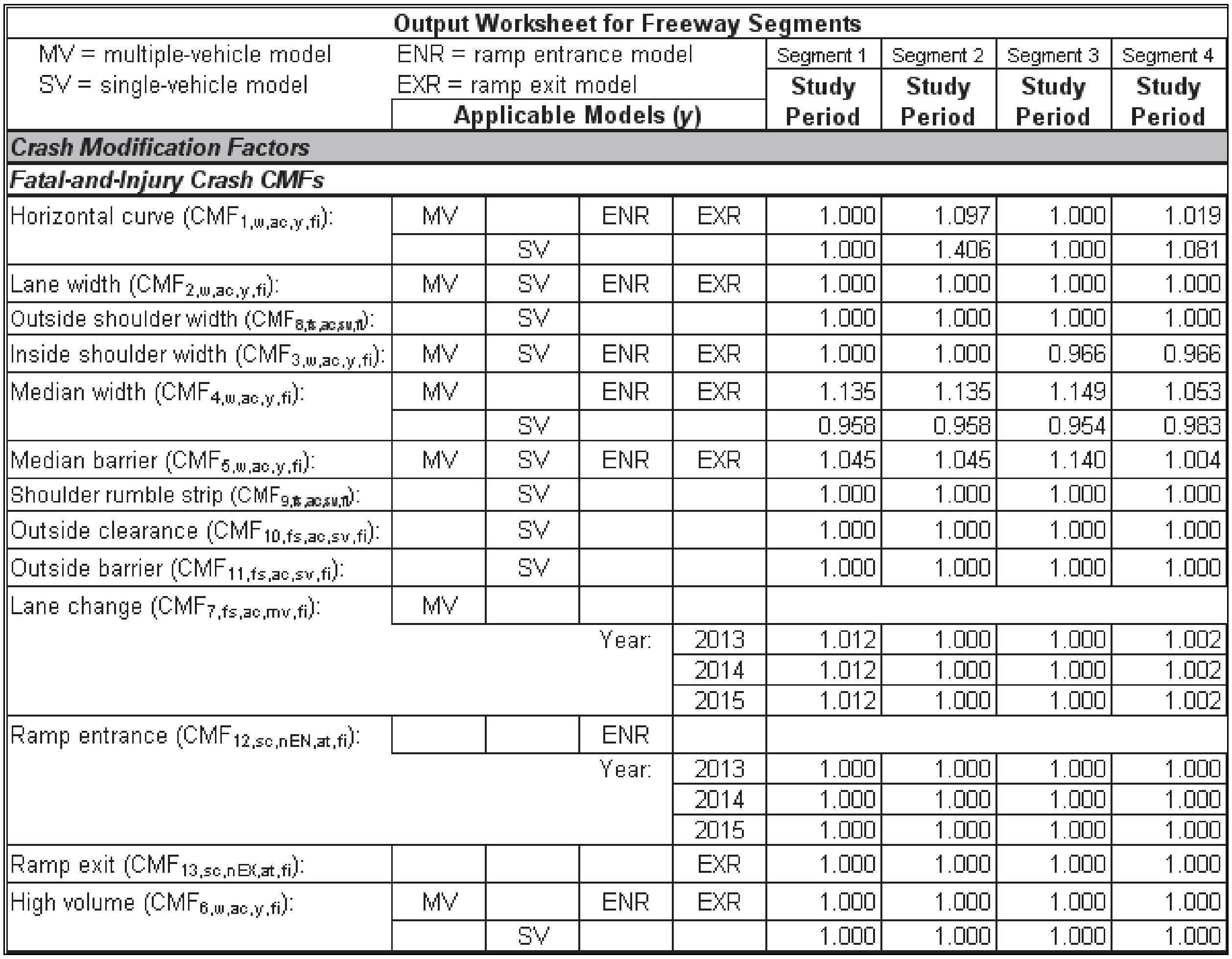
Figure 47. A1: Output Summary Worksheet—Estimated Crash Statistics

Detailed Output Data

On the Output Freeway Segments worksheet, the following data are provided:

- Crash modification factors (CMFs) for fatal-and-injury (FI) crashes.
- CMFs for property-damage-only (PDO) crashes.
- Predicted average crash frequency, including the following quantities:
  - FI crash frequency (for multiple-vehicle, single-vehicle, ramp entrance, and ramp exit crashes).
  - PDO crash frequency (for multiple-vehicle, single-vehicle, ramp entrance, and ramp exit crashes).
  - Crash severity distribution (fatal K, incapacitating injury A, non-incapacitating injury B, possible injury C, and PDO).
- Intermediate results for curve, barrier, and weaving section calculations.
- Traffic data (the projected AADT volumes for the freeway segments and ramps by year).

The CMF calculations for FI crashes are shown in Figure 48. Note that some of the CMFs are computed multiple times because their values may depend on manner of crash or the volume for the associated year. Similar calculations are provided in ISATe for PDO crashes, but are not repeated here.

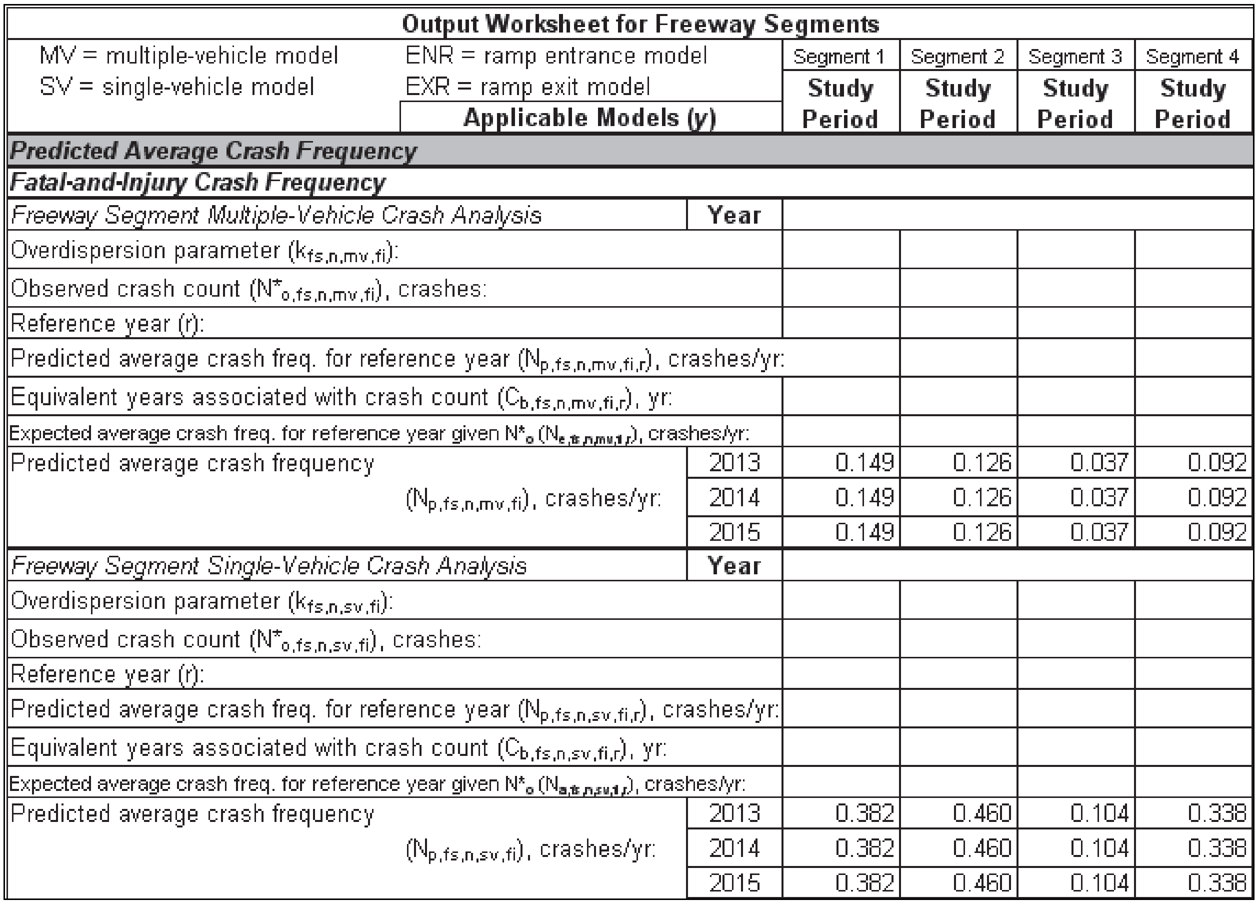


Output Worksheet for Freeway Segments								
MV = multiple-vehicle model SV = single-vehicle model	ENR = ramp entrance model EXR = ramp exit model				Segment 1	Segment 2	Segment 3	Segment 4
	Applicable Models (*y*)				**Study Period**	**Study Period**	**Study Period**	**Study Period**
Crash Modification Factors								
Fatal-and-Injury Crash CMFs								
Horizontal curve ($CMF_{1,w,ac,y,fi}$):	MV		ENR	EXR	1.000	1.097	1.000	1.019
		SV			1.000	1.406	1.000	1.081
Lane width ($CMF_{2,w,ac,y,fi}$):	MV	SV	ENR	EXR	1.000	1.000	1.000	1.000
Outside shoulder width ($CMF_{8,fs,ac,sv,fi}$):		SV			1.000	1.000	1.000	1.000
Inside shoulder width ($CMF_{3,w,ac,y,fi}$):	MV	SV	ENR	EXR	1.000	1.000	0.966	0.966
Median width ($CMF_{4,w,ac,y,fi}$):	MV		ENR	EXR	1.135	1.135	1.149	1.053
		SV			0.958	0.958	0.954	0.983
Median barrier ($CMF_{5,w,ac,y,fi}$):	MV	SV	ENR	EXR	1.045	1.045	1.140	1.004
Shoulder rumble strip ($CMF_{9,fs,ac,sv,fi}$):		SV			1.000	1.000	1.000	1.000
Outside clearance ($CMF_{10,fs,ac,sv,fi}$):		SV			1.000	1.000	1.000	1.000
Outside barrier ($CMF_{11,fs,ac,sv,fi}$):		SV			1.000	1.000	1.000	1.000
Lane change ($CMF_{7,fs,ac,mv,fi}$):	MV							
			Year:	2013	1.012	1.000	1.000	1.002
				2014	1.012	1.000	1.000	1.002
				2015	1.012	1.000	1.000	1.002
Ramp entrance ($CMF_{12,sc,nEN,at,fi}$):			ENR					
			Year:	2013	1.000	1.000	1.000	1.000
				2014	1.000	1.000	1.000	1.000
				2015	1.000	1.000	1.000	1.000
Ramp exit ($CMF_{13,sc,nEX,at,fi}$):				EXR	1.000	1.000	1.000	1.000
High volume ($CMF_{6,w,ac,y,fi}$):	MV		ENR	EXR	1.000	1.000	1.000	1.000
		SV			1.000	1.000	1.000	1.000

Figure 48. A1: Output Freeway Segments Worksheet—CMFs for FI Crashes

Inspection of the median width and median barrier CMFs reveals that the narrow median tends to correspond to a higher crash frequency on the freeway section than would otherwise occur with a wide median. The increase is most notable for segment 3, where the combined CMF for median width and barrier is 1.310 (= 1.149 × 1.140) for multiple-vehicle crashes, and 1.088 (= 0.954 × 1.140) for single-vehicle crashes. Inspection of the horizontal curve CMFs reveals that curvature is associated with more frequent crashes for segments 2 and 4, relative to the tangent segments.

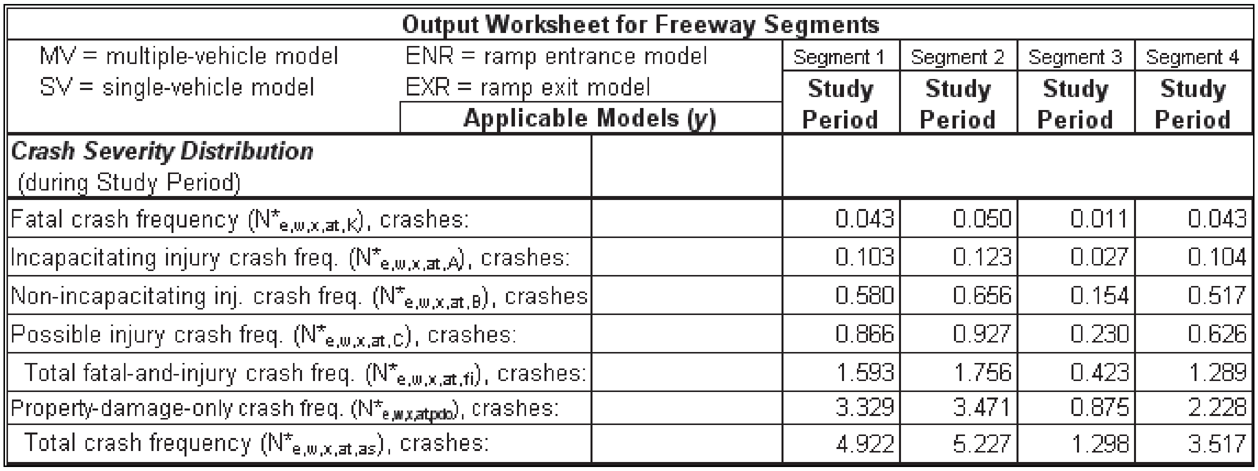
The predicted average crash frequency calculations for FI crashes are shown in Figure 49. In this sample application, no crash data are available and the EB Method is not used. As a result, rows relating to these calculations are blank. Three rows each are shown for multiple-vehicle crash frequency calculations, one row for each year of the study period. Similarly, three rows each are shown for single-vehicle crash frequency calculations. Unused rows for additional years are omitted from the figure.



Output Worksheet for Freeway Segments					
MV = multiple-vehicle model SV = single-vehicle model	ENR = ramp entrance model EXR = ramp exit model	Segment 1	Segment 2	Segment 3	Segment 4
	Applicable Models (y)	Study Period	Study Period	Study Period	Study Period
Predicted Average Crash Frequency					
Fatal-and-Injury Crash Frequency					
Freeway Segment Multiple-Vehicle Crash Analysis	**Year**				
Overdispersion parameter ($k_{fs,n,mv,fi}$):					
Observed crash count ($N^*_{o,fs,n,mv,fi}$), crashes:					
Reference year (r):					
Predicted average crash freq. for reference year ($N_{p,fs,n,mv,fi,r}$), crashes/yr:					
Equivalent years associated with crash count ($C_{b,fs,n,mv,fi,r}$), yr:					
Expected average crash freq. for reference year given N^*_o ($N_{e,fs,n,mv,fi,r}$), crashes/yr:					
Predicted average crash frequency ($N_{p,fs,n,mv,fi}$), crashes/yr:	2013	0.149	0.126	0.037	0.092
	2014	0.149	0.126	0.037	0.092
	2015	0.149	0.126	0.037	0.092
Freeway Segment Single-Vehicle Crash Analysis	**Year**				
Overdispersion parameter ($k_{fs,n,sv,fi}$):					
Observed crash count ($N^*_{o,fs,n,sv,fi}$), crashes:					
Reference year (r):					
Predicted average crash freq. for reference year ($N_{p,fs,n,sv,fi,r}$), crashes/yr:					
Equivalent years associated with crash count ($C_{b,fs,n,sv,fi,r}$), yr:					
Expected average crash freq. for reference year given N^*_o ($N_{e,fs,n,sv,fi,r}$), crashes/yr:					
Predicted average crash frequency ($N_{p,fs,n,sv,fi}$), crashes/yr:	2013	0.382	0.460	0.104	0.338
	2014	0.382	0.460	0.104	0.338
	2015	0.382	0.460	0.104	0.338

Figure 49. A1: Output Freeway Segments Worksheet—Predicted FI Crash Frequency

The crash severity distribution calculations are shown in Figure 50. These calculations are shown in the worksheet rows located just below the rows that show the predicted average crash frequency. The estimated number of crashes are given for each segment and aggregated for the entire study period.



Output Worksheet for Freeway Segments					
MV = multiple-vehicle model SV = single-vehicle model	ENR = ramp entrance model EXR = ramp exit model	Segment 1	Segment 2	Segment 3	Segment 4
	Applicable Models (y)	Study Period	Study Period	Study Period	Study Period
Crash Severity Distribution (during Study Period)					
Fatal crash frequency ($N^*_{e,w,x,at,K}$), crashes:		0.043	0.050	0.011	0.043
Incapacitating injury crash freq. ($N^*_{e,w,x,at,A}$), crashes:		0.103	0.123	0.027	0.104
Non-incapacitating inj. crash freq. ($N^*_{e,w,x,at,B}$), crashes		0.580	0.656	0.154	0.517
Possible injury crash freq. ($N^*_{e,w,x,at,C}$), crashes:		0.866	0.927	0.230	0.626
Total fatal-and-injury crash freq. ($N^*_{e,w,x,at,fi}$), crashes:		1.593	1.756	0.423	1.289
Property-damage-only crash freq. ($N^*_{e,w,x,at,pdo}$), crashes:		3.329	3.471	0.875	2.228
Total crash frequency ($N^*_{e,w,x,at,as}$), crashes:		4.922	5.227	1.298	3.517

Figure 50. A1: Output Freeway Segments Worksheet—Crash Severity Distribution

Results

A freeway section consisting of four segments was analyzed for a three-year study period. The total predicted average crash frequency (shown in Figure 47) was found to be about 5.0 crashes per year, or 15.0 crashes during the study period. Of these, about 11.7 of the predicted crashes would be single-vehicle crashes with fixed objects.

Inspection of the computed CMFs reveals that the median width and the presence of median barrier are associated with higher crash risk, relative to typical freeways. Safety improvements to the freeway section could include widening the median, ideally to the point that a median barrier would no longer be needed. Flattening the curve in segment 2 could also yield notable improvement in safety performance.

APPLICATION 2. COMBINED FREEWAY AND INTERCHANGE

The freeway facility of interest includes a freeway section between two diamond interchanges. The facility is located in an urban area. The two interchange crossroads are about one mile apart. The traffic volume on the freeway is 140,000 vehicles per day. The freeway includes a weaving section because of the close proximity of the two interchanges. The objective of this sample application is to evaluate the safety of the facility, with a focus on the safety performance of the weaving section and the crossroad ramp terminals.

The facility consists of three freeway segments, five ramp segments, and four crossroad ramp terminals. The segments are shown in Figure 51.

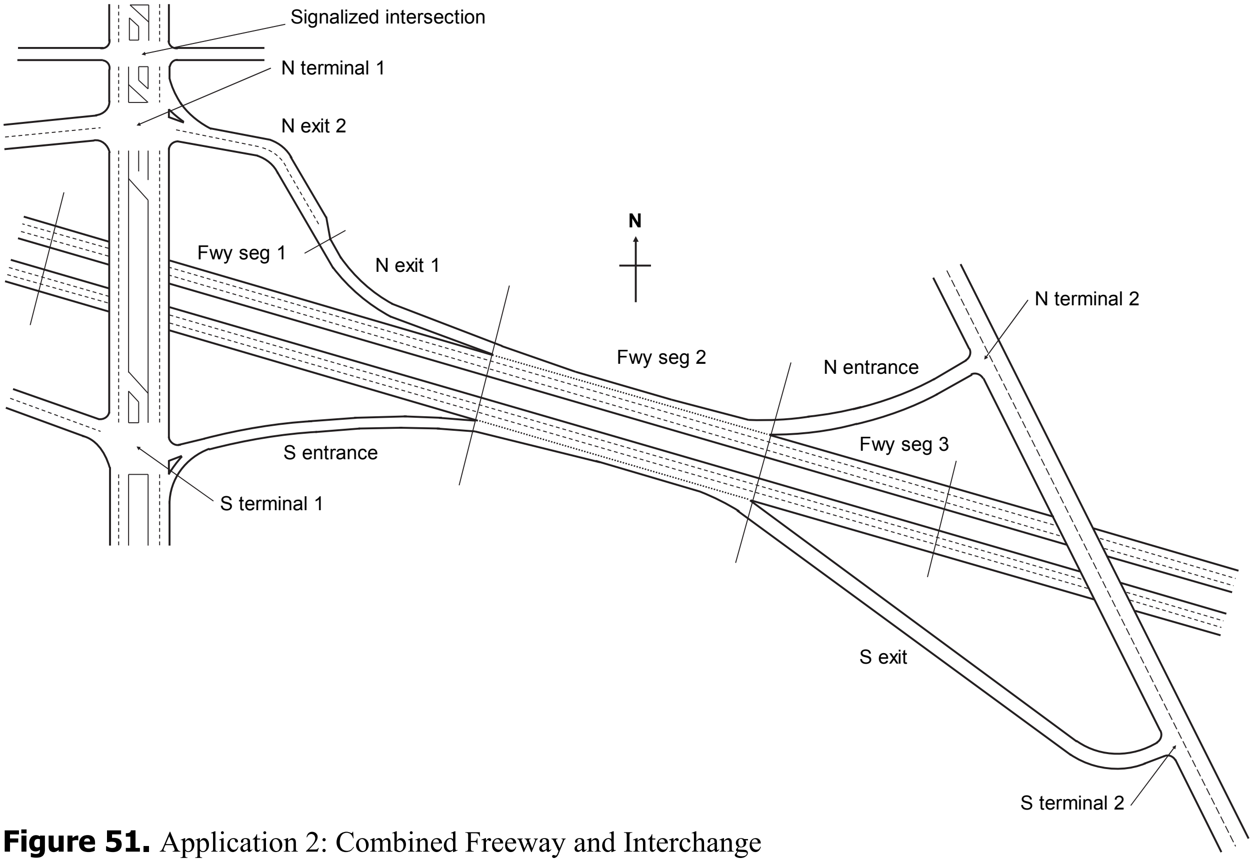
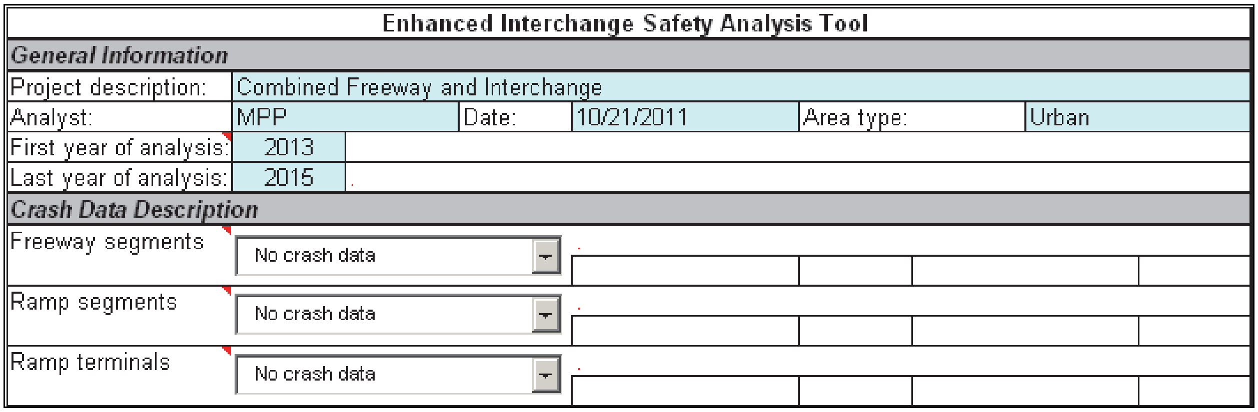


Figure 51. Application 2: Combined Freeway and Interchange

The divisions between the freeway segments occur at the gore points where the four ramps connect to the freeway mainline. The division between the ramp segments labeled “N exit 1” and “N exit 2” occurs at the upstream start of taper for the lane-add taper on the ramp. A basic weaving section is located on each side of the segment labeled “Fwy seg 2.”

Input Data

The facility has three different component types—freeway segments, ramp segments, and crossroad ramp terminals. Hence, all three input worksheets within ISATe are used to model the facility. The data entry cells in the sections titled General Information and Crash Data Description are shown in Figure 52. As indicated in this figure, the area type is urban, the analysis period includes the years 2013 to 2015, and no crash data are available.



Enhanced Interchange Safety Analysis Tool

General Information

Project description:	Combined Freeway and Interchange				
Analyst:	MPP	Date:	10/21/2011	Area type:	Urban
First year of analysis:	2013				
Last year of analysis:	2015				

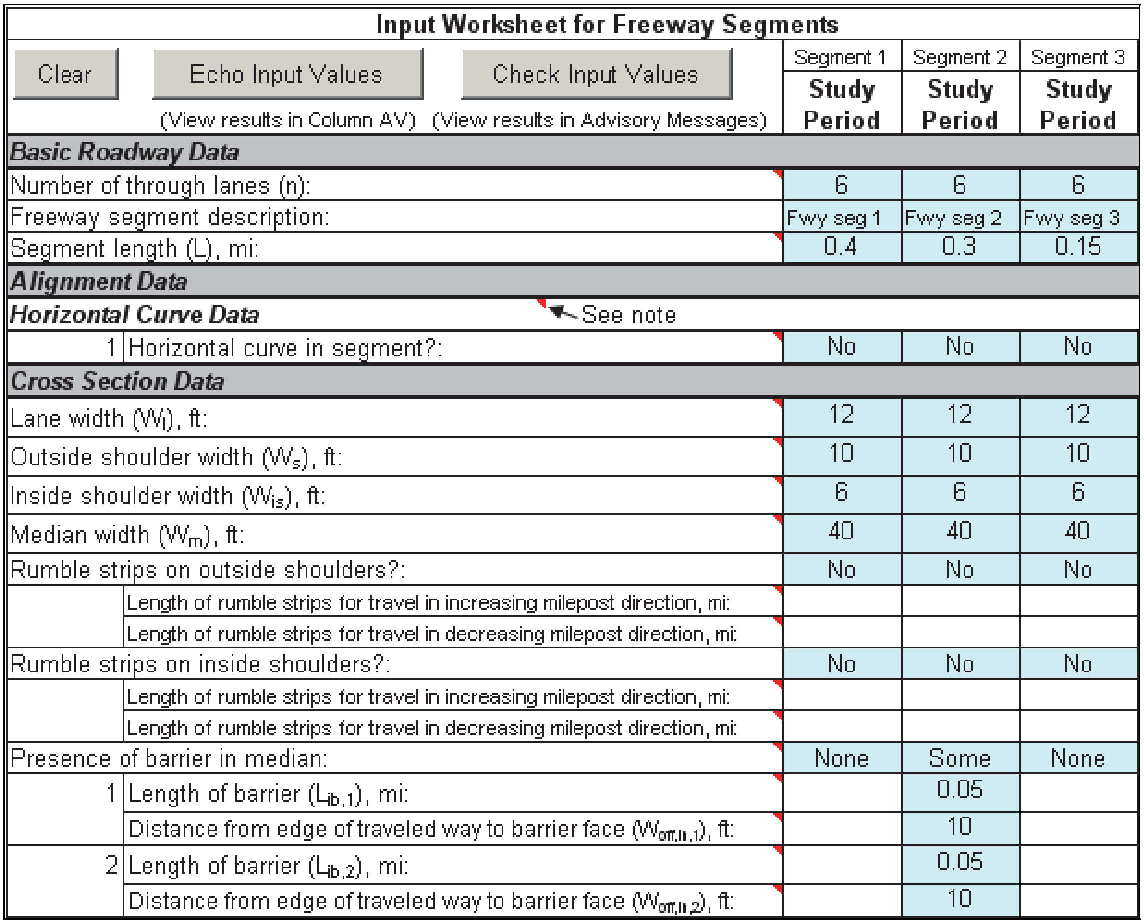
Crash Data Description

Freeway segments	No crash data
Ramp segments	No crash data
Ramp terminals	No crash data

Figure 52. A2: Main Worksheet—General Information and Crash Data Description

Freeway Segments

Figure 53 identifies the basic roadway, alignment, and cross section data used that describe the freeway segments. The segments do not have horizontal curvature, so the unused alignment-data rows are omitted from the figure. All segments are indicated to have 12-ft lanes, 10-ft outside shoulders, 6-ft inside shoulders, and a 40-ft median. Segment 2 is coded as having two short barrier pieces in the median. These barrier pieces protect a sign structure in the segment.



