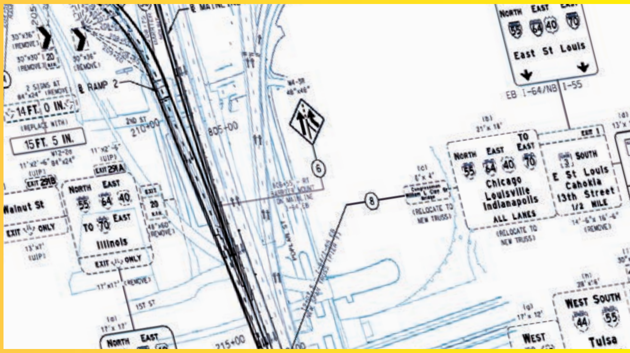
Scale and Scope of Safety Assessment Methods in the Project Development Process



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16. Abstract This document is intended to help users identify and apply suitable methods to assess quantitatively the safety performance impacts of project development decisions in terms of crash frequency and severity. This Guide suggests safety assessment methods that may be suitable for answering safety performance related questions that typically arise during each phase of the development process and for projects of various types. It also provides examples that illustrate the thought process for selecting a safety assessment method. This information on safety performance can then be considered in concert with other project criteria to make more informed highway investment decisions.			
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SI* (MODERN METRIC) CONVERSION FACTORS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
APPROXIMATE CONVERSIONS TO SI UNITS				
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.0305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectacres	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME (Note: Volumes greater than 1000 L shall be shown in m^3)				
fl oz	fluid ounces	29.57	millileters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
k	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yard	yd^2
ha	hectacres	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	millileters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsuis	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of American Society for Testing and Materials E380.

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List of Abbreviations and Acronyms

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	average daily traffic
B/C	benefit/cost
CMF	Crash Modification Factor
DOT	department of transportation
EB	Empirical Bayes
EPDO	equivalent property damage only
FAQ	frequently asked questions
FHWA	Federal Highway Administration
FI	fatal and injury
HSM	Highway Safety Manual
IHSDM	Interactive Highway Safety Design Model
ISATe	Enhanced Interchange Safety Analysis Tool
ITE	Institute of Transportation Engineers
LOSS	level of service of safety
MP	mile post
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
PDO	property damage only
S.E.	standard error
SPF	Safety Performance Function
vpd	vehicles per day

CHAPTER 1. INTRODUCTION

Safety is a key consideration in many project development decisions. Project development professionals—who include planners, designers, analysts, safety and operations specialists, managers, or others—can use a variety of safety assessment methods to inform, justify, and defend these decisions. These professionals are the target audience for this informational guide.

A relatively new safety resource, the *Highway Safety Manual* (HSM), is the motivation for this *Scale and Scope of Safety Assessment Methods in the Project Development Process* guide (Guide). The American Association of State Highway and Transportation Officials (AASHTO) published the first edition of the HSM in 2010. The HSM describes itself as:

> …a resource that provides safety knowledge and tools in a useful form to facilitate improved decision making based on safety performance. The focus of the HSM is to provide quantitative information for decision making. The HSM assembles currently available information and methodologies on measuring, estimating and evaluating roadways in terms of crash frequency (number of crashes per year) and crash severity (level of injuries due to crashes). The HSM presents tools and methodologies for consideration of "safety" across the range of highway activities: planning, programming, project development, construction, operations, and maintenance. The purpose is to convey present knowledge regarding highway safety information for use by a broad array of transportation professionals.[1]

This purpose of this Guide is to help transportation professionals select suitable safety assessment methods at each step of the project development processes.

In many States, project development professionals are still on the learning curve of *when* and *how* they can make effective use of the methods in the HSM. The purpose of the Guide is to help transportation professionals select safety assessment methods suitable at each step in their project development processes.

1.1 Overview of the Project Development Process

Transportation agencies differ in how they characterize the project development process, the phases in the process, and the functions performed in each phase. This section, therefore, describes the generalized process used in this Guide so that professionals can relate it to their own agency's approach. Figure 1 illustrates the process within the broader context of the overall project life cycle.

1 The American Association of State Highway and Transportation Officials. ***Highway Safety Manual, 1st Edition.*** 2010

1.1.1 Project Development Activity Organization

As noted in Figure 1, the overall project life cycle encompasses system planning and programming, project development, construction, and maintenance and operation activities. The project development process generally includes activities associated with planning and scoping, alternatives analysis, environmental analysis, and preliminary and final design of an individual project. Many of these activities can directly benefit from safety assessment methods described in the HSM. These are discussed in greater detail in chapters 2 through 4.

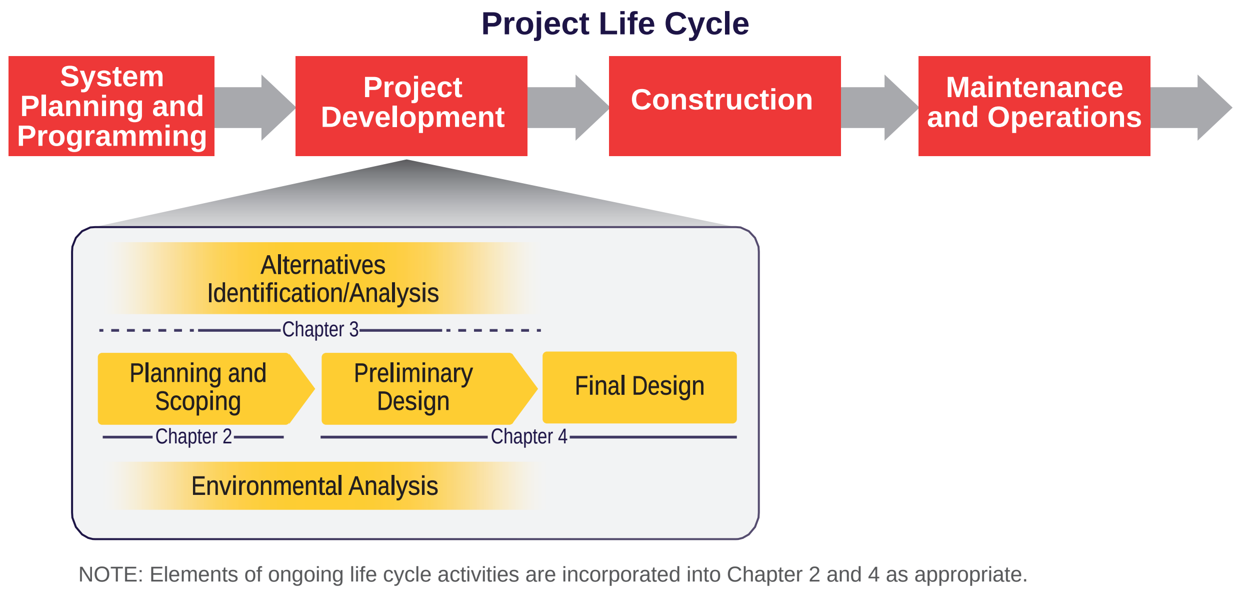

Figure 1. Project Development Phases and Corresponding Chapter Organization

1.1.2 Integrating Safety into the Project Development Process

Several existing documents provide concepts for integrating safety into the project development process. For example:

- The Federal Highway Administration's (FHWA's) *Integrating Road Safety into NEPA Analysis: A Practitioner's Primer*[2] provides basic information to help practitioners get started in understanding how to improve consideration of safety in NEPA [National Environmental Policy Act] analysis.
- FHWA's *Integrating the HSM into the Highway Project Development Process*[3] provides general concepts and a few examples of how the HSM can be used in the process.

This Guide focuses on selection of suitable safety assessment methods for the following project development phases:

- Planning and scoping,
- Alternatives identification and analysis,
- Preliminary design, and
- Final design.

2 Federal Highway Administration, *Integrating Road Safety into NEPA Analysis: A Practitioner's Primer.* Publication No. FHWA-SA-11-37. June 2011. Available at: http://safety.fhwa.dot.gov/p/fhwasa1137/.

3 Federal Highway Administration, *Integrating the HSM into the Highway Project Development Process*. Publication No. FHWA-SA-11-50. May 2012. Available at: http://safety.fhwa.dot.gov/hsm/hsm_integration/.

- ITE's *Integration of Safety in the Project Development Process and Beyond: A Context Sensitive Approach*[4] provides additional details on how to integrate safety into the project development process (using tools like the HSM) and presents 12 case studies illustrating how these concepts and tools have been applied to real-world projects.

As noted above, this document is an information guide; that is, it provides information intended to help users identify and apply suitable methods for qualitatively assessing the safety performance impacts of project development decisions in terms of crash frequency and severity. This Guide suggests safety assessment methods that may be suitable for answering questions related to safety performance that typically arise during each phase of the development process and for projects of various types. It also provides examples that illustrate the thought process for selecting a safety assessment method. This information on safety performance can then be considered in concert with other project criteria to make more informed highway investment decisions.

1.2 Safety Assessment Methods for Varying Project Applications

Recently developed methods included in the HSM can estimate safety performance based upon road characteristic and traffic volume information in combination with or in lieu of observed crash information. These methods may provide a more reliable basis for estimating an existing or proposed facility's safety performance than assessments that consider only crash history.

> The alternative safety assessment methods illustrated in this Guide can provide more statistically reliable estimates of a facility's future safety performance as compared to crash history alone.

1.2.1 Foundational Elements for Safety Assessment Methods

The safety assessment methods described in the HSM and presented in this Guide use one or more of the following basic "foundational elements":

- Observed crashes,
- Crash modification factors/functions, and
- Safety performance functions.

Observed crashes refer to one or more years of crash history for a location. Safety assessments that focus on observed crashes can provide meaningful information for existing facilities.

A **crash modification factor (CMF)** is a measure of the safety effectiveness for a particular roadway treatment or design element. For example, a CMF value of 0.85 would suggest that the presence of that treatment or element would result in a 15 percent decrease in crashes. A CMF value of 1.0 suggests that a particular feature would have no effect on the number of crashes.

There are CMFs for a wide variety of roadway treatments and alternative design element dimensions. These CMFs are available in Part D (Volume 3) of the HSM, at the Crash Modification Factors Clearinghouse (www.cmfclearinghouse.org), or in State-specific guidelines in which some State departments of transportation have customized CMFs for their regional conditions. Each CMF is uniquely defined by associated base conditions, road type, and crash type.

4 Institute of Transportation Engineers, ***Integration of Safety in the Project Development Process and Beyond: A Context Sensitive Approach***. May 2015. Available at: http://library.ite.org/pub/e4edb88b-bafd-b6c9-6a19-22e98fedc8a9.

A **safety performance function (SPF)** is a statistically derived equation that estimates (or *predicts*) the average number of crashes per year likely to occur on a roadway of a particular type (e.g., two-way two-lane roadways or urban arterials) with a particular traffic volume. Using SPFs can enhance a safety assessment method's predictive reliability by taking advantage of crash information for other similar roadways and not relying solely on recent crash history for the specific roadway to be treated.

When site-specific geometric conditions are known, CMFs can be used with SPFs to provide more refined insights into the predicted safety performance (resulting in a calculated *predicted* number of crashes for roadways with similar conditions). Similar to CMFs, States may also customize SPFs to reflect local conditions.

Combining *observed* crash data with *predicted* crash values (calculated using the CMF and SPF combination) can further improve the predictive reliability of crash prediction methods for a specific location (resulting in a calculated *expected* number of crashes).

In summary, the three levels of analysis presented in the HSM are *observed, predicted*, and *expected*:

Observed: Historical crash data for a location will tend to fluctuate over time, but an average (or mean) value can be calculated. These average crash values are referred to as observed crashes.

Three Common Levels of Analysis

- Observed Crashes
- Predicted Crashes
- Expected Crashes

Predicted: Additional information from similar facilities and for similar volumes is likely to strengthen the estimated prediction by considering more crashes and to result in a more reliable estimate of the average number of crashes. This additional information can also include crash trends for varying traffic volumes and road geometry (presented in the format of SPFs and CMFs). This type of data strengthens the estimate for typical roads with the varying volumes and geometry and so is referred to as **predicted crashes**.

Expected: Weighting the site-specific crashes with the crash estimates for similar roads further improves the reliability for predicted crashes. The HSM refers to these estimates as *expected crashes*.

1.2.2 Candidate Safety Assessment Methods

Safety assessment methods that use the three foundational elements, identified in Section 1.2.1, can be generally categorized as basic, intermediate, and advanced.

- The **basic safety assessment methods** evaluate observed crashes and/or use CMFs related to the observed crashes. The basic methods introduced in this Guide include:
    - *Site Evaluation or Audit*
    - *Historical Crash Data Evaluation*
    - *CMF Applied to Observed Crashes*
    - *CMF Relative Comparison*
- **Intermediate safety assessment method**s include the use of SPFs and generally result in more reliable predictions of the average number of crashes. The intermediate methods introduced in this Guide include:
    - *AADT-only SPF*
    - *SPF with CMF Adjustment*

- **Advanced safety assessment methods** include all three foundational elements and generally result in the most reliable predictions for estimates of the expected average number of crashes. The advanced safety assessment method introduced in this Guide is:
  - *SPF with CMF Weighted with Observed Crashes.*

Table 1. Primary Analysis Application for Safety Assessment Methods

Application	Basic				Intermediate		Advanced
	Site Evaluation or Audit	Historical Crash Data Evaluation	CMFApplied to Observed Crashes	CMF Relative Comparison	AADT-Only SPF	SPF with CMF Adjustment	SPF with CMF Weighted with Observed Crashes
	Observed Crashes				*Predicted Crashes*		*Expected Crashes*
Performance of an Existing Road	1	1, 2	1, 2, 3	1, 3	1, 4	1, 3, 4	1, 2, 3, 4
Future Impact of Minor Geometric Changes to Existing Road			1, 2, 3	1, 3		1, 3, 4	1, 2, 3, 4
Future Impact of Major Geometric Changes to Existing Road						1, 3, 4	
Future Performance for a New Facility					1, 4	1, 3, 4	

Note: AADT = average annual daily traffic. CMF = crash modification factor. SPF = safety performance function.
Basis for Analysis: 1 = site characteristics, 2 = crash history, 3 = CMF values, and 4 = AADT.

Table 1 shows, at a glance, the typical analysis application for which these safety assessment methods are best suited. For many years, transportation professionals evaluated safety performance based on observed (i.e., historical) crash frequencies or crash rates. Although observed crashes can be very relevant and useful in evaluating the recent safety performance on existing facilities, they become less relevant and useful in estimating the future safety performance of existing facilities when traffic conditions on those facilities change significantly and/or when projects make substantial design changes to those facilities. Observed crashes may be of limited or no relevance for project alternatives that substantially change the type and character of the roadway or for facilities on new locations. There is a need, therefore, to select the appropriate safety assessment method or methods for the unique project development task. The following descriptions briefly introduce these individual methods.

Basic Methods (Observed Crashes)

The four basic safety assessment methods presented in this Guide can be used for evaluating observed crash conditions or for comparing prospective roadway features. Often, practitioners use basic methods for smaller-scale projects at existing locations. These four methods are:

Site evaluation or audit – Safety assessment and diagnosis for existing facilities may include a field review of site conditions. A typical site evaluation or audit focuses on (1) identifying site characteristics, (2) observing traffic operations and user interactions, and (3) evaluating potential site features that may contribute to a crash. Example information that may be documented during the evaluation includes site geometric characteristics; traffic control devices; heavy truck, motor vehicle, pedestrian, and bicycle volumes; unusual site features; and any potential elements of the road that may suggest a safety concern. The subsequent evaluation includes a diagnostic component to identify opportunities to eliminate or mitigate potential safety concerns at the site. The use of historic crash data, when available, further enhances the evaluation.