Input Worksheet for Freeway Segments

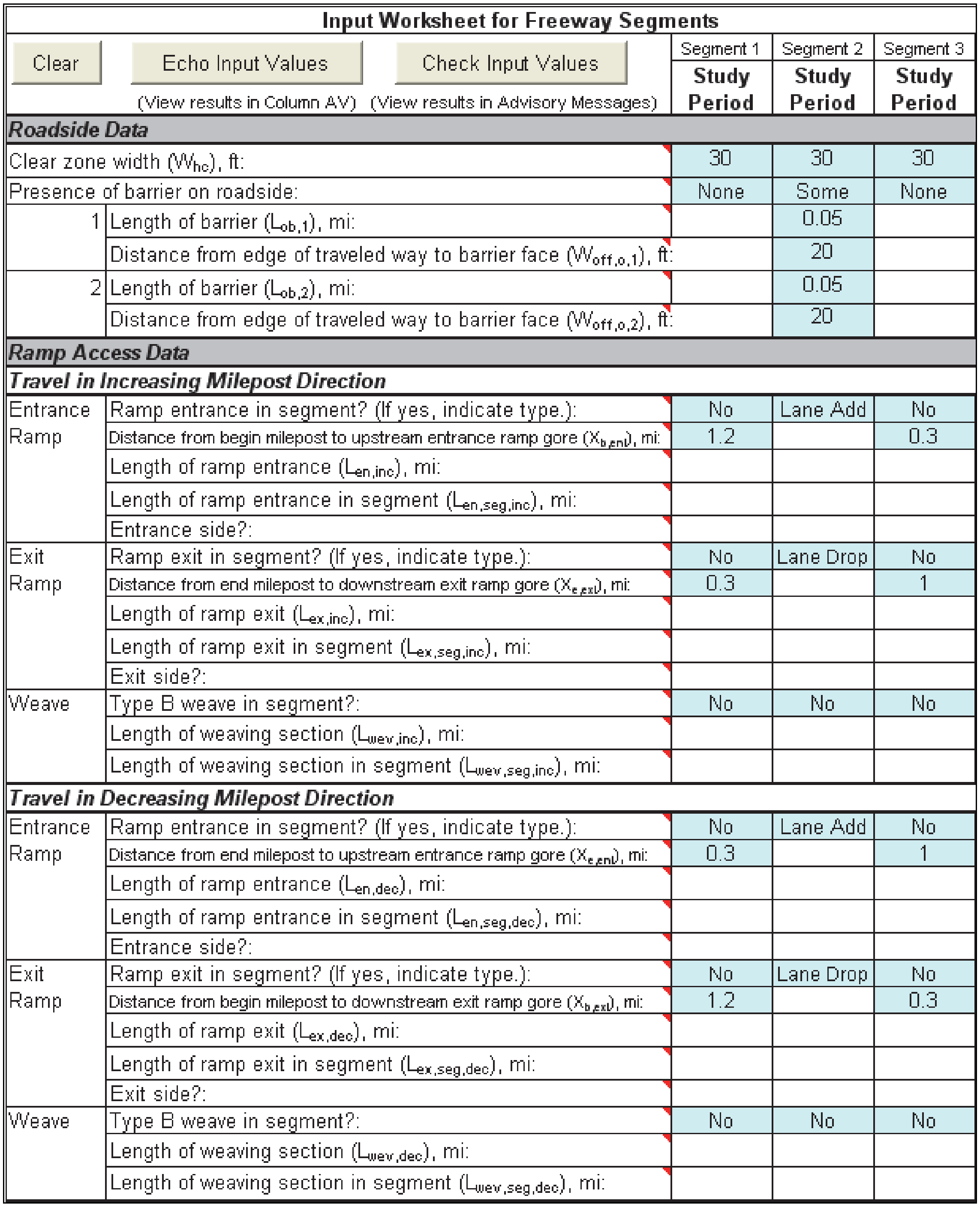
		Segment 1	Segment 2	Segment 3
		Study Period	Study Period	Study Period
Basic Roadway Data				
Number of through lanes (n):		6	6	6
Freeway segment description:		Fwy seg 1	Fwy seg 2	Fwy seg 3
Segment length (L), mi:		0.4	0.3	0.15
Alignment Data				
Horizontal Curve Data				
1	Horizontal curve in segment?:	No	No	No
Cross Section Data				
Lane width (W_l), ft:		12	12	12
Outside shoulder width (W_s), ft:		10	10	10
Inside shoulder width (W_{is}), ft:		6	6	6
Median width (W_m), ft:		40	40	40
Rumble strips on outside shoulders?:		No	No	No
	Length of rumble strips for travel in increasing milepost direction, mi:			
	Length of rumble strips for travel in decreasing milepost direction, mi:			
Rumble strips on inside shoulders?:		No	No	No
	Length of rumble strips for travel in increasing milepost direction, mi:			
	Length of rumble strips for travel in decreasing milepost direction, mi:			
Presence of barrier in median:		None	Some	None
1	Length of barrier ($L_{ib,1}$), mi:		0.05	
	Distance from edge of traveled way to barrier face ($W_{off,li,1}$), ft:		10	
2	Length of barrier ($L_{ib,2}$), mi:		0.05	
	Distance from edge of traveled way to barrier face ($W_{off,li,2}$), ft:		10	

Figure 53. A2: Input Freeway Segments Worksheet—Roadway, Alignment, and Cross Section Data

The roadside data and ramp access data associated with the freeway segments are shown in Figure 54. Unused rows in the roadside data section are omitted from the figure.

The weaving sections in segment 2 are described by indicating that the segment has a lane-drop and a lane-add in each travel direction. The guidance associated with Figure 8 indicates that neither weaving section has the Type B configuration.

Segment 2 is coded as having two short barrier pieces on the roadside. These barrier pieces protect a sign structure in the segment.



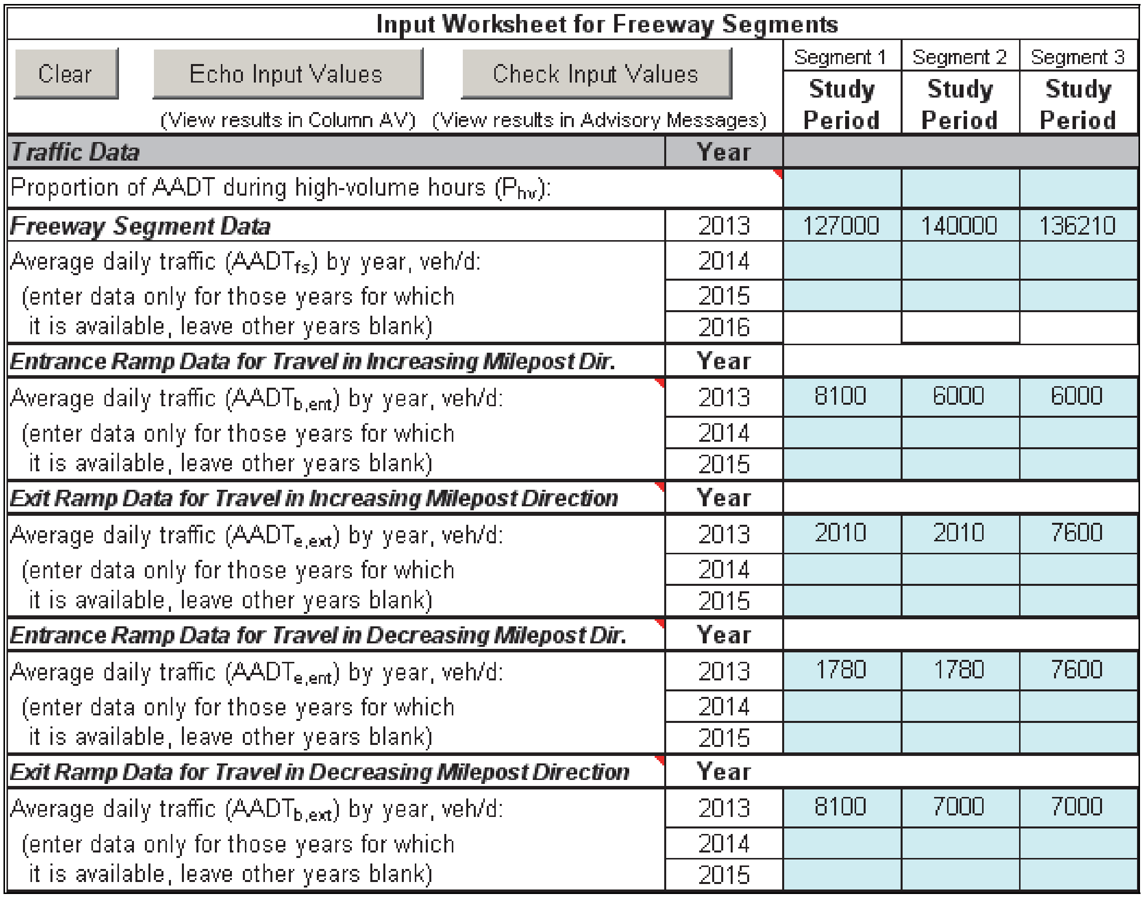
Input Worksheet for Freeway Segments

(View results in Column AV) (View results in Advisory Messages)

		Segment 1 Study Period	Segment 2 Study Period	Segment 3 Study Period
Roadside Data				
Clear zone width (W_{hc}), ft:		30	30	30
Presence of barrier on roadside:		None	Some	None
1	Length of barrier ($L_{ob,1}$), mi:		0.05	
	Distance from edge of traveled way to barrier face ($W_{off,o,1}$), ft:		20	
2	Length of barrier ($L_{ob,2}$), mi:		0.05	
	Distance from edge of traveled way to barrier face ($W_{off,o,2}$), ft:		20	
Ramp Access Data				
Travel in Increasing Milepost Direction				
Entrance Ramp	Ramp entrance in segment? (If yes, indicate type.):	No	Lane Add	No
	Distance from begin milepost to upstream entrance ramp gore ($X_{b,ent}$), mi:	1.2		0.3
	Length of ramp entrance ($L_{en,inc}$), mi:			
	Length of ramp entrance in segment ($L_{en,seg,inc}$), mi:			
	Entrance side?:			
Exit Ramp	Ramp exit in segment? (If yes, indicate type.):	No	Lane Drop	No
	Distance from end milepost to downstream exit ramp gore ($X_{e,ext}$), mi:	0.3		1
	Length of ramp exit ($L_{ex,inc}$), mi:			
	Length of ramp exit in segment ($L_{ex,seg,inc}$), mi:			
	Exit side?:			
Weave	Type B weave in segment?:	No	No	No
	Length of weaving section ($L_{wev,inc}$), mi:			
	Length of weaving section in segment ($L_{wev,seg,inc}$), mi:			
Travel in Decreasing Milepost Direction				
Entrance Ramp	Ramp entrance in segment? (If yes, indicate type.):	No	Lane Add	No
	Distance from end milepost to upstream entrance ramp gore ($X_{e,ent}$), mi:	0.3		1
	Length of ramp entrance ($L_{en,dec}$), mi:			
	Length of ramp entrance in segment ($L_{en,seg,dec}$), mi:			
	Entrance side?:			
Exit Ramp	Ramp exit in segment? (If yes, indicate type.):	No	Lane Drop	No
	Distance from begin milepost to downstream exit ramp gore ($X_{b,ext}$), mi:	1.2		0.3
	Length of ramp exit ($L_{ex,dec}$), mi:			
	Length of ramp exit in segment ($L_{ex,seg,dec}$), mi:			
	Exit side?:			
Weave	Type B weave in segment?:	No	No	No
	Length of weaving section ($L_{wev,dec}$), mi:			
	Length of weaving section in segment ($L_{wev,seg,dec}$), mi:			

Figure 54. A2: Input Freeway Segments Worksheet—Roadside and Ramp Access Data

The data entry cells in the section titled Traffic Data are shown in Figure 55. Note that the unused rows are omitted from the figure. Volumes are entered for the freeway mainline and four ramps. The proportion of AADT occurring during high-volume hours (P_{hv}) is not entered; as a result, the default value for this quantity was computed by the program (based on the values shown in Table 4).



Input Worksheet for Freeway Segments

		Segment 1	Segment 2	Segment 3
		Study Period	**Study Period**	**Study Period**
Traffic Data	**Year**			
Proportion of AADT during high-volume hours (P_{hv}):				
Freeway Segment Data	2013	127000	140000	136210
Average daily traffic ($AADT_{fs}$) by year, veh/d:	2014			
(enter data only for those years for which	2015			
it is available, leave other years blank)	2016			
Entrance Ramp Data for Travel in Increasing Milepost Dir.	**Year**			
Average daily traffic ($AADT_{b,ent}$) by year, veh/d:	2013	8100	6000	6000
(enter data only for those years for which	2014			
it is available, leave other years blank)	2015			
Exit Ramp Data for Travel in Increasing Milepost Direction	**Year**			
Average daily traffic ($AADT_{e,ext}$) by year, veh/d:	2013	2010	2010	7600
(enter data only for those years for which	2014			
it is available, leave other years blank)	2015			
Entrance Ramp Data for Travel in Decreasing Milepost Dir.	**Year**			
Average daily traffic ($AADT_{e,ent}$) by year, veh/d:	2013	1780	1780	7600
(enter data only for those years for which	2014			
it is available, leave other years blank)	2015			
Exit Ramp Data for Travel in Decreasing Milepost Direction	**Year**			
Average daily traffic ($AADT_{b,ext}$) by year, veh/d:	2013	8100	7000	7000
(enter data only for those years for which	2014			
it is available, leave other years blank)	2015			

Figure 55. A2: Input Freeway Segments Worksheet—Traffic Data

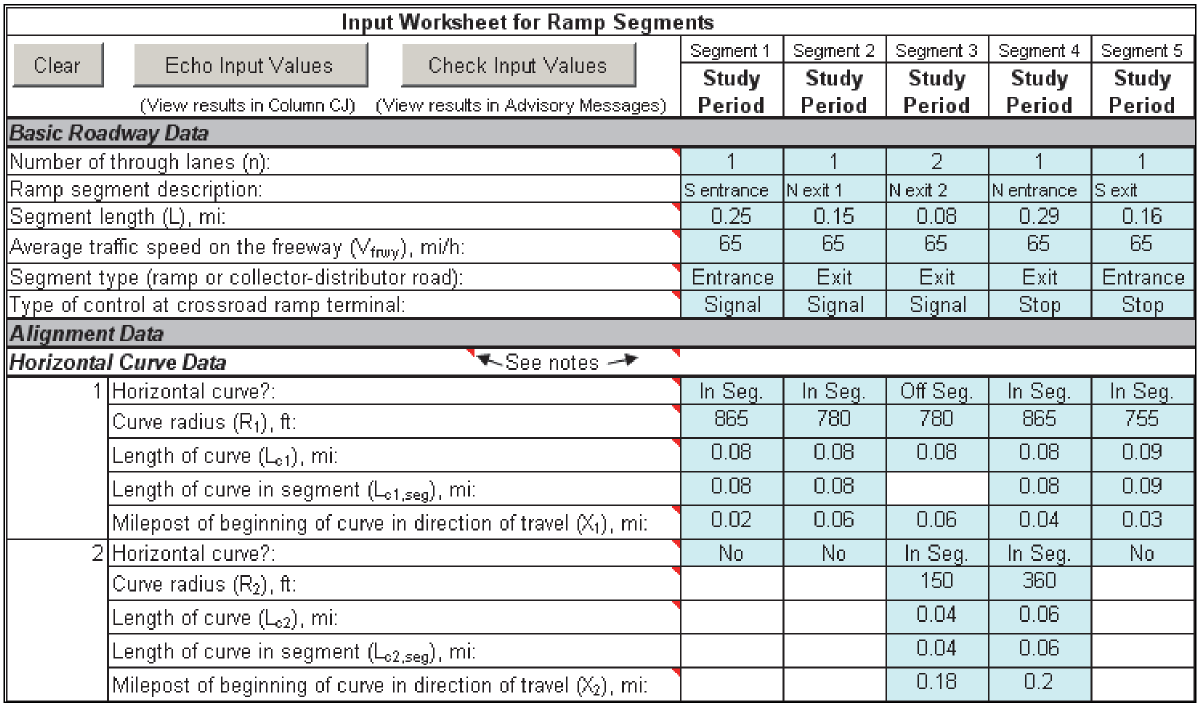
Ramp Segments

Figure 56 identifies the basic roadway and alignment data that describe the four ramps. Five ramp segments are used for this purpose. The ramp labeled "N exit" is described using two segments. The other ramps are described using one segment. The Input Ramp Segments worksheet accommodates up to five curves on each ramp segment, but because none of the ramp segments have more than two curves, the unused curve data rows are not shown.

The first curve on the ramp labeled "N exit" in Figure 51 is described in terms of two segments (i.e., N exit 2 and N exit 1). They are shown in Figure 56 as segments 2 and 3. The first curve is located in segment 2, but it is also described in the column for segment 3 because its presence upstream of segment 3 affects vehicle speeds on this segment. In the column for segment 3, the first curve is described as "off segment" to indicate that it is located entirely upstream of segment 3.

Figure 57 identifies the cross section, roadside, ramp access, and traffic data that describe the four ramps. Note that a lane-add taper of 0.03 mi in length is indicated in segment 3. The upstream start of taper for this lane-add taper defines the break between segments 2 and 3.

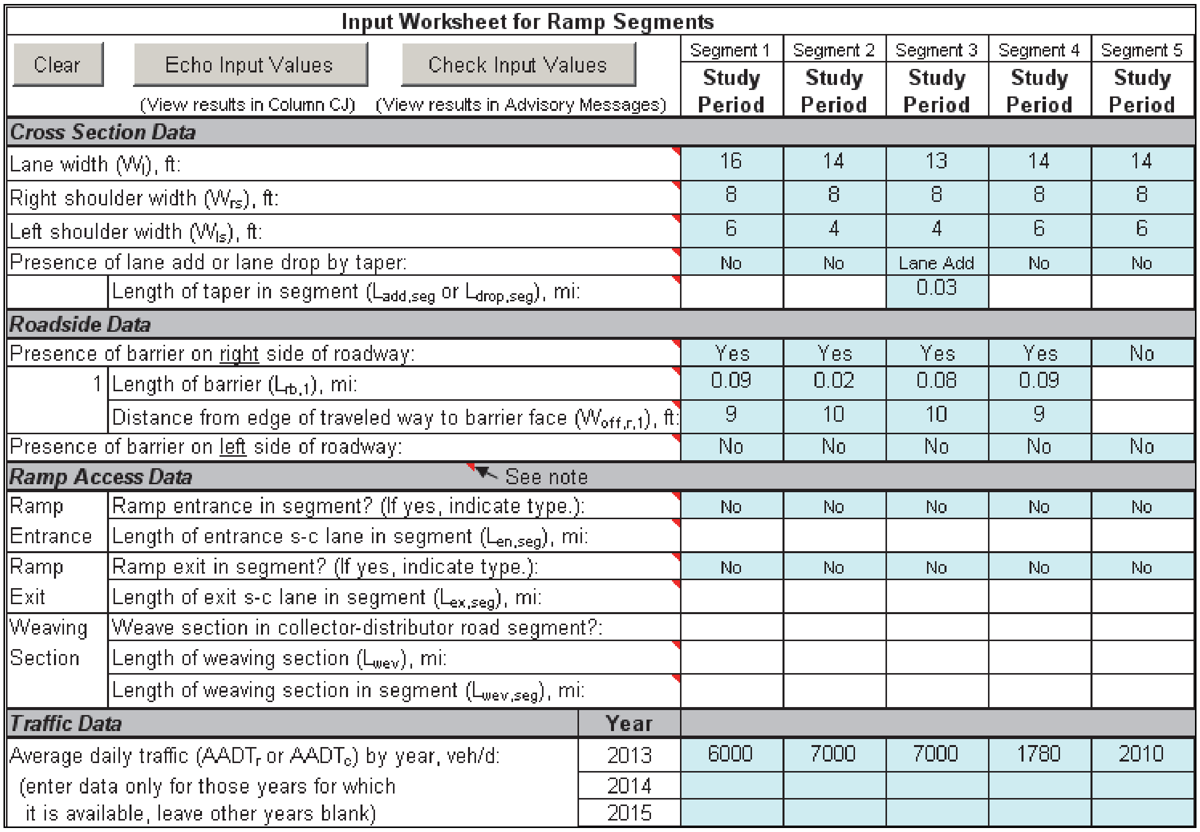
The lane and shoulder widths are entered in the same manner as for the freeway segments. None of the ramp segments are coded as having additional ramp entrances or exits along their length. Segments 1 through 4 are coded as having some roadside barrier on their right side.



Input Worksheet for Ramp Segments

		Segment 1 Study Period	Segment 2 Study Period	Segment 3 Study Period	Segment 4 Study Period	Segment 5 Study Period
Basic Roadway Data						
Number of through lanes (n):		1	1	2	1	1
Ramp segment description:		S entrance	N exit 1	N exit 2	N entrance	S exit
Segment length (L), mi:		0.25	0.15	0.08	0.29	0.16
Average traffic speed on the freeway (V_{frwy}), mi/h:		65	65	65	65	65
Segment type (ramp or collector-distributor road):		Entrance	Exit	Exit	Exit	Entrance
Type of control at crossroad ramp terminal:		Signal	Signal	Signal	Stop	Stop
Alignment Data						
Horizontal Curve Data ← See notes →						
1	Horizontal curve?:	In Seg.	In Seg.	Off Seg.	In Seg.	In Seg.
	Curve radius (R_1), ft:	865	780	780	865	755
	Length of curve (L_{c1}), mi:	0.08	0.08	0.08	0.08	0.09
	Length of curve in segment ($L_{c1,seg}$), mi:	0.08	0.08		0.08	0.09
	Milepost of beginning of curve in direction of travel (X_1), mi:	0.02	0.06	0.06	0.04	0.03
2	Horizontal curve?:	No	No	In Seg.	In Seg.	No
	Curve radius (R_2), ft:			150	360	
	Length of curve (L_{c2}), mi:			0.04	0.06	
	Length of curve in segment ($L_{c2,seg}$), mi:			0.04	0.06	
	Milepost of beginning of curve in direction of travel (X_2), mi:			0.18	0.2	

Figure 56. A2: Input Ramp Segments Worksheet—Roadway and Alignment Data



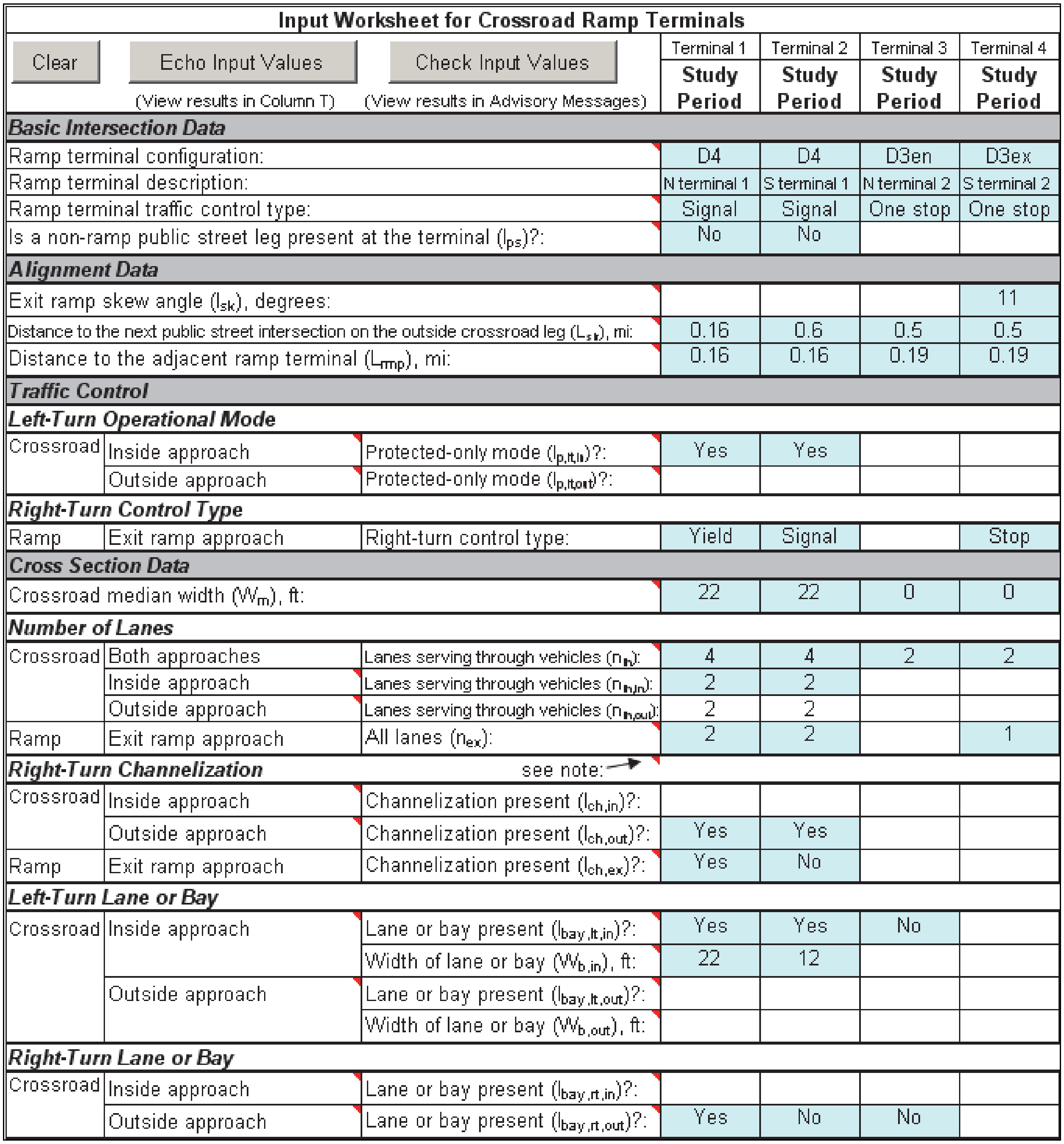
Input Worksheet for Ramp Segments

		Segment 1 Study Period	Segment 2 Study Period	Segment 3 Study Period	Segment 4 Study Period	Segment 5 Study Period
Cross Section Data						
Lane width (W_l), ft:		16	14	13	14	14
Right shoulder width (W_{rs}), ft:		8	8	8	8	8
Left shoulder width (W_{ls}), ft:		6	4	4	6	6
Presence of lane add or lane drop by taper:		No	No	Lane Add	No	No
	Length of taper in segment ($L_{add,seg}$ or $L_{drop,seg}$), mi:			0.03		
Roadside Data						
Presence of barrier on right side of roadway:		Yes	Yes	Yes	Yes	No
1	Length of barrier ($L_{rb,1}$), mi:	0.09	0.02	0.08	0.09	
	Distance from edge of traveled way to barrier face ($W_{off,r,1}$), ft:	9	10	10	9	
Presence of barrier on left side of roadway:		No	No	No	No	No
Ramp Access Data ← See note						
Ramp Entrance	Ramp entrance in segment? (If yes, indicate type.):	No	No	No	No	No
	Length of entrance s-c lane in segment ($L_{en,seg}$), mi:					
Ramp Exit	Ramp exit in segment? (If yes, indicate type.):	No	No	No	No	No
	Length of exit s-c lane in segment ($L_{ex,seg}$), mi:					
Weaving Section	Weave section in collector-distributor road segment?:					
	Length of weaving section (L_{wev}), mi:					
	Length of weaving section in segment ($L_{wev,seg}$), mi:					
Traffic Data	**Year**					
Average daily traffic ($AADT_r$ or $AADT_c$) by year, veh/d:	2013	6000	7000	7000	1780	2010
(enter data only for those years for which	2014					
it is available, leave other years blank)	2015					

Figure 57. A2: Input Ramp Segments Worksheet—Cross Section, Roadside, Ramp Access, and Traffic Data

Ramp Terminals

Figure 58 identifies the basic intersection, alignment, traffic control, and cross section data that describe the four crossroad ramp terminals. The terminal configuration codes entered in the first row were determined using Figure 1.