HSM Reference: Sections 5.3 and 5.4

Additional Resources: FHWA Road Safety Audit website, http://safety.fhwa.dot.gov/rsa

Historical crash data evaluation – The evaluation of the crashes, typically for a period of 3 to 5 years, can provide meaningful information about crashes with specific information regarding crash trends over time, including those related to crash types and severity. While this evaluation period is typical, if conditions (e.g., roadway, traffic volumes/patterns, adjacent development, and access) have not changed considerably, evaluating additional years of data can more clearly reveal locations with potential geometric issues. This method applies to existing sites and requires observed crash data. Knowledge of the road type and road characteristics can provide additional valuable information for practitioners using this method.

HSM Reference: Section 5.2

Additional Resources: ITE *Traffic Engineering Handbook*, 7th Edition, pp. 131 - 145

CMF applied to observed crashes – One of the simplest safety assessment methods is to adjust the observed number of crashes for a given site/corridor by a percent increase or decrease based on proposed changes to roadway characteristics. The number of observed crashes multiplied by a CMF that represents a potential change in a road characteristic can provide information about how the change may help to reduce the number of crashes. This method applies to existing sites that are candidates for roadway improvement projects and requires observed crash data and CMFs that represent the recommended change for the specific road type and road characteristics.

HSM Reference: Sections C.6.3 and/or C.7, Section D.4, Method 4

Additional Resources: CMFs in Practice Series (FHWA-SA-13-010 through 016), http://safety.fhwa.dot.gov/tools/crf/resources/cmfs/

CMF relative comparison – In some cases, the historic crash data is not always available for a site. If a potential improvement project is being considered, one option is to compare CMFs with similar base conditions in order to help determine the appropriate roadway characteristics. This CMF comparison approach can be accomplished without the use of observed crash data.

HSM Reference: Section D.4

Additional Resources: CMFs in Practice Series (FHWA-SA-13-010 through 016), http://safety.fhwa.dot.gov/tools/crf/resources/cmfs/

Intermediate Methods (Predicted Crashes)

Two intermediate safety assessment methods also incorporate traffic volume into the analysis and, therefore, can be used to predict current and future crashes for a road type with specific characteristics. This procedure also incorporates a calibration factor that allows the SPFs to be further adjusted for local conditions. These two methods are:

AADT-only SPF – An SPF that is based only on traffic volume can be used for larger-scale system-wide evaluations or for locations with similar base condition road characteristics. This method applies to existing or proposed facility types and requires traffic volume information for a specific road type.

HSM Reference: Part C, Volume 2

Additional Resources: CMFs in Practice Series (FHWA-SA-13-010 through 016), http://safety.fhwa.dot.gov/tools/crf/resources/cmfs/

SPF with CMF adjustment – An SPF combined with CMF adjustments can be used to evaluate unique roadway configurations that differ from common (base) conditions. This method applies to existing or proposed facility types and requires traffic volume information as well as the varying road characteristic information for the specific road type. For some States, multivariate models can be an alternative to SPFs with CMF adjustments.

HSM Reference: Section C.7, Methods 1, 2, and 3

Additional Resources: CMFs in Practice Series (FHWA-SA-13-010 through 016), http://safety.fhwa.dot.gov/tools/crf/resources/cmfs/

Advanced Method (Expected Crashes)

The following advanced method can be used for projects with traffic volume information and observed crash data for a specific existing location.

SPF with CMF weighted with observed crashes – The predicted number of crashes identified using the SPF with CMF adjustment method for a facility type can be weighted with observed crashes to provide a more statistically reliable method for estimating expected crashes at a particular location. This technique, referred to as the Empirical Bayes or EB method, is simply a weighting of observed and predicted crashes. This method is considered the most statistically reliable of the seven safety assessment methods because it takes advantage of both information about observed crashes at the location in question and information on predicted crashes based upon crash experience at other similar sites.

HSM Reference: Section A.2, Part C, Volume 3, pp. A-15 to A-23

Additional Resources: *Observational Before-After Studies in Road Safety* by Ezra Hauer, Emerald Group Publishing Ltd, UK, 1997

1.3 Selecting Suitable Safety Assessment Methods

The goal of this Guide is to provide information that helps project development professionals select a safety assessment method for their project task. This section introduces the range of safety assessment methods that may be suitable for various project development phases and project types. "Suitable", in this context, means that a method has the capability to answer most of the questions that generally arise using data typically available during that particular project development phase and task for that particular project type.

Table 2 summarizes the safety assessment methods generally suitable for each project development phase. Chapters 2, 3, and 4 provide more detailed companion tables for planning and scoping, alternatives identification and evaluation, and preliminary and final design, respectively.

Table 2. Safety Assessment Methods for Project Phase, Task, and Type

Project Phase	Related Task	Project Type[1]	Safety Assessment Method to Consider		
			Basic	Intermediate	Advanced
Planning and Scoping (Chapter 2)	Preliminary Planning and Needs Assessment	1R, 2R, 3R, 4R, NL	✓		
	Establish Project Purpose and Need	2R	✓		
		3R, 4R	✓	✓	✓
		NL		✓	
	Establish Project Scope	2R	✓		
		3R	✓	✓	
		4R	✓	✓	✓
		NL		✓	
Alternatives Identification and Evaluation (Chapter 3)	Alternative Selection	2R	✓		
		3R, 4R	✓	✓	✓
		NL	✓	✓	
	Interchange Access Justification and Documentation	3R, 4R	✓	✓	✓
		NL		✓	
Preliminary and Final Design (Chapter 4)	Selecting specific design elements and their dimensions	2R	✓		
		3R, 4R	✓	✓	✓
		NL	✓	✓	
	Design Exception	3R, 4R	✓	✓	✓
		NL		✓	
	Value Engineering	4R	✓	✓	✓
		NL		✓	
	Establishing the Work Zone Transportation Management Plan	2R	✓		
		3R, 4R			
		NL			

Note: ✓= suitable safety assessment method. R1 = routine maintenance. R2 = resurfacing existing facilities. R3 = major rehabilitation of an existing facility. R4 = major retrofit construction efforts. NL = highway construction at a new location.

Within each project development phase, several related tasks may benefit from targeted safety assessments. These related tasks, and the safety performance related questions that arise during the execution of the tasks, are the first important considerations in selecting a suitable safety assessment method.

The type of project is a second important consideration in selecting a suitable safety assessment method. The project types shown in Table 2 represent a wide range of construction activities. The project type abbreviations 1R, 2R, 3R, 4R, and NL represent different types of pavement work. Of primary importance to this Guide are the companion design and operational changes typically included in these projects. Table 3 summarizes these project types and the associated design and operational changes that would be the focus of a safety assessment.

Table 3. Example Project Type Descriptions for Safety Assessment Method Identification

Project Type	Example Description
1R	The 1R project type designation is often associated with routine maintenance activities. This type of project could include a pavement overlay, roadside maintenance, or a minor upgrade to existing roadside hardware. For 1R projects, there are very few, if any, new improvements.
2R	The 2R project type designation is generally associated with resurfacing existing facilities or restoring road characteristics that are in need of an upgrade. As part of the 2R project, a limited number of new design or operational changes may be incorporated. These enhancements are minor and do not change the overall character of the facility.
3R	The 3R project type is often associated with major rehabilitation of an existing facility. This could include pavement improvements for the existing road, minor roadway widening, roadside shoulder improvement projects, and construction of select low-cost safety improvements at the site or system-wide level.
4R	The 4R project type includes major retrofit construction efforts including modification of the design to meet geometric criteria standards. This type of project generally includes substantial changes to the character of the road (significant widening, realignment, major operational modifications).
NL	The NL project type indicates constructing a highway at a new location. This type of project has all new construction for the majority of the alignment.

A third important consideration in selecting a suitable safety assessment method is the project data typically available during the project development phase in relation to the data required by the safety assessment method. Table 4 summarizes the general types of data needed for the seven safety assessment methods identified in this Guide.

Table 4. Data Needs for Safety Assessment Methods

Safety Assessment Method	Data Needs			
	Road Type[1]	Road Characteristics[2]	Traffic Volume[3]	Observed Crash Data[4]
Site Evaluation or Audit	✓	✓		×
Historical Crash Data Evaluation	×	×		✓
CMF Applied to Observed Crashes	✓	✓		✓
CMF Relative Comparison	✓	✓		
AADT-Only SPF	✓		✓	
SPF with CMF Adjustment	✓	✓	✓	
SPF with CMF Weighted with Observed Crashes	✓	✓	✓	✓

[1] Road Type refers to rural two-lane highway, rural multi-lane highway, urban freeway, etc.
[2] Road Characteristics includes physical features such as lane widths, access density, etc.
[3] Traffic Volume is the average daily traffic (ADT) or annual average daily traffic (AADT) in vehicles per day.
[4] Observed Crash Data represents the historic crash data at the study site.
Note: ✓ = required data. × = recommended data

1.4 How to Navigate This Guide

This Guide is organized to align with the individual phases of the project development process. The safety assessment methods described in this Guide can be used for a variety of analyses, but are organized in a format intended to help an analyst easily locate methods most suitable for a given project type, phase, and task. The tables included in this introductory chapter provide an initial introduction to the seven potential safety assessment methods and their common applications, including the range of safety assessment methods generally suitable for project development phases, related tasks, and project types.

Chapters 2, 3, and 4 provide additional information to help make a selection among the range of suitable safety assessment methods for a particular project development phase, related task, and project type. Each chapter begins with an overview of the specific project development phase, including an associated safety assessment method option table (see Table 5, Table 8, and Table 9) that narrows down prospective candidate methods for a related task and project type.

Chapters 2, 3, and 4 also provide examples that illustrate the selection and application of the various methods. Each example begins with a summary header similar to Figure 2. The header identifies the safety assessment method, the project development phase, the related task, and the project type (Table 3). All seven of the safety assessment methods can be hand calculated, but computerized tools are available for the intermediate and advanced methods. Example problems developed using the available computerized tools may, in some cases, have a companion hand-calculated version included in the appendix of the Guide. A note is shown in the calculation method example problem header section that indicates when an alternative hand-calculated version is available. Finally, the example problem header includes a section for comments and level of analysis.

PROBLEM OVERVIEW	
Safety Assessment Method: Historical Crash Data Evaluation	
Project Phase: **Planning & Scoping**	Project Type: **2R**
Related Task: **Establish Project Scope**	**Calculation Method:** ☒ **Hand Calculated** ☐ **Tool Based**
Comments: This example problem demonstrates how to prioritize potential intersection improvements based on crash data.	
LEVEL OF ANALYSIS	
Basic — Intermediate — Advanced	

Figure 2. Example Problem Sample Header

Each example reviews the scope of the problem, notes the data available for the analysis, summarizes how to select the appropriate safety assessment method, identifies linkage to the AASHTO HSM, and provides a detailed analysis. The examples conclude with a summary of findings and interpretation of results, possible errors to avoid, and alternative analysis approaches.

To use this Guide, a project development professional with a question related to safety performance can begin by reviewing Table 1 and Table 2 to determine the applicable project development phase and related task. The next step is to go to the Chapter corresponding to that phase:

- Planning and Scoping: Chapter 2,
- Alternatives Identification and Evaluation: Chapter 3, and
- Preliminary and Final Design: Chapter 4.

Within the appropriate chapter, the professional would review the introductory content and associated navigation table (see Table 5, Table 8, and Table 9) to determine candidate safety assessment methods suitable to their task. In many cases, several different assessment methods may be available for a specific project type and phase, but the selection of the analysis method should be based on the practitioner's specific question about safety performance. For example, a basic and an intermediate method may both be candidates under consideration. The analyst should determine the type of analysis appropriate for answering the specific question. Data requirements and availability also often play a major role in narrowing down suitable assessment methods.

The examples presented in this Guide are not intended to cover all project development task phases or potential questions related to safety performance analysis, but rather to demonstrate how an analyst can select a suitable assessment method based on the required level of effort, phase of the project development process, associated type of project, and available data.

1.5 Chapter References

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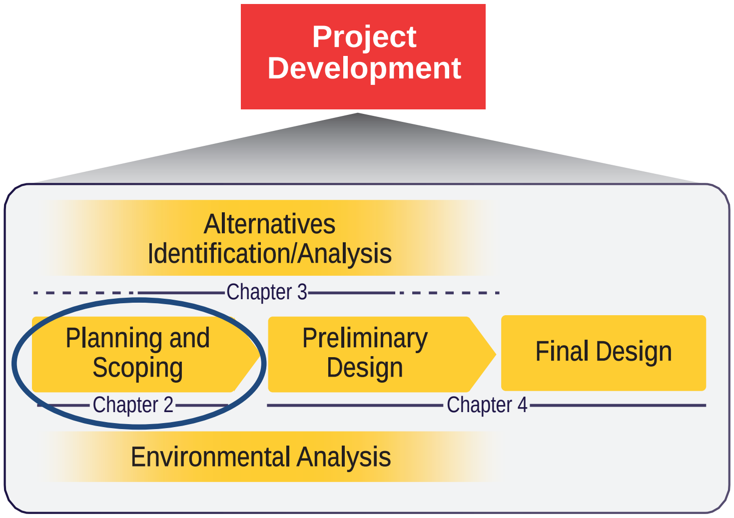
CHAPTER 2. Planning and Scoping Applications



NOTE: Elements of ongoing life cycle activities are incorporated into Chapter 2 and 4 as appropriate

Figure 3. The Project Development Cycle and Corresponding Planning and Scoping Chapter

Planning and scoping activities occur early in the project development process and involve identifying the needs and range of actions, alternatives, and impacts to be addressed as part of the specific project scope. This Guide specifically focuses on project-level (rather than system-level) planning activities.

Common considerations in this project development phase vary based on the type of project and may include operational efficiency, construction cost, right-of-way needs, effects on the human and natural environment, and safety.

This chapter provides information to help practitioners select safety assessment methods suitable for addressing questions about safety performance that arise during planning and scoping based upon the related task and project type. This Guide describes planning- and scoping-related tasks in three general categories:

- Conduct preliminary planning and needs assessment,
- Establish project purpose and need, and
- Establish project scope.

Preliminary planning and needs assessment occurs early in project development and may be part of a corridor or project planning study. The goal of this task is to assess the current and future needs of a transportation facility. As the planning process evolves, the transportation agency will **establish a project purpose and need** where the term "purpose" can generally be defined as what will be addressed and the "need" provides data to support that purpose. Following some level of project planning, the transportation agency can then **establish the project scope**, which often includes identifying and diagnosing opportunities to reduce crashes and then determining potential limits and types of treatments or mitigation strategies.

Table 5 identifies the safety assessment methods generally suitable for tasks related to planning and scoping and the objective of their safety performance analysis. The check marks in Table 5 suggest suitable safety assessment methods for each related task and objective and are, in some cases, distinguished by project type. In this context, the term "suitable" means that the method generally has the capability to address the safety performance related analysis objective with the data typically available for the related task and project type.

The following example questions demonstrate the type of questions the analyst may develop at the beginning of the safety assessment. These questions are based on the example problems included in this chapter.

1. How does the analyst assess where the limited funding could be most effectively spent?
2. What can the analyst do to assess if there is actually a need for safety treatments at this location?
3. How can the analyst estimate the safety performance of previously identified candidate low-cost countermeasures?
4. How can the analyst estimate which curves are functioning as anticipated and which ones could benefit from low-cost treatments?
5. How does the analyst estimate the reduction in the number of fatal and injury crashes due to these potential incremental improvements?

Table 5 shows that the level of predictive reliability generally increases along the spectrum of methods from basic to advanced. At the same time, the required resources for the analysis also will increase. In some cases, it may not be feasible to implement the preferred safety assessment method fully due to limitations in site information, crash data, traffic volume, or similar information. For example, the *Basic* safety assessment method for a *CMF Applied to Observed Crashes* cannot be executed if historic crash data is not available.