Input Worksheet for Crossroad Ramp Terminals

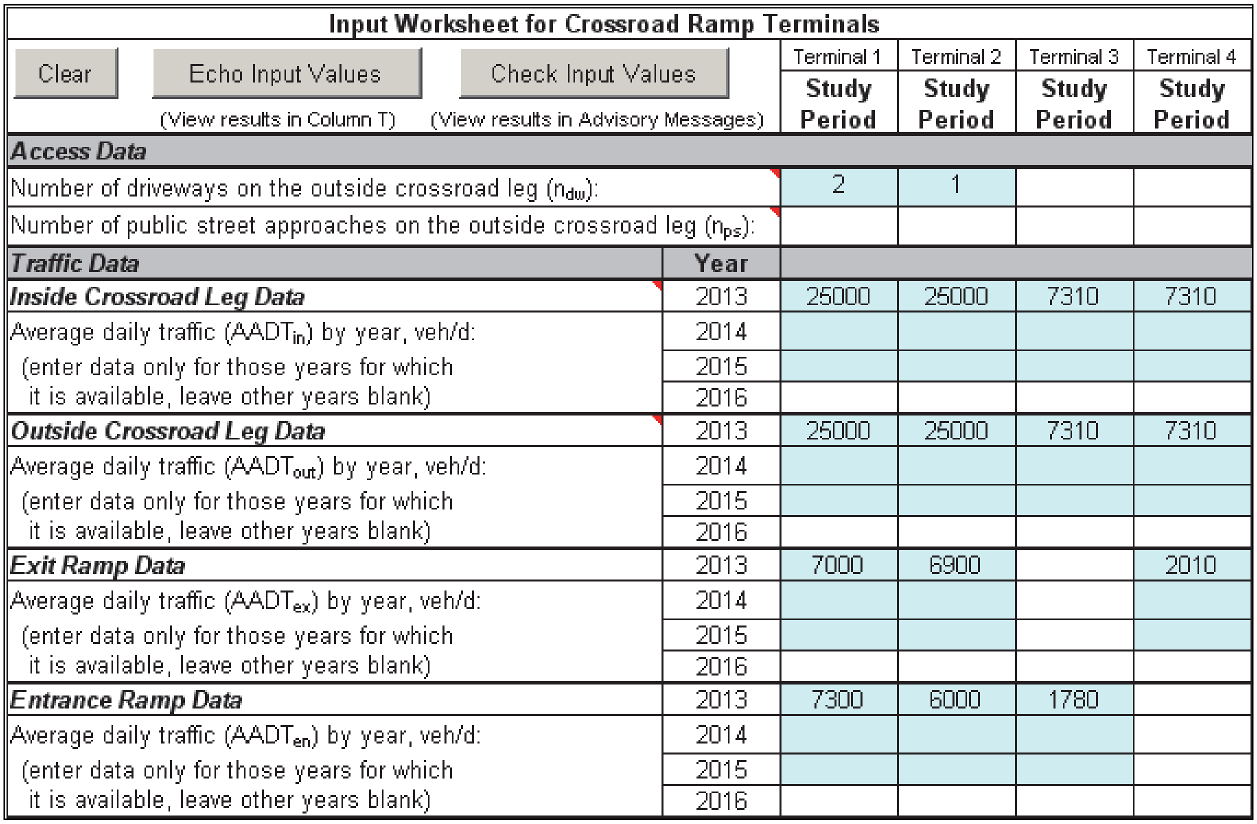
			Terminal 1 Study Period	Terminal 2 Study Period	Terminal 3 Study Period	Terminal 4 Study Period
Basic Intersection Data						
Ramp terminal configuration:			D4	D4	D3en	D3ex
Ramp terminal description:			N terminal 1	S terminal 1	N terminal 2	S terminal 2
Ramp terminal traffic control type:			Signal	Signal	One stop	One stop
Is a non-ramp public street leg present at the terminal (I_{ps})?:			No	No		
Alignment Data						
Exit ramp skew angle (I_{sk}), degrees:						11
Distance to the next public street intersection on the outside crossroad leg (L_{str}), mi:			0.16	0.6	0.5	0.5
Distance to the adjacent ramp terminal (L_{rmp}), mi:			0.16	0.16	0.19	0.19
Traffic Control						
Left-Turn Operational Mode						
Crossroad	Inside approach	Protected-only mode ($I_{p,lt,in}$)?:	Yes	Yes		
	Outside approach	Protected-only mode ($I_{p,lt,out}$)?:				
Right-Turn Control Type						
Ramp	Exit ramp approach	Right-turn control type:	Yield	Signal		Stop
Cross Section Data						
Crossroad median width (W_m), ft:			22	22	0	0
Number of Lanes						
Crossroad	Both approaches	Lanes serving through vehicles (n_{th}):	4	4	2	2
	Inside approach	Lanes serving through vehicles ($n_{th,in}$):	2	2		
	Outside approach	Lanes serving through vehicles ($n_{th,out}$):	2	2		
Ramp	Exit ramp approach	All lanes (n_{ex}):	2	2		1
Right-Turn Channelization		see note: →				
Crossroad	Inside approach	Channelization present ($I_{ch,in}$)?:				
	Outside approach	Channelization present ($I_{ch,out}$)?:	Yes	Yes		
Ramp	Exit ramp approach	Channelization present ($I_{ch,ex}$)?:	Yes	No		
Left-Turn Lane or Bay						
Crossroad	Inside approach	Lane or bay present ($I_{bay,lt,in}$)?:	Yes	Yes	No	
		Width of lane or bay ($W_{b,in}$), ft:	22	12		
	Outside approach	Lane or bay present ($I_{bay,lt,out}$)?:				
		Width of lane or bay ($W_{b,out}$), ft:				
Right-Turn Lane or Bay						
Crossroad	Inside approach	Lane or bay present ($I_{bay,rt,in}$)?:				
	Outside approach	Lane or bay present ($I_{bay,rt,out}$)?:	Yes	No	No	

Figure 58. A2: Input Ramp Terminals Worksheet—Intersection, Alignment, Traffic Control, and Cross Section Data

The two terminals on the west end of the facility are shown to be signalized (i.e., N terminal 1 and S terminal 1). The other two terminals are indicated to have stop control for the ramp movements. Terminal 3 (i.e., N terminal 2) does not strictly have stop control for the left-turn movement from the crossroad, but this movement does have to yield to oncoming traffic. Regardless, “one stop” is the appropriate input for the unsignalized version of this terminal configuration when using ISATe.

In the Alignment Data section, intersection skew angle is provided for the stop-controlled ramp terminal that has an exit ramp approach. The distances to the nearest public street intersections and the adjacent ramp terminals are also provided. Figure 51 shows that a signalized intersection is in close proximity to the ramp terminal labeled “N terminal 1.” This intersection is not modeled in ISATe because it is not part of the interchange, but its proximity to “N terminal 1” (a distance of 0.16 mi) is indicated in the alignment data for terminal 1 (i.e., in the row labeled “Distance to the next public street intersection on the outside crossroad leg”).

Figure 59 identifies the access and traffic data that describe the crossroad ramp terminals. Note that some unused rows are omitted from the figure.



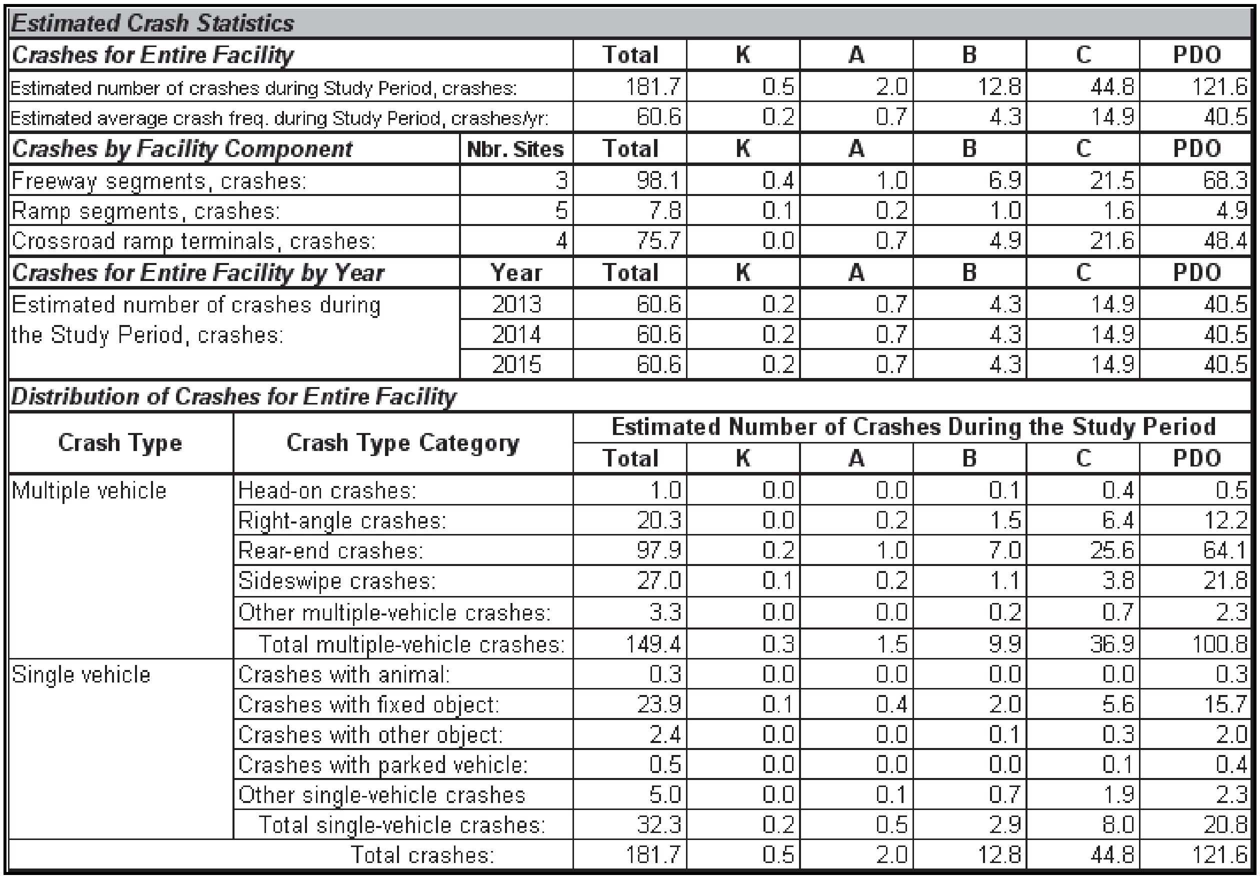
Input Worksheet for Crossroad Ramp Terminals

		Terminal 1 Study Period	Terminal 2 Study Period	Terminal 3 Study Period	Terminal 4 Study Period
Access Data					
Number of driveways on the outside crossroad leg (n_{dw}):		2	1		
Number of public street approaches on the outside crossroad leg (n_{ps}):					
Traffic Data	**Year**				
Inside Crossroad Leg Data	2013	25000	25000	7310	7310
Average daily traffic ($AADT_{in}$) by year, veh/d:	2014				
(enter data only for those years for which	2015				
it is available, leave other years blank)	2016				
Outside Crossroad Leg Data	2013	25000	25000	7310	7310
Average daily traffic ($AADT_{out}$) by year, veh/d:	2014				
(enter data only for those years for which	2015				
it is available, leave other years blank)	2016				
Exit Ramp Data	2013	7000	6900		2010
Average daily traffic ($AADT_{ex}$) by year, veh/d:	2014				
(enter data only for those years for which	2015				
it is available, leave other years blank)	2016				
Entrance Ramp Data	2013	7300	6000	1780	
Average daily traffic ($AADT_{en}$) by year, veh/d:	2014				
(enter data only for those years for which	2015				
it is available, leave other years blank)	2016				

Figure 59. A2: Input Ramp Terminals Worksheet—Access and Traffic Data

Output Summary

The Estimated Crash Statistics output cells are shown in Figure 60. Note that the unused rows are omitted from the figure. The two rows under the heading Crashes for Entire Facility provide the estimated number of crashes and crash frequency for the study period.



Estimated Crash Statistics

Crashes for Entire Facility	**Total**	**K**	**A**	**B**	**C**	**PDO**
Estimated number of crashes during Study Period, crashes:	181.7	0.5	2.0	12.8	44.8	121.6
Estimated average crash freq. during Study Period, crashes/yr:	60.6	0.2	0.7	4.3	14.9	40.5

Crashes by Facility Component	**Nbr. Sites**	**Total**	**K**	**A**	**B**	**C**	**PDO**
Freeway segments, crashes:	3	98.1	0.4	1.0	6.9	21.5	68.3
Ramp segments, crashes:	5	7.8	0.1	0.2	1.0	1.6	4.9
Crossroad ramp terminals, crashes:	4	75.7	0.0	0.7	4.9	21.6	48.4

Crashes for Entire Facility by Year	**Year**	**Total**	**K**	**A**	**B**	**C**	**PDO**
Estimated number of crashes during the Study Period, crashes:	2013	60.6	0.2	0.7	4.3	14.9	40.5
	2014	60.6	0.2	0.7	4.3	14.9	40.5
	2015	60.6	0.2	0.7	4.3	14.9	40.5

Distribution of Crashes for Entire Facility

Crash Type	**Crash Type Category**	**Estimated Number of Crashes During the Study Period**					
		Total	**K**	**A**	**B**	**C**	**PDO**
Multiple vehicle	Head-on crashes:	1.0	0.0	0.0	0.1	0.4	0.5
	Right-angle crashes:	20.3	0.0	0.2	1.5	6.4	12.2
	Rear-end crashes:	97.9	0.2	1.0	7.0	25.6	64.1
	Sideswipe crashes:	27.0	0.1	0.2	1.1	3.8	21.8
	Other multiple-vehicle crashes:	3.3	0.0	0.0	0.2	0.7	2.3
	Total multiple-vehicle crashes:	149.4	0.3	1.5	9.9	36.9	100.8
Single vehicle	Crashes with animal:	0.3	0.0	0.0	0.0	0.0	0.3
	Crashes with fixed object:	23.9	0.1	0.4	2.0	5.6	15.7
	Crashes with other object:	2.4	0.0	0.0	0.1	0.3	2.0
	Crashes with parked vehicle:	0.5	0.0	0.0	0.0	0.1	0.4
	Other single-vehicle crashes	5.0	0.0	0.1	0.7	1.9	2.3
	Total single-vehicle crashes:	32.3	0.2	0.5	2.9	8.0	20.8
Total crashes:		181.7	0.5	2.0	12.8	44.8	121.6

Figure 60. A2: Output Summary Worksheet—Estimated Crash Statistics

The three rows under the heading Crashes by Facility Component provide the estimated number of crashes for the three component types (freeway segment, ramp segment, and crossroad ramp terminal) modeled by ISATe. In this sample application, the facility is comprised of freeway segments, ramp segments, and crossroad ramp terminals. Separate crash estimates are provided for these three component types for the three-year study period. These calculations show that most of the crashes at the facility are expected to occur on the freeway mainline or at the crossroad ramp terminals. Hence, if safety improvement treatments are implemented on these components, they are more likely to yield significant benefits.

The three rows under the heading Crashes for Entire Facility by Year provide the estimated number of crashes for each of the three years included in the study period. In this sample application, the estimated number of crashes is the same for all three years in the study period because the same volumes were used for the three years.

The rows under the heading Distribution of Crashes for Entire Facility provide the estimated number of crashes by severity and crash type. This distribution represents crashes at all sites for the entire study period.

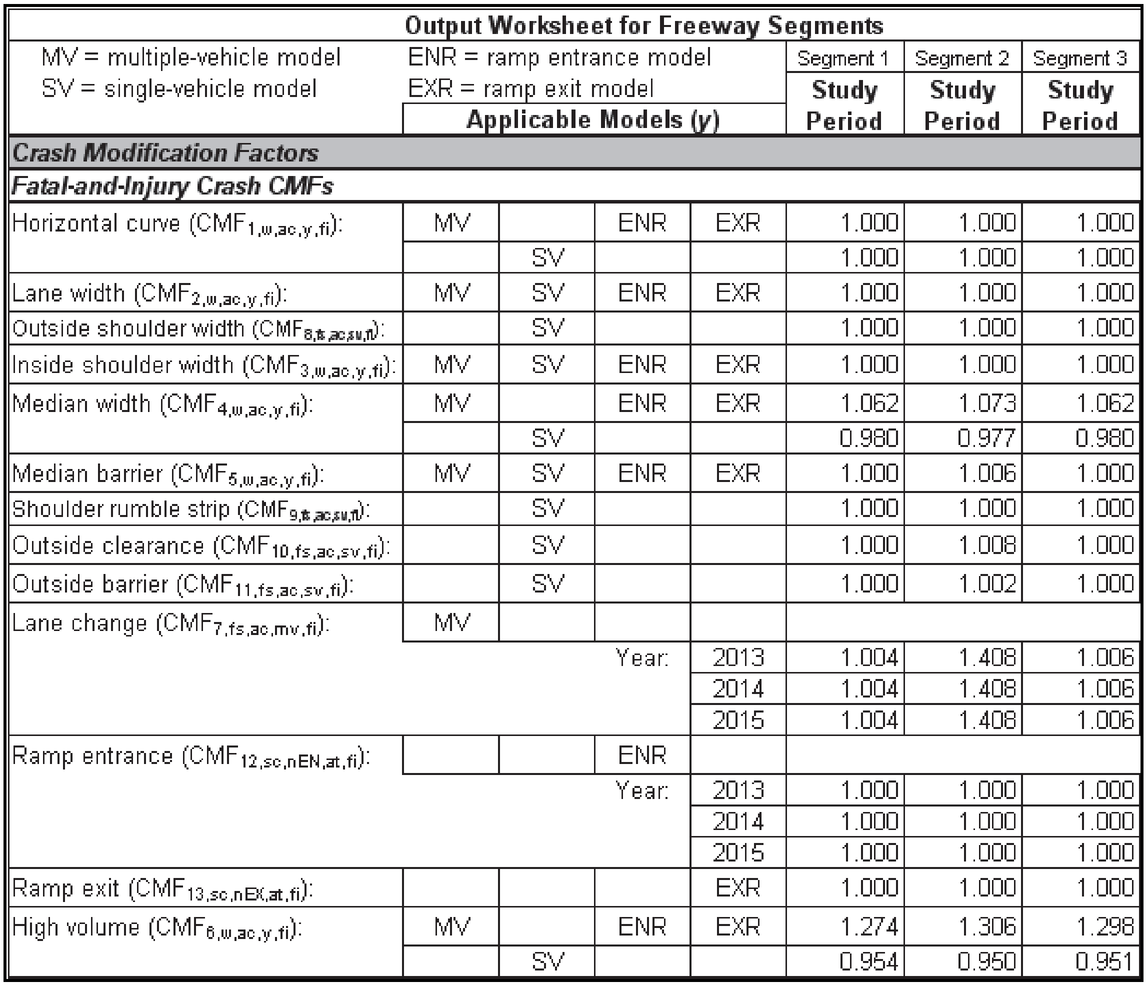
Detailed Output Data

On the Output Freeway Segments, Output Ramp Segments, and Output Ramp Terminals worksheets, the following data are provided:

- CMFs for FI crashes.
- CMFs for PDO crashes.
- Predicted average crash frequency, including the following quantities:
  - FI crash frequency (for multiple-vehicle, single-vehicle, ramp entrance, ramp exit, and crossroad ramp terminal crashes).
  - PDO crash frequency (for multiple-vehicle, single-vehicle, ramp entrance, ramp exit, and crossroad ramp terminal crashes).
  - Crash severity distribution (K, A, B, C, and PDO).
- Intermediate results for curve, barrier, weaving section, and volume proportion calculations.
- Traffic data (the projected volumes for all facility components, varied by year if volume projections are used).

Freeway Segments

The CMFs for FI crashes on the freeway segments are shown in Figure 61. The lane change CMF is 1.408 for segment 2. It suggests that the weaving section is likely to be associated with 40.8 percent more crashes that occur on a basic freeway segment with similar geometry and traffic volume. An examination of the other CMFs shown suggests that recurring congestion associated with high lane volume during peak hours may also explain a 30 percent increase in multiple-vehicle crashes, relative to freeway segments with similar geometry and volume but with traffic volume spread more evenly throughout the day.



Output Worksheet for Freeway Segments

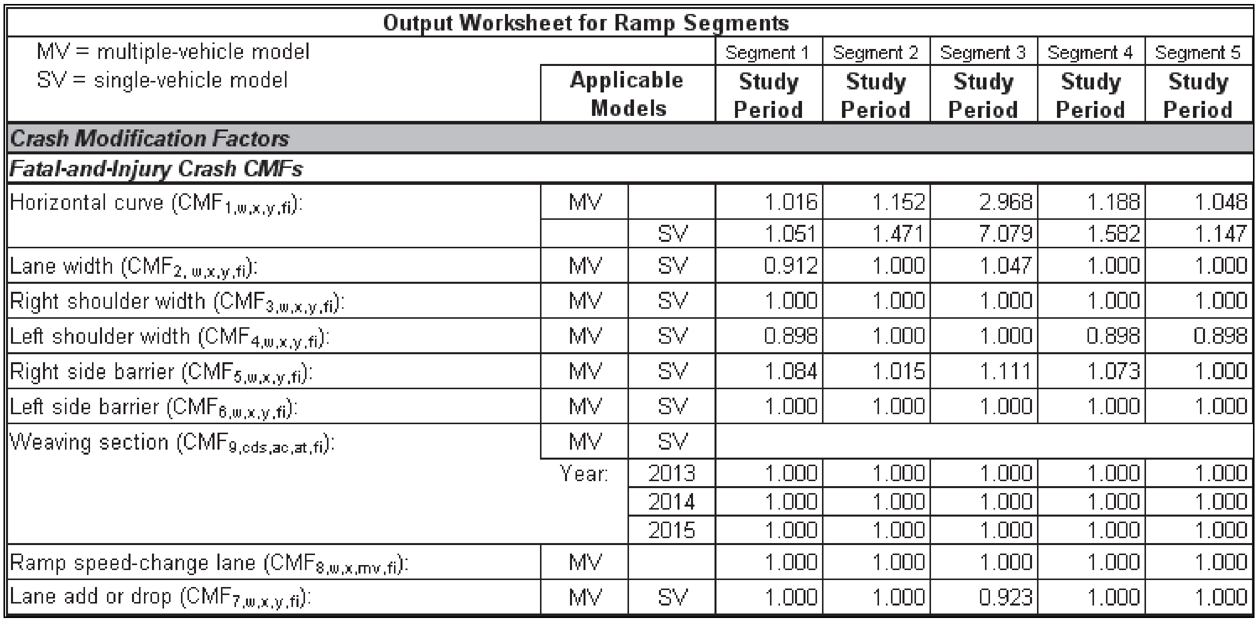
MV = multiple-vehicle model
SV = single-vehicle model
ENR = ramp entrance model
EXR = ramp exit model

	Applicable Models (y)				Segment 1 Study Period	Segment 2 Study Period	Segment 3 Study Period
Crash Modification Factors							
Fatal-and-Injury Crash CMFs							
Horizontal curve ($CMF_{1,w,ac,y,fi}$):	MV		ENR	EXR	1.000	1.000	1.000
		SV			1.000	1.000	1.000
Lane width ($CMF_{2,w,ac,y,fi}$):	MV	SV	ENR	EXR	1.000	1.000	1.000
Outside shoulder width ($CMF_{8,fs,ac,sv,fi}$):		SV			1.000	1.000	1.000
Inside shoulder width ($CMF_{3,w,ac,y,fi}$):	MV	SV	ENR	EXR	1.000	1.000	1.000
Median width ($CMF_{4,w,ac,y,fi}$):	MV		ENR	EXR	1.062	1.073	1.062
		SV			0.980	0.977	0.980
Median barrier ($CMF_{5,w,ac,y,fi}$):	MV	SV	ENR	EXR	1.000	1.006	1.000
Shoulder rumble strip ($CMF_{9,fs,ac,sv,fi}$):		SV			1.000	1.000	1.000
Outside clearance ($CMF_{10,fs,ac,sv,fi}$):		SV			1.000	1.008	1.000
Outside barrier ($CMF_{11,fs,ac,sv,fi}$):		SV			1.000	1.002	1.000
Lane change ($CMF_{7,fs,ac,mv,fi}$):	MV						
			Year:	2013	1.004	1.408	1.006
				2014	1.004	1.408	1.006
				2015	1.004	1.408	1.006
Ramp entrance ($CMF_{12,sc,nEN,at,fi}$):			ENR				
			Year:	2013	1.000	1.000	1.000
				2014	1.000	1.000	1.000
				2015	1.000	1.000	1.000
Ramp exit ($CMF_{13,sc,nEX,at,fi}$):				EXR	1.000	1.000	1.000
High volume ($CMF_{6,w,ac,y,fi}$):	MV		ENR	EXR	1.274	1.306	1.298
		SV			0.954	0.950	0.951

Figure 61. A2: Output Freeway Segments Worksheet—CMFs for FI Crashes

Ramp Segments

The CMFs for FI crashes on the ramp segments are shown in Figure 62. The curvature in segment 3 is shown to have a significant effect on the segment's crash frequency. The horizontal curve CMF on this segment is 2.968 for multiple-vehicle FI crashes and 7.079 for single-vehicle FI crashes. These large values suggest that the curves on this ramp are fairly sharp, relative to the estimated speed exiting vehicles are likely to have when they arrive at these curves.



Output Worksheet for Ramp Segments

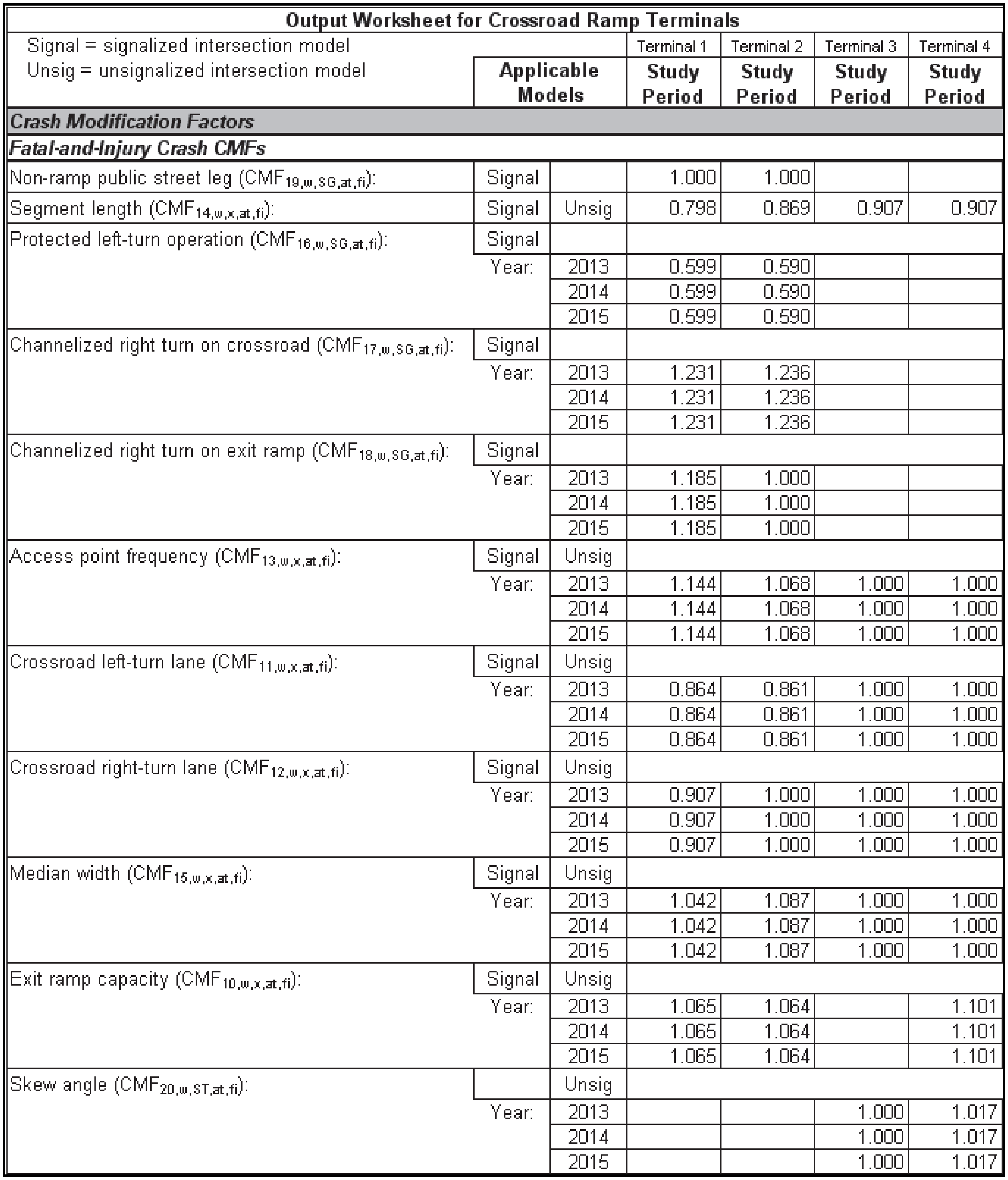
MV = multiple-vehicle model			Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
SV = single-vehicle model	**Applicable Models**		**Study Period**	**Study Period**	**Study Period**	**Study Period**	**Study Period**
Crash Modification Factors							
Fatal-and-Injury Crash CMFs							
Horizontal curve (CMF$_{1,w,x,y,fi}$):	MV		1.016	1.152	2.968	1.188	1.048
		SV	1.051	1.471	7.079	1.582	1.147
Lane width (CMF$_{2, w,x,y,fi}$):	MV	SV	0.912	1.000	1.047	1.000	1.000
Right shoulder width (CMF$_{3,w,x,y,fi}$):	MV	SV	1.000	1.000	1.000	1.000	1.000
Left shoulder width (CMF$_{4,w,x,y,fi}$):	MV	SV	0.898	1.000	1.000	0.898	0.898
Right side barrier (CMF$_{5,w,x,y,fi}$):	MV	SV	1.084	1.015	1.111	1.073	1.000
Left side barrier (CMF$_{6,w,x,y,fi}$):	MV	SV	1.000	1.000	1.000	1.000	1.000
Weaving section (CMF$_{9,cds,ac,at,fi}$):	MV	SV					
	Year:	2013	1.000	1.000	1.000	1.000	1.000
		2014	1.000	1.000	1.000	1.000	1.000
		2015	1.000	1.000	1.000	1.000	1.000
Ramp speed-change lane (CMF$_{8,w,x,mv,fi}$):	MV		1.000	1.000	1.000	1.000	1.000
Lane add or drop (CMF$_{7,w,x,y,fi}$):	MV	SV	1.000	1.000	0.923	1.000	1.000

Figure 62. A2: Output Ramp Segments Worksheet—CMFs for FI Crashes

Ramp Terminals

In the case of crossroad ramp terminals, most of the CMFs are sensitive to volume. Values for these CMFs are computed for every year in the study period because the volumes may vary between years. The calculated CMFs for FI crashes are shown in Figure 63. Unused rows are omitted from the figure.