The approach for selecting a safety assessment method for planning and scoping looks like this:

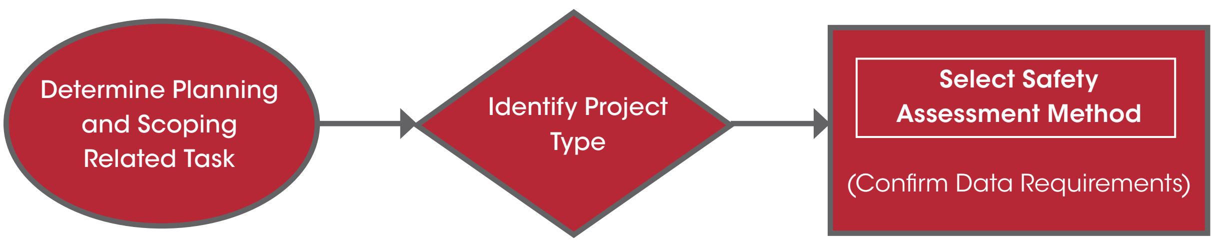


Figure 4. The Approach for Selecting a Safety Assessment Method for Planning and Scoping

A second safety assessment decision is the selection of the appropriate performance measure for the specific study question. In some cases, the performance measure may simply be based on average crash frequency or crash rate for an existing facility. Often, however, the performance measure is used to estimate some future performance (referred to as estimated, predicted, or expected crashes). Table 6 demonstrates several of these potential performance measures and their companion needs.

Table 5. Planning and Scoping Safety Assessment Objective

Related Task	Objective	Project Type	Basic				Intermediate		Advanced
			Site Evaluation or Audit	Historical Crash Data Evaluation	CMF Applied to Observed Crashes	CMF Relative Comparison	AADT Only SPF	SPF with CMF Adjustment	SPF with CMF Weighted with Observed Crashes
			Observed Crashes				Predicted Crashes		Expected Crashes
Safety Assessments:			Increasing Level of Predictive Reliability →						
Preliminary Planning and Needs Assessment	Characterize Existing Safety Performance	All	✓[6]	✓[6]					
Establish Project Purpose and Need	Diagnose Safety Issues the Project Should Address	2R	✓	✓					
		3R, 4R	✓	✓			✓	✓[9]	✓[10]
		NL					✓	✓	
Establish Project Scope	Refine Extent of Project and Safety Assessment Needs	2R	✓	✓[5]	✓[7]	✓[7]			
		3R	✓	✓	✓	✓	✓	✓[8]	
		4R	✓	✓	✓	✓	✓	✓	✓
		NL					✓	✓	
Data Requirements:			Increasing Level of Resources Needed (Staff, Analysis, Time, etc.) →						
Road Type [1]			✓		✓	✓	✓	✓	✓
Road Characteristics [2]			✓		✓	✓		✓	✓
Traffic Volume (vpd) [3]							✓	✓	✓
Observed Crash Data [4]			✓	✓	✓				✓

[1]Road Type refers to rural two-lane highway, rural multi-lane highway, urban freeway, etc. [2]Road Characteristics includes physical features such as lane widths, access density, etc. [3]Traffic Volume is the ADT or AADT in vehicles per day. [4]Observed Crash Data represents the historic crash data at the study site for a period of more than 1 year (preferably 3 to 5 years). [5]See Example Problem 2.1. [6]See Example Problem 2.2. [7]See Example Problem 2.3. [8]See Example Problem 2.4. [9]See Example Problem 2.5. [10]See Example Problem 5.1.

Note: R2 = resurfacing existing facilities. R3 = major rehabilitation of an existing facility. R4 = major retrofit construction efforts. NL = highway construction at a new location.

✓ = suitable safety assessment method. ADT = average daily traffic. AADT = annual average daily traffic.

Table 6. Safety Assessment Performance Measures and Data Needs

Performance Measure	Data Requirements			Other Inputs
	Road Type / Characteristic	Traffic Volume	Observed Crash Data	
Average Crash Frequency	✓		✓	
Crash Rate	✓	✓	✓	
Equivalent Property Damage Only (EPDO) Average Crash Frequency	✓		✓	EPDO Weighting Factors
Relative Severity Index	✓		✓	Relative Severity Indices
Critical Rate	✓	✓	✓	
Excess Predicted Average Crash Frequency Using Method of Moments	✓	✓	✓	
Level of Service of Safety	✓	✓	✓	Calibrated SPF with Overdispersion Parameter
Excess Predicted Average Crash Frequency Using SPFs	✓	✓	✓	Calibrated SPF
Probability of Specific Crash Types Exceeding Threshold Proportion	✓		✓	
Excess Proportion of Specific Crash Types	✓		✓	
Expected Average Crash Frequency with EB Adjustment	✓	✓	✓	Calibrated SPF with Overdispersion Parameter
EPDO Average Crash Frequency with EB Adjustment	✓	✓	✓	Calibrated SPF with Overdispersion Parameter & EPDO Weighting Factors
Excess Expected Average Crash Frequency with EB Adjustment	✓	✓	✓	Calibrated SPF with Overdispersion Parameter

Note: SPF = Safety Performance Function, EB = Empirical Bayes

Source: Adapted from the AASHTO Highway Safety Manual, Table 4-1, p. 4-8.

This chapter provides examples that demonstrate the selection process for the planning and scoping safety assessment methods. These examples are simplified hypothetical problems intended to illustrate the thought process for selecting a method and demonstrate how to apply the method to answer the associated safety question.

2.1 Priority Ranking Urban Signalized Intersections based on Pedestrian Crashes

PROBLEM OVERVIEW

Safety Assessment Method: Historical Crash Data Evaluation

Project Phase: **Planning & Scoping**	Project Type: **2R**
Related Task: **Establish Project Scope**	**Calculation Method:** ☒ **Hand Calculated** ☐ **Tool Based**

Comments:

This example problem demonstrates how to prioritize potential intersection improvements based on crash data.

LEVEL OF ANALYSIS

Basic Intermediate Advanced

Note: See table 3 for a full definition of Project Type designations.

PROBLEM DESCRIPTION

As part of planning and scoping activities, a city has identified six candidate intersections for rehabilitation of pedestrian facilities; however, the city needs to narrow the list to only four of the sites. The associated **Project Type** is 2R and the **Related Task** is to *Establish Project Scope.* The expected improvements will include replacing/widening the sidewalks and installing/updating crosswalks. **How does the analyst assess where the limited funding could be most effectively spent?**

Summary of Available Data:

Table 7 presents a 3-year summary of observed crashes for the six signalized intersections. The sidewalks and crosswalks currently located at the intersections are of similar age and design. Pedestrian and vehicle volumes are unknown. Additional site information can be obtained, if needed, by reviewing aerial photographs or by visiting the six intersection locations.

Table 7. Example Summary of Available Data

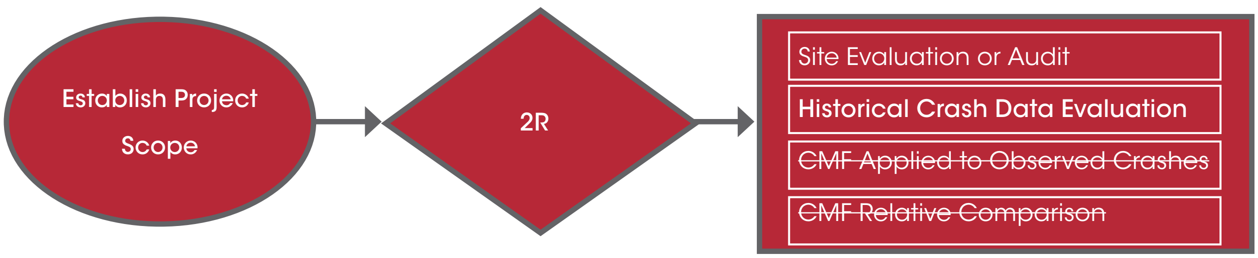
Intersection Number	Number of Crashes (Three Years)		Number of Crashes (Average per Year)	
	K+A* Pedestrian Crashes	Total Crashes	K+A* Pedestrian Crashes	Total Crashes
1	12	144	4	48
2	6	141	2	47
3	12	99	4	33
4	18	99	6	33
5	9	150	3	50
6	12	96	4	32
Average	11.5	121.5	3.8	40.5

*K+A refers to fatal and serious injury crashes.

ANALYSIS

Selecting Appropriate Safety Assessment Method(s):

The analyst can first review the potential safety assessment methods shown in Table 5. The **Establish Project Scope** task and the **2R** project type are associated with one of the four *Basic* safety assessment methods shown in Table 5. Table 1 (see Chapter 1) indicates that an evaluation of existing performance can be accomplished with the *Site Evaluation or Audit* or *Historical Crash Data Evaluation* safety assessment methods. The CMF-based methods require the use of CMF values as key elements of the analysis. Recall that a CMF commonly represents the change in the number of crashes due to varying a road characteristic. The analyst plans to use consistent improvements for the four selected intersections, and so the CMF assessment methods are not informative for this analysis.



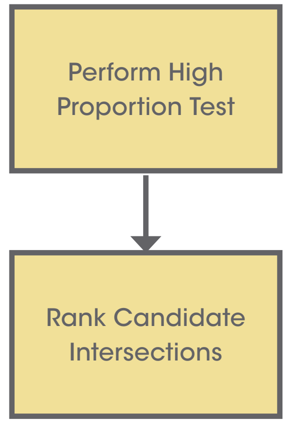
The analyst can narrow down the prospective analysis approach to the remaining two basic safety assessment methods of S*ite Evaluation or Audit* or *Historical Crash Data Evaluation*. A review of the data requirements for the safety assessment methods shown in Table 5 confirms that observed crash data is required or recommended for both assessment methods. In addition, the road type and road characteristics can be considered if a site evaluation is the selected assessment method. The requirements for each of the two assessments are comparable, and the analyst may choose to perform one or both.

Because every intersection is unique and site evaluations or audits can help isolate location-specific issues but may not help to establish priorities, the analyst selected the *Historical Crash Data Evaluation* method for the initial ranking of sites. The *Site Evaluation or Audit* method could then be conducted to reinforce the recommendations resulting from this *Historical Crash Data Evaluation* effort.

Linkage to the Highway Safety Manual (HSM):

The HSM provides a list of potential ranking methods commonly used for network screening purposes. These are summarized in Table 6 (based on HSM Table 4-1, p. 4-8). Several potential performance measures shown in Table 6 may be suitable for this screening, but may also require additional data not available for these sites. Two potentially suitable performance measures are (1) Average Crash Frequency (HSM p. 4-24), and (2) Excess Proportions of Specific Crash Types (HSM p. 4-52). In addition, the HSM includes suggestions for site evaluations if the analyst elects to pursue the additional *Site Evaluation or Audit* assessment method (HSM Chapter 5, pp. 5-1 to 5-24).

Detailed Analysis:



The average crash frequency can be ranked for K+A pedestrian crashes or for total crashes. Because the focus of this analysis is on improved pedestrian facilities and the expectation is to reduce the number of fatal or serious injury pedestrian crashes, evaluating K+A pedestrian crashes is important. In some locations, crash report information for this type of pedestrian crash may be limited. Similarly, a review of total crashes may help further clarify prevailing conditions at the intersection that are not clearly indicated when evaluating K+A pedestrian crashes alone. For these reasons, evaluation of these crashes can be complimented with a safety assessment of total crashes to confirm overall issues that may contribute to the number of crashes at the intersection.

Where possible, the crash frequency method can be applied to locations with similar volumes. The excess proportions of specific crash types method ranks sites based on the proportion of a target crash type—in this case, K+A pedestrian crashes. The following steps summarize these calculations.

STEP 1: Summarize the crash data.

Develop a summary table that includes average K+A pedestrian crashes per year, average total intersection crashes per year, and associated K+A pedestrian proportion of total crashes. A threshold to assess the proportion of the K+A pedestrian crashes at each site would be the total proportion of all K+A pedestrian crashes for the six potential locations.

The threshold proportion is calculated as 23 ÷ 243 = 0.09. Locations with K+A pedestrian proportion of total crash values greater 0.09 merit consideration, based on this performance measure, during the ranking process.

Intersection Number	Average K+A Pedestrian Crashes per Year	Total Intersection Crashes per Year	K+A Pedestrian Proportion of Total Crashes[1]	Ranking by K+A Pedestrian Crash Frequency	Ranking by Total Crash Frequency	Ranking by Proportion
1	4	48	0.08	2	2	4
2	2	47	0.04	6	3	6
3	4	33	0.12	2	4	3
4	6	33	0.18	1	4	1
5	3	50	0.06	5	1	5
6	4	32	0.13	2	6	2
Total:	**23**	**243**	N/A	N/A	N/A	N/A

[1]The proportion of total crashes is calculated by dividing K+A pedestrian crashes by total intersection crashes.

Note: N/A = Not applicable. The threshold proportion of K+A pedestrian crashes (for these 6 sites) is 0.09. Shaded cells represent the top ranked intersections for the specific performance measure.

STEP 2: Assess calculation of variance and probabilities.

The excess proportions ranking method calculations can be expanded to calculate the probability that the K+A pedestrian crashes exceed the threshold proportion. This process requires an additional calculation of a sample variance and the development of a probability to rank the sites that exceeded the threshold proportion. For this analysis, the analyst intends to select four intersections for improvement. Upon inspection, it is notable that only three of the intersections exceed the proportion and so all three will be considered. As a result, the analyst does not elect to compute the additional assessment values that are based on the simple variance.

STEP 3: Select and treat the highest ranked overrepresented sites.

Ranking based on the crash proportion test can be expected to produce different results than when the intersections are ranked by the average frequency of pedestrian crashes only or by total crashes. The shading in the summary table represents the top ranked intersections for each column. The four most critical intersections, based on the K+A Pedestrian Crash Frequency ranking, are Intersections #1, 3, 4, and 6. For intersections based solely on total crashes, Intersections #1, 2, and 5 are ranked the highest. Intersections #3 and 4 tied for fourth place. The ranking based on proportion includes sites where the proportion exceeds the overall threshold proportion value of 0.09 (or 9 percent) for all six intersections. This resulted in identification of Intersections #3, 4, and 6. Though the proportion value did not exceed 0.09, Intersection #1 did rank fourth using this proportion ranking method.

Intersections #1, 3, and 4 may be the clear priorities since they were ranked in the top four for all three ranking methods. The selection of the 4th priority among the remaining intersections boils down to a judgment call between intersections with more total crashes (#1 and 5) versus the intersection with more pedestrian K&A crashes (#6).

FINDINGS

Interpreting the Results:

This simple analysis identified three intersections that have an overrepresented proportion of K+A pedestrian crashes. The intersection rankings based on total crashes provide very different recommendations than rankings based on average K+A pedestrian crashes or their associated proportion. Indications are that the analyst may want to recommend improving Intersections #1, 3, 4, and 6; however, the agency may want to evaluate additional site features (i.e. traffic volume, pedestrian crossing distance, etc.) to further confirm the sites with the greatest potential for K+A pedestrian crash reduction.

Possible Errors to Avoid:

Analysts should guard against making decisions about intersections involving a small number of crashes or using only 1 or 2 years of crash data. For the purposes of an intersection ranking analysis, a small number of crashes can be assumed to be less than 10 total crashes per year. Analysts should use a minimum of 3 years of crash data.

This demonstration included three common ranking methods. All three methods produce different results; therefore, using multiple ranking methods and selecting locations that are highly ranked by more than one ranking procedure will enable practitioners to consider varying dimensions of pedestrian and intersection safety.

Alternative Analysis Approaches:

The focus on evaluating observed K+A pedestrian crashes resulted in the analyst evaluating three performance measures associated with the *Historical Crash Data Evaluation* safety assessment method. If traffic volume information can be acquired, this analysis could be expanded to consider additional performance measures shown in Table 6, such as the crash rate or critical rate measures. As the project shifts from the planning to the design phase, the analyst will assemble more detailed site-specific information. At that time, additional analysis procedures that incorporate CMFs and/or SPFs can strengthen the overall analysis.