A review of the CMFs in this figure indicates that right-turn channelization is associated with a higher crash risk, relative to terminals without right-turn channelization. Conversely, crash risk tends to be reduced by the presence of a wide median, turn bays on the crossroad approaches, and the use of protected left-turn operation.



Output Worksheet for Crossroad Ramp Terminals

Signal = signalized intersection model Unsig = unsignalized intersection model	**Applicable Models**		Terminal 1 **Study Period**	Terminal 2 **Study Period**	Terminal 3 **Study Period**	Terminal 4 **Study Period**
Crash Modification Factors						
Fatal-and-Injury Crash CMFs						
Non-ramp public street leg ($\text{CMF}_{19,w,SG,at,fi}$):	Signal		1.000	1.000		
Segment length ($\text{CMF}_{14,w,x,at,fi}$):	Signal	Unsig	0.798	0.869	0.907	0.907
Protected left-turn operation ($\text{CMF}_{16,w,SG,at,fi}$):	Signal					
	Year:	2013	0.599	0.590		
		2014	0.599	0.590		
		2015	0.599	0.590		
Channelized right turn on crossroad ($\text{CMF}_{17,w,SG,at,fi}$):	Signal					
	Year:	2013	1.231	1.236		
		2014	1.231	1.236		
		2015	1.231	1.236		
Channelized right turn on exit ramp ($\text{CMF}_{18,w,SG,at,fi}$):	Signal					
	Year:	2013	1.185	1.000		
		2014	1.185	1.000		
		2015	1.185	1.000		
Access point frequency ($\text{CMF}_{13,w,x,at,fi}$):	Signal	Unsig				
	Year:	2013	1.144	1.068	1.000	1.000
		2014	1.144	1.068	1.000	1.000
		2015	1.144	1.068	1.000	1.000
Crossroad left-turn lane ($\text{CMF}_{11,w,x,at,fi}$):	Signal	Unsig				
	Year:	2013	0.864	0.861	1.000	1.000
		2014	0.864	0.861	1.000	1.000
		2015	0.864	0.861	1.000	1.000
Crossroad right-turn lane ($\text{CMF}_{12,w,x,at,fi}$):	Signal	Unsig				
	Year:	2013	0.907	1.000	1.000	1.000
		2014	0.907	1.000	1.000	1.000
		2015	0.907	1.000	1.000	1.000
Median width ($\text{CMF}_{15,w,x,at,fi}$):	Signal	Unsig				
	Year:	2013	1.042	1.087	1.000	1.000
		2014	1.042	1.087	1.000	1.000
		2015	1.042	1.087	1.000	1.000
Exit ramp capacity ($\text{CMF}_{10,w,x,at,fi}$):	Signal	Unsig				
	Year:	2013	1.065	1.064		1.101
		2014	1.065	1.064		1.101
		2015	1.065	1.064		1.101
Skew angle ($\text{CMF}_{20,w,ST,at,fi}$):		Unsig				
	Year:	2013			1.000	1.017
		2014			1.000	1.017
		2015			1.000	1.017

Figure 63. A2: Output Ramp Terminals Worksheet—CMFs for FI Crashes

Results

The freeway facility consisting of three freeway segments, five ramp segments, and four crossroad ramp terminals was analyzed for a three-year study period. The total predicted average crash frequency (shown in Figure 60) was found to be about 60.6 crashes per year, or 181.7 crashes during the study period. Most of these crashes are expected to occur at the crossroad ramp terminals (about 76 crashes) and on the freeway segments (about 98 crashes).

Examination of CMFs revealed that the design elements most likely to increase crash risk (relative to typical facilities) include the weaving section on the freeway mainline and the curvature on the ramps. Addressing these issues would require closure, relocation, or realignment of the ramps. One possible option is to build braided ramps. This design would allow the ramps to be lengthened (resulting in flatter curves), and would reduce the intensity of lane-changing activity on the freeway mainline.

APPLICATION 3. PARTIAL CLOVERLEAF INTERCHANGE

The interchange is a partial cloverleaf in an urban area. The traffic volumes on the ramps range from 2,700 to 7,500 vehicles per day. This interchange is of interest because the ramps at this location have a poor safety record. The objective of this sample application is to evaluate the safety of the interchange, with focus on ramp curvature and the presence of a non-ramp public street leg at the northern ramp terminal.

The interchange consists of six ramp segments and two crossroad ramp terminals. The segments are shown in Figure 64.

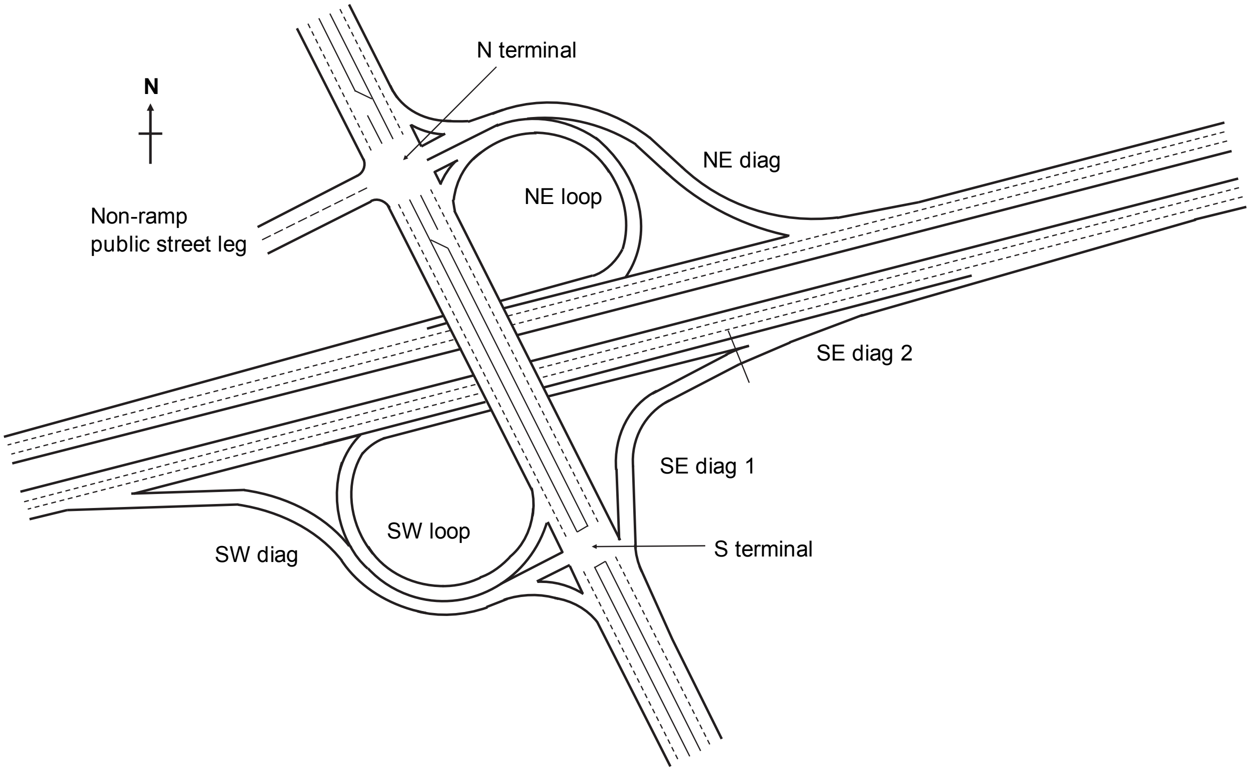


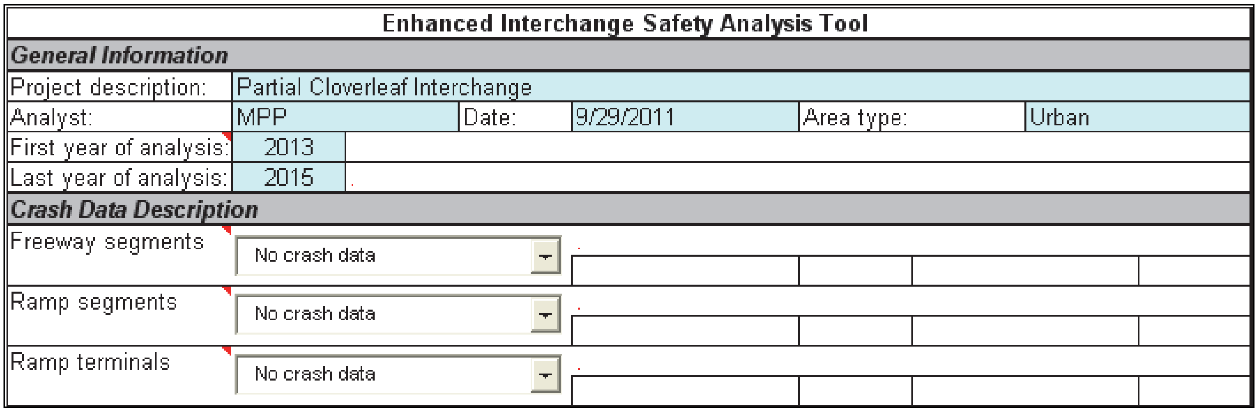
Figure 64. Application 3: Partial Cloverleaf Interchange

The division between the ramp segments labeled “SW loop”, “SE diag 1”, and “SE diag 2” occurs at the gore point of the merge between the two ramps. Based on the guidance in Figure 20, the “SE diag 2” segment is considered to be part of the southeastern diagonal ramp rather than the southwestern loop ramp because the diagonal ramp has a higher volume than the loop ramp. The ramp terminal labeled

"N terminal" has a non-ramp public street leg which is part of the terminal, though the associated street is not considered to be part of the interchange.

Input Data

The partial cloverleaf interchange has two different component types—ramp segments and crossroad ramp terminals. Hence, two input worksheets within ISATe are used to model the facility. The data entry cells in the sections titled General Information and Crash Data Description are shown in Figure 65. As indicated, the area type is urban, the analysis period includes the years 2013 to 2015, and no crash data are available.



Enhanced Interchange Safety Analysis Tool

General Information

Project description: Partial Cloverleaf Interchange

Analyst: MPP Date: 9/29/2011 Area type: Urban

First year of analysis: 2013

Last year of analysis: 2015

Crash Data Description

Freeway segments: No crash data

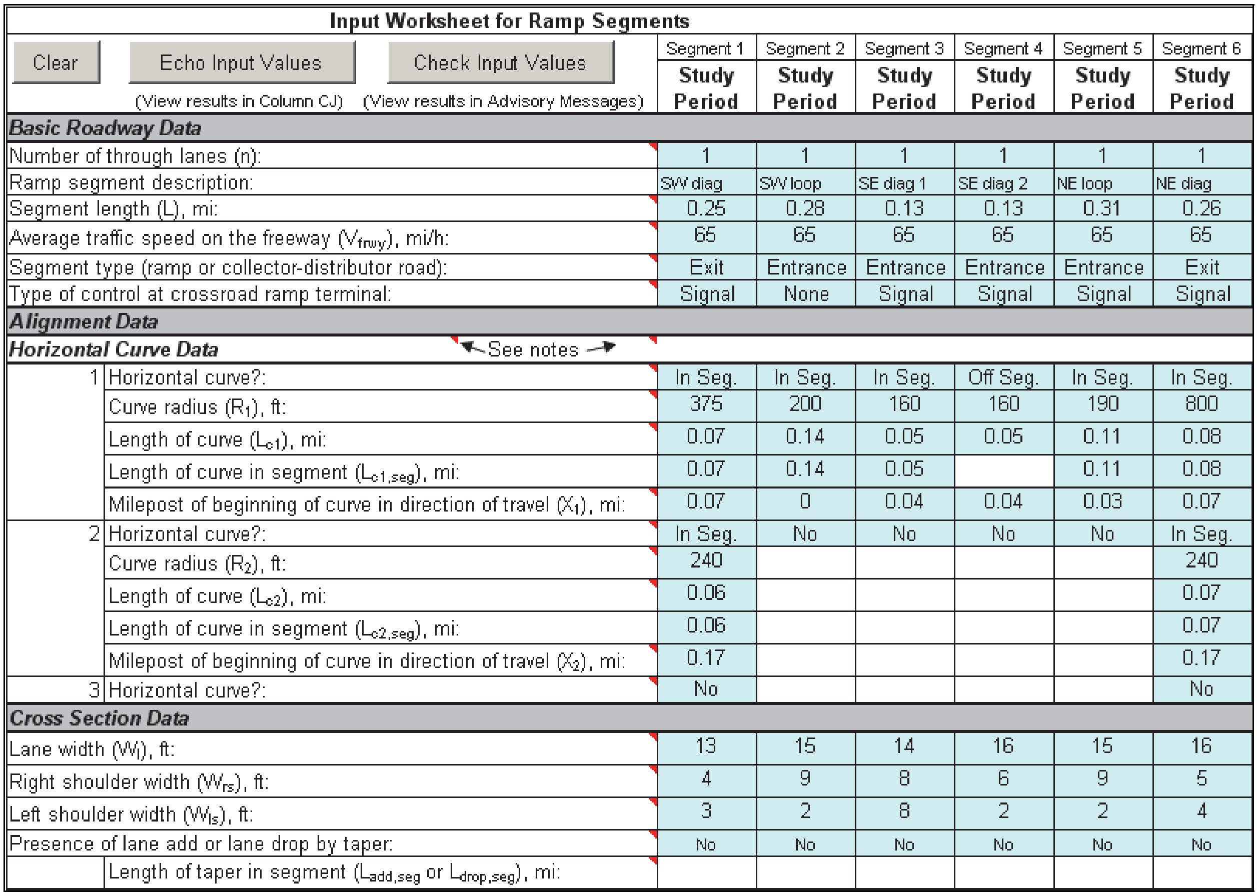
Ramp segments: No crash data

Ramp terminals: No crash data

Figure 65. A3: Main Worksheet—General Information and Crash Data Description

Ramp Segments

Figure 66 identifies the basic roadway data, alignment data, and cross section data that describe the six ramp segments. The southwestern and northeastern diagonal ramps both have two curves. Segment 4 (i.e., SE diag 2) is coded as having one off-segment curve. This curve is located in segment 3 (i.e., SE diag 1). Segment 4 does not include a curve so the CMF for horizontal curvature will be 1.000, regardless of the speed vehicles reach when arriving to this segment. As a result, the data entered for the off-segment curve for segment 4 have no effect on the estimated crash frequency. However, it is considered good practice to be complete and consistent in coding all segments, so the off-segment curve data are entered for segment 4 (as shown).

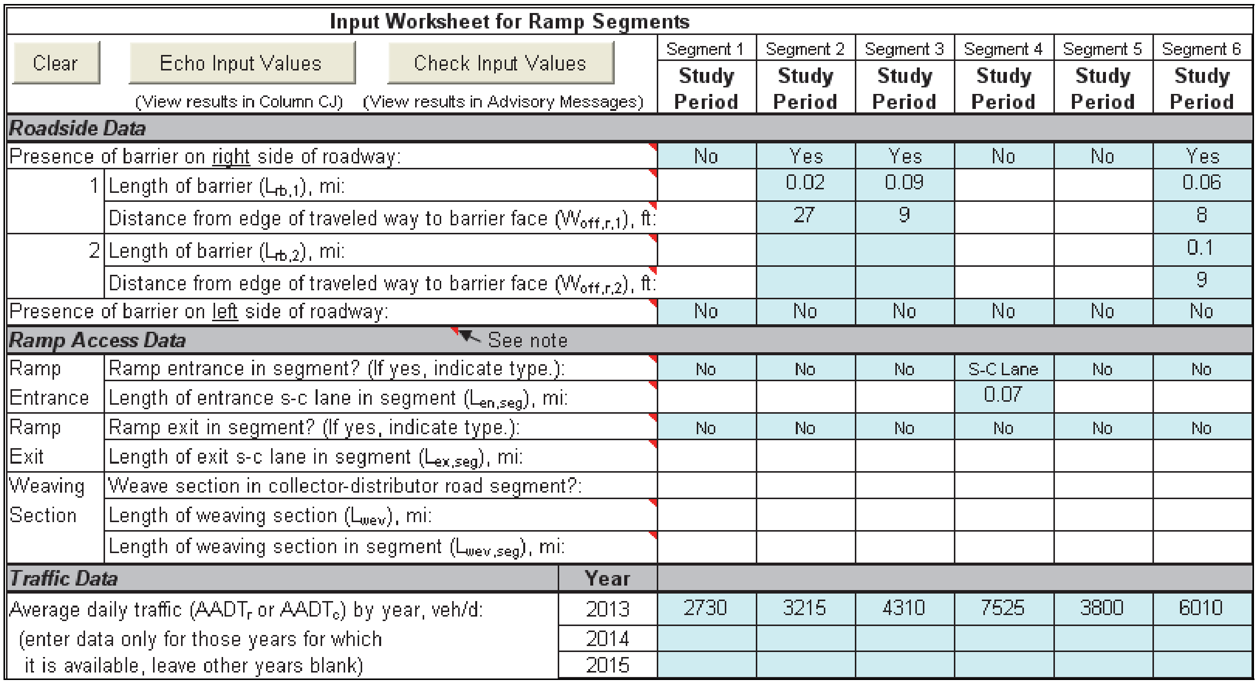


Input Worksheet for Ramp Segments

		Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6
		Study Period	**Study Period**	**Study Period**	**Study Period**	**Study Period**	**Study Period**
Basic Roadway Data							
Number of through lanes (n):		1	1	1	1	1	1
Ramp segment description:		SW diag	SW loop	SE diag 1	SE diag 2	NE loop	NE diag
Segment length (L), mi:		0.25	0.28	0.13	0.13	0.31	0.26
Average traffic speed on the freeway (V_{frwy}), mi/h:		65	65	65	65	65	65
Segment type (ramp or collector-distributor road):		Exit	Entrance	Entrance	Entrance	Entrance	Exit
Type of control at crossroad ramp terminal:		Signal	None	Signal	Signal	Signal	Signal
Alignment Data							
Horizontal Curve Data ← See notes →							
1	Horizontal curve?:	In Seg.	In Seg.	In Seg.	Off Seg.	In Seg.	In Seg.
	Curve radius (R_1), ft:	375	200	160	160	190	800
	Length of curve (L_{c1}), mi:	0.07	0.14	0.05	0.05	0.11	0.08
	Length of curve in segment ($L_{c1,seg}$), mi:	0.07	0.14	0.05		0.11	0.08
	Milepost of beginning of curve in direction of travel (X_1), mi:	0.07	0	0.04	0.04	0.03	0.07
2	Horizontal curve?:	In Seg.	No	No	No	No	In Seg.
	Curve radius (R_2), ft:	240					240
	Length of curve (L_{c2}), mi:	0.06					0.07
	Length of curve in segment ($L_{c2,seg}$), mi:	0.06					0.07
	Milepost of beginning of curve in direction of travel (X_2), mi:	0.17					0.17
3	Horizontal curve?:	No					No
Cross Section Data							
Lane width (W_l), ft:		13	15	14	16	15	16
Right shoulder width (W_{rs}), ft:		4	9	8	6	9	5
Left shoulder width (W_{ls}), ft:		3	2	8	2	2	4
Presence of lane add or lane drop by taper:		No	No	No	No	No	No
	Length of taper in segment ($L_{add,seg}$ or $L_{drop,seg}$), mi:						

Figure 66. A3: Input Ramp Segments Worksheet—Roadway, Alignment, and Cross Section Data

Figure 67 identifies the roadside, ramp access, and traffic data that describe the ramp segments. Segment 6 (i.e., “NE diag”) is shown to have two right-side barrier pieces. Segments 2 and 3 are shown to each have one right-side barrier piece. The speed-change lane formed by the merging of the southwestern loop ramp and the southeastern diagonal ramp is coded for segment 4 (i.e., “SE Diag 2”).



Input Worksheet for Ramp Segments

(View results in Column CJ) (View results in Advisory Messages)

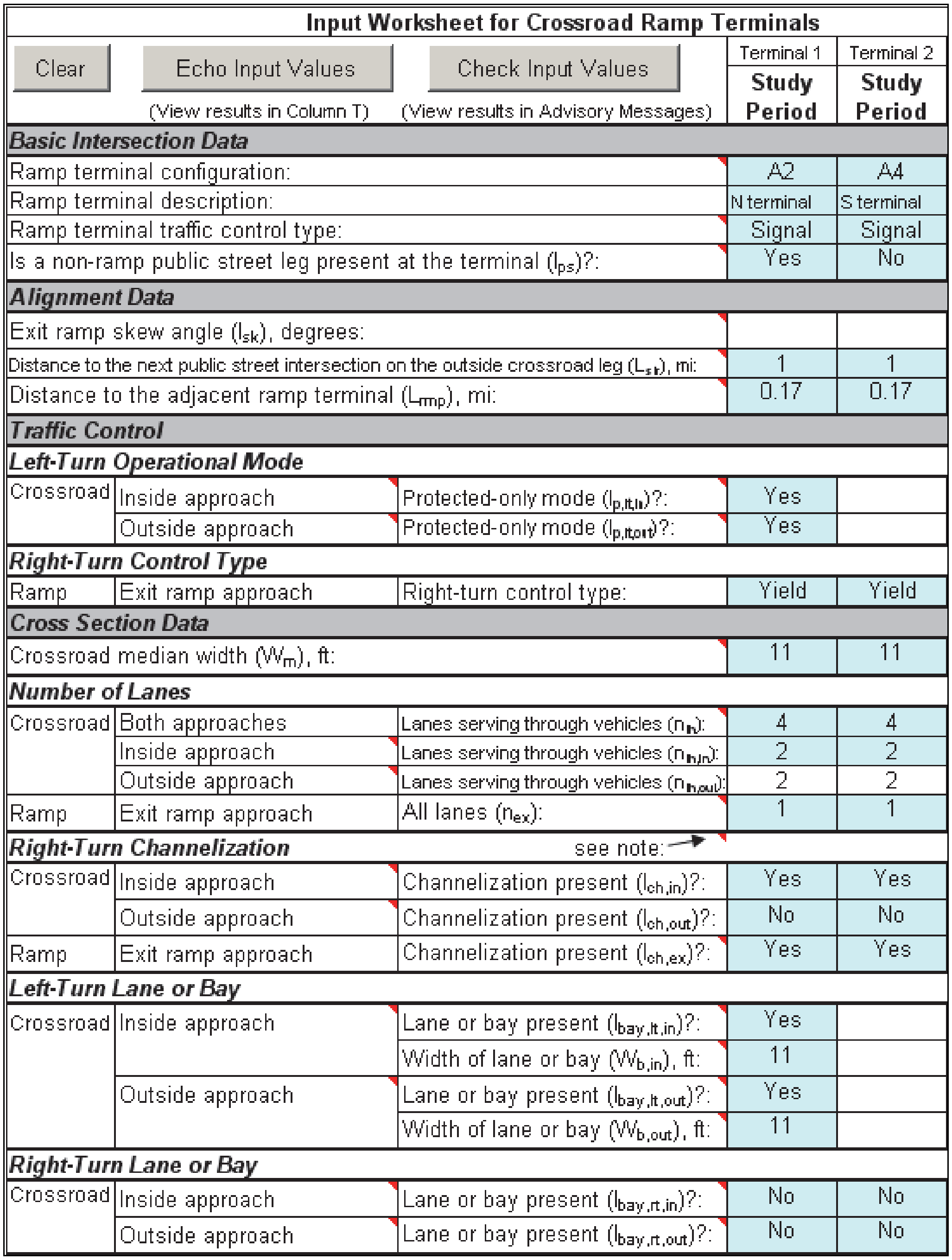
		Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6
		Study Period	**Study Period**	**Study Period**	**Study Period**	**Study Period**	**Study Period**
Roadside Data							
Presence of barrier on right side of roadway:		No	Yes	Yes	No	No	Yes
1	Length of barrier ($L_{rb,1}$), mi:		0.02	0.09			0.06
	Distance from edge of traveled way to barrier face ($W_{off,r,1}$), ft:		27	9			8
2	Length of barrier ($L_{rb,2}$), mi:						0.1
	Distance from edge of traveled way to barrier face ($W_{off,r,2}$), ft:						9
Presence of barrier on left side of roadway:		No	No	No	No	No	No
Ramp Access Data	See note						
Ramp Entrance	Ramp entrance in segment? (If yes, indicate type.):	No	No	No	S-C Lane	No	No
	Length of entrance s-c lane in segment ($L_{en,seg}$), mi:				0.07		
Ramp Exit	Ramp exit in segment? (If yes, indicate type.):	No	No	No	No	No	No
	Length of exit s-c lane in segment ($L_{ex,seg}$), mi:						
Weaving Section	Weave section in collector-distributor road segment?:						
	Length of weaving section (L_{wev}), mi:						
	Length of weaving section in segment ($L_{wev,seg}$), mi:						
Traffic Data	**Year**						
Average daily traffic ($AADT_r$ or $AADT_c$) by year, veh/d:	2013	2730	3215	4310	7525	3800	6010
(enter data only for those years for which	2014						
it is available, leave other years blank)	2015						

Figure 67. A3: Input Ramp Segments Worksheet—Roadside, Ramp Access, and Traffic Data

Ramp Terminals

Figure 68 identifies the basic intersection, alignment, traffic control, and cross section data that describe the two signalized ramp terminals. The southern terminal is coded as type A4 based on the configuration codes shown in Figure 1. The northern terminal is coded as type A2. However, it is noted to have a non-ramp public street leg. The presence of this leg is identified in the Basic Intersection Data section (i.e., in the row labeled “Is a non-ramp public street present at the terminal”).

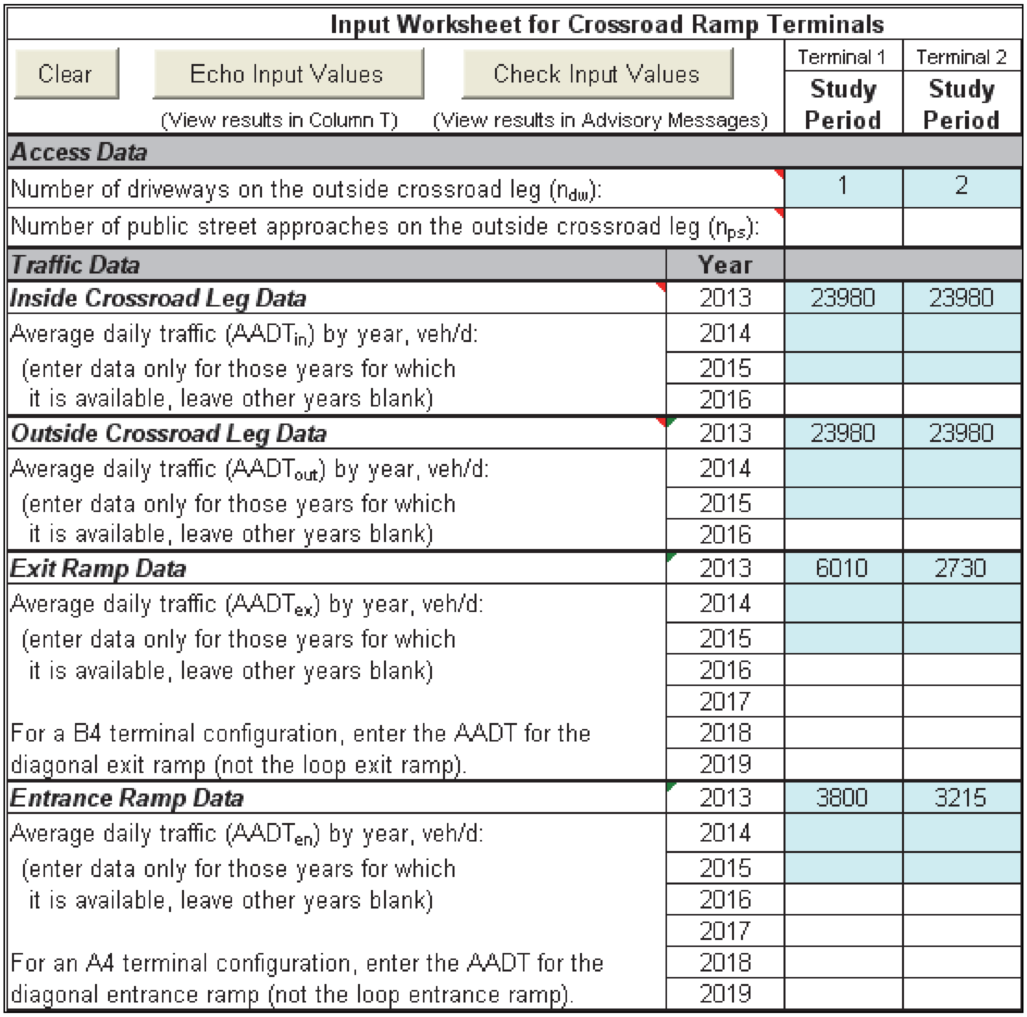
In the Cross Section Data section, the exit ramp approaches at both terminals are indicated to have one approach lane and right-turn channelization. As shown in Figure 64, no right-turn lanes are provided upstream of the right-turn channelization. On the crossroad, the inside approach to both terminals has a channelizing island for the right-turn movement. In contrast, the outside approach at both terminals does *not* have a channelizing island for the right-turn movement.



Input Worksheet for Crossroad Ramp Terminals				
(View results in Column T)		(View results in Advisory Messages)	Terminal 1 **Study Period**	Terminal 2 **Study Period**
Basic Intersection Data				
Ramp terminal configuration:			A2	A4
Ramp terminal description:			N terminal	S terminal
Ramp terminal traffic control type:			Signal	Signal
Is a non-ramp public street leg present at the terminal (I_{ps})?:			Yes	No
Alignment Data				
Exit ramp skew angle (I_{sk}), degrees:				
Distance to the next public street intersection on the outside crossroad leg ($L_{s,r}$), mi:			1	1
Distance to the adjacent ramp terminal (L_{rmp}), mi:			0.17	0.17
Traffic Control				
Left-Turn Operational Mode				
Crossroad	Inside approach	Protected-only mode ($I_{p,lt,in}$)?:	Yes	
	Outside approach	Protected-only mode ($I_{p,lt,out}$)?:	Yes	
Right-Turn Control Type				
Ramp	Exit ramp approach	Right-turn control type:	Yield	Yield
Cross Section Data				
Crossroad median width (W_m), ft:			11	11
Number of Lanes				
Crossroad	Both approaches	Lanes serving through vehicles (n_{th}):	4	4
	Inside approach	Lanes serving through vehicles ($n_{th,in}$):	2	2
	Outside approach	Lanes serving through vehicles ($n_{th,out}$):	2	2
Ramp	Exit ramp approach	All lanes (n_{ex}):	1	1
Right-Turn Channelization		see note: →		
Crossroad	Inside approach	Channelization present ($I_{ch,in}$)?:	Yes	Yes
	Outside approach	Channelization present ($I_{ch,out}$)?:	No	No
Ramp	Exit ramp approach	Channelization present ($I_{ch,ex}$)?:	Yes	Yes
Left-Turn Lane or Bay				
Crossroad	Inside approach	Lane or bay present ($I_{bay,lt,in}$)?:	Yes	
		Width of lane or bay ($W_{b,in}$), ft:	11	
	Outside approach	Lane or bay present ($I_{bay,lt,out}$)?:	Yes	
		Width of lane or bay ($W_{b,out}$), ft:	11	
Right-Turn Lane or Bay				
Crossroad	Inside approach	Lane or bay present ($I_{bay,rt,in}$)?:	No	No
	Outside approach	Lane or bay present ($I_{bay,rt,out}$)?:	No	No

Figure 68. A3: Input Ramp Terminals Worksheet—Intersection, Alignment, Traffic Control, and Cross Section Data

Figure 69 identifies the access data and traffic data that describe the crossroad ramp terminals. Unused rows are omitted from the figure. Although not shown in Figure 64, there is a driveway on the outside crossroad leg at terminal 1 (i.e., N terminal) and two driveways on the outside crossroad leg at terminal 2. The four volumes entered for entrance-ramp or exit-ramp approaches are the same as those that were entered for ramp segments 1, 2, 5, and 6 in Figure 67.



Input Worksheet for Crossroad Ramp Terminals

		Terminal 1 Study Period	Terminal 2 Study Period
Access Data			
Number of driveways on the outside crossroad leg (n_{dw}):		1	2
Number of public street approaches on the outside crossroad leg (n_{ps}):			
Traffic Data	**Year**		
Inside Crossroad Leg Data	2013	23980	23980
Average daily traffic ($AADT_{in}$) by year, veh/d:	2014		
(enter data only for those years for which	2015		
it is available, leave other years blank)	2016		
Outside Crossroad Leg Data	2013	23980	23980
Average daily traffic ($AADT_{out}$) by year, veh/d:	2014		
(enter data only for those years for which	2015		
it is available, leave other years blank)	2016		
Exit Ramp Data	2013	6010	2730
Average daily traffic ($AADT_{ex}$) by year, veh/d:	2014		
(enter data only for those years for which	2015		
it is available, leave other years blank)	2016		
	2017		
For a B4 terminal configuration, enter the AADT for the	2018		
diagonal exit ramp (not the loop exit ramp).	2019		
Entrance Ramp Data	2013	3800	3215
Average daily traffic ($AADT_{en}$) by year, veh/d:	2014		
(enter data only for those years for which	2015		
it is available, leave other years blank)	2016		
	2017		
For an A4 terminal configuration, enter the AADT for the	2018		
diagonal entrance ramp (not the loop entrance ramp).	2019		

Figure 69. A3: Input Ramp Terminals Worksheet—Access and Traffic Data

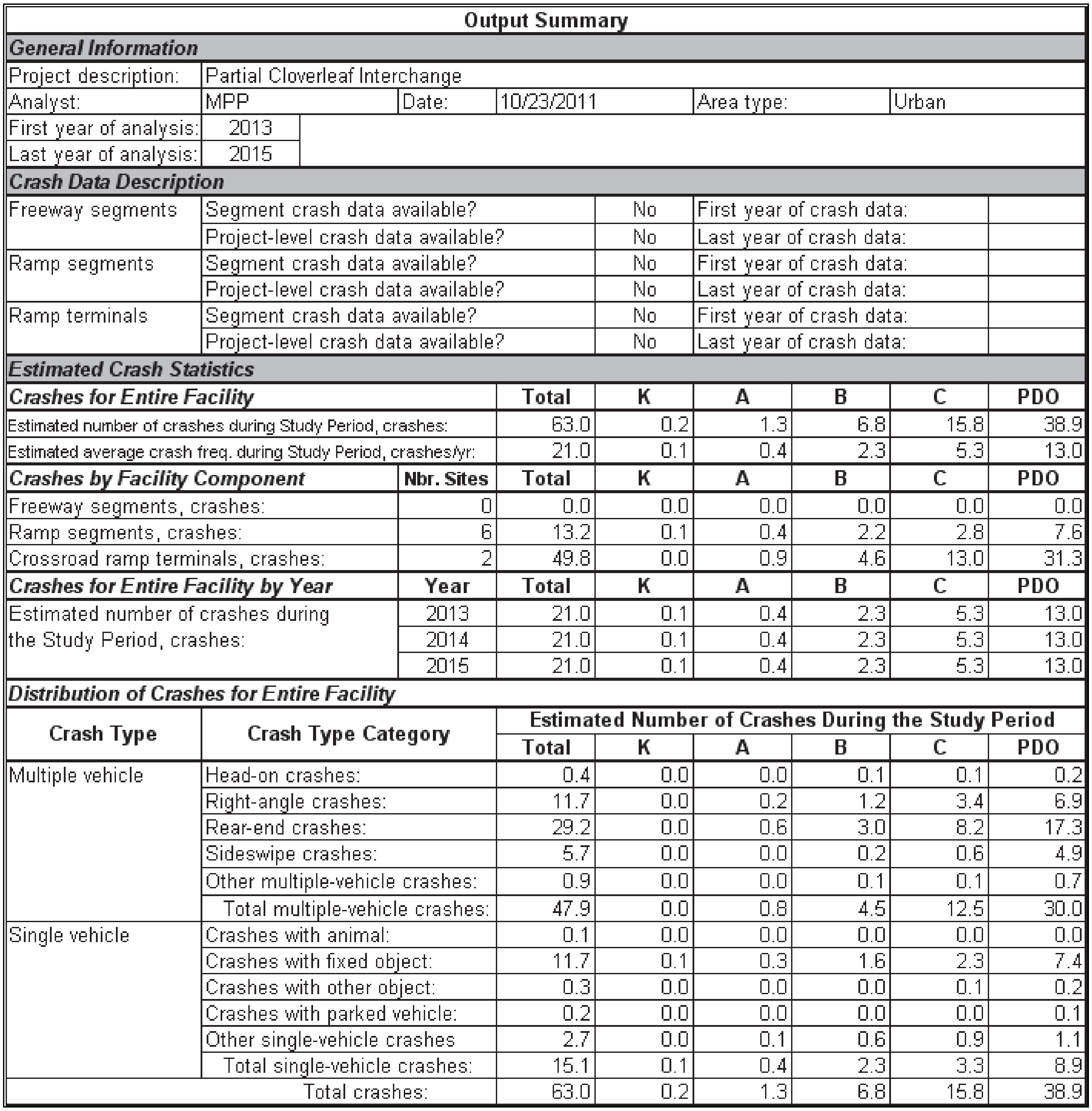
Output Summary

The Estimated Crash Statistics output cells are shown in Figure 70. Note that the unused rows are omitted from the figure. The two rows under the heading Crashes for Entire Facility provide the estimated number of crashes and crash frequency for the study period.

The three rows under the heading Crashes by Facility Component provide the estimated number of crashes for the three component types (freeway segment, ramp segment, and crossroad ramp terminal) modeled by ISATe. In this sample application, the facility is comprised of ramp segments and crossroad ramp terminals, and separate crash estimates are provided for these two component types for the three-year study period.

The three rows under the heading Crashes for Entire Facility by Year provide the estimated number of crashes for each of the three years included in the study period. In this sample application, the estimated number of crashes is the same for all three years in the study period because the same volumes were used for the three years.

The rows under the heading Distribution of Crashes for Entire Facility provide the estimated number of crashes by severity and crash type. This distribution represents crashes at all sites for the entire study period.



Output Summary

General Information

Project description:	Partial Cloverleaf Interchange				
Analyst:	MPP	Date:	10/23/2011	Area type:	Urban
First year of analysis:	2013				
Last year of analysis:	2015				

Crash Data Description

Freeway segments	Segment crash data available?	No	First year of crash data:	
	Project-level crash data available?	No	Last year of crash data:	
Ramp segments	Segment crash data available?	No	First year of crash data:	
	Project-level crash data available?	No	Last year of crash data:	
Ramp terminals	Segment crash data available?	No	First year of crash data:	
	Project-level crash data available?	No	Last year of crash data:	

Estimated Crash Statistics

Crashes for Entire Facility	**Total**	**K**	**A**	**B**	**C**	**PDO**
Estimated number of crashes during Study Period, crashes:	63.0	0.2	1.3	6.8	15.8	38.9
Estimated average crash freq. during Study Period, crashes/yr:	21.0	0.1	0.4	2.3	5.3	13.0

Crashes by Facility Component	**Nbr. Sites**	**Total**	**K**	**A**	**B**	**C**	**PDO**
Freeway segments, crashes:	0	0.0	0.0	0.0	0.0	0.0	0.0
Ramp segments, crashes:	6	13.2	0.1	0.4	2.2	2.8	7.6
Crossroad ramp terminals, crashes:	2	49.8	0.0	0.9	4.6	13.0	31.3

Crashes for Entire Facility by Year	**Year**	**Total**	**K**	**A**	**B**	**C**	**PDO**
Estimated number of crashes during the Study Period, crashes:	2013	21.0	0.1	0.4	2.3	5.3	13.0
	2014	21.0	0.1	0.4	2.3	5.3	13.0
	2015	21.0	0.1	0.4	2.3	5.3	13.0

Distribution of Crashes for Entire Facility

Crash Type	**Crash Type Category**	**Estimated Number of Crashes During the Study Period**					
		Total	**K**	**A**	**B**	**C**	**PDO**
Multiple vehicle	Head-on crashes:	0.4	0.0	0.0	0.1	0.1	0.2
	Right-angle crashes:	11.7	0.0	0.2	1.2	3.4	6.9
	Rear-end crashes:	29.2	0.0	0.6	3.0	8.2	17.3
	Sideswipe crashes:	5.7	0.0	0.0	0.2	0.6	4.9
	Other multiple-vehicle crashes:	0.9	0.0	0.0	0.1	0.1	0.7
	Total multiple-vehicle crashes:	47.9	0.0	0.8	4.5	12.5	30.0
Single vehicle	Crashes with animal:	0.1	0.0	0.0	0.0	0.0	0.0
	Crashes with fixed object:	11.7	0.1	0.3	1.6	2.3	7.4
	Crashes with other object:	0.3	0.0	0.0	0.0	0.1	0.2
	Crashes with parked vehicle:	0.2	0.0	0.0	0.0	0.0	0.1
	Other single-vehicle crashes	2.7	0.0	0.1	0.6	0.9	1.1
	Total single-vehicle crashes:	15.1	0.1	0.4	2.3	3.3	8.9
	Total crashes:	63.0	0.2	1.3	6.8	15.8	38.9

Figure 70. A3: Output Summary Worksheet—Estimated Crash Statistics

Detailed Output Data

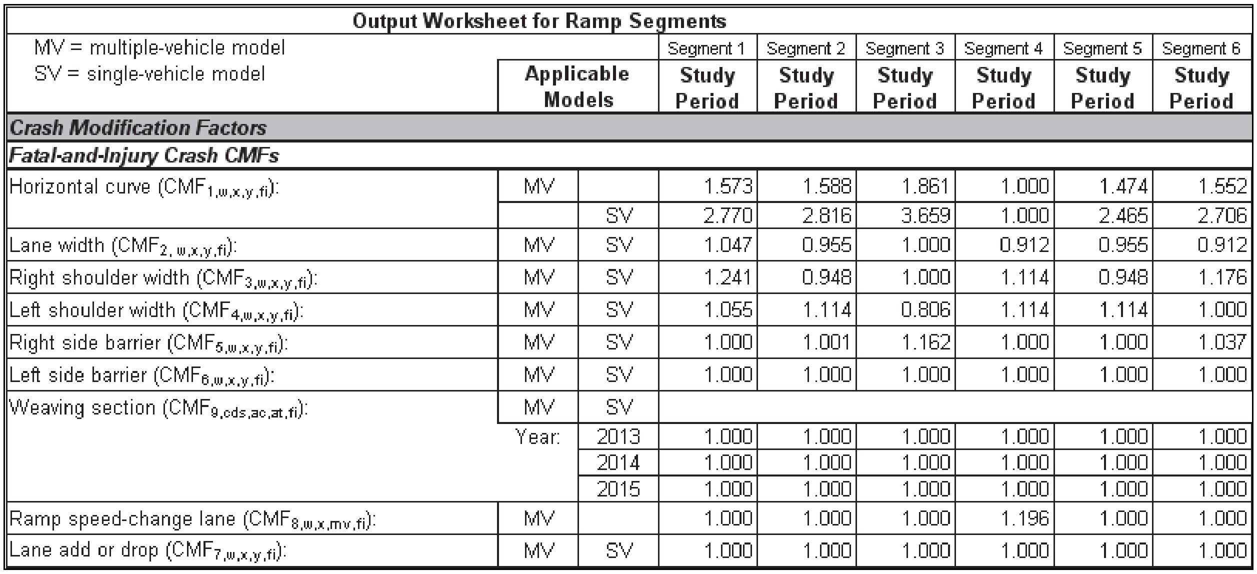
On the Output Ramp Segments and Output Ramp Terminals worksheets, the following data are provided:

- CMFs for FI crashes.
- CMFs for PDO crashes.

- Predicted average crash frequency, including the following quantities:
    - FI crash frequency (for multiple-vehicle, single-vehicle, ramp entrance, ramp exit, and crossroad ramp terminal crashes).
    - PDO crash frequency (for multiple-vehicle, single-vehicle, ramp entrance, ramp exit, and crossroad ramp terminal crashes).
    - Crash severity distribution (K, A, B, C, and PDO).
- Intermediate results for curve, barrier, weaving section, and volume proportion calculations.
- Traffic data (the projected volumes for all facility components, varied by year if volume projections are used).

Ramp Segments

The computed CMF values for FI crashes on the ramp segments are provided in Figure 71. Inspection of the CMF values reveals that curves on several of the ramp segments are associated with relatively high crash risk. Of particular note is the 160-ft radius in segment 3 (i.e., "SE diag 1") which has the largest horizontal curve CMF values (i.e., 1.861 for multiple-vehicle crashes and 3.659 for single-vehicle crashes).



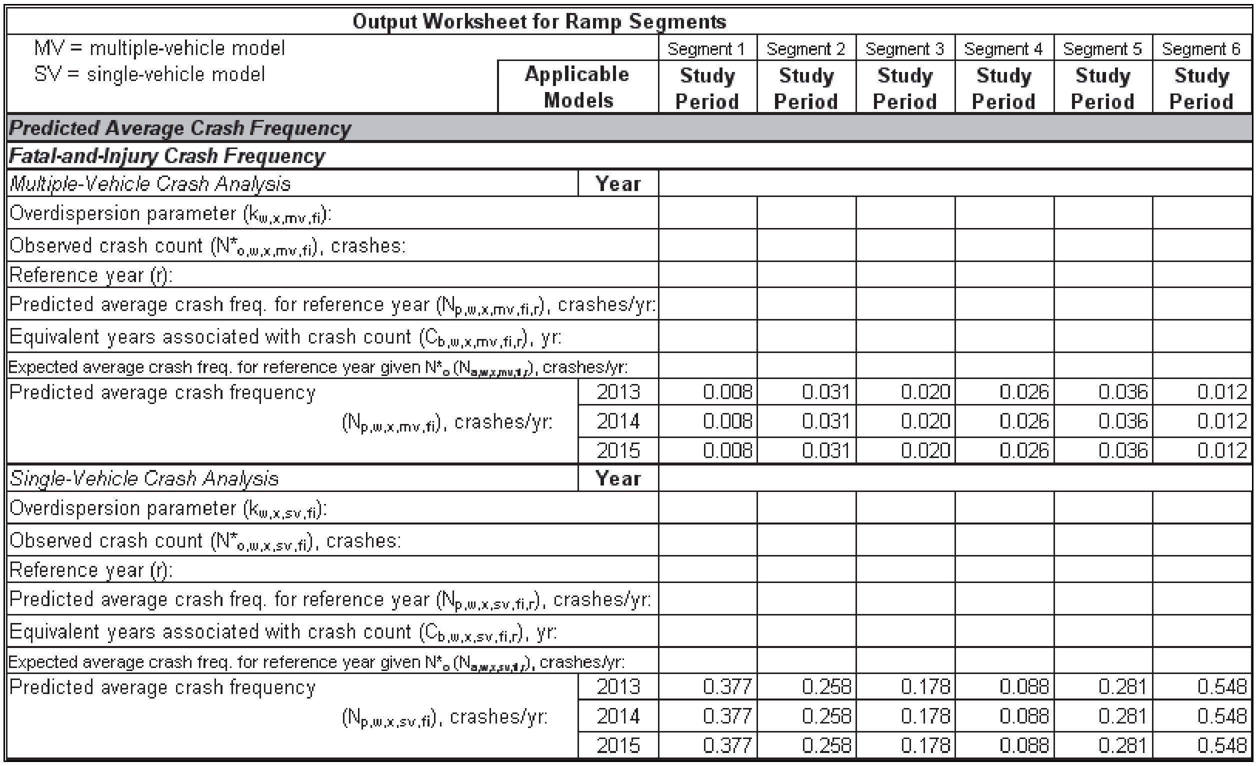
Output Worksheet for Ramp Segments

MV = multiple-vehicle model SV = single-vehicle model	Applicable Models		Segment 1 Study Period	Segment 2 Study Period	Segment 3 Study Period	Segment 4 Study Period	Segment 5 Study Period	Segment 6 Study Period
Crash Modification Factors								
Fatal-and-Injury Crash CMFs								
Horizontal curve ($CMF_{1,w,x,y,fi}$):	MV		1.573	1.588	1.861	1.000	1.474	1.552
		SV	2.770	2.816	3.659	1.000	2.465	2.706
Lane width ($CMF_{2,w,x,y,fi}$):	MV	SV	1.047	0.955	1.000	0.912	0.955	0.912
Right shoulder width ($CMF_{3,w,x,y,fi}$):	MV	SV	1.241	0.948	1.000	1.114	0.948	1.176
Left shoulder width ($CMF_{4,w,x,y,fi}$):	MV	SV	1.055	1.114	0.806	1.114	1.114	1.000
Right side barrier ($CMF_{5,w,x,y,fi}$):	MV	SV	1.000	1.001	1.162	1.000	1.000	1.037
Left side barrier ($CMF_{6,w,x,y,fi}$):	MV	SV	1.000	1.000	1.000	1.000	1.000	1.000
Weaving section ($CMF_{9,cds,ac,at,fi}$):	MV	SV						
	Year:	2013	1.000	1.000	1.000	1.000	1.000	1.000
		2014	1.000	1.000	1.000	1.000	1.000	1.000
		2015	1.000	1.000	1.000	1.000	1.000	1.000
Ramp speed-change lane ($CMF_{8,w,x,mv,fi}$):	MV		1.000	1.000	1.000	1.196	1.000	1.000
Lane add or drop ($CMF_{7,w,x,y,fi}$):	MV	SV	1.000	1.000	1.000	1.000	1.000	1.000

Figure 71. A3: Output Ramp Segments Worksheet—CMFs for FI Crashes

The predicted average crash frequency calculations for FI crashes on the ramp segments are shown in Figure 72. In this sample application, no crash data are available and the EB Method is not used. As a result, rows relating to these calculations are blank. Three rows each are shown for multiple-vehicle and single-vehicle crash frequency calculations. Unused rows for additional years are omitted from the figure.

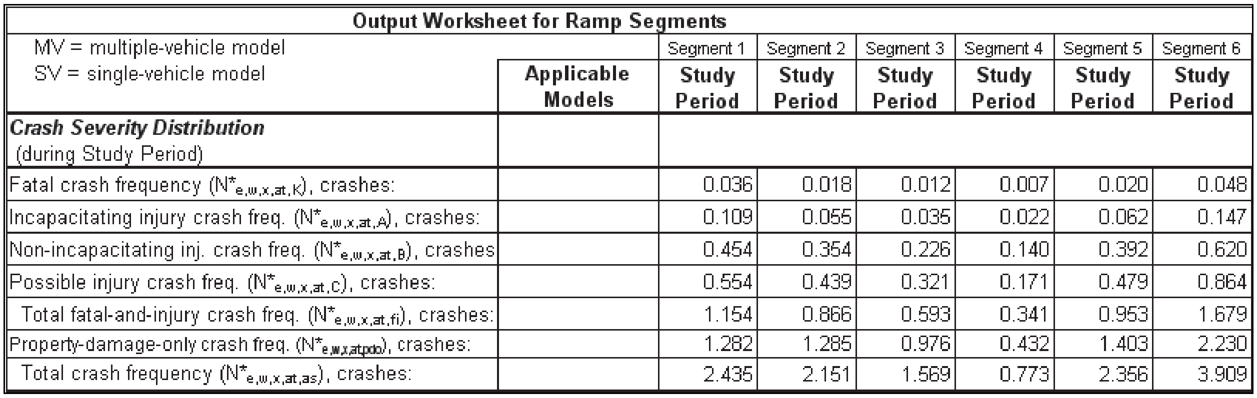
The crash severity distribution calculations for the ramp segments are shown in Figure 73. These calculations are shown in the worksheet rows located just below the rows that show the predicted average crash frequency. The estimated number of crashes are given for each segment and aggregated for the entire study period.



Output Worksheet for Ramp Segments

		Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6
MV = multiple-vehicle model SV = single-vehicle model	**Applicable Models**	**Study Period**	**Study Period**	**Study Period**	**Study Period**	**Study Period**	**Study Period**
Predicted Average Crash Frequency							
Fatal-and-Injury Crash Frequency							
Multiple-Vehicle Crash Analysis	**Year**						
Overdispersion parameter ($k_{w,x,mv,fi}$):							
Observed crash count ($N^*_{o,w,x,mv,fi}$), crashes:							
Reference year (r):							
Predicted average crash freq. for reference year ($N_{p,w,x,mv,fi,r}$), crashes/yr:							
Equivalent years associated with crash count ($C_{b,w,x,mv,fi,r}$), yr:							
Expected average crash freq. for reference year given N^*_o ($N_{a,w,x,mv,fi,r}$), crashes/yr:							
Predicted average crash frequency ($N_{p,w,x,mv,fi}$), crashes/yr:	2013	0.008	0.031	0.020	0.026	0.036	0.012
	2014	0.008	0.031	0.020	0.026	0.036	0.012
	2015	0.008	0.031	0.020	0.026	0.036	0.012
Single-Vehicle Crash Analysis	**Year**						
Overdispersion parameter ($k_{w,x,sv,fi}$):							
Observed crash count ($N^*_{o,w,x,sv,fi}$), crashes:							
Reference year (r):							
Predicted average crash freq. for reference year ($N_{p,w,x,sv,fi,r}$), crashes/yr:							
Equivalent years associated with crash count ($C_{b,w,x,sv,fi,r}$), yr:							
Expected average crash freq. for reference year given N^*_o ($N_{a,w,x,sv,fi,r}$), crashes/yr:							
Predicted average crash frequency ($N_{p,w,x,sv,fi}$), crashes/yr:	2013	0.377	0.258	0.178	0.088	0.281	0.548
	2014	0.377	0.258	0.178	0.088	0.281	0.548
	2015	0.377	0.258	0.178	0.088	0.281	0.548

Figure 72. A3: Output Ramp Segments Worksheet—Predicted FI Crash Frequency



Output Worksheet for Ramp Segments

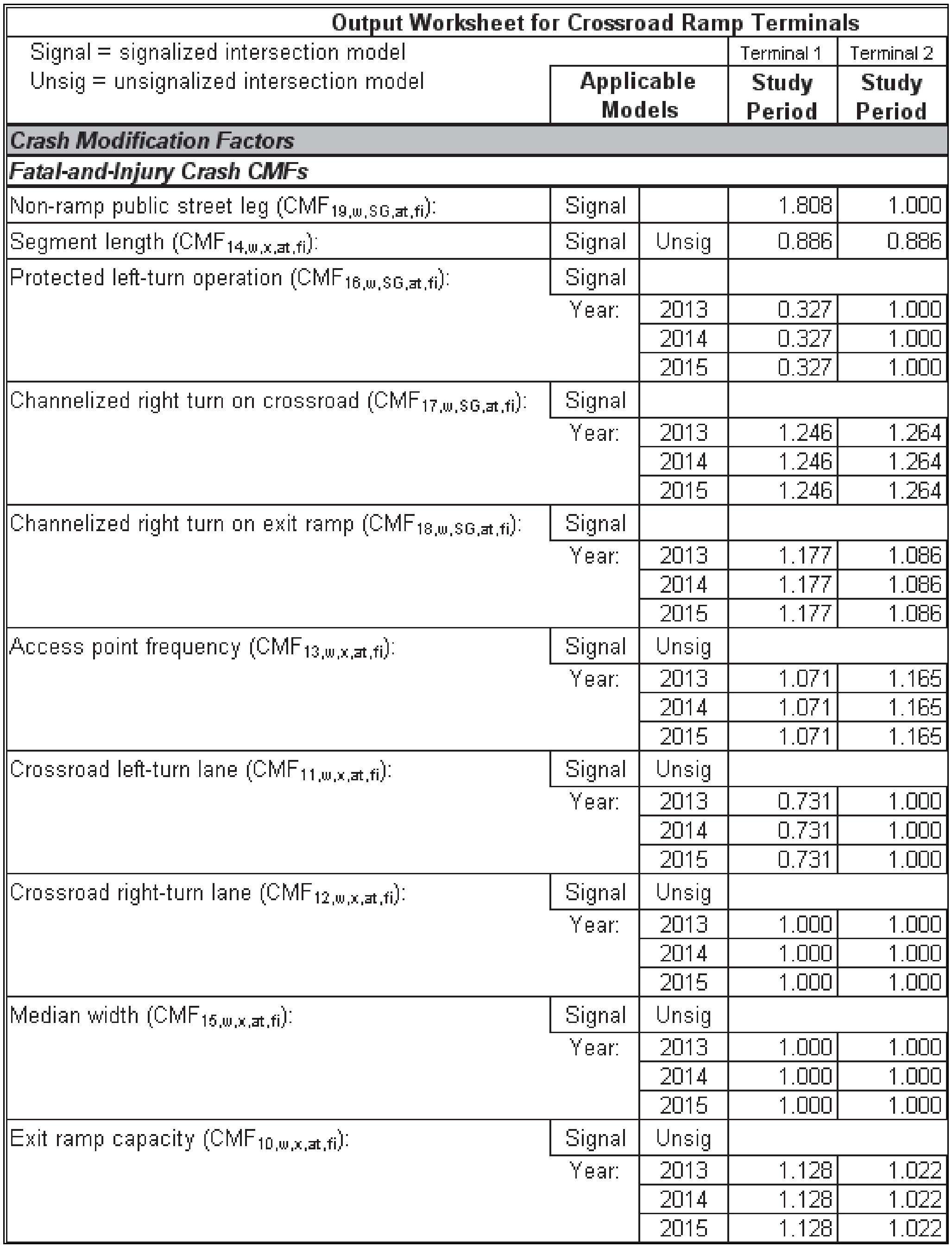
		Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6
MV = multiple-vehicle model SV = single-vehicle model	**Applicable Models**	**Study Period**	**Study Period**	**Study Period**	**Study Period**	**Study Period**	**Study Period**
Crash Severity Distribution (during Study Period)							
Fatal crash frequency ($N^*_{e,w,x,at,K}$), crashes:		0.036	0.018	0.012	0.007	0.020	0.048
Incapacitating injury crash freq. ($N^*_{e,w,x,at,A}$), crashes:		0.109	0.055	0.035	0.022	0.062	0.147
Non-incapacitating inj. crash freq. ($N^*_{e,w,x,at,B}$), crashes		0.454	0.354	0.226	0.140	0.392	0.620
Possible injury crash freq. ($N^*_{e,w,x,at,C}$), crashes:		0.554	0.439	0.321	0.171	0.479	0.864
Total fatal-and-injury crash freq. ($N^*_{e,w,x,at,fi}$), crashes:		1.154	0.866	0.593	0.341	0.953	1.679
Property-damage-only crash freq. ($N^*_{e,w,x,at,pdo}$), crashes:		1.282	1.285	0.976	0.432	1.403	2.230
Total crash frequency ($N^*_{e,w,x,at,as}$), crashes:		2.435	2.151	1.569	0.773	2.356	3.909

Figure 73. A3: Output Ramp Segments Worksheet—Crash Severity Distribution

Ramp Terminals

In the case of the crossroad ramp terminals, most of the CMFs are sensitive to volume. Values for these CMFs are computed for every year in the study period because the volumes may vary between years. The calculated CMFs for FI crashes are shown in Figure 74. Unused rows are omitted from the figure.