2.2 Conducting Site Evaluations Supplemented by Collision Diagrams for an Urban Arterial Intersection

PROBLEM OVERVIEW	
Safety Assessment Method: Site Evaluation or Audit	
Project Phase: **Planning & Scoping**	Project Type: **2R**
Related Task: **Preliminary Planning & Needs Assessment**	**Calculation Method:** ☒ **Hand Calculated** ☐ **Tool Based**
Comments: This example problem demonstrates early project evaluation diagnostics for determining if a need exists.	
LEVEL OF ANALYSIS	
Basic (selected) — Intermediate — Advanced	

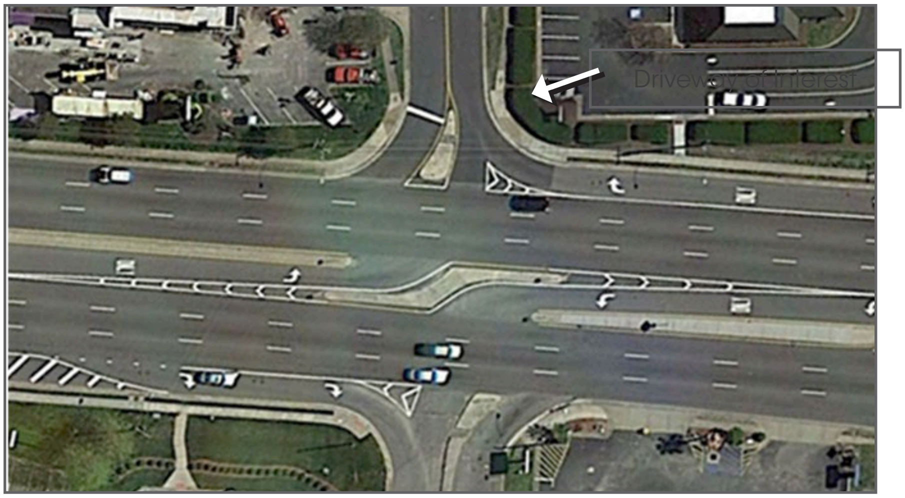
Note: See table 3 for a full definition of Project Type designations.

PROBLEM DESCRIPTION

The city has been asked to determine whether the entrance from an urban arterial to an unsignalized commercial driveway is in need of safety enhancements. In recent years, this location has experienced a number of minor crashes near the driveway entrance. The associated **Project Type** is *2R* and the **Related Task** can be classified as *Preliminary Planning and Needs Assessment.* **What can the analyst do to find out whether there is actually a need for safety treatments at this location?**

Summary of Available Data:

The urban arterial corridor has two-way traffic with a total of six through lanes in the region of the unsignalized driveway, as shown on the following aerial photograph.



Source: ©Google Earth

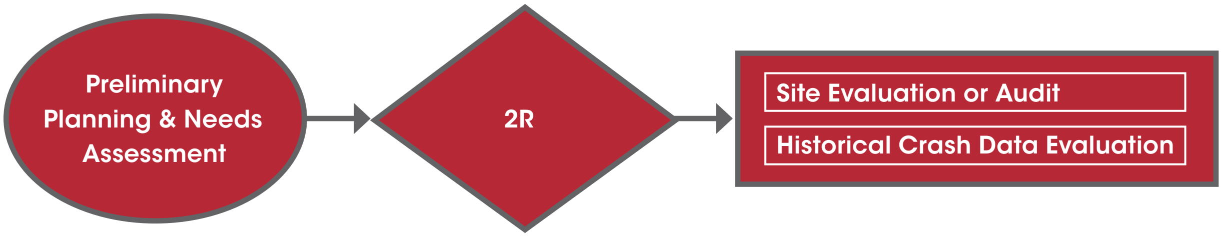
The annual average daily traffic (AADT) for the study corridor (at the driveway location) is 8,400 vpd. The 3-year crash information for this location includes three angle crashes and five rear end crashes for a 3-year total of eight crashes. This information is summarized in the following table.

Mile point	Time/ Date	Direction of Travel for V1, V2, V3	KABCO Severity Level	Maneuver Type	Light Condition	Road Surface Condition	Weather Condition
Angle Crashes:							
19.16	18:18 / 1-17-13	North, West	C	V1: Turning Left V2: Straight	Dusk	Dry	Clear / Cloudy
19.13	07:25 / 3-2-14	North, West	C	V1: Turning Left V2: Straight	Daylight	Wet	Rain
19.11	14:15 / 4-28-12	North, West	C	V1: Turning Left V2: Straight	Daylight	Dry	Clear / Cloudy
Rear End Crashes:							
19.25	12:15 / 8-6-13	West, West	O	V1: Straight V2: Slowing	Daylight	Wet	Rain
19.22	08:06 / 11-18-12	West, West, West	O	V1: Slowing V2: Stopped V3: Stopped	Daylight	Dry	Clear / Cloudy
19.17	00:38 / 10-31-14	East, East	C	V1: Straight V2: Straight	Dark (Lighted)	Dry	Clear / Cloudy
19.18	08:00 / 10-3-13	West, West, West	O	V1: Slowing V2: Stopped V3: Stopped	Daylight	Dry	Clear / Cloudy
19.33	18:50 / 1-30-14	East, East	O	V1: Slowing V2: Stopped	Dark (Lighted)	Dry	Clear / Cloudy
Note: C = Possible Injury. O = Property Damage Only. V1 = Vehicle 1. V2 = Vehicle 2. V3 = Vehicle 3.							

ANALYSIS

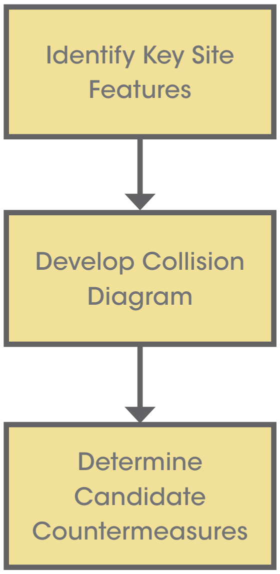
Selecting Appropriate Safety Assessment Method(s):

The analyst should review the prospective safety assessment methods shown in Table 5. Based on the related task and project scope, the analyst can narrow the focus to two prospective safety assessment methods to consider: *Site Evaluation or Audit or Historical Crash Data Evaluation*. Based on Table 1 (see Chapter 1), both of these options are viable analysis techniques for evaluating existing performance.



The analyst notes that a *Site Evaluation* or *Audit* will allow an inspection of visual crash trends or vehicle conflicts that could provide useful information. The *Historical Crash Data Evaluation* can also provide valuable insights. Both safety assessment methods are applicable and can provide useful information using similar data requirements. The analyst elects to conduct the *Historical Crash Data Evaluation* by developing a collision diagram prior to the site visit. The analyst also selects the *Site Evaluation* or *Audit method*.

Linkage to the HSM:



Chapter 5 of the HSM addresses options for summarizing crashes by location (HSM Section 5.2.2, pp. 5-4 to 5-7). An example diagram is shown in HSM Figure 5-3 (p. 5-5). If the site evaluation highlights an issue that may be contributing to crashes at the site, the analyst can refer to Chapter 6 of the HSM (pp. 6-3 to 6-9) for help identify specific contributing factors. During subsequent stages of the project development process, the personnel may have a need to explore and select potential countermeasures presented in the HSM Part D (Volume 3) or available on the FHWA-sponsored CMF Clearinghouse (www.cmfclearinghouse.org).

In addition, the HSM provides a list of potential performance measures and their associated data needs that can be considered if the analyst ultimately conducts the *Historical Crash Data Evaluation* method. These are summarized in Table 6 (based on HSM Table 4-1, p. 4-8). A suitable performance measure for this study is the Critical Rate method (HSM p. 4-11).

Detailed Analysis:

A first step in conducting a site evaluation is to use collision diagrams to diagnose potential safety issues and prevailing crash types at a location.

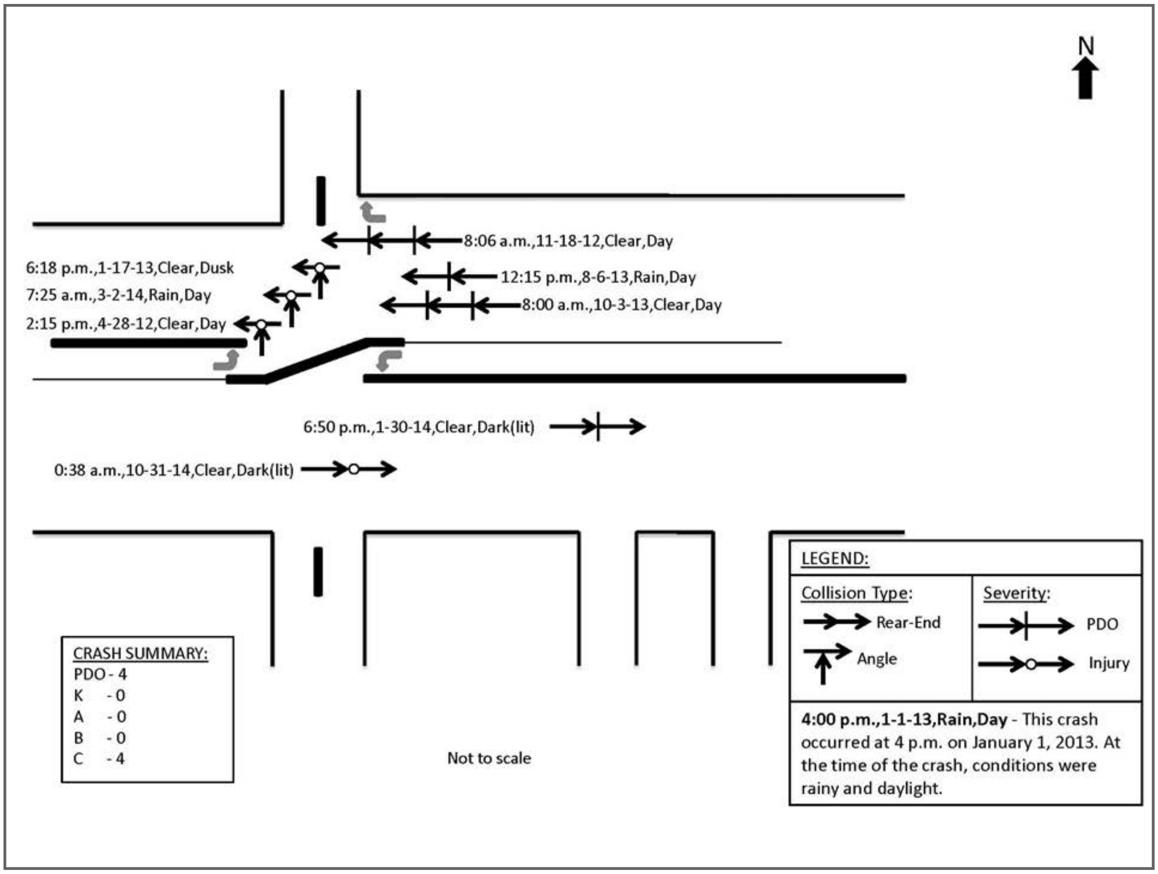
A diagram that shows the intersection/roadway alignment with the crashes superimposed is known as a **collision diagram.** This diagram typically includes relevant information including type and severity of crash, date and time of crash, weather, and lighting conditions. Plotting the general crash location and associated information can help to highlight crash trends, if present. The following steps depict this process.

STEP 1: Identify key site features.

An aerial photo or a condition diagram (refer to HSM Figure 5-5, p. 5-7) can be used to identify and document important site characteristics. By inspecting the aerial imagery for this location, one sees that there is a directional median opening that allows left-turns into the driveway, but restricts vehicles exiting the driveways to a right-turn only.

STEP 2: Develop the collision diagram.

The historical (observed) crash data can be used as the basis for developing the collision diagram. The following collision diagram shows the study site crashes for the three-year period.



This location predominantly experienced angle and rear-end crashes. The angle crashes appear to be due to the conflict between the left-turning vehicles and the opposing through vehicles at the unsignalized entrance on the north side of the road. These crashes could be a result of restricted sight distance, sun glare issues, or high total intersection volumes with few gaps in traffic. Two of these crashes occurred during rainy conditions. The rear end crashes could be associated with large traffic volumes (and potentially queues from a downstream signalized intersection) or similar issues.

STEP 3: Identify potential countermeasures.

Prior to the field inspection and study by the analyst, it is helpful to explore potential treatments for future mitigation of issues. For the crashes observed at this site, example candidate countermeasures may include:

- Installation of traffic signals (refer to the *Manual on Uniform Traffic Control Devices*).
- Adjustment of upstream or downstream signal timing to allow progression or to create longer gaps.

FINDINGS

Interpreting the Results:

This simple analysis method used collision and condition diagram techniques to identify specific crash types, prevailing conditions, and potential contributing factors. At this location, eight crashes occurred over a 3-year period. Four of the eight crashes included at least one injury. Based on the collision diagram, it appears that suitable countermeasures will target rear-end and angle crashes; however, due to the small number of crashes the analyst may want to assess how crashes at this location are comparable to crashes at similar locations in an effort to determine whether this location merits improvement at this time.

Possible Errors to Avoid:

The crash data for this site spanned a period of 3 years. It is recommended that analysts gather data from at least 3 to 5 years of crashes to avoid drawing conclusions that do not accurately reflect the crash history. On a cautionary note, for locations with a limited number of observed crashes, the analyst should not attempt to draw definitive conclusions without extending the analysis to similar sites or by comparing the number of crashes to how many would be predicted for the specific facility using intermediate or advanced safety assessment methods.

Alternative Analysis Approaches:

The *Historical Crash Data Evaluation* safety assessment methods can also be used to supplement this analysis. If the analyst determines that there is sufficient justification to extend the assessment to a detailed evaluation of the candidate location, the next step would be to acquire specific site characteristic information. This added information would then enable the analyst to predict crashes (using the SPF with CMF Adjustment procedure). The predicted number of crashes represents an estimate of how many crashes are typically observed for facilities with similar traffic volumes and roadway characteristics. This additional comparison will strengthen the analysis and help clarify if the location has more crashes than similar locations.

2.3 Justifying the Need for Potential Cost-effective Safety Countermeasures for a Rural Two-lane Highway

PROBLEM OVERVIEW	
Safety Assessment Method: CMF Applied to Observed Crashes and CMF Relative Comparison	
Project Phase: **Planning & Scoping**	Project Type: **2R**
Related Task: **Establish Project Scope**	**Calculation Method:** ☒ **Hand Calculated** ☐ **Tool Based**
Comments: This example problem shows how a basic analysis can be used to identify potential countermeasures that will reduce crashes.	
LEVEL OF ANALYSIS	
Basic / Intermediate / Advanced (level indicated: Basic)	

Note: See table 3 for a full definition of Project Type designations.

PROBLEM DESCRIPTION

As part of the planning and scoping activities, a roadway agency has identified a 10-mile section of rural two-way, two-lane highway targeted for safety improvements. Many of the crashes appear to be due to vehicles running off of the road. In the most recent 3 years, almost 40 crashes have occurred within this 10-mile section of highway. During the diagnosis process, the roadway agency identified potential treatments that included removal or relocation of fixed objects, installation of center line rumble strips, and delineation of obstacles. The associated **Project Type** is *2R* and the **Related Task** is to *Establish Project Scope*. **How can the analyst estimate the safety performance of previously identified candidate low-cost countermeasures?**

Summary of Available Data:

The following data describes the current conditions and associated crash data.

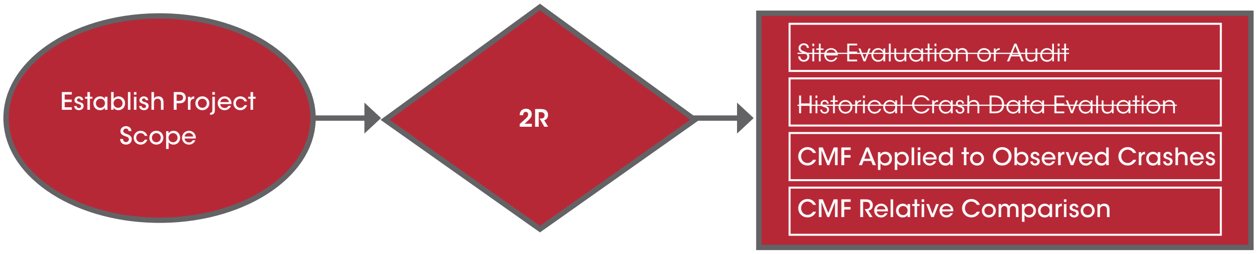
- Two-lane, two-way operation with lane widths of 11 ft.
- No paved or graded shoulders.
- Average annual daily traffic (AADT) 1,723 vehicles per day (vpd).
- Rolling terrain with numerous horizontal curves.
- Average side slope 1V:3H (1 ft. vertical for every 3 ft. horizontal).
- Three-year crash count = 38 total.
    - *Two fatal.*
    - *Nine injury crashes.*
    - *Twenty-seven PDO crashes.*

The crash data currently does not include extensive detail about the individual vehicle maneuvers for each crash, and so the analyst will focus on total crashes and crash severity for this evaluation.

ANALYSIS

Selecting Appropriate Safety Assessment Method(s):

The roadway agency can evaluate the candidate safety assessment methods shown in Table 5. The purpose for this analysis is to use the crash information to assess what types of improvements can be implemented to help reduce future crashes along the corridor. This task and project type is associated with one of the four *Basic* safety assessment methods. Since a CMF-based method considers a change in road characteristics, the two candidate safety assessment methods that use CMFs are applicable for this analysis. Both methods can be considered. The *CMF Applied to Observed Crashes* method can be directly applied to the observed crashes. The estimated future crashes can be compared to historical crash data to evaluate the potential reduction in crashes based on the individual improvements. The cost of the reduced number of crashes can then be quantified by applying the equivalent property damage method of calculating a benefit/cost (B/C) ratio.



The *CMF Relative Comparison* approach does not explicitly consider historical crashes at the site and so is simply used to compare two candidate improvements.

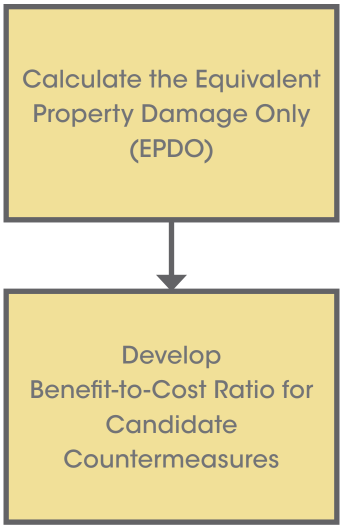
Linkage to the HSM:

Chapter 6 of the HSM (Section 6.2.2, pp. 6-3 to 6-9) summarizes contributing factors to consider when selecting appropriate countermeasures. Section 6.3 of the HSM (p. 6-9 to 6-10) provides guidance for selecting potential countermeasures. Finally, Part D (Volume 3) of the HSM and the FHWA sponsored CMF Clearinghouse (www.cmfclearinghouse.org) include a wide variety of potential improvements. These CMF resources identify the base conditions and applicable site applications for the individual countermeasure of interest.

Detailed Analysis:

Method 1: CMF Applied to Observed Crashes

The analyst will evaluate the candidate treatments recommended as a result of the site diagnosis. There are many potential improvements designed to help mitigate run-off-the-road crashes, but this detailed analysis focused on the three low-cost options.



The following steps review the use of the equivalent property damage only (EPDO) performance measure to first identify the value of the crashes and then the *CMF Applied to Observed Crashes* safety assessment method to further evaluate how the low-cost improvements may help to reduce crashes. A benefit/cost (B/C) ratio can then be used to assess which treatments would be the most cost effective.

STEP 1: Calculate the EPDO value for existing crashes.

The HSM provides sample weighting factors to calculate the EPDO (HSM Table 4-7, p. 4-29). The roadway agency performing this analysis uses the following cost values and resulting weighting factors; however, the values can vary by agency and so it is recommended that they be confirmed prior to analysis.

Severity	Comprehensive Crash Costs ($f_{(cost)}$)	Weighting Factor Calculation	Weighting Factor ($f_{(weight)}$)
Fatal (K)	$4,008,900	$f_{k\ (weight)} = \frac{4,008,900}{7,400}$	542
Injury (A/B/C)	$82,600	$f_{inj\ (weight)} = \frac{82,600}{7,400}$	11
PDO (O)	$7,400	$f_{PDO\ (weight)} = \frac{7,400}{7,400}$	1
Note: A=incapacitating injury. B=serious injury. C=possible injury. PDO = property damage only.			

The EPDO weighting factors are then applied to the individual crash severity frequencies to calculate the equivalent number of property damage only (PDO) crashes.

Total EPDO Calculation	Notes
$=f_{k(weight)}\ (N_{(observed,k)})+f_{inj(weight)}\ (N_{observed,inj})+f_{PDO(weight)}\ (N_{observed,PDO})$	None.
$=(542)(2)+(11)(9)+(1)(27)=1210$	The makeup of the existing crashes (all severity levels) is equivalent to having 1210 PDO crashes.
Note: EPDO = equivalent property damage only. PDO = property damage only.	

STEP 2: Calculate the B/C ratio of the candidate treatments.

For this evaluation, the analyst is considering improving the clear zone (removing roadside obstacles and trees), adding center line rumble strips, or delineating obstacles where appropriate. The following summary presents these three low-cost treatment options and information related to the cost and effectiveness of each.

Proposed Treatment	Estimated Cost (for 10-mile segment)	CMF (S.E.)[1]	Crash Type (Base Condition)	Crash Severity	Source
Remove or relocate fixed objects outside of clear zone	$200,000	0.62 (0.103)	★★★ All crash types and roadway types	All	http://www.cmfclearinghouse.org/detail.cfm?facid=1024
Install center line rumble strips	$30,000	0.91 (0.02)	★★★★★ All crash types and rural roadway types	All	http://www.cmfclearinghouse.org/detail.cfm?facid=3361
Delineate obstacles	$10,000	1.0 (0.1)	All crash types and roadway types	All	The HSM CMF value is 1.0. Because CMFs are multiplicative, a value of 1.0 has no effect on crash reduction for these crash types.

[1] S.E. refers to the standard error
★ CMF Clearinghouse Star Rating.
Note: CMF = crash modification factor. HSM = Highway Safety Manual.

For these potential improvements, the crash type is the "all" or total crash category. Many of the available CMF values focus on run-off-road crashes. Since this level of information is not available for the study site, the analyst must check to be sure that the correct CMF base conditions are applicable to the study site. For these three specific proposed treatments, the CMFs do apply to "All" crashes and not just to run-off-road collisions. Whenever the data is available, a preferred CMF comparison would be to evaluate the target crashes by type for each CMF. This requires information about the individual crash types at the site as well as CMFs that have the crash type base condition of interest. For this calculation, the target crash level of detail is limited (thus the "all crash type" approach).

Using the Total EPDO in Step 1 as a baseline, apply the CMF to calculate the estimated EPDO for each potential treatment.

Calculations	Notes
Remove or relocate fixed objects outside of clear zone:	
Estimated EPDO= Total EPDO×CMF=1210×0.62=750.2	–
Cost of Existing EPDO= 1210×$7,400=$8,954,000	This is the estimated cost of the **existing crashes** on the roadway.
Cost of Estimated EPDO= 750.2×$7,400=$5,551,480	This is the estimated cost of the **future crashes** for a similar time period if this treatment is selected
B/C Ratio = $\frac{\text{Cost of Existing EPDO-Cost of Estimated EPDO}}{\text{Cost of Treatment}}$ B/C Ratio = $\frac{\$8{,}954{,}000-\$5{,}551{,}480}{\$200{,}000}$ = 17.0	This indicates that the benefits outweigh the cost of the countermeasure (for every $1 the agency spends there is an equivalent benefit of $17).
Install center line rumble strips:	
Estimated EPDO = 1210×0.91=1101.1	--
Cost of Existing EPDO = 1210×$7400=$8,954,000	This is the estimated cost of the **existing crashes** on the roadway.
Cost of Estimated EPDO = 1101.1×$7400=$8,148,140	This is the estimated cost of the **future crashes** on the roadway if this treatment is selected
B/C Ratio = $\frac{\$8{,}954{,}000-\$8{,}148{,}140}{\$30{,}000}$ = 26.9	This indicates that the benefits outweigh the cost of the countermeasure (for every $1 the agency spends there is an equivalent benefit of $27).
Delineate obstacles:	
Estimated EPDO= Total EPDO×CMF=1210×1.0=1210	
Cost of Existing EPDO= 1210×$7400=$8,954,000	This is the estimated cost of the **existing crashes** on the roadway. (same as the other treatments)
Cost of Estimated EPDO= 1,210×$7400=$8,954,000	This is the estimated cost of the **future crashes** on the roadway if this treatment is selected.
B/C Ratio = $\frac{\$8{,}954{,}000-\$8{,}954{,}000}{\$10{,}000}$ = 0.0	This indicates that there is no real financial benefit for choosing this countermeasure if the objective is to target all crash types.
Note: B/C = benefit/cost. CMF = crash modification factor. EPDO = equivalent property damage only.	

Based on the resulting B/C ratios, the analyst concludes that the recommended treatments, in order of priority, should be:

1. Install center line rumble strips (B/C ratio of 26.9), and then
2. Remove or relocate fixed objects outside of the clear zone (associated with a B/C ratio of 17.0).

The analyst eliminates the delineate obstacles option because it has a B/C ratio of 0.0, indicting no real financial benefit.

Method 2: CMF Relative Comparison

The CMF Relative Comparison safety assessment method can be used to compare potential CMFs to evaluate which have the greatest impact on reducing crashes. Whereas in the previous *CMF Applied to Observed Crashes* calculations, the analyst used observed crash data as a key input into the analysis, only the CMF information is required for the relative comparison approach.

STEP 1: Review the three CMFs previously identified and compare their relative values.

The information for the three previously reviewed CMFs is summarized in the following table. Recall that a CMF value less than 1.0 is associated with a larger reduction in future crashes when compared to a CMF with a value of one (assumed to have no real effect on reducing crashes). Based on this simple comparison, the analyst concludes that the recommended treatments, in order of priority, should be:

1. Remove or relocate fixed objects outside of the clear zone (associated with an estimated 38 percent reduction in crashes), and then
2. Install center line rumble strips (associated with a 9 percent estimated crash reduction).

For the purposes of reducing crashes, the analyst removes delineating obstacles from consideration.

Proposed Treatment	CMF (S.E.)[1]	Crash Type (Base Condition)	Crash Severity
Remove or relocate fixed objects outside of clear zone	0.62 (0.103)	★★★ All crash types and roadway types	All
Install center line rumble strips	0.91 (0.02)	★★★★★ All crash types and rural roadway types	All
Delineate obstacles	1.0 (0.1)	All crash types and roadway types	All

[1] S.E. refers to the standard error.

★ CMF Clearinghouse Star Rating.

Note: CMF = crash modification factor. HSM = Highway Safety Manual.

FINDINGS

Interpreting the Results:

Based on the low-cost improvements considered using Method 1, the analyst concluded that the center line rumble strips and clear zone improvements provide evidence that the societal benefit of installing the treatments will outweigh the cost of installation. Other considerations may include whether there are any ordinances that limit where rumble strips can be installed. Because this evaluation targeted all crash severities and all crash types, the effect of countermeasures specifically expected to reduce roadside crashes may not be clear.

The Method 2 approach similarly identified the same two CMFs, but did not directly consider crash data, weighting of severity levels, or benefit/cost analysis. This relative comparison approach, based simply on anticipated treatment effectiveness, prioritized the clear zone improvements above the center line rumble strips. This more basic approach provided useful information, but did not include site-specific information required for Method 1.

Possible Errors to Avoid:

It is recommended that analysts utilize crash cost estimations and weighting based on their State or local crash cost databases. Appropriate CMFs used for this type of analysis will have crash type and base condition characteristics that match those of the project highway.

Alternative Analysis Approaches:

The two methods may be effective approaches to initially narrow down the large list of potential safety treatments. If additional data that includes individual road geometry and crash type could be acquired for this location, a more comprehensive evaluation based on predicted or expected crashes could be performed during the preliminary and final project development phases.

2.4 Predicting Crashes to Evaluate Level of Service of Safety for a Rural Two-lane Highway

PROBLEM OVERVIEW	
Safety Assessment Method: SPF with CMF Adjustment	
Project Phase: **Planning & Scoping**	Project Type: **3R**
Related Task: **Establish Project Scope**	**Calculation Method:** ☐ **Hand Calculated** ☒ **Tool Based**
Comments: This example problem calculates the predicted number of crashes for alternative curve geometry options along a rural two-lane highway and then applies a level of service of safety ranking.	
LEVEL OF ANALYSIS	
Basic Intermediate Advanced	
Note: See table 3 for a full definition of Project Type designations.	

PROBLEM DESCRIPTION

As part of planning and scoping activities, a DOT is developing plans to resurface a seven-mile section of a rural two-lane highway that contains 13 horizontal curves. The analyst wants to ensure that any low-cost curve countermeasures deployed as part of this project will have a positive impact on reducing crashes. The DOT does not have information about the roadside hazard rating or the driveway access density for each curve, and so the analyst visually inspected several of the curve locations and developed an average value to use for these road characteristics during this preliminary analysis phase. The associated **Project Type** is *3R* and the **Related Task** is to *Establish Project Scope.* **How can the analyst estimate which curves are functioning as anticipated and which ones could benefit from low-cost treatments?**

Summary of Available Data:

The relevant curve characteristics include the following for all 13 curves:

- AADT = 10,250 vpd (Curves #1 through #11), AADT = 9,700 (Curves #12 and #13).
- Lane width = 11 ft.
- Paved shoulder width = 6 ft. (right and left shoulders).
- No spiral transitions.
- Superelevation at curves compatible with design values.
- Level grade.
- No center line rumble strips, passing lanes, or two-way left-turn lanes.
- Driveway density = 5 driveways/mi (estimated average).
- Roadside hazard rating = 3 (estimated average).

The individual curve characteristics are further described as follows:

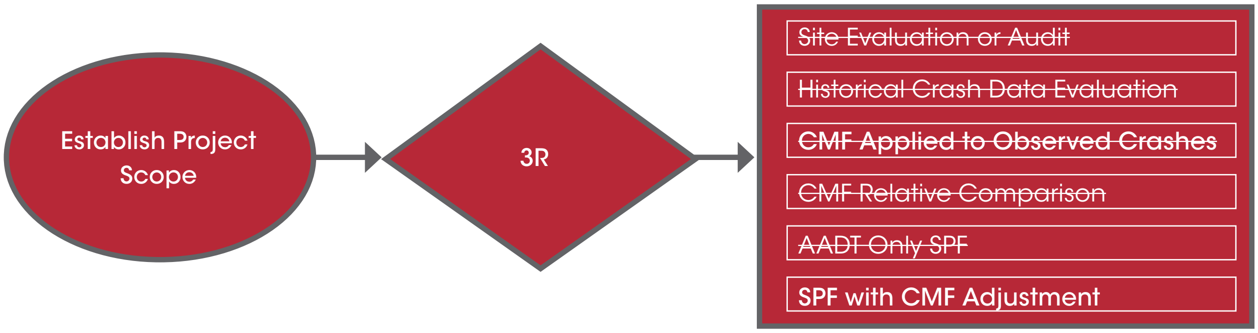
Curve Number	Delineation Devices Present	Length (mi)	Radius (ft)	Superelevation rate (percent)	3-Year Total Crash Count
1	None	0.25	1229	4.7	7
2	None	0.26	1269	5.5	3
3	Chevrons	0.12	384	7.8	1
4	Delineators	0.08	588	3.1	2
5	None	0.09	629	3.1	1
6	None	0.19	750	6.2	1
7	None	0.08	1124	6.2	2
8	Delineators	0.06	309	7.0	5
9	None	0.05	818	6.2	0
10	Delineators	0.15	794	9.4	1
11	Chevrons	0.17	678	3.9	2
12	Chevrons	0.22	706	3.9	0
13	None	0.15	800	7.8	1

Note that total crash count information is currently the only available crash data.