A review of the CMFs in this figure indicates the non-ramp public street leg at terminal 1 (i.e., N terminal) is associated with a CMF value of 1.808. This value suggests that the public street leg increases crash risk 80.8 percent, relative to terminals without a public street leg. The review also indicates that right-turn channelization and driveway presence is associated with a higher crash risk, relative to terminals without right-turn channelization or driveways. Conversely, crash risk tends to be reduced at terminal 1 by the presence of left-turn bays on the crossroad approaches and the use of protected left-turn operation.

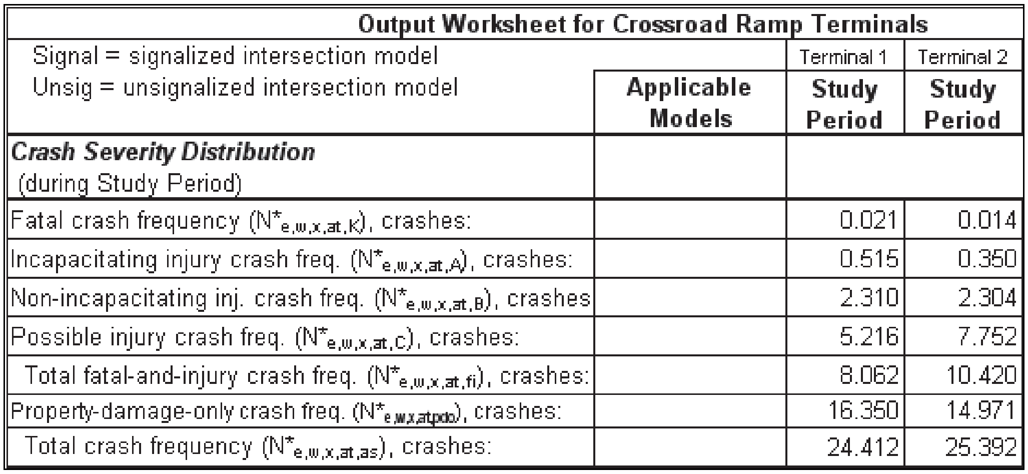


Output Worksheet for Crossroad Ramp Terminals

Signal = signalized intersection model Unsig = unsignalized intersection model	Applicable Models		Terminal 1 Study Period	Terminal 2 Study Period
Crash Modification Factors				
Fatal-and-Injury Crash CMFs				
Non-ramp public street leg ($\text{CMF}_{19,w,SG,at,fi}$):	Signal		1.808	1.000
Segment length ($\text{CMF}_{14,w,x,at,fi}$):	Signal	Unsig	0.886	0.886
Protected left-turn operation ($\text{CMF}_{16,w,SG,at,fi}$):	Signal			
	Year:	2013	0.327	1.000
		2014	0.327	1.000
		2015	0.327	1.000
Channelized right turn on crossroad ($\text{CMF}_{17,w,SG,at,fi}$):	Signal			
	Year:	2013	1.246	1.264
		2014	1.246	1.264
		2015	1.246	1.264
Channelized right turn on exit ramp ($\text{CMF}_{18,w,SG,at,fi}$):	Signal			
	Year:	2013	1.177	1.086
		2014	1.177	1.086
		2015	1.177	1.086
Access point frequency ($\text{CMF}_{13,w,x,at,fi}$):	Signal	Unsig		
	Year:	2013	1.071	1.165
		2014	1.071	1.165
		2015	1.071	1.165
Crossroad left-turn lane ($\text{CMF}_{11,w,x,at,fi}$):	Signal	Unsig		
	Year:	2013	0.731	1.000
		2014	0.731	1.000
		2015	0.731	1.000
Crossroad right-turn lane ($\text{CMF}_{12,w,x,at,fi}$):	Signal	Unsig		
	Year:	2013	1.000	1.000
		2014	1.000	1.000
		2015	1.000	1.000
Median width ($\text{CMF}_{15,w,x,at,fi}$):	Signal	Unsig		
	Year:	2013	1.000	1.000
		2014	1.000	1.000
		2015	1.000	1.000
Exit ramp capacity ($\text{CMF}_{10,w,x,at,fi}$):	Signal	Unsig		
	Year:	2013	1.128	1.022
		2014	1.128	1.022
		2015	1.128	1.022

Figure 74. A3: Output Ramp Terminals Worksheet—CMFs for FI Crashes

The crash severity distribution calculations for the crossroad ramp terminals are shown in Figure 75. When these calculations are compared to those in Figure 73, it can be seen that the fatal crash frequency is roughly the same between the ramp segments and the terminals, but the frequency of injury crashes (i.e., A, B, or C) and PDO crashes tends to be higher at the terminals.



Output Worksheet for Crossroad Ramp Terminals

Signal = signalized intersection model Unsig = unsignalized intersection model	Applicable Models	Terminal 1 Study Period	Terminal 2 Study Period
Crash Severity Distribution (during Study Period)			
Fatal crash frequency ($N^*_{e,w,x,at,K}$), crashes:		0.021	0.014
Incapacitating injury crash freq. ($N^*_{e,w,x,at,A}$), crashes:		0.515	0.350
Non-incapacitating inj. crash freq. ($N^*_{e,w,x,at,B}$), crashes		2.310	2.304
Possible injury crash freq. ($N^*_{e,w,x,at,C}$), crashes:		5.216	7.752
Total fatal-and-injury crash freq. ($N^*_{e,w,x,at,fi}$), crashes:		8.062	10.420
Property-damage-only crash freq. ($N^*_{e,w,x,at,pdo}$), crashes:		16.350	14.971
Total crash frequency ($N^*_{e,w,x,at,as}$), crashes:		24.412	25.392

Figure 75. A3: Output Ramp Terminals Worksheet—Crash Severity Distribution

Results

A partial cloverleaf interchange consisting of six ramp segments and two crossroad ramp terminals was analyzed for a three-year study period. The total predicted average crash frequency (shown in Figure 70) was found to be about 21.0 crashes per year, or 63.0 crashes during the study period. Of these, about 13.2 crashes are expected to occur on the ramp segments, and 49.8 crashes are expected to occur at the crossroad ramp terminals.

Inspection of the computed CMFs revealed that the geometric design elements most likely to increase crash risk are the horizontal curves on the ramps and the public street leg at the north crossroad ramp terminal. Safety improvements at the terminals (e.g., driveway relocation) may yield a larger reduction in crash frequency because the estimated number of terminal-related crashes is larger than the estimated number of ramp-related crashes.

APPLICATION 4. FULL CLOVERLEAF INTERCHANGE

The interchange is a full cloverleaf in an urban area. It is a service interchange at the junction between a freeway and a minor arterial cross street. Only the ramps forming the southern portion of the interchange are included in the analysis. The ramp traffic volumes range from 900 to 6,200 vehicles per day on the C-D road and 850 to 2,750 vehicles per day on the ramps. The interchange is of interest because of curves on the ramps and weaving maneuvers on the C-D road between the two loop ramps. The objective of this sample application is to evaluate the safety of the interchange, with focus on ramp curvature and weaving maneuvers.

The interchange consists of four ramp segments and five C-D road segments. The segmentation is shown in Figure 76. The divisions between the C-D road segments occur at the gore points where the four ramps connect to the C-D road.

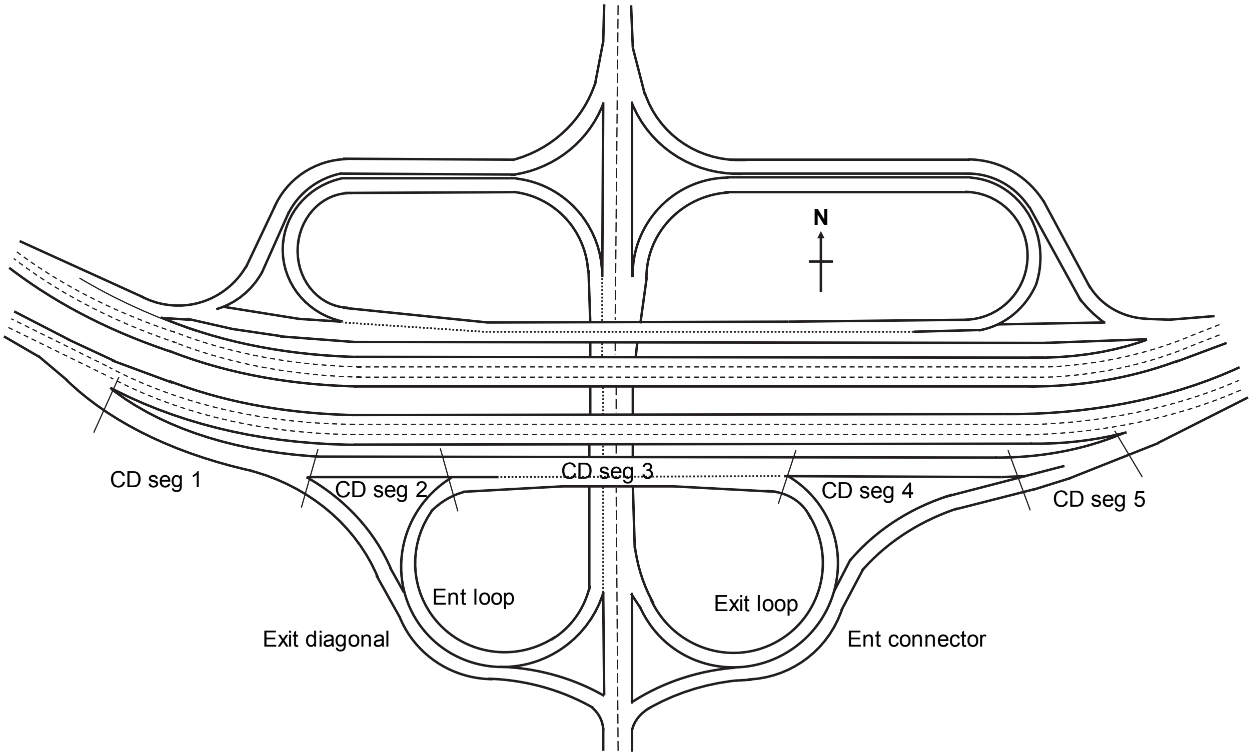


Figure 76. Application 4: Full Cloverleaf Interchange

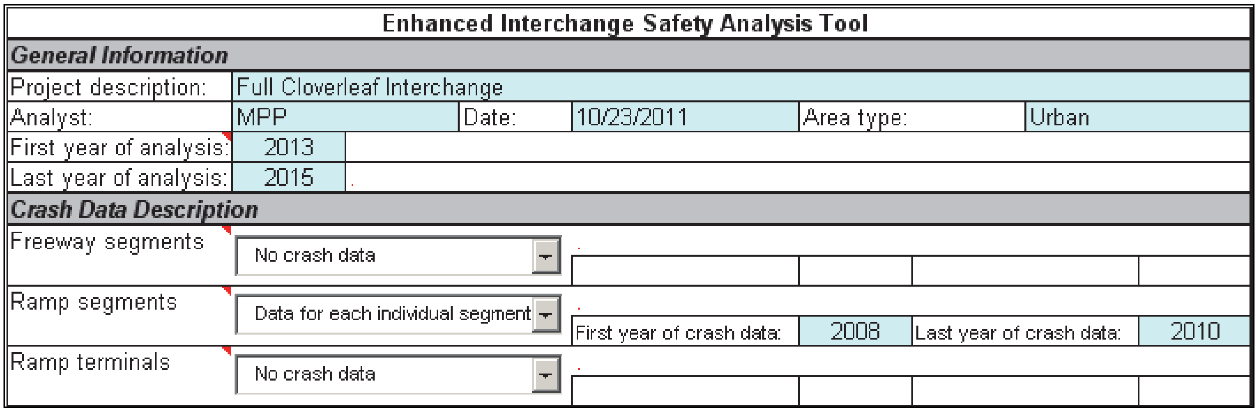
Input Data

The split diamond interchange has two different component types—ramp segments and C-D road segments. The Input Ramp Segments worksheet is used to model these components. The data entry cells in the sections titled General Information and Crash Data Description are shown in Figure 77. As indicated, the area type is urban, the analysis period includes the years 2013 to 2015, and crash data are available for each ramp segment for the years 2008 to 2010.

C-D Road Segments

The basic roadway data, alignment data, and cross section data that describe the five C-D road segments are shown in Figure 78. Two columns are shown for each segment. One column is used to describe the geometric design and traffic control features that existed during the crash period. The second column is used to describe the features that are planned for the study period. For this application, these features are identical for both periods so the input data are repeated in the second column.

The segment type specified as "C-D Road" for the five C-D road segments. Segment 1 has a curve with a radius of 1,150 ft. This curve is coded as an off-segment curve on C-D road segments 2 and 3. A second curve with a radius of 2,835 ft starts in segment 4 and ends in segment 5. The curve is 0.15 mi in length, with 0.10 mi of this length in segment 4 and 0.05 mi in segment 5. Segments 1, 2, 4, and 5 have the same cross section widths. Segment 3 has narrower lanes and a wider right shoulder. This segment differs from the others because it has a weaving section. However, the auxiliary lane associated with the weaving section is *not* counted when determining the number of through lanes for segment 3.



Enhanced Interchange Safety Analysis Tool

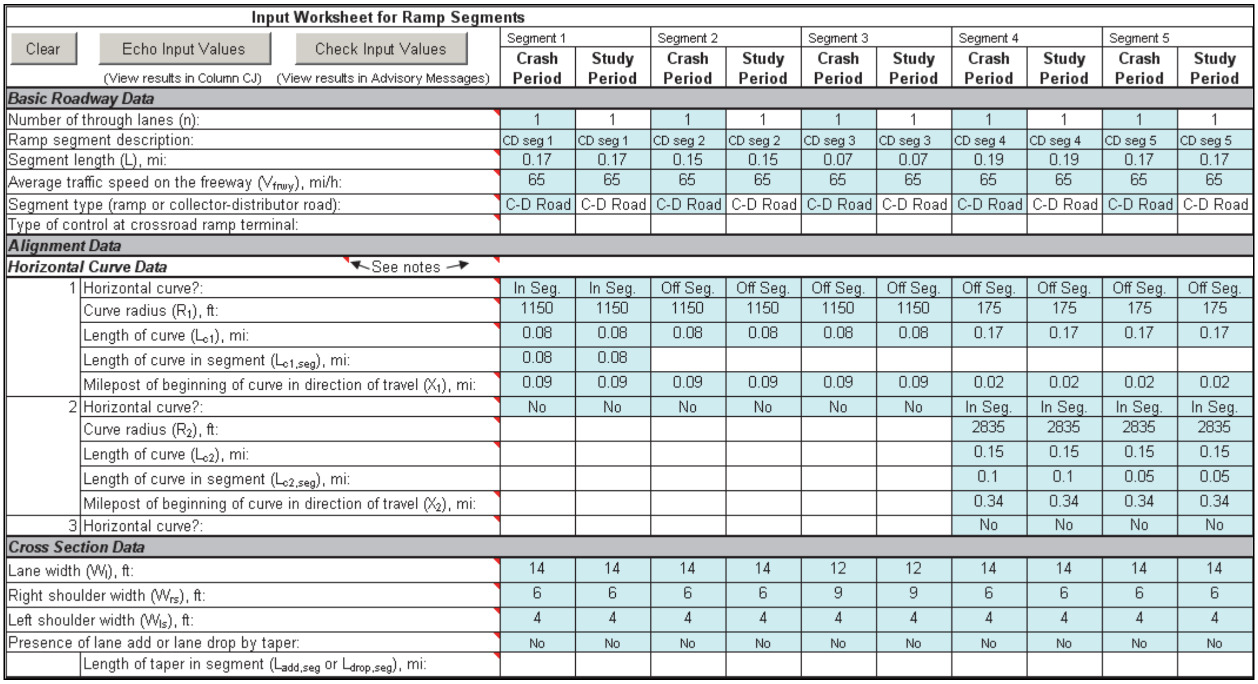
General Information

Project description:	Full Cloverleaf Interchange				
Analyst:	MPP	Date:	10/23/2011	Area type:	Urban
First year of analysis:	2013				
Last year of analysis:	2015				

Crash Data Description

Freeway segments	No crash data				
Ramp segments	Data for each individual segment	First year of crash data:	2008	Last year of crash data:	2010
Ramp terminals	No crash data				

Figure 77. A4: Main Worksheet—General Information and Crash Data Description



Input Worksheet for Ramp Segments

(View results in Column CJ) (View results in Advisory Messages)

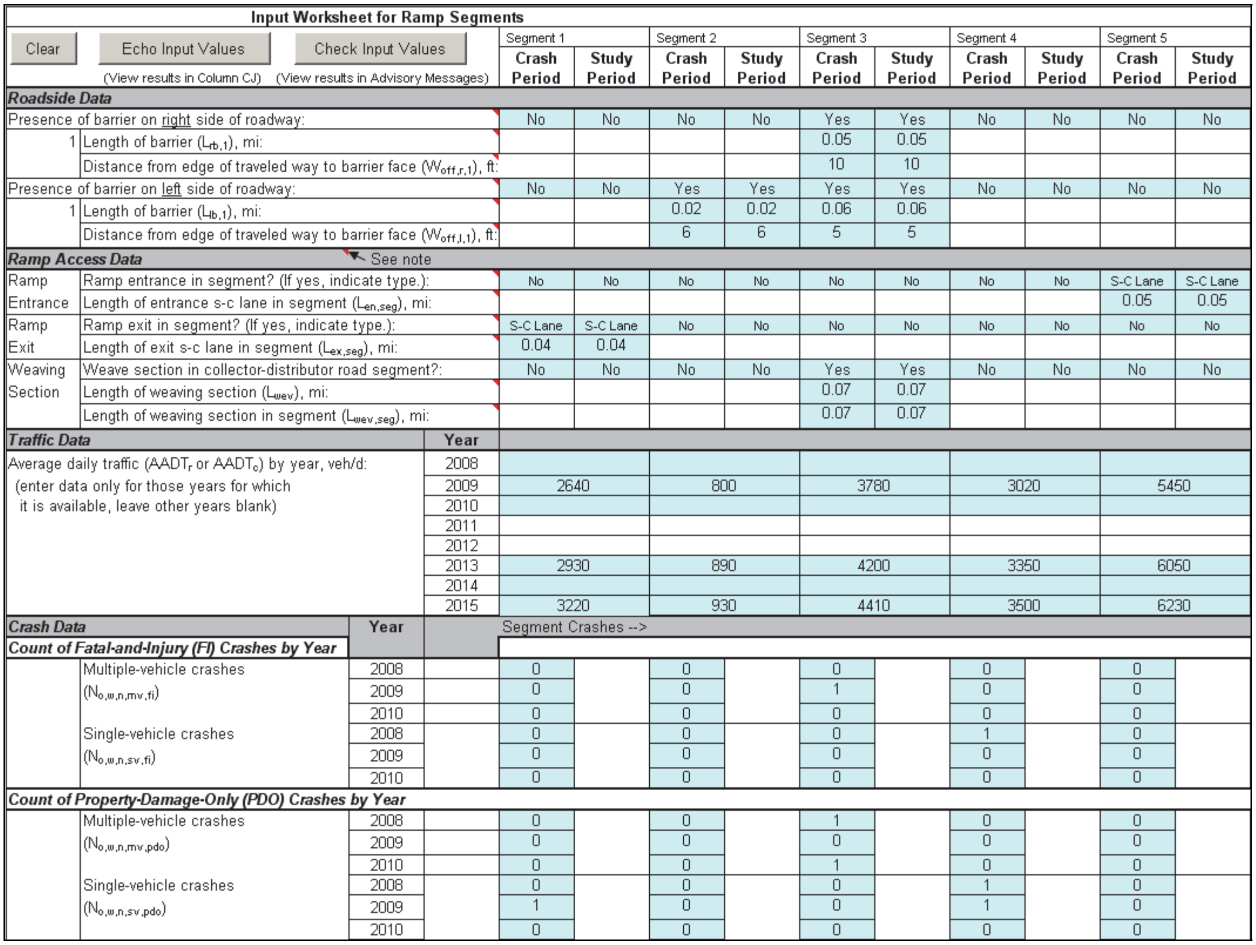
	Segment 1		Segment 2		Segment 3		Segment 4		Segment 5	
	Crash Period	**Study Period**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**
Basic Roadway Data										
Number of through lanes (n):	1	1	1	1	1	1	1	1	1	1
Ramp segment description:	CD seg 1	CD seg 1	CD seg 2	CD seg 2	CD seg 3	CD seg 3	CD seg 4	CD seg 4	CD seg 5	CD seg 5
Segment length (L), mi:	0.17	0.17	0.15	0.15	0.07	0.07	0.19	0.19	0.17	0.17
Average traffic speed on the freeway (V_{frwy}), mi/h:	65	65	65	65	65	65	65	65	65	65
Segment type (ramp or collector-distributor road):	C-D Road	C-D Road	C-D Road	C-D Road	C-D Road	C-D Road	C-D Road	C-D Road	C-D Road	C-D Road
Type of control at crossroad ramp terminal:										
Alignment Data										
Horizontal Curve Data ↖See notes →										
1 Horizontal curve?:	In Seg.	In Seg.	Off Seg.	Off Seg.	Off Seg.	Off Seg.	Off Seg.	Off Seg.	Off Seg.	Off Seg.
Curve radius (R_1), ft:	1150	1150	1150	1150	1150	1150	175	175	175	175
Length of curve (L_{c1}), mi:	0.08	0.08	0.08	0.08	0.08	0.08	0.17	0.17	0.17	0.17
Length of curve in segment ($L_{c1,seg}$), mi:	0.08	0.08								
Milepost of beginning of curve in direction of travel (X_1), mi:	0.09	0.09	0.09	0.09	0.09	0.09	0.02	0.02	0.02	0.02
2 Horizontal curve?:	No	No	No	No	No	No	In Seg.	In Seg.	In Seg.	In Seg.
Curve radius (R_2), ft:							2835	2835	2835	2835
Length of curve (L_{c2}), mi:							0.15	0.15	0.15	0.15
Length of curve in segment ($L_{c2,seg}$), mi:							0.1	0.1	0.05	0.05
Milepost of beginning of curve in direction of travel (X_2), mi:							0.34	0.34	0.34	0.34
3 Horizontal curve?:							No	No	No	No
Cross Section Data										
Lane width (W_l), ft:	14	14	14	14	12	12	14	14	14	14
Right shoulder width (W_{rs}), ft:	6	6	6	6	9	9	6	6	6	6
Left shoulder width (W_{ls}), ft:	4	4	4	4	4	4	4	4	4	4
Presence of lane add or lane drop by taper:	No	No	No	No	No	No	No	No	No	No
Length of taper in segment ($L_{add,seg}$ or $L_{drop,seg}$), mi:										

Figure 78. A4: Input Ramp Segments Worksheet—Roadway, Alignment, and Cross Section Data

The curve on the entrance loop ramp is coded for C-D road segments 4 and 5 based on the guidance in Figure 20. Using year 2013 volumes, the AADT volume for segment 4 includes 3,310 veh/day from the loop ramp and 40 veh/day from the C-D road. As a result, curve speed prediction for segment 4 should be based on the loop ramp curve. Similarly, the AADT volume for segment 5 includes 3,310 veh/day from the loop ramp and 2,700 veh/day from the entrance connector ramp, so curve speed prediction for segment 5 should be based on the loop ramp curve.

Figure 79 identifies the roadside, ramp access, traffic, and crash data that describe the five C-D road segments. Segments 1 and 5 are coded as having speed-change lanes. These speed-change lanes are associated with the diverging or merging of the diagonal ramps with the C-D road, as is illustrated in Figure 76. The length of the weaving section on the third C-D road is also entered. This weaving section is associated with the merging and diverging of the loop ramps.

The AADT volume estimates are available for the years 2009, 2013, and 2015. The AADT volumes for the years 2008, 2010, and 2014 are estimated by ISATe using the rules described in the section titled Analysis Steps.