ANALYSIS

Selecting Appropriate Safety Assessment Method(s):

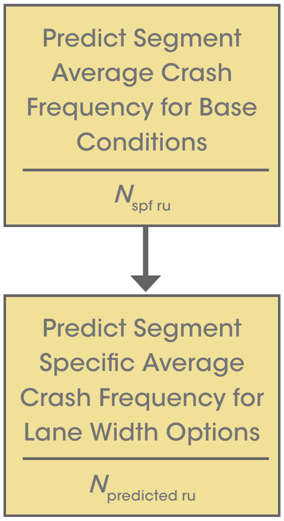
The analyst must first review the potential safety assessment methods shown in Table 5 for 3R project types and the task of establishing the project scope. This task and project type is associated with the four *Basic* and the two *Intermediate* safety assessment methods. For this analysis, the DOT only has limited funds available for select curve improvements. The analysis needs to include enough detail to evaluate the individual curves so that the limited funds are targeted effectively. Note that an intersection located between curves #11 and #12 results in different (lower) traffic volumes for the last two curves.



Of the four *Basic* methods, only the CMF-related safety assessment methods can directly consider horizontal curve radius, but the two basic CMF-related methods do not consider the varying traffic volume. For the two *Intermediate* safety assessment methods, the *SPF with CMF Adjustment* safety assessment method can also evaluate the horizontal curve geometry. The *AADT-Only SPF* safety assessment method does not consider varying geometric characteristics and can be eliminated as a candidate for this analysis.

The *SPF with CMF Adjustment* will allow an evaluation of the different curve radii as well as varying traffic volume for the last two curves. This method also results in predicted crash information as noted in Table 1. To most effectively use this approach, an agency should calibrate the SPF for their local jurisdiction. A calibration factor of 1.0 can be used if this information is not available, but the results will not be refined to local conditions.

Once predicted crashes are calculated, a variety of analysis approaches can be used to then determine which curves merit additional treatment. For this assessment, the analyst will calculate the predicted crash frequencies and then compare these frequencies to the observed crash frequencies by applying the measure of Level of Service of Safety (LOSS).



Linkage to the HSM:

The HSM can be used to estimate the number of predicted crashes for a rural, two-lane highway by applying the procedures introduced in HSM Chapter 10 (pp. 10-1 to 10-74). By determining predicted crashes, the analyst can estimate how many crashes may be expected for a specific road type with varying road conditions (in this case the curve radii and traffic volumes). The HSM provides manual calculations, but a spreadsheet tool is available and can be used to simplify this analysis.

Once the number of predicted crashes has been calculated, the predicted crashes can be compared to the historical (observed) average crash frequency to identify which curves have diminished levels of service of safety (LOSS) that merit additional consideration. This LOSS procedure is reviewed on p. 4-12 of the HSM. An example problem is included on pp. 4-44 to 4-48 of the HSM.

Detailed Analysis:

The following steps provide the calculations for predicting rural two-lane highway crashes based on using the HSM "Smart Spreadsheets" available for download at: http://www.highwaysafetymanual.org/Pages/tools_sub.aspx#4. For this example problem, the analyst can use the "HSM prediction rural two-lane roads" spreadsheet tool.

STEP 1: Input the data describing each curve into the spreadsheet tool.

Note that no lighting or automated speed enforcement is present. The following graphic shows a representation of Worksheet 1A. This roadway segment worksheet includes input information similar to that shown in the HSM worksheet (see HSM p. 10-68). The input data shown in the graphic represents data cells for the first curve on the highway section (radius of 1229 ft).

Worksheet 1A – General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments						
General Information		**Location Information**				
Analyst	SD	Roadway	Section 3			
Agency or Company	TTI	Roadway Section	Segment 1			
Date Performed	09/07/15	Jurisdiction				
		Analysis Year	2015			
Input Data		**Base Conditions**	**Site Conditions**			
Length of segment, L (mi)		--	0.25			
AADT (veh/day)	AADTMAX = 17,800 (veh/day)	--	10,250			
Lane width (ft)		12	11			
Shoulder width (ft)		6	Right Shld:	6	Left Shld:	6
Shoulder type		Paved	Right Shld:	Paved	Left Shld:	Paved
Length of horizontal curve (mi)		0	0.25			
Radius of curvature (ft)		0	1229			
Spiral transition curve (present/not present)		Not Present	Not Present			
Superelevation variance (ft/ft)		< 0.01	0			
Grade (%)		0	0			
Driveway density (driveways/mile)		5	5			
Centerline rumble strips (present/not present)		Not Present	Not Present			
Passing lanes [present (1 lane) / present (2 lane) / not present]		Not Present	Not Present			
Two-way left-turn lane (present/not present)		Not Present	Not Present			
Roadside hazard rating (1-7 scale)		3	3			
Segment lighting (present/not present)		Not Present	Not Present			
Auto speed enforcement (present/not present)		Not Present	Not Present			
Calibration Factor, Cr		1	1.00			
Note: AADT = annual average daily traffic, TTI = Texas Transportation Institute.						

STEP 2: Tabulate the predicted crash frequency for each curve and convert the frequencies to predicted 3-year crash counts.

The following graphic shows a representation of Worksheet 1C. This roadway segment worksheet summarizes the predicted crash frequency for each year. The values shown represent segment #1. This worksheet includes input information similar to that shown in the HSM worksheet (see HSM p. 10-69).

Worksheet 1C – Roadway Segment Crashes for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	$N_{spf\ rs}$	Overdispersion Parameter, k	Crash Severity Distribution	$N_{spf\ rs}$ by Severity Distribution	Combined CMFs	Calibration Factor, Cr	Predicted average crash frequency, $N_{predicted\ rs}$ (crashes/year)
	from Equation 10-6	from Equation 10-7	from Table 10-3 (proportion)	(2) TOTAL x (4)	(13) from Worksheet 1B		(5) x (6) x (7)
Total	0.685	0.94	1.000	0.685	1.20	1.00	0.823
Fatal and Injury (FI)	--	--	0.321	0.220	1.20	1.00	0.264
Property Damage Only (PDO)	--	--	0.679	0.465	1.20	1.00	0.559
Note: CMF = crash modification factor.							

The total predicted numbers of crashes per year, the equivalent total predicted crashes for 3 years, and the observed 3-year crash frequency are shown in the following table. The 3-year predicted crash count for Curve #1 is calculated as 2.47 (= 0.823 crashes/year x 3 years). Upon inspection of the crash values, the design team notes that Curves #1, 2, 4, 7, and 8 all have more observed crashes than were predicted for a road of this type with similar volume and curve radii characteristics, though when compared to rounded predicted crashes, only Curves #1 and #8 have observed crashes that are noticeably higher. Additional evaluations can help determine if these five curve locations should be the final improvement curves. This evaluation is included in Step 3.

STEP 3: Use the crash counts to compute the level of service of safety procedure described in HSM Section 4.4.2.7 (HSM pp. 4-44 to 4-48).

The level of service of safety is based on assessing the amount of deviation between the predicted and the observed crashes. To calculate the LOSS, the curves are separated into four categories (I to IV). Sites with a moderate to high potential for crash reduction (or LOSS category rankings of III or IV) are then identified for future study.

Curve Number	Predicted Crashes			Observed Crash Total for 3 years
	Calculated Total for 1 year	Total for 3 years		
		Calculated	Rounded	
1	0.823	2.47	3	7
2	0.847	2.54	3	3
3	0.718	2.15	3	1
4	0.473	1.42	2	2
5	0.485	1.46	2	1
6	0.730	2.19	3	1
7	0.355	1.07	2	2
8	0.641	1.92	2	5
9	0.319	0.96	1	0
10	0.606	1.82	2	1
11	0.694	2.08	3	2
12	0.782	2.35	3	0
13	0.572	1.72	2	1

The LOSS category criteria are summarized as follows:
Category I: $\sigma < N_{observed} < (N - (1.5 \times \sigma))$ [Low potential for crash reduction].
Category II: $(N - (1.5 \times \sigma)) \leq N_{observed} \leq N$ [Low to moderate potential for crash reduction].
Category III: $N \leq N_{observed} \leq (N + (1.5 \times \sigma))$ [Moderate to high potential for crash reduction].
Category IV: $N_{observed} \geq (N + (1.5 \times \sigma))$ [High potential for crash reduction].

For these classifications, the standard deviation, σ, is calculated as follows (Equation 4-16 of the HSM):

$$\sigma = \sqrt{k \times N^2}$$

Where:

- *k* represents the overdispersion parameter of the SPF (this specific SPF has a value of 0.236 ÷ *L* as noted in the HSM equation 10-7, p. 10-16).
- *N* represents the predicted crash frequency.
- *L* represents the length of roadway segment in miles.

The following summary table identifies the individual LOSS rankings for the 13 curve locations. The shaded curves are the same five curves identified during the Step 2 evaluation. All five curves have LOSS category classifications of III and IV, suggesting that they are the curves that merit attention.

As an example, the standard deviation (σ) for Curve Number 1 is calculated as follows:

$$\sigma = \sqrt{k \times N2} = \sqrt{\frac{0.236}{0.25} \times 2.47^2} = 2.40$$

The four potential LOSS category classifications can then be evaluated. As an example, the LOSS assessment for Curve Number 1 is calculated as follows:

<u>Category I Assessment – Curve #1:</u>

Is $\sigma < N_{observed} < (N - (1.5 \times \sigma))$?
Is 2.40 < 7 < [(2.47 – (1.5 x 2.4)) = -3.6]?
No, 7 is not less than -3.6, so proceed to evaluate Category II.

<u>Category II Assessment – Curve #1:</u>
Is $(N - (1.5 \times \sigma) \leq N_{observed} \leq N$?
Is [(2.47 – (1.5 x 2.4)) = -3.6] ≤ 7 ≤ 2.47?
No, 7 is not less than 2.47, so proceed to evaluate Category III.

<u>Category III Assessment – Curve #1:</u>

Is $N \leq N_{observed} \leq (N + (1.5 \times \sigma))$?
Is 2.47 ≤ 7 ≤ [(2.47 + (1.5 x 2.40)) = 6.07]?
No, 7 is not less than 6.07, so proceed to evaluate Category IV.

<u>Category IV Assessment – Curve #1:</u>

Is $N_{observed} \geq (N + (1.5 \times \sigma))$?
Is 7 ≥ [(2.47 + (1.5 x 2.40)) = 6.07]?
Yes, so Curve #1 has a Category IV LOSS.

Curve Number	3-Year Crash Count		σ	Level of Service of Safety
	Predicted	Observed		
1	2.47	7	2.40	IV
2	2.54	3	2.42	III
3	2.15	1	3.02	II
4	1.42	2	2.44	III
5	1.46	1	2.36	II
6	2.19	1	2.44	II
7	1.07	2	1.84	III
8	1.92	5	3.81	III
9	0.96	0	2.09	II
10	1.82	1	2.28	II
11	2.08	2	2.45	II
12	2.48	0	2.57	II
13	1.82	1	2.28	II

FINDINGS

Interpreting the Results:

The results of the level of service of safety analysis show that there is a high potential for crash reduction (i.e. LOSS Category of IV) on Curve #1 and a moderate-to-high potential for crash reduction (i.e. LOSS Category III) for Curves #2, #4, #7, and #8. These curves are candidates for additional crash reduction treatments. The simple comparison between rounded predicted values and observed crashes, however, further indicates that Curves #1 and #8 merit priority attention.

Possible Errors to Avoid:

When using the HSM predictive method, the input value for superelevation differential can be confusing. The value used in the procedure is for a difference (in ft. per ft) of how the existing superelevation slope deviates from the design slope. As an example, if the proposed superelevation design value for a curve is 4.80 percent but instead the actual slope is 2.20 percent, the deviation would be calculated as: 0.048 –0.022 = 0.026. For this evaluation, there were not any superelevations variances of significance, and so this value would be 0.00.

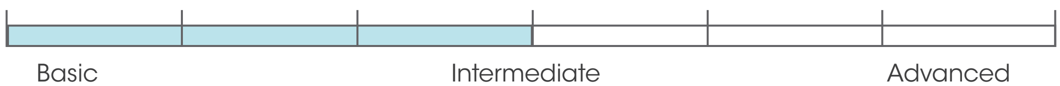
Alternative Analysis Approaches:

The analyst could have used the *CMF Applied to Observed Crashes* safety assessment method to compare Curves #1 through #11 since they all had the same traffic volume. A separate, similar analysis for Curves #12 and #13 could also be performed. The result of this procedure, however, provides estimated crashes (instead of predicted crashes that are calculated when using an SPF).

LOSS is one of several measures that are presented in Chapter 4 of the HSM for use in planning and programming highway improvements that can reduce crash frequency or severity. As shown in Table 6, an alternative performance measure that also uses SPF information as it applies to contrasting predicted crashes is the *Excess Predicted Average Crash Frequency Using SPFs.*

Expected crashes can also be considered for comparing site-specific conditions prior to making substantial changes. As the project shifts from the planning stage to the design stage, these more detail-oriented procedures may be appropriate as they can prove to be particularly useful as input into benefit/cost analyses during the final stages of the project.

2.5 Predicting Incremental Benefits Associated with Increased Lane Width for a Rural Two-lane Highway

PROBLEM OVERVIEW	
Safety Assessment Method: SPF with CMF Adjustment	
Project Phase: **Planning & Scoping**	Project Type: **3R**
Related Task: **Establish Project Scope**	**Calculation Method:** ☐ **Hand Calculated** ☒ **Tool Based**
Comments: This example problem will evaluate the effect lane widening can have on reducing fatal and injury crashes for a two-lane undivided rural highway at a site where crash data is not available.	
LEVEL OF ANALYSIS	
	
Note: See table 3 for a full definition of Project Type designations.	

PROBLEM DESCRIPTION

A two-lane county highway serving a newly developed residential community is in need of some upgrades. Currently, the two-lane highway has 10-ft. lanes and the road does not have any graded or paved shoulders (a typical rural low-volume design at the time it was constructed). The county has funding limitations but intends to widen the travel lanes as a short-term solution to help improve corridor operations. The analyst would also like to evaluate safety estimates and compare the added incremental benefits of widening the lanes from 10-ft. to 11-ft. wide and from 10-ft. to 12-ft. wide. A specific goal would be to evaluate how these improvements would reduce the number of fatal or injury crashes annually along this corridor. A future project could also consider adding graded shoulders, but due to limited funding, this option must be deferred to a later date. The affected corridor is approximately 20 miles long with a current AADT of 10,000 vpd. The **Project Type** is *3R* and the **Related Task** is to *Establish Project Scope*. **How does the analyst estimate the reduction in the number of fatal and injury crashes due to these potential incremental improvements?**

Summary of Available Data:

The County does not have any available crash data for this corridor. To simplify this initial assessment, the analyst has made the following assumptions:

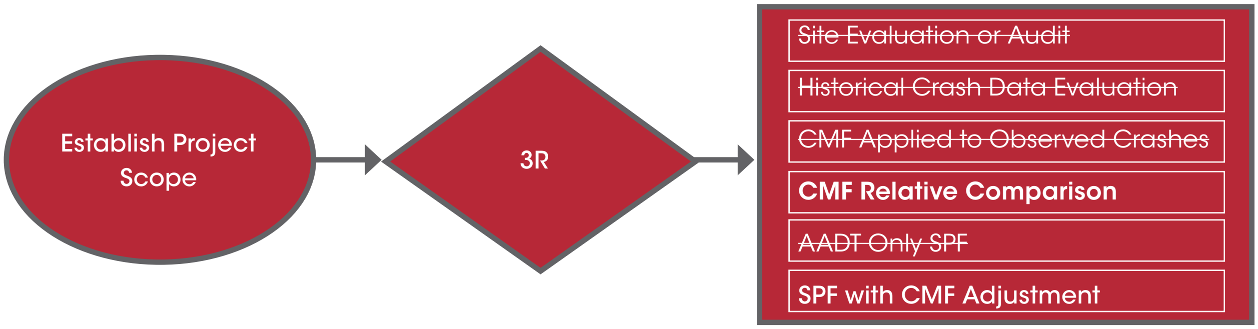
- No horizontal curves.
- No vertical grades steeper than 2 percent.
- Driveway density of five driveways per mile.

- No center line rumble strips, passing lanes, or two-way left turn lanes.
- Roadside hazard rating of three.
- No street lights.
- No automated speed enforcement.

ANALYSIS

Selecting Appropriate Safety Assessment Method(s):

Based on Table 5, the Establish Project Scope task and the 3R project type are associated with the four *Basic* and the two *Intermediate* safety assessment methods. There is limited data available for the corridor and the goal is to estimate the reduction in fatal and injury crashes due to incremental widening. Because this condition eliminates methods that only evaluate existing conditions (see Table 1 in Chapter 1), the *Site Evaluation or Audit* and the *Historical Crash Data Evaluation* safety assessment methods are not applicable. In addition, the *CMF Applied to Observed Crashes* is also not feasible due to the lack of available crash data. The *AADT-Only SPF* method does not explicitly allow evaluation of unique road features and so this method also does not apply.

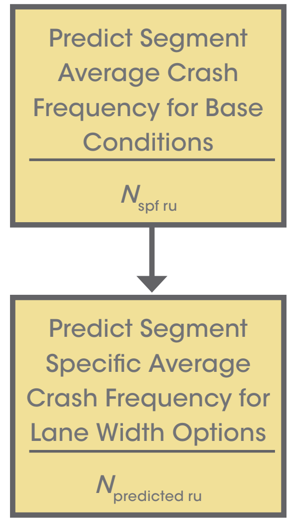


The remaining potential safety assessment methods include *CMF Relative Comparison* and *SPF with CMF Adjustment*. The relative comparison method can be used if CMFs are available for the proposed lane widening.

The analyst conducts a quick search on the FHWA CMF Clearinghouse (http://www.cmfclearinghouse.org/) to determine if CMFs are available for the widening scenario (i.e., widen lane from 10 ft. to 11 ft., widen lane from 10 ft. to 12 ft.). Note that the base condition would be 10 ft. lane widths for the two options. In addition, the lane width CMFs that the analyst does locate do not provide information about the number of fatal or injury crashes. Based on this assessment, the analyst concludes that the SPF with CMF Adjustment method appears to be the preferred safety assessment method for this evaluation.

Linkage to the HSM:

The HSM can be used to estimate the number of predicted crashes for a rural, two-lane highway by applying the procedures introduced in HSM Chapter 10 (pp. 10-1 to 10-74). By determining the predicted total, fatal and injury, and property damage only crashes for the 10 ft, 11 ft, and 12 ft. lane scenarios, the analyst can assess the incremental benefits associated with the lane widening options. The HSM provides manual calculations, but a spreadsheet tool is available and can be used to simplify this analysis.



Detailed Analysis:

The analyst reviews the criteria for the *SPF with CMF Adjustment* safety assessment method and notes that the SPF from the HSM has not been calibrated for the region. Therefore, the analyst can simply use a calibration factor value of 1.0. Because the evaluation compares lane-width options for the same facility, the absence of a calibration factor for the region will not adversely affect the process of comparing design options for the same road. The predicted number of crashes may not be exact, but the procedure can accurately calculate the relationship between the predicted numbers of crashes for varying lane widths. Due to the absence of a calibrated SPF, the analyst will report the results as a percentage reduction in crashes instead of a specific number of reduced crashes. This reporting format is appropriate because reporting the number of crashes would imply more precision than the calculations (that do not incorporate a calibration factor) represent.

The following steps provide the calculations based on using the HSM "Smart Spreadsheets" available for download at: http://www.highwaysafetymanual.org/Pages/tools_sub.aspx#4. For this example problem, the analyst can use the "HSM rural two lane roads" spreadsheet tool.

STEP 1: Input the data describing each lane width option into the spreadsheet tool.

As previously indicated, the analyst used a calibration factor of 1.0. She also included the base conditions for each feature, a volume of 10,000 vpd, and length of 20 miles. The following graphic shows Worksheet 1A. This roadway segment worksheet includes input information similar to that shown in the HSM worksheet (see HSM p. 10-68). The input data shown in the graphic represents data cells for the 10-ft.-lane-width option (existing conditions).

Worksheet 1A - General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments					
General Information		**Location Information**			
Analyst	Analyst Name	Roadway	Example two-lane rural highway		
Agency or Company	--	Roadway Section	Example segment		
Date Performed	--	Jurisdiction	Anywhere, USA		
		Analysis Year	2015		
Input Data		**Base Conditions**	**Site Conditions**		
Length of segment, L (mi)		--	20		
AADT (veh/day)	AADTMAX = 17,800 (veh/day)	--	10,000		
Lane width (ft)		12	10		
Shoulder width (ft)		6	Right Shld: 0	Left Shld: 0	
Shoulder type		Paved	Right Shld: Paved	Left Shld: Paved	
Length of horizontal curve (mi)		0	0.000		
Radius of curvature (ft)		0	0		
Spiral transition curve (present/not present)		Not Present	Not Present		
Superelevation variance (ft/ft)		< 0.01	0		
Grade (%)		0	0		
Driveway density (driveways/mile)		5	5		
Centerline rumble strips (present/not present)		Not Present	Not Present		
Passing lanes [present (1 lane) / present (2 lane) / not present]		Not Present	Not Present		
Two-way left-turn lane (present/not present)		Not Present	Not Present		
Roadside hazard rating (1-7 scale)		3	3		
Segment lighting (present/not present)		Not Present	Not Present		
Auto speed enforcement (present/not present)		Not Present	Not Present		
Calibration Factor, Cr		1	1.00		

This analysis can be repeated for the 11-ft. and the 12-ft. lanes by changing the lane width field value. The input data for the 11-ft. alternative is shown with the applicable field outlined in red.

Worksheet 1A - General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments						
General Information		**Location Information**				
Analyst	Analyst Name	Roadway	Example two-lane rural highway			
Agency or Company	--	Roadway Section	Example segment			
Date Performed	--	Jurisdiction	Anywhere, USA			
		Analysis Year	2015			
Input Data		**Base Conditions**	**Site Conditions**			
Length of segment, L (mi)		--	20			
AADT (veh/day)	AADTMAX = 17,800 (veh/day)	--	10,000			
Lane width (ft)		12	11			
Shoulder width (ft)		6	Right Shld:	0	Left Shld:	0
Shoulder type		Paved	Right Shld:	Paved	Left Shld:	Paved
Length of horizontal curve (mi)		0	0.000			
Radius of curvature (ft)		0	0			
Spiral transition curve (present/not present)		Not Present	Not Present			
Superelevation variance (ft/ft)		< 0.01	0			
Grade (%)		0	0			
Driveway density (driveways/mile)		5	5			
Centerline rumble strips (present/not present)		Not Present	Not Present			
Passing lanes [present (1 lane) / present (2 lane) / not present)]		Not Present	Not Present			
Two-way left-turn lane (present/not present)		Not Present	Not Present			
Roadside hazard rating (1-7 scale)		3	3			
Segment lighting (present/not present)		Not Present	Not Present			
Auto speed enforcement (present/not present)		Not Present	Not Present			
Calibration Factor, Cr		1	1.00			

STEP 2: Tabulate the predicted crash frequency for each lane width option.

Following input in Step 1, the spreadsheet tool automatically calculates the predicted number of crashes. To review the example results for the segment calculations, see the CMF results for the **Existing Condition** (shown in Worksheet 1B with the lane width CMF outlined in red) and predicted number of crashes (Worksheet 1C). These roadway segment worksheets are similar to the HSM worksheets with the same numbering format (see HSM p. 10-69).

Worksheet 1B - Crash Modification Factors for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CMF for Lane Width	CMF for Shoulder Width and Type	CMF for Horizontal Curves	CMF for Super-elevation	CMF for Grades	CMF for Driveway Density	CMF for Centerline Rumble Strips
CMF 1r	CMF 2r	CMF 3r	CMF 4r	CMR 5r	CMF 6r	CMF 7r
from Equation 10-11	from Equation 10-12	from Equation 10-13	from Equations 10-14, 10-15, or 10-16	from Table 10-11	from Equation 10-17	from Section 10.7.1
1.17	1.29	1.00	1.00	1.00	1.00	1.00

(8)	(9)	(10)	(11)	(12)	(13)
CMF for Passing Lanes	CMF for Two-Way Left-Turn Lane	CMF for Roadside Design	CMF for Lighting	CMF for Automated Speed Enforcement	Combined CMF
CMF 8r	CMF 9r	CMF 10r	CMF 11r	CMF 12r	CMF comb
from Section 10.7.1	from Equation 10-18 & 10-19	from Equation 10-20	from Equation 10-21	from Section 10.7.1	(1)x(2)x … x(11)x(12)
1.00	1.00	1.00	1.00	1.00	1.509

Worksheet 1C - Roadway Segment Crashes for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	$N_{spf\ rs}$	Overdispersion Parameter, k	Crash Severity Distribution	$N_{spf\ rs}$ by Severity Distribution	Combined CMFs	Calibration Factor, Cr	Predicted average crash frequency, $N_{predicted\ rs}$ (crashes/year)
	from Equation 10-6	from Equation 10-7	from Table 10-3 (proportion)	(2) TOTAL x (4)	(13) from Worksheet 1B		(5) x (6) x (7)
Total	53.435	0.01	1.000	53.435	1.51	1.00	80.613
Fatal and Injury (FI)	--	--	0.321	17.153	1.51	1.00	25.877
Property Damage Only (PDO)	--	--	0.679	36.283	1.51	1.00	54.736

The summary results are shown in Worksheet 1E (see HSM p. 10-70). The segment analysis results for the **Existing Condition** are shown below. These values are used in Step 3.

Worksheet 1E – Summary Results for Rural Two-Lane Two-Way Roadway Segments				
(1)	**(2)**	**(3)**	**(4)**	**(5)**
Crash Severity Level	Crash Severity Distribution (proportion)	Predicted average crash frequency (crashes/year)	Roadway segment length (mi)	Crash rate (crashes/mi/year)
	(4) from Worksheet 1C	(8) from Worksheet 1C		(3)/(4)
Total	1.000	80.6	20	4.0
Fatal and Injury (FI)	0.321	25.9	20	1.3
Property Damage Only (PDO)	0.679	54.7	20	2.7

The results for the **11 ft. lane width alternative** (Worksheet 1E) are shown below.

Worksheet 1E – Summary Results for Rural Two-Lane Two-Way Roadway Segments				
(1)	**(2)**	**(3)**	**(4)**	**(5)**
Crash Severity Level	Crash Severity Distribution (proportion)	Predicted average crash frequency (crashes/year)	Roadway segment length (mi)	Crash rate (crashes/mi/year)
	(4) from Worksheet 1C	(8) from Worksheet 1C		(3)/(4)
Total	1.000	70.7	20	3.5
Fatal and Injury (FI)	0.321	22.7	20	1.1
Property Damage Only (PDO)	0.679	48.0	20	2.4

The results for the **12 ft. lane width alternative** (Worksheet 1E) are shown below.

Worksheet 1E – Summary Results for Rural Two-Lane Two-Way Roadway Segments				
(1)	**(2)**	**(3)**	**(4)**	**(5)**
Crash Severity Level	Crash Severity Distribution (proportion)	Predicted average crash frequency (crashes/year)	Roadway segment length (mi)	Crash rate (crashes/mi/year)
	(4) from Worksheet 1C	(8) from Worksheet 1C		(3)/(4)
Total	1.000	68.8	20	3.4
Fatal and Injury (FI)	0.321	22.1	20	1.1
Property Damage Only (PDO)	0.679	46.7	20	2.3

STEP 3: Summarize the total number of crashes.

The analyst next created the following table that summarizes the total number of predicted crashes per year for the three scenarios (based on the assumed calibration factor of 1.0).

Alternative	Predicted Crashes per Year ($N_{predicted}$)		
	Total	Fatal and Injury	Property Damage Only
10-ft. Existing Lanes	80.6	25.9	54.7
11-ft. Lane Alternative	70.7	22.7	48.0
12-ft. Lane Alternative	68.8	22.1	46.7

The spreadsheet values do not include any rounding errors as would be expected when performing calculations by hand. As a result, these numbers will be similar, but may not exactly match predicted crashes calculated manually.

STEP 4: Summarize the total reduction in fatal and injury crashes.

The analyst's ultimate goal is to evaluate if the reduction in the number of fatal and injury crashes due to widening the lanes from 10 ft. to 11 ft., which would be substantially different from widening the lanes from 10 ft. to 12 ft. The following table summarizes this analysis.

Roadway Improvement Scenario	Number of Predicted Fatal and Injury Crashes per year		Predicted Reduction in the Number of Fatal and Injury Crashes	Reduction in the Number of Fatal and Injury Crashes (percent)
	Existing Width	Final Width		
Widening lanes from 10 to 11 ft.	26	23	3	12
Widening lanes from 10 to 12 ft.	26	22	4	15

FINDINGS

Interpreting the Results:

Based solely on an evaluation of the predicted number of crashes, a road with the characteristics described for the existing configuration can be expected to experience approximately 81 crashes per year, of which about 26 would involve a fatality or injury.

11-ft. Lanes: By adding 1 ft. of pavement to each lane (increasing to 11-ft. lanes), the analyst can expect to see an approximate 12 percent reduction in fatal and injury crashes per year.

12-ft. Lanes: Adding 2 ft. of pavement to each lane to create 12-ft. lanes leads to a predicted reduction of approximately 15 percent for fatal and injury crashes.

Based on these findings, the analyst concludes that widening lanes from 10-ft. to 12-ft. lanes will result in a 2 to 3 percent additional benefit when compared to widening from 10-ft. to 11-ft. lanes.

These calculations do not consider any local aspects of the roadway that may impact the benefits or costs associated with the increased lane widths. They also do not consider potential improvements in operational level of service associated with wider lanes.

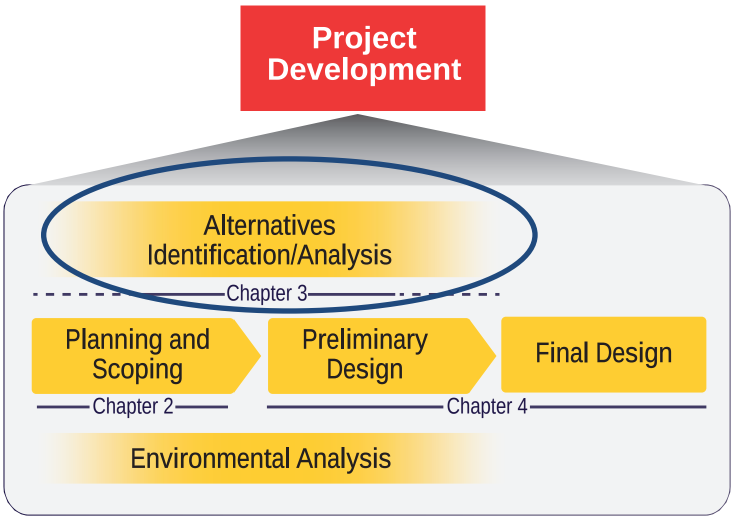
Possible Errors to Avoid:

The HSM spreadsheet simplifies the effort associated with using the predictive method. This planning analysis included several assumptions such as no horizontal curves and vertical grades that are two percent or less. The results, therefore, are suitable for comparative purposes but do not represent the final roadway geometric conditions. A more detailed analysis during the design stage would provide additional useful information about predicted crashes.