Input Worksheet for Ramp Segments

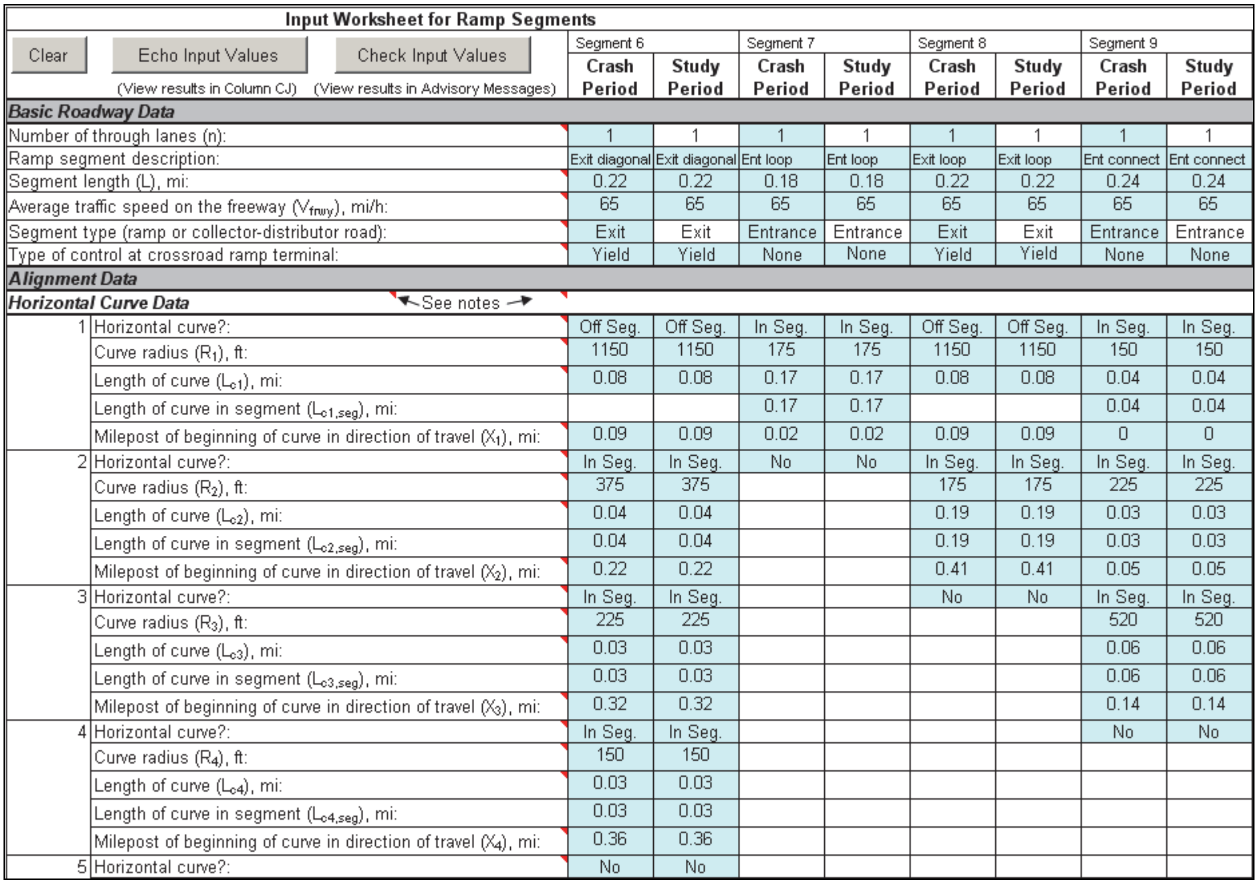
			Segment 1		Segment 2		Segment 3		Segment 4		Segment 5	
			Crash Period	Study Period	Crash Period	Study Period	Crash Period	Study Period	Crash Period	Study Period	Crash Period	Study Period
Roadside Data												
Presence of barrier on right side of roadway:			No	No	No	No	Yes	Yes	No	No	No	No
1	Length of barrier ($L_{rb,1}$), mi:						0.05	0.05				
	Distance from edge of traveled way to barrier face ($W_{off,r,1}$), ft:						10	10				
Presence of barrier on left side of roadway:			No	No	Yes	Yes	Yes	Yes	No	No	No	No
1	Length of barrier ($L_{lb,1}$), mi:				0.02	0.02	0.06	0.06				
	Distance from edge of traveled way to barrier face ($W_{off,l,1}$), ft:				6	6	5	5				
Ramp Access Data												
Ramp Entrance	Ramp entrance in segment? (If yes, indicate type.):		No	No	No	No	No	No	No	No	S-C Lane	S-C Lane
	Length of entrance s-c lane in segment ($L_{en,seg}$), mi:										0.05	0.05
Ramp Exit	Ramp exit in segment? (If yes, indicate type.):		S-C Lane	S-C Lane	No	No	No	No	No	No	No	No
	Length of exit s-c lane in segment ($L_{ex,seg}$), mi:		0.04	0.04								
Weaving Section	Weave section in collector-distributor road segment?:		No	No	No	No	Yes	Yes	No	No	No	No
	Length of weaving section (L_{wev}), mi:						0.07	0.07				
	Length of weaving section in segment ($L_{wev,seg}$), mi:						0.07	0.07				
Traffic Data		Year										
Average daily traffic ($AADT_r$ or $AADT_c$) by year, veh/d:		2008										
(enter data only for those years for which it is available, leave other years blank)		2009	2640		800		3780		3020		5450	
		2010										
		2011										
		2012										
		2013	2930		890		4200		3350		6050	
		2014										
		2015	3220		930		4410		3500		6230	
Crash Data		Year	Segment Crashes -->									
Count of Fatal-and-Injury (FI) Crashes by Year												
	Multiple-vehicle crashes ($N_{o,w,n,mv,fi}$)	2008	0		0		0		0		0	
		2009	0		0		1		0		0	
		2010	0		0		0		0		0	
	Single-vehicle crashes ($N_{o,w,n,sv,fi}$)	2008	0		0		0		1		0	
		2009	0		0		0		0		0	
		2010	0		0		0		0		0	
Count of Property-Damage-Only (PDO) Crashes by Year												
	Multiple-vehicle crashes ($N_{o,w,n,mv,pdo}$)	2008	0		0		1		0		0	
		2009	0		0		0		0		0	
		2010	0		0		1		0		0	
	Single-vehicle crashes ($N_{o,w,n,sv,pdo}$)	2008	0		0		0		1		0	
		2009	1		0		0		1		0	
		2010	0		0		0		0		0	

Figure 79. A4: Input Ramp Segments Worksheet—Roadside, Ramp Access, Traffic, and Crash Data

The crash data for years 2008, 2009, and 2010 are shown in the bottom portion of Figure 79. These data are categorized by severity (i.e., fatal-and-injury or property-damage-only), crash type (multiple-vehicle or single-vehicle), and year of occurrence. Segment 1 is shown to be associated with one single-vehicle property-damage-only crash in 2009. Segments 3 and 4 are each associated with three crashes.

Ramp Segments

The basic roadway data and alignment data that describe the four ramps are shown in Figure 80. The data are entered into the Input Ramp Segments worksheet, with the segment type specified as "Entrance" or "Exit." The exit diagonal ramp is coded as segment 6. It has one off-segment curve and three in-segment curves. The off-segment curve is located on the first C-D road segment, but it is also described for segment 6 because its presence affects vehicle speed on the exit ramp. For the same reason, the curve on the first C-D road segment is also described as an off-segment curve for the exit loop ramp (i.e., segment 8).



Input Worksheet for Ramp Segments

(View results in Column CJ) (View results in Advisory Messages)

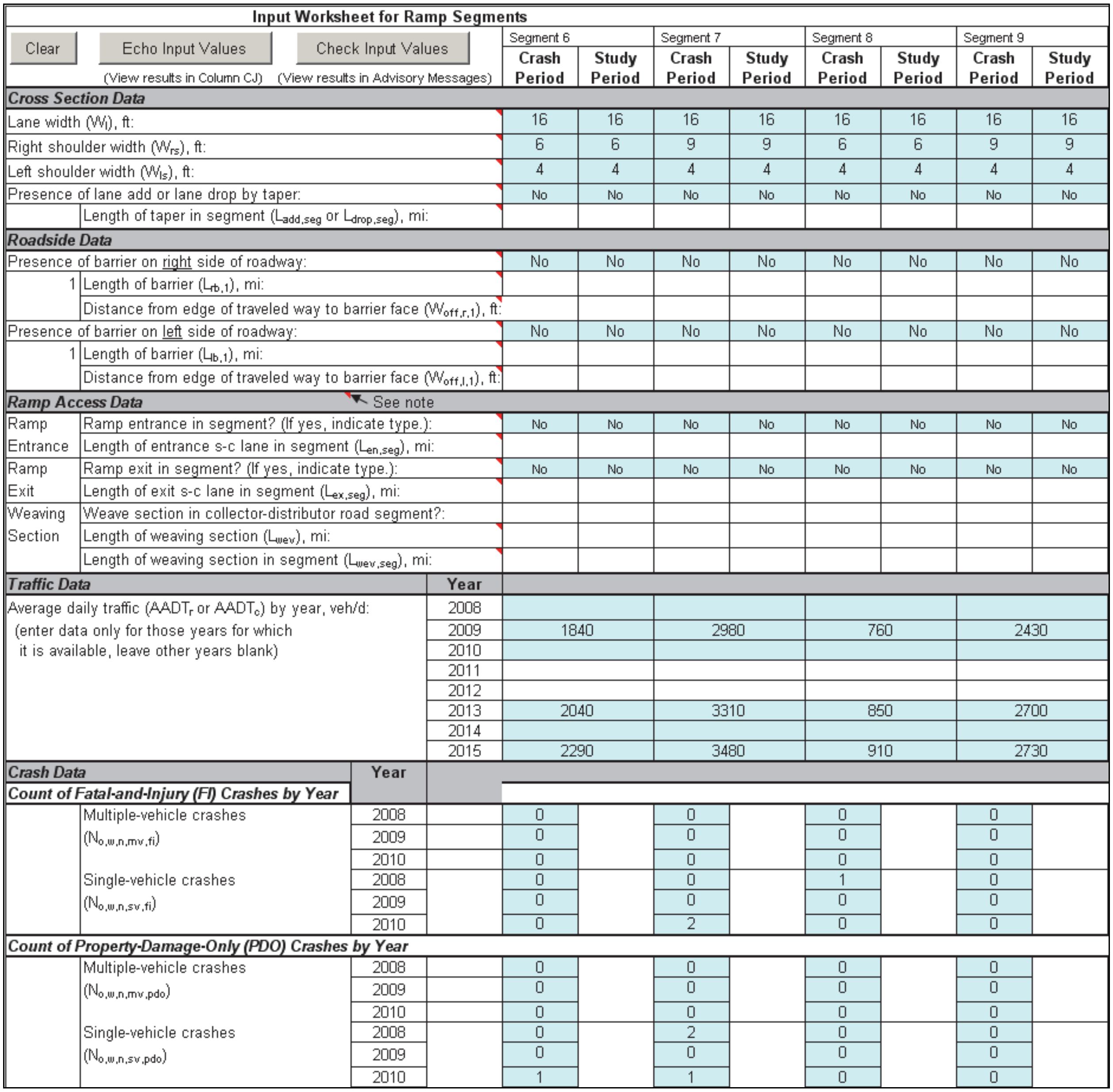
		Segment 6		Segment 7		Segment 8		Segment 9	
		Crash Period	Study Period	Crash Period	Study Period	Crash Period	Study Period	Crash Period	Study Period
Basic Roadway Data									
Number of through lanes (n):		1	1	1	1	1	1	1	1
Ramp segment description:		Exit diagonal	Exit diagonal	Ent loop	Ent loop	Exit loop	Exit loop	Ent connect	Ent connect
Segment length (L), mi:		0.22	0.22	0.18	0.18	0.22	0.22	0.24	0.24
Average traffic speed on the freeway (V_{frwy}), mi/h:		65	65	65	65	65	65	65	65
Segment type (ramp or collector-distributor road):		Exit	Exit	Entrance	Entrance	Exit	Exit	Entrance	Entrance
Type of control at crossroad ramp terminal:		Yield	Yield	None	None	Yield	Yield	None	None
Alignment Data									
Horizontal Curve Data	←See notes →								
1	Horizontal curve?:	Off Seg.	Off Seg.	In Seg.	In Seg.	Off Seg.	Off Seg.	In Seg.	In Seg.
	Curve radius (R_1), ft:	1150	1150	175	175	1150	1150	150	150
	Length of curve (L_{c1}), mi:	0.08	0.08	0.17	0.17	0.08	0.08	0.04	0.04
	Length of curve in segment ($L_{c1,seg}$), mi:			0.17	0.17			0.04	0.04
	Milepost of beginning of curve in direction of travel (X_1), mi:	0.09	0.09	0.02	0.02	0.09	0.09	0	0
2	Horizontal curve?:	In Seg.	In Seg.	No	No	In Seg.	In Seg.	In Seg.	In Seg.
	Curve radius (R_2), ft:	375	375			175	175	225	225
	Length of curve (L_{c2}), mi:	0.04	0.04			0.19	0.19	0.03	0.03
	Length of curve in segment ($L_{c2,seg}$), mi:	0.04	0.04			0.19	0.19	0.03	0.03
	Milepost of beginning of curve in direction of travel (X_2), mi:	0.22	0.22			0.41	0.41	0.05	0.05
3	Horizontal curve?:	In Seg.	In Seg.			No	No	In Seg.	In Seg.
	Curve radius (R_3), ft:	225	225					520	520
	Length of curve (L_{c3}), mi:	0.03	0.03					0.06	0.06
	Length of curve in segment ($L_{c3,seg}$), mi:	0.03	0.03					0.06	0.06
	Milepost of beginning of curve in direction of travel (X_3), mi:	0.32	0.32					0.14	0.14
4	Horizontal curve?:	In Seg.	In Seg.					No	No
	Curve radius (R_4), ft:	150	150						
	Length of curve (L_{c4}), mi:	0.03	0.03						
	Length of curve in segment ($L_{c4,seg}$), mi:	0.03	0.03						
	Milepost of beginning of curve in direction of travel (X_4), mi:	0.36	0.36						
5	Horizontal curve?:	No	No						

Figure 80. A4: Input Ramp Segments Worksheet—Roadway and Alignment Data

Figure 81 identifies the cross section, roadside, ramp access, traffic, and crash data that describe the ramp segments. All ramp segments have a lane width of 16 ft and a left shoulder width of 4 ft, while the right shoulder widths vary from 6 ft to 9 ft between the segments. No roadside barriers, ramp entrances, or ramp exits are present in the segments.

The AADT volume estimates are available for the years 2009, 2013, and 2015. The AADT volumes for the years 2008, 2010, and 2014 are estimated by ISATe using the rules described in the section titled Analysis Steps.

The crash data are shown in the bottom portion of Figure 81. Segment 8 is shown to be associated with one single-vehicle fatal-or-injury crash in 2008. Segment 6 is associated with one crash. Segment 7 is associated with five crashes. Segment 9 is not associated with any crashes in the three-year crash period.



Input Worksheet for Ramp Segments

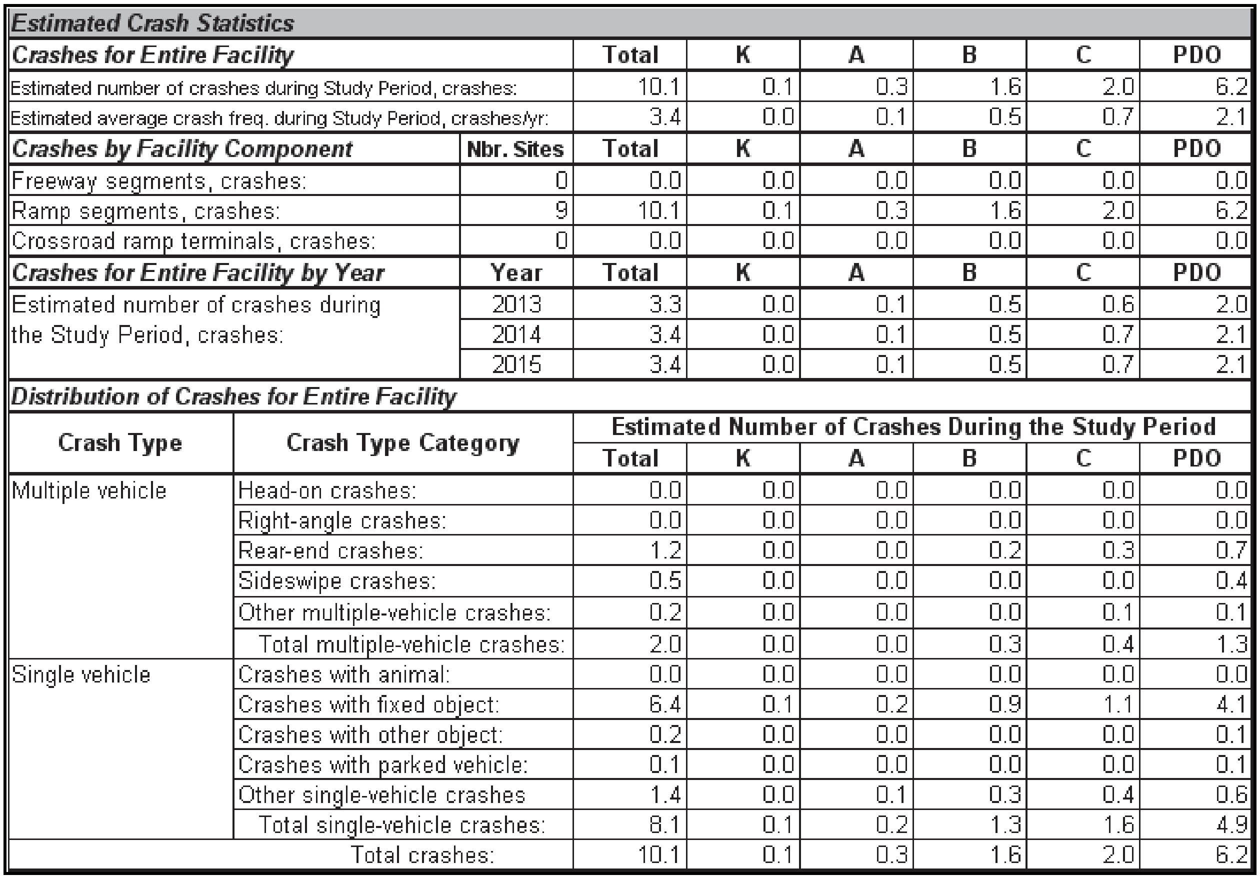
			Segment 6		Segment 7		Segment 8		Segment 9	
			Crash Period	Study Period	Crash Period	Study Period	Crash Period	Study Period	Crash Period	Study Period
Cross Section Data										
Lane width (W_l), ft:			16	16	16	16	16	16	16	16
Right shoulder width (W_{rs}), ft:			6	6	9	9	6	6	9	9
Left shoulder width (W_{ls}), ft:			4	4	4	4	4	4	4	4
Presence of lane add or lane drop by taper:			No	No	No	No	No	No	No	No
	Length of taper in segment ($L_{add,seg}$ or $L_{drop,seg}$), mi:									
Roadside Data										
Presence of barrier on right side of roadway:			No	No	No	No	No	No	No	No
1	Length of barrier ($L_{rb,1}$), mi:									
	Distance from edge of traveled way to barrier face ($W_{off,r,1}$), ft:									
Presence of barrier on left side of roadway:			No	No	No	No	No	No	No	No
1	Length of barrier ($L_{lb,1}$), mi:									
	Distance from edge of traveled way to barrier face ($W_{off,l,1}$), ft:									
Ramp Access Data See note										
Ramp Entrance	Ramp entrance in segment? (If yes, indicate type.):		No	No	No	No	No	No	No	No
	Length of entrance s-c lane in segment ($L_{en,seg}$), mi:									
Ramp Exit	Ramp exit in segment? (If yes, indicate type.):		No	No	No	No	No	No	No	No
	Length of exit s-c lane in segment ($L_{ex,seg}$), mi:									
Weaving Section	Weave section in collector-distributor road segment?:									
	Length of weaving section (L_{wev}), mi:									
	Length of weaving section in segment ($L_{wev,seg}$), mi:									
Traffic Data		Year								
Average daily traffic ($AADT_r$ or $AADT_c$) by year, veh/d:		2008								
(enter data only for those years for which it is available, leave other years blank)		2009	1840		2980		760		2430	
		2010								
		2011								
		2012								
		2013	2040		3310		850		2700	
		2014								
		2015	2290		3480		910		2730	
Crash Data		Year								
Count of Fatal-and-Injury (FI) Crashes by Year										
	Multiple-vehicle crashes	2008	0		0		0		0	
	($N_{o,w,n,mv,fi}$)	2009	0		0		0		0	
		2010	0		0		0		0	
	Single-vehicle crashes	2008	0		0		1		0	
	($N_{o,w,n,sv,fi}$)	2009	0		0		0		0	
		2010	0		2		0		0	
Count of Property-Damage-Only (PDO) Crashes by Year										
	Multiple-vehicle crashes	2008	0		0		0		0	
	($N_{o,w,n,mv,pdo}$)	2009	0		0		0		0	
		2010	0		0		0		0	
	Single-vehicle crashes	2008	0		2		0		0	
	($N_{o,w,n,sv,pdo}$)	2009	0		0		0		0	
		2010	1		1		0		0	

Figure 81. A4: Input Ramp Segments Worksheet—Cross Section, Roadside, Ramp Access, Traffic, and Crash Data

Output Summary

The Estimated Crash Statistics output cells are shown in Figure 82. Note that the unused rows are omitted from the figure. The two rows under the heading Crashes for Entire Facility provide the estimated number of crashes and crash frequency for the study period.

The three rows under the heading Crashes by Facility Component provide the estimated number of crashes for the three component types (freeway segment, ramp segment, and crossroad ramp terminal) modeled by ISATe. In this sample application, the facility is comprised of ramp segments and C-D road segments, both of which are modeled using the Input Ramp Segments worksheet. Hence, one crash estimate is provided for these two component types for the three-year study period.



Estimated Crash Statistics							
Crashes for Entire Facility		Total	K	A	B	C	PDO
Estimated number of crashes during Study Period, crashes:		10.1	0.1	0.3	1.6	2.0	6.2
Estimated average crash freq. during Study Period, crashes/yr:		3.4	0.0	0.1	0.5	0.7	2.1
Crashes by Facility Component	Nbr. Sites	Total	K	A	B	C	PDO
Freeway segments, crashes:	0	0.0	0.0	0.0	0.0	0.0	0.0
Ramp segments, crashes:	9	10.1	0.1	0.3	1.6	2.0	6.2
Crossroad ramp terminals, crashes:	0	0.0	0.0	0.0	0.0	0.0	0.0
Crashes for Entire Facility by Year	Year	Total	K	A	B	C	PDO
Estimated number of crashes during the Study Period, crashes:	2013	3.3	0.0	0.1	0.5	0.6	2.0
	2014	3.4	0.0	0.1	0.5	0.7	2.1
	2015	3.4	0.0	0.1	0.5	0.7	2.1
Distribution of Crashes for Entire Facility							
Crash Type	Crash Type Category	Estimated Number of Crashes During the Study Period					
		Total	K	A	B	C	PDO
Multiple vehicle	Head-on crashes:	0.0	0.0	0.0	0.0	0.0	0.0
	Right-angle crashes:	0.0	0.0	0.0	0.0	0.0	0.0
	Rear-end crashes:	1.2	0.0	0.0	0.2	0.3	0.7
	Sideswipe crashes:	0.5	0.0	0.0	0.0	0.0	0.4
	Other multiple-vehicle crashes:	0.2	0.0	0.0	0.0	0.1	0.1
	Total multiple-vehicle crashes:	2.0	0.0	0.0	0.3	0.4	1.3
Single vehicle	Crashes with animal:	0.0	0.0	0.0	0.0	0.0	0.0
	Crashes with fixed object:	6.4	0.1	0.2	0.9	1.1	4.1
	Crashes with other object:	0.2	0.0	0.0	0.0	0.0	0.1
	Crashes with parked vehicle:	0.1	0.0	0.0	0.0	0.0	0.1
	Other single-vehicle crashes	1.4	0.0	0.1	0.3	0.4	0.6
	Total single-vehicle crashes:	8.1	0.1	0.2	1.3	1.6	4.9
Total crashes:		10.1	0.1	0.3	1.6	2.0	6.2

Figure 82. A4: Output Summary Worksheet—Estimated Crash Statistics

The three rows under the heading Crashes for Entire Facility by Year provide the estimated number of crashes for each of the three years included in the study period. In this sample application, the estimates vary by year because different volume estimates were available for the years 2013 and 2015 (and estimated for the year 2014).

The rows under the heading Distribution of Crashes for Entire Facility provide the estimated number of crashes by severity and crash type. This distribution is given for the entire study period.

Detailed Output Data

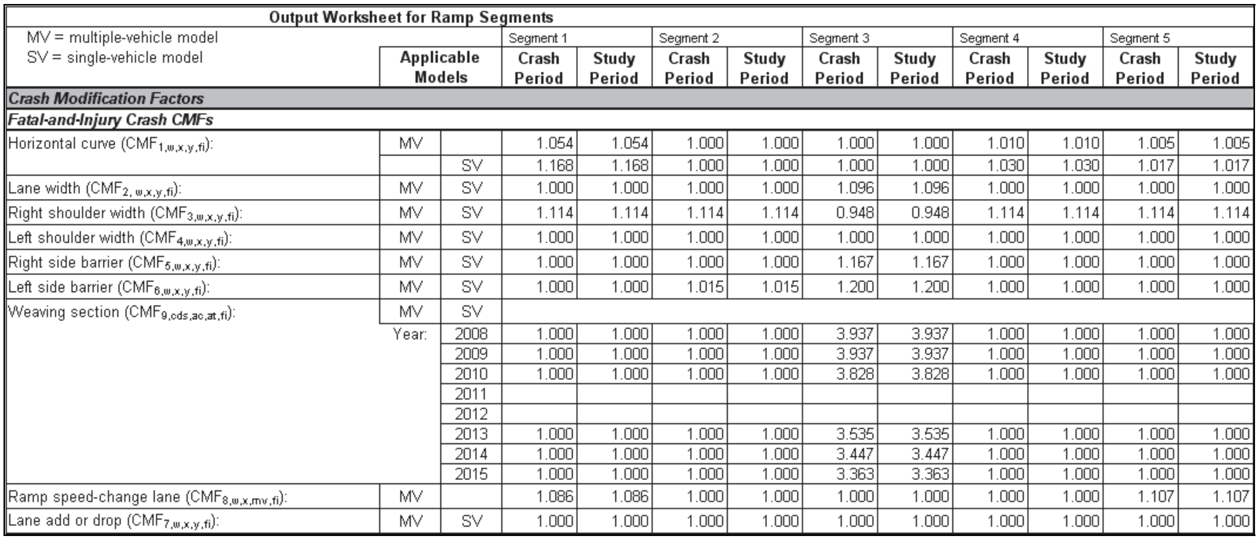
On the Output Ramp Segments worksheet, the following data are provided:

- CMFs for FI crashes.
- CMFs for PDO crashes.
- Expected average crash frequency, including the following quantities:
  - FI crash frequency (for multiple-vehicle and single-vehicle crashes).
  - PDO crash frequency (for multiple-vehicle and single-vehicle crashes).
  - Crash severity distribution (K, A, B, C, and PDO).

- Intermediate results for curve, barrier, and volume proportion calculations.
- Traffic data (the projected volumes for all facility components, varied by year if volume projections are used).

C-D Road Segments

The computed CMF values for FI crashes on the C-D road segments are provided in Figure 83. Inspection of the CMFs reveals that the presence of a weaving section on the third C-D road segment significantly increases crash risk on that segment. Different values for the weaving section CMF are provided for each of the three years in the study period because this CMF is sensitive to volume.



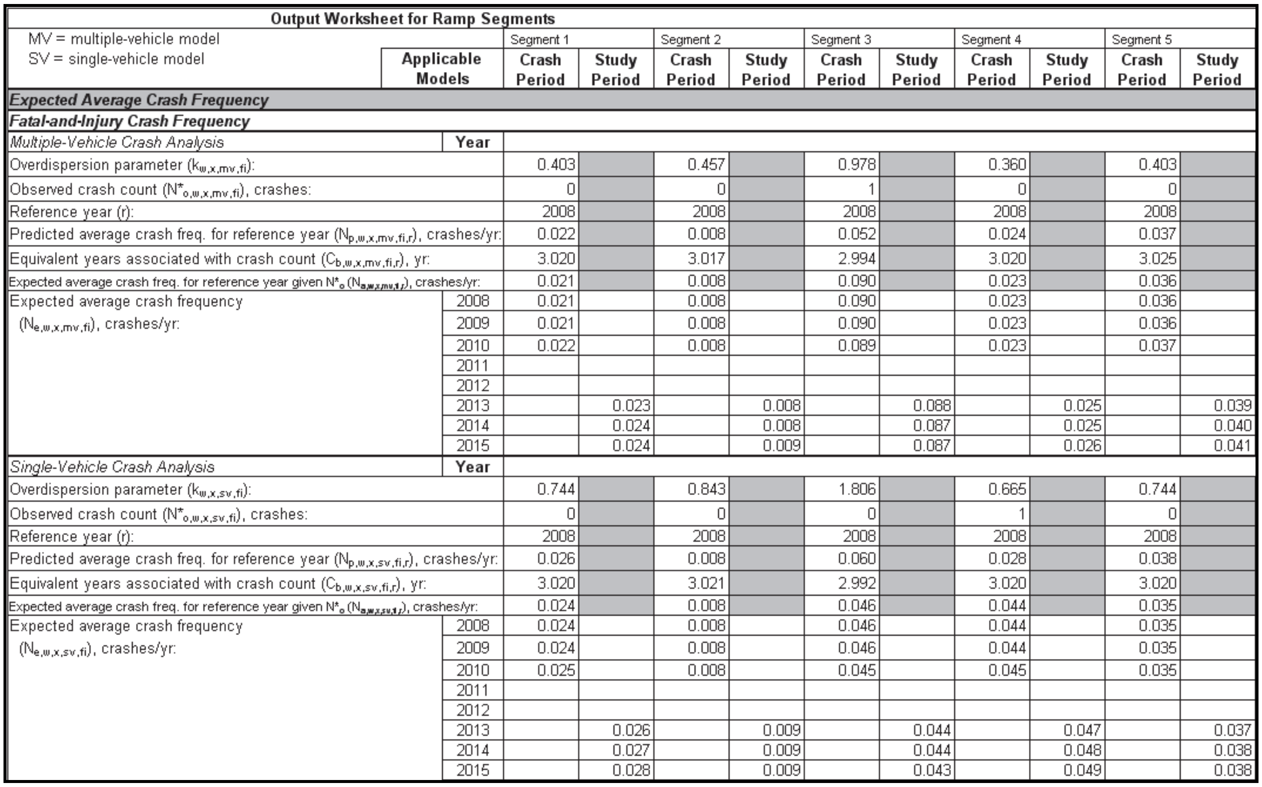
Output Worksheet for Ramp Segments

MV = multiple-vehicle model SV = single-vehicle model			Segment 1		Segment 2		Segment 3		Segment 4		Segment 5	
	Applicable Models		**Crash Period**	**Study Period**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**
Crash Modification Factors												
Fatal-and-Injury Crash CMFs												
Horizontal curve (CMF$_{1,w,x,y,fi}$):	MV		1.054	1.054	1.000	1.000	1.000	1.000	1.010	1.010	1.005	1.005
		SV	1.168	1.168	1.000	1.000	1.000	1.000	1.030	1.030	1.017	1.017
Lane width (CMF$_{2,w,x,y,fi}$):	MV	SV	1.000	1.000	1.000	1.000	1.096	1.096	1.000	1.000	1.000	1.000
Right shoulder width (CMF$_{3,w,x,y,fi}$):	MV	SV	1.114	1.114	1.114	1.114	0.948	0.948	1.114	1.114	1.114	1.114
Left shoulder width (CMF$_{4,w,x,y,fi}$):	MV	SV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Right side barrier (CMF$_{5,w,x,y,fi}$):	MV	SV	1.000	1.000	1.000	1.000	1.167	1.167	1.000	1.000	1.000	1.000
Left side barrier (CMF$_{6,w,x,y,fi}$):	MV	SV	1.000	1.000	1.015	1.015	1.200	1.200	1.000	1.000	1.000	1.000
Weaving section (CMF$_{9,cds,ac,at,fi}$):	MV	SV										
	Year:	2008	1.000	1.000	1.000	1.000	3.937	3.937	1.000	1.000	1.000	1.000
		2009	1.000	1.000	1.000	1.000	3.937	3.937	1.000	1.000	1.000	1.000
		2010	1.000	1.000	1.000	1.000	3.828	3.828	1.000	1.000	1.000	1.000
		2011										
		2012										
		2013	1.000	1.000	1.000	1.000	3.535	3.535	1.000	1.000	1.000	1.000
		2014	1.000	1.000	1.000	1.000	3.447	3.447	1.000	1.000	1.000	1.000
		2015	1.000	1.000	1.000	1.000	3.363	3.363	1.000	1.000	1.000	1.000
Ramp speed-change lane (CMF$_{8,w,x,mv,fi}$):	MV		1.086	1.086	1.000	1.000	1.000	1.000	1.000	1.000	1.107	1.107
Lane add or drop (CMF$_{7,w,x,y,fi}$):	MV	SV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Figure 83. A4: Output Ramp Segments Worksheet—CMFs for FI Crashes

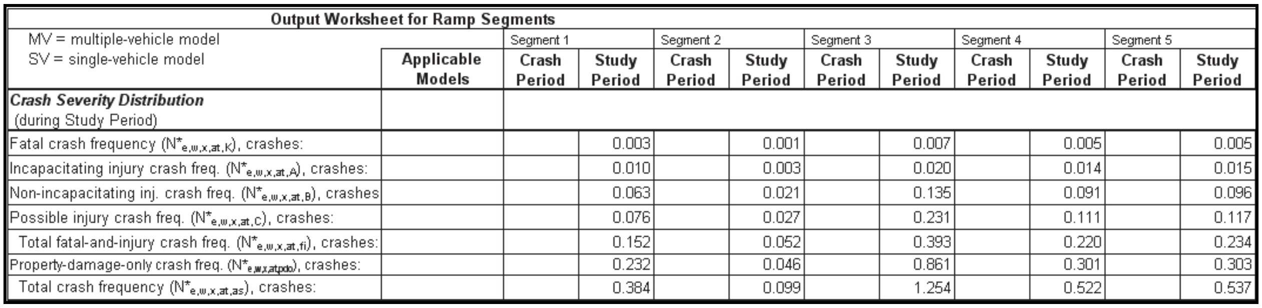
The expected average crash frequency calculations for FI crashes on the C-D road segments are shown in Figure 84. The EB Method is used in this application so rows relating to these calculations are shown, starting with the overdispersion parameter. For multiple-vehicle crash calculations, there are three rows of crash estimates for the crash period (i.e., years 2008 to 2010) and three rows of crash estimates for the study period (i.e., years 2013 to 2015). This pattern is repeated for the single-vehicle crash frequency calculations. Unused rows for additional years are omitted from the figure.

The crash severity distribution calculations for the C-D road segments are shown in Figure 85. These calculations are shown in the worksheet rows just below the rows that show the expected average crash frequency. The estimated number of crashes are given for each segment and aggregated for the entire study period.



Output Worksheet for Ramp Segments											
MV = multiple-vehicle model SV = single-vehicle model		Segment 1		Segment 2		Segment 3		Segment 4		Segment 5	
	Applicable Models	Crash Period	Study Period	Crash Period	Study Period	Crash Period	Study Period	Crash Period	Study Period	Crash Period	Study Period
Expected Average Crash Frequency											
Fatal-and-Injury Crash Frequency											
Multiple-Vehicle Crash Analysis	**Year**										
Overdispersion parameter ($k_{w,x,mv,fi}$):		0.403		0.457		0.978		0.360		0.403	
Observed crash count ($N^*_{o,w,x,mv,fi}$), crashes:		0		0		1		0		0	
Reference year (r):		2008		2008		2008		2008		2008	
Predicted average crash freq. for reference year ($N_{p,w,x,mv,fi,r}$), crashes/yr:		0.022		0.008		0.052		0.024		0.037	
Equivalent years associated with crash count ($C_{b,w,x,mv,fi,r}$), yr:		3.020		3.017		2.994		3.020		3.025	
Expected average crash freq. for reference year given N^*_o ($N_{a,w,x,mv,fi,r}$), crashes/yr:		0.021		0.008		0.090		0.023		0.036	
Expected average crash frequency ($N_{e,w,x,mv,fi}$), crashes/yr:	2008	0.021		0.008		0.090		0.023		0.036	
	2009	0.021		0.008		0.090		0.023		0.036	
	2010	0.022		0.008		0.089		0.023		0.037	
	2011										
	2012										
	2013		0.023		0.008		0.088		0.025		0.039
	2014		0.024		0.008		0.087		0.025		0.040
	2015		0.024		0.009		0.087		0.026		0.041
Single-Vehicle Crash Analysis	**Year**										
Overdispersion parameter ($k_{w,x,sv,fi}$):		0.744		0.843		1.806		0.665		0.744	
Observed crash count ($N^*_{o,w,x,sv,fi}$), crashes:		0		0		0		1		0	
Reference year (r):		2008		2008		2008		2008		2008	
Predicted average crash freq. for reference year ($N_{p,w,x,sv,fi,r}$), crashes/yr:		0.026		0.008		0.060		0.028		0.038	
Equivalent years associated with crash count ($C_{b,w,x,sv,fi,r}$), yr:		3.020		3.021		2.992		3.020		3.020	
Expected average crash freq. for reference year given N^*_o ($N_{a,w,x,sv,fi,r}$), crashes/yr:		0.024		0.008		0.046		0.044		0.035	
Expected average crash frequency ($N_{e,w,x,sv,fi}$), crashes/yr:	2008	0.024		0.008		0.046		0.044		0.035	
	2009	0.024		0.008		0.046		0.044		0.035	
	2010	0.025		0.008		0.045		0.045		0.035	
	2011										
	2012										
	2013		0.026		0.009		0.044		0.047		0.037
	2014		0.027		0.009		0.044		0.048		0.038
	2015		0.028		0.009		0.043		0.049		0.038

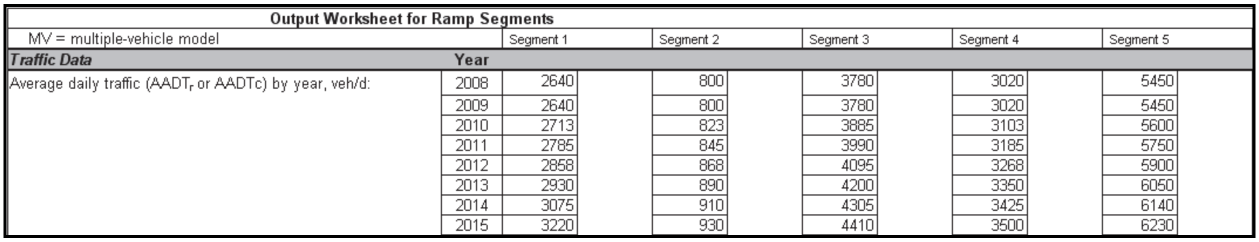
Figure 84. A4: Output Ramp Segments Worksheet—Expected FI Crash Frequency



Output Worksheet for Ramp Segments											
MV = multiple-vehicle model SV = single-vehicle model		Segment 1		Segment 2		Segment 3		Segment 4		Segment 5	
	Applicable Models	Crash Period	Study Period	Crash Period	Study Period	Crash Period	Study Period	Crash Period	Study Period	Crash Period	Study Period
Crash Severity Distribution (during Study Period)											
Fatal crash frequency ($N^*_{e,w,x,at,K}$), crashes:			0.003		0.001		0.007		0.005		0.005
Incapacitating injury crash freq. ($N^*_{e,w,x,at,A}$), crashes:			0.010		0.003		0.020		0.014		0.015
Non-incapacitating inj. crash freq. ($N^*_{e,w,x,at,B}$), crashes			0.063		0.021		0.135		0.091		0.096
Possible injury crash freq. ($N^*_{e,w,x,at,C}$), crashes:			0.076		0.027		0.231		0.111		0.117
Total fatal-and-injury crash freq. ($N^*_{e,w,x,at,fi}$), crashes:			0.152		0.052		0.393		0.220		0.234
Property-damage-only crash freq. ($N^*_{e,w,x,at,pdo}$), crashes:			0.232		0.046		0.861		0.301		0.303
Total crash frequency ($N^*_{e,w,x,at,as}$), crashes:			0.384		0.099		1.254		0.522		0.537

Figure 85. A4: Output Ramp Segments Worksheet—Crash Severity Distribution

The traffic data calculations for the C-D road segments are shown in Figure 86. The AADT volume estimates that were entered in the Input Ramp Segments worksheet for the years 2009, 2013, and 2015 are repeated in this section of the Output Ramp Segments worksheet. The computed volume estimates for the other years are also shown. These estimates were determined using the rules described in the section titled Analysis Steps.

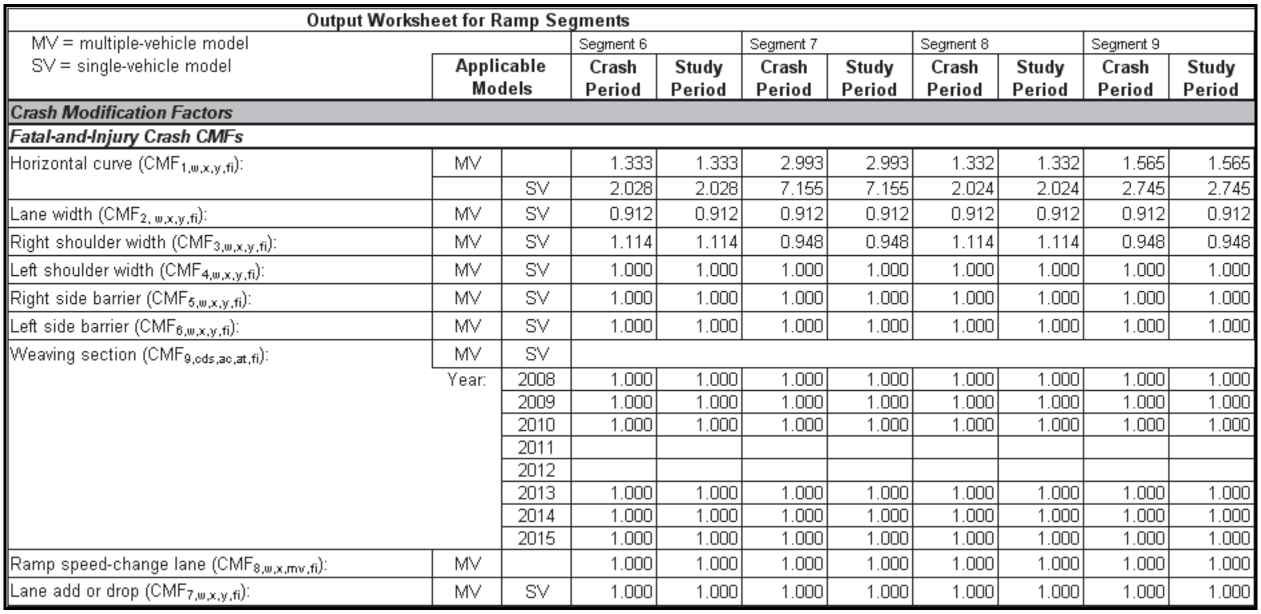


Output Worksheet for Ramp Segments						
MV = multiple-vehicle model		Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
Traffic Data	**Year**					
Average daily traffic (AADT_r or AADTc) by year, veh/d:	2008	2640	800	3780	3020	5450
	2009	2640	800	3780	3020	5450
	2010	2713	823	3885	3103	5600
	2011	2785	845	3990	3185	5750
	2012	2858	868	4095	3268	5900
	2013	2930	890	4200	3350	6050
	2014	3075	910	4305	3425	6140
	2015	3220	930	4410	3500	6230

Figure 86. A4: Output Ramp Segments Worksheet—Traffic Data

Ramp Segments

The computed CMF values for FI crashes on the ramp segments are provided in Figure 87. Inspection of the CMF values reveals that horizontal curvature on the loop ramps is associated with relatively high crash risk. On the other hand, the 16-ft lane width tends to reduce crash risk, relative to ramps with narrower lanes.

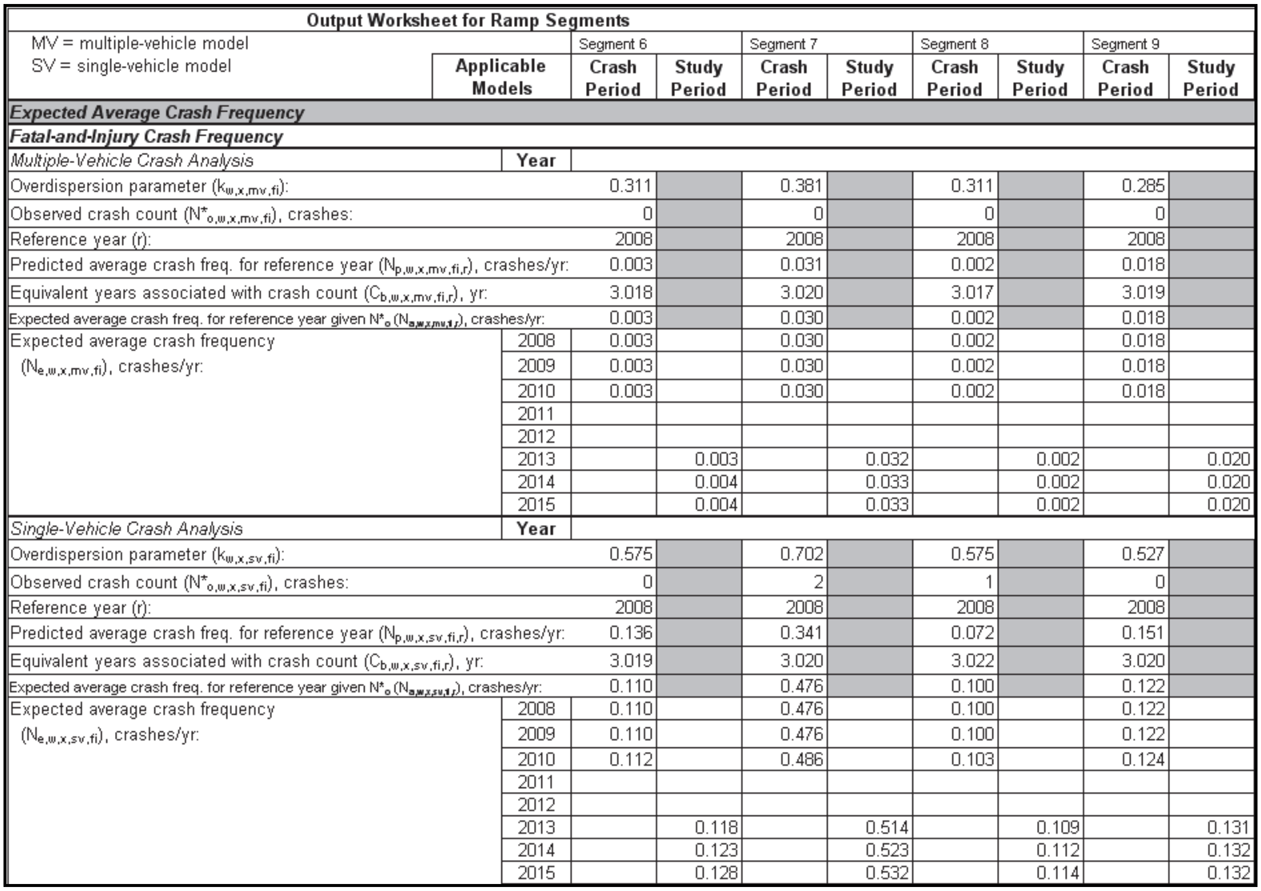


Output Worksheet for Ramp Segments										
MV = multiple-vehicle model			Segment 6		Segment 7		Segment 8		Segment 9	
SV = single-vehicle model	**Applicable Models**		**Crash Period**	**Study Period**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**
Crash Modification Factors										
Fatal-and-Injury Crash CMFs										
Horizontal curve ($\text{CMF}_{1,w,x,y,fi}$):	MV		1.333	1.333	2.993	2.993	1.332	1.332	1.565	1.565
		SV	2.028	2.028	7.155	7.155	2.024	2.024	2.745	2.745
Lane width ($\text{CMF}_{2,w,x,y,fi}$):	MV	SV	0.912	0.912	0.912	0.912	0.912	0.912	0.912	0.912
Right shoulder width ($\text{CMF}_{3,w,x,y,fi}$):	MV	SV	1.114	1.114	0.948	0.948	1.114	1.114	0.948	0.948
Left shoulder width ($\text{CMF}_{4,w,x,y,fi}$):	MV	SV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Right side barrier ($\text{CMF}_{5,w,x,y,fi}$):	MV	SV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Left side barrier ($\text{CMF}_{6,w,x,y,fi}$):	MV	SV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Weaving section ($\text{CMF}_{9,cds,ac,at,fi}$):	MV	SV								
	Year:	2008	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
		2009	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
		2010	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
		2011								
		2012								
		2013	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
		2014	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
		2015	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Ramp speed-change lane ($\text{CMF}_{8,w,x,mv,fi}$):	MV		1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Lane add or drop ($\text{CMF}_{7,w,x,y,fi}$):	MV	SV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Figure 87. A4: Output Ramp Segments Worksheet—CMFs for FI Crashes

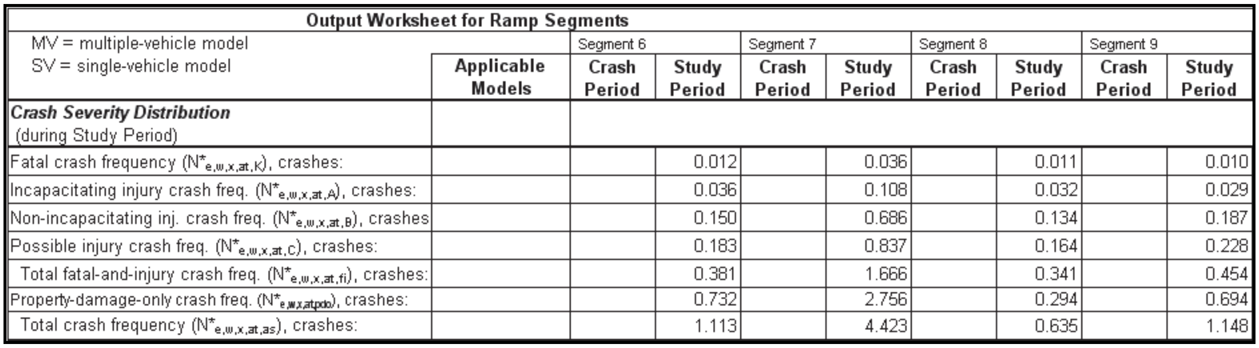
The expected average crash frequency calculations for FI crashes on the ramp segments are shown in Figure 88. The EB Method is used in this application so rows relating to these calculations are shown, starting with the overdispersion parameter. For multiple-vehicle crash calculations, there are three rows of crash estimates for the crash period (i.e., years 2008 to 2010) and three rows of crash estimates for the study period (i.e., years 2013 to 2015). This pattern is repeated for the single-vehicle crash frequency calculations. Unused rows for additional years are omitted from the figure.

The crash severity distribution calculations for the ramp segments are shown in Figure 89. These calculations are shown in the worksheet rows located just below the rows that show the expected average crash frequency. The estimated number of crashes are given for each segment and aggregated for the entire study period.



Output Worksheet for Ramp Segments									
MV = multiple-vehicle model		Segment 6		Segment 7		Segment 8		Segment 9	
SV = single-vehicle model	**Applicable Models**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**
Expected Average Crash Frequency									
Fatal-and-Injury Crash Frequency									
Multiple-Vehicle Crash Analysis	**Year**								
Overdispersion parameter ($k_{w,x,mv,fi}$):		0.311		0.381		0.311		0.285	
Observed crash count ($N^*_{o,w,x,mv,fi}$), crashes:		0		0		0		0	
Reference year (r):		2008		2008		2008		2008	
Predicted average crash freq. for reference year ($N_{p,w,x,mv,fi,r}$), crashes/yr:		0.003		0.031		0.002		0.018	
Equivalent years associated with crash count ($C_{b,w,x,mv,fi,r}$), yr:		3.018		3.020		3.017		3.019	
Expected average crash freq. for reference year given N^*_o ($N_{a,w,x,mv,fi,r}$), crashes/yr:		0.003		0.030		0.002		0.018	
Expected average crash frequency ($N_{e,w,x,mv,fi}$), crashes/yr:	2008	0.003		0.030		0.002		0.018	
	2009	0.003		0.030		0.002		0.018	
	2010	0.003		0.030		0.002		0.018	
	2011								
	2012								
	2013		0.003		0.032		0.002		0.020
	2014		0.004		0.033		0.002		0.020
	2015		0.004		0.033		0.002		0.020
Single-Vehicle Crash Analysis	**Year**								
Overdispersion parameter ($k_{w,x,sv,fi}$):		0.575		0.702		0.575		0.527	
Observed crash count ($N^*_{o,w,x,sv,fi}$), crashes:		0		2		1		0	
Reference year (r):		2008		2008		2008		2008	
Predicted average crash freq. for reference year ($N_{p,w,x,sv,fi,r}$), crashes/yr:		0.136		0.341		0.072		0.151	
Equivalent years associated with crash count ($C_{b,w,x,sv,fi,r}$), yr:		3.019		3.020		3.022		3.020	
Expected average crash freq. for reference year given N^*_o ($N_{a,w,x,sv,fi,r}$), crashes/yr:		0.110		0.476		0.100		0.122	
Expected average crash frequency ($N_{e,w,x,sv,fi}$), crashes/yr:	2008	0.110		0.476		0.100		0.122	
	2009	0.110		0.476		0.100		0.122	
	2010	0.112		0.486		0.103		0.124	
	2011								
	2012								
	2013		0.118		0.514		0.109		0.131
	2014		0.123		0.523		0.112		0.132
	2015		0.128		0.532		0.114		0.132

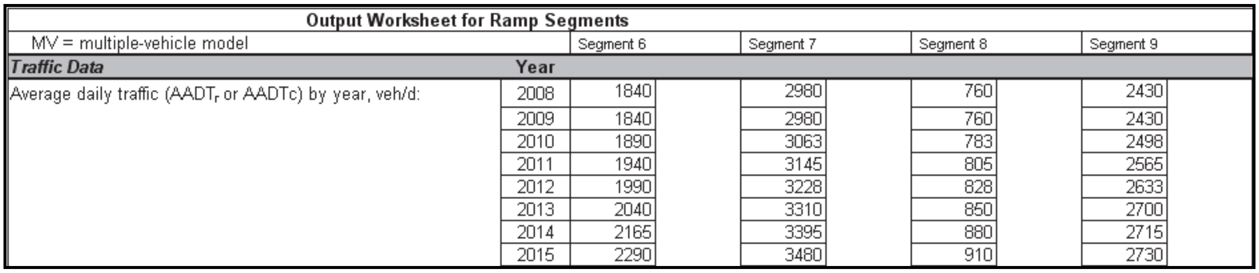
Figure 88. A4: Output Ramp Segments Worksheet—Expected FI Crash Frequency



Output Worksheet for Ramp Segments									
MV = multiple-vehicle model		Segment 6		Segment 7		Segment 8		Segment 9	
SV = single-vehicle model	**Applicable Models**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**	**Crash Period**	**Study Period**
Crash Severity Distribution (during Study Period)									
Fatal crash frequency ($N^*_{e,w,x,at,K}$), crashes:			0.012		0.036		0.011		0.010
Incapacitating injury crash freq. ($N^*_{e,w,x,at,A}$), crashes:			0.036		0.108		0.032		0.029
Non-incapacitating inj. crash freq. ($N^*_{e,w,x,at,B}$), crashes			0.150		0.686		0.134		0.187
Possible injury crash freq. ($N^*_{e,w,x,at,C}$), crashes:			0.183		0.837		0.164		0.228
Total fatal-and-injury crash freq. ($N^*_{e,w,x,at,fi}$), crashes:			0.381		1.666		0.341		0.454
Property-damage-only crash freq. ($N^*_{e,w,x,at,pdo}$), crashes:			0.732		2.756		0.294		0.694
Total crash frequency ($N^*_{e,w,x,at,as}$), crashes:			1.113		4.423		0.635		1.148

Figure 89. A4: Output Ramp Segments Worksheet—Crash Severity Distribution

The traffic data calculations for the ramp segments are shown in Figure 90. The AADT volume estimates that were entered in the Input Ramp Segments worksheet for the years 2009, 2013, and 2015 are repeated in this section of the Output Ramp Segments worksheet. The computed volume estimates for the other years are also shown. These estimates were determined using the rules described in the section titled Analysis Steps.



Output Worksheet for Ramp Segments

MV = multiple-vehicle model		Segment 6	Segment 7	Segment 8	Segment 9
Traffic Data	**Year**				
Average daily traffic ($AADT_r$ or AADTc) by year, veh/d:	2008	1840	2980	760	2430
	2009	1840	2980	760	2430
	2010	1890	3063	783	2498
	2011	1940	3145	805	2565
	2012	1990	3228	828	2633
	2013	2040	3310	850	2700
	2014	2165	3395	880	2715
	2015	2290	3480	910	2730

Figure 90. A4: Output Ramp Segments Worksheet—Traffic Data

Results

Portions of a full cloverleaf interchange consisting of four ramp segments and five C-D road segments were analyzed for a three-year study period. The total expected average crash frequency (shown in Figure 82) was found to be about 3.4 crashes per year, or 10.1 crashes during the study period. Of these, about 80 percent are expected to be single-vehicle crashes. The entrance loop ramp has the highest crash frequency. However, all of the ramp curves are somewhat sharp for the estimated ramp speeds. The weaving section on the C-D road is associated with a notably high crash risk, relative to the other C-D road segments.