Alternative Analysis Approaches:

A common method for evaluating design alternatives is to use CMF comparisons that do not directly consider traffic volume. This approach is less reliable than the predictive methods, but can be used to evaluate alternatives when an SPF is not available for the condition. Although the analyst could not locate suitable CMFs for this application, many transportation agencies develop and maintain agency-specific CMFs that could be useful for similar analyses.

Chapter 3. Alternatives Analysis Applications



NOTE: Elements of ongoing life cycle activities are incorporated into Chapter 2 and 4 as appropriate

Figure 5. The Project Development Cycle and Corresponding Alternative Analysis Chapter

The *Alternatives Analysis* phase is typically conducted after a project need has been determined but before a solution has been identified. This phase may coincide with the *Planning and Scoping* phase and can extend into the early stages of *Preliminary Design*. The purpose of safety assessments in the Alternatives Analysis phase is to estimate the impact of each alternative on safety performance.

This chapter provides information to help select safety assessment methods suitable for addressing questions related to safety performance that arise during alternatives analysis tasks based upon the related task and project type. This section describes alternatives analysis-related tasks in two general categories:

- Alternative selection, and
- Interstate access justification and documentation.

The **alternative selection** activities generally occur following the preliminary planning activities and may be part of a corridor or project alternatives assessment. The objective of the safety assessment for this task is to estimate the safety performance of alternatives. This information can then be used to help refine the proposed alternatives as the project progresses into the preliminary and final design phases.

New or modified points of access to the Interstate system require **Interstate access justification and documentation** activities. The Federal Highway Administration's (FHWA) Policy on Access to the Interstate System provides the requirements, which include an analysis of the access point's impact on the safety performance of the Interstate facility and the local street system under both the current and the planned future traffic projections.

Table 7 identifies the five (out of a possible seven) safety assessment methods generally suitable for alternatives analysis tasks and the objective of the associated safety performance analysis. The check marks in Table 7 suggest suitable safety assessment methods for each related task and objective and, in some cases, are distinguished by project type. In this context, the term "suitable" means that the method generally has the capability to address the objective of the safety performance analysis with the data typically available for the related task and project type.

The following questions illustrate the types of questions the analyst may develop at the beginning of the safety assessment. These questions are based on the example problems included in this chapter.

1. How can the analyst calculate the estimated reduction in injury crashes for a facility's design alternatives?
2. How can the analyst compare the estimated crash frequency for two alternatives and the existing configuration?
3. How can the analyst estimate the difference in the average annual crash reduction for a 5-ft. shoulder compared to that of an 8-ft. shoulder over a 20-year period?
4. How can the analyst predict the estimated number of crashes for an interchange freeway loop ramp for a 3-year study period of 2013 to 2015 while directly considering the annual average daily traffic (AADT) in the analysis?

Table 8 shows that the level of predictive reliability generally increases as the methodology used becomes more complex. At the same time, the required resources for the analysis also will increase. In some cases, it may not be feasible to fully implement the preferred safety assessment method due to limitations in site information, crash data, traffic volume, or similar information. For example, the *Basic* safety assessment method for a *CMF Applied to Observed Crashes* cannot be executed if historic crash data is not available.

The approach for selecting a safety assessment method for alternatives evaluation and identification looks like this:

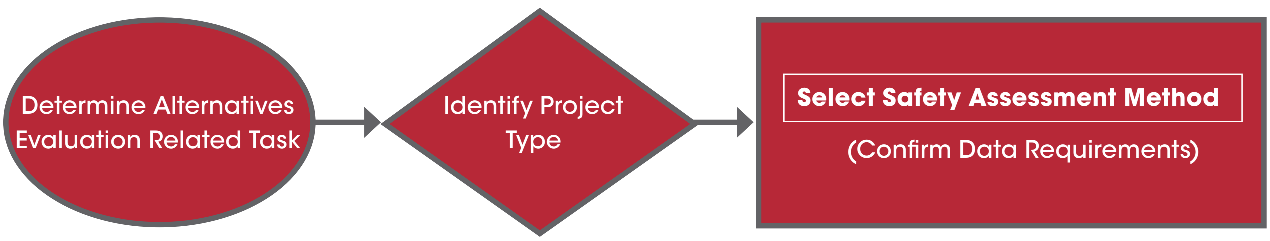


Table 8. Alternatives Evaluation and Identification Safety Assessment Objective

Related Task	Objective	Project Type	Basic				Intermediate		Advanced
			Site Evaluation or Audit	Historical Crash Data Evaluation	CMF Applied to Observed Crashes	CMF Relative Comparison	AADT Only SPF	SPF with CMF Adjustment	SPF with CMF Weighted with Observed Crashes
			Observed Crashes				Predicted Crashes		Expected Crashes
Safety Assessments:			Increasing Level of Predictive Reliability →						
Alternative Selection	Estimate the safety performance of alternatives	2R			✓	✓	✓	✓ [6]	
		3R, 4R			✓ [5]	✓	✓	✓ [9]	✓ [7]
		NL			✓	✓	✓	✓	
Interchange Access Justification	Estimate the safety performance impact of new or modified points of access	3R, 4R			✓	✓	✓	✓	✓ [8]
		NL					✓	✓	
Data Requirements:			Increasing Level of Resources Needed (Staff, Analysis, Time, etc.) →						
Road Type [1]			✓		✓	✓	✓	✓	✓
Road Characteristics [2]			✓		✓	✓		✓	✓
Traffic Volume (vpd) [3]							✓	✓	✓
Observed Crash Data [4]			✓	✓	✓				✓

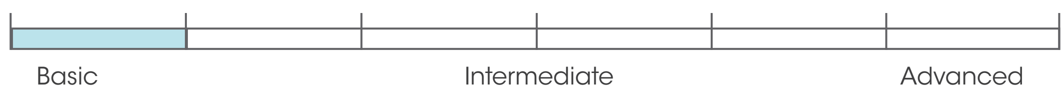
[1] Road Type refers to rural two-lane highway, rural multi-lane highway, urban freeway, etc. [2] Road Characteristics includes physical features such as lane widths, access density, etc. [3] Traffic Volume is the ADT or AADT in vehicles per day. [4] Observed Crash Data represents the historic crash data at the study site for a period of more than one year (preferably 3 to 5 years). [5] See Example Problem 3.1. [6] See Example Problem 3.2. [7] See Example Problem 3.3. [8] See Example Problem 3.4. [9] See Example Problem 5.2.

Note: Project type definitions are as follows: R2 = resurfacing existing facilities. R3 = major rehabilitation of an existing facility. R4 = major retrofit construction efforts. NL = highway construction at a new location. See Table 3 for a full definition of each Project Type. ✓ = suitable safety assessment method. ADT = average daily traffic. AADT = annual average daily traffic. CMF = crash modification factor. SPF = safety performance function. vpd = vehicles per day.

This chapter provides examples that demonstrate the selection process for the alternatives analysis safety assessment methods. These examples are simplified hypothetical problems intended to illustrate the thought process for selecting a method and demonstrate how to apply the method to answer the associated safety-based question.

3.1 Comparing Design Alternatives for Seven-Lane Urban Arterial

PROBLEM OVERVIEW	
Safety Assessment Method: CMF Applied to Observed Crashes	
Project Phase: **Alternative Analysis**	Project Type: **3R**
Related Task: **Alternative Selection**	**Calculation Method:** ☒ **Hand Calculated** ☐ **Tool Based**
Comments: This example problem demonstrates how to evaluate the comparative crash reductions due to alternative treatment options for urban arterial mid-block locations.	
LEVEL OF ANALYSIS	



Note: See table 3 for a full definition of Project Type designations.

PROBLEM DESCRIPTION

A city is redesigning a seven-lane arterial urban roadway. As part of the redesign, an analyst for the city is considering two design modifications that are also expected to help reduce the number of injury crashes. Based on their estimated effectiveness, the City may select one or both alternatives. The two alternatives under consideration are:

1. A raised median, and
2. Install automated speed enforcement.

The **Project Type** is *3R* and the **Related Task** is *Alternative Selection* for this activity. **How can the analyst calculate the estimated reduction in injury crashes for design alternatives on this facility?**

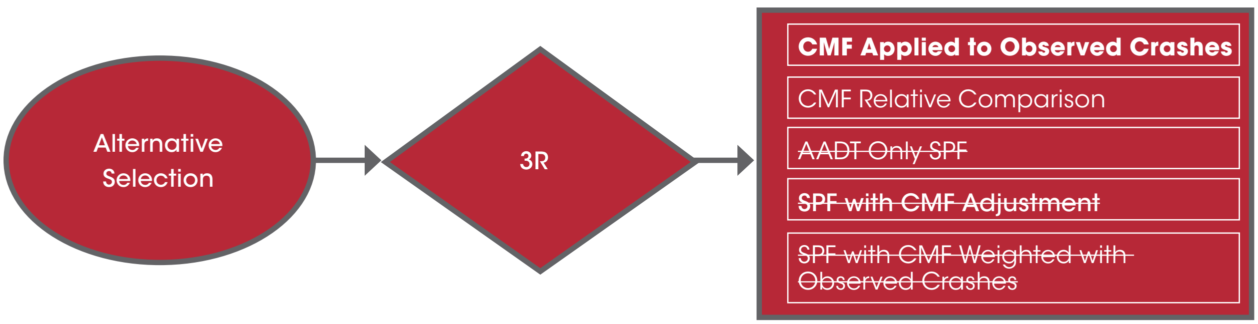
Summary of Available Data:

Currently, there are three travel lanes in each direction with a two-way left-turn lane. Over the past 5 years there have been a total of 362 injury crashes (72.4 average injury crashes per year) along the 1-mile segment. Fortunately, there have not been any fatal crashes at this location during the study period. The city does not have a current AADT value for this corridor.

ANALYSIS

Selecting Appropriate Safety Assessment Method(s):

The analyst for the city can evaluate the candidate safety assessment methods shown in Table 8 and contrast the table information with the 3R project type and the alternative selection task. There are five potential safety assessment methods for the analyst to consider: two basic, two intermediate, and one advanced. Because this assessment will likely require the use of the injury crash information as input into the evaluation, and the analyst's goal is to calculate the estimated reduction in injury crashes following construction of a raised median or implementation of corridor-specific traffic calming measures, a CMF-based method that accounts for the a change in road characteristics is appropriate. In addition, the city does not have a current AADT value for the corridor, so volume-based methods are not feasible at this time. These constraints result in the elimination of the SPF-based methods.



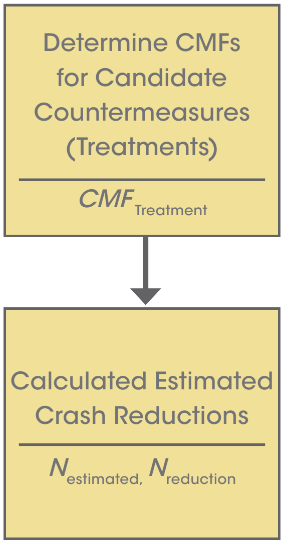
The two remaining safety assessment methods that use CMFs include *CMF Applied to Observed Crashes* and *CMF Relative Comparison*. Both methods can be considered.

The *CMF Applied to Observed Crashes* method can directly evaluate the proposed road design modification and the observed injury crashes. Using the observed crash injury frequency to represent the existing conditions and then applying an appropriate CMF, the analyst can estimate the average injury crash frequency for the proposed condition. For these reasons, the analyst selected the *CMF Applied to Observed Crashes* safety assessment method.

The *CMF Relative Comparison* approach does not explicitly consider the historical (observed) crashes along the corridor, but can be used for simple comparison purposes between the two proposed treatments. (Refer to Problem 2.2 for an example where the analyst elected to apply both methods.)

Linkage to the Highway Safety Manual (HSM):

Chapter 6 of the HSM (Section 6.2.2, pp. 6-3 to 6-9) summarizes contributing factors to consider when selecting appropriate countermeasures. Section 6.3 of the HSM (p. 6-9 to 6-10) provides guidance for selecting potential countermeasures. Finally, Part D (Volume 3) of the HSM and the FHWA sponsored CMF Clearinghouse (www.cmfclearinghouse.org) include a wide variety of potential improvements to consider.



Detailed Analysis:

The estimated average crash frequency is calculated by multiplying the appropriate CMF for the alternative treatment by the number of observed crashes that apply to the selected CMF.

STEP 1: Identify CMFs for each treatment

The CMF Clearinghouse (www.cmfclearinghouse.org) and the HSM are two resources for this activity. It is important to confirm that the CMFs have similar crash types and base conditions. The following table shows potential CMFs for the two candidate treatments. The CMF Clearinghouse star rating is based on a scale (1 to 5), where 5 stars represent the highest or most reliable rating. The standard error is one of the rating criteria for the star rating (small standard errors are preferred). The analyst should select CMFs (from the Clearinghouse) with the highest star rating, lowest standard error, and most applicable conditions for the scenario.

Proposed Treatment	CMF (S.E.)	Setting (Road Type and Traffic Volume)	Crash Severity	Source
Treatment –Raised Median				
Provide a Raised Median	0.78 (0.02)	★★★★★ Urban Arterial Multilane (Traffic Volume-unspecified)	Serious or Minor Injury	HSM Table 13-11, p. 13-14 and http://www.cmfclearinghouse.org/detail.cfm?facid=22
Treatment – Traffic Calming Measures				
Implement Automated Speed Enforcement Cameras	0.83 (0.01)	★★★★★ All Roads (Traffic Volume-unspecified)	Fatal, Serious Injury, Minor Injury	HSM Table 17-5, p. 17-6 and http://www.cmfclearinghouse.org/detail.cfm?facid=4583
Note: AADT = average annual daily traffic. CMF = crash modification factor. HSM = Highway Safety Manual. S.E. = standard error. ★ CMF Clearinghouse Star Rating.				

STEP 2: Calculate estimated crash reductions for each alternative.

The following tables contain the calculations for determining the injury crash reductions based on the two individual alternatives. This step can be used to eliminate any treatment combinations that increase the total number of crashes or that have very little effect on the number of injury crashes.

Alternative 1 – Install Raised Median:

Calculations	Notes
Total Injury Crashes:	
$N_{estimated(in\ jury)}=CMF_{Raisedmedian} \times N_{observed(injury)}$	Multiply CMF times observed number of injury crashes at location where $CMF_{Raised\ Median}=0.78$
$N_{estimated(injury)}=0.78 \times 72.4=56.5$ crashes	362 crashes in 5 years = 72.4 crashes/yr. Approximately 57 injury crashes if this treatment were implemented
$N_{reduction\ (per\ year)}=72.4-56.5=15.9$ crashes	Approximately 16 fewer injury crashes each year
CMF = crash modification factor.	

Alternative 2 – Implement Automated Speed Enforcement Cameras:

Calculations	Notes
Total Injury Crashes:	
$N_{estimated(injury)}=CMF_{Automated\ Speed\ Enforcement} \times N_{observed(injury)}$	Multiply CMF times observed number of injury crashes at location where $CMF_{Automated\ Speed\ Enforcement}=0.83$
$N_{estimated(injury)}=0.83 \times 72.4=60.0$ crashes	362 crashes in 5 years = 72.4 crashes/yr Approximately 60 injury crashes if this treatment were implemented
$N_{reduction\ (per\ year)}=72.4-60.0=12.4$ crashes	Approximately 12 to 13 fewer injury crashes each year
CMF = crash modification factor.	

FINDINGS

Interpreting the Results:

For this seven-lane arterial, the installation of a raised median is estimated to reduce the total number of injury crashes by approximately 16 per year, equivalent to an approximate 22 percent reduction in injury crashes. The application of automated speed enforcement is similarly estimated to reduce injury crashes but only by 12 to 13 per year (a 17 percent reduction). These findings demonstrate that the raised median will be more effective at reducing injury crashes than the implementation of automated speed enforcement cameras. The safety treatment effectiveness would then be considered in terms of cost to identify the preferred alternative. Because the two treatments target different crash types, the selection of both options may also be preferable for this location.

Possible Errors to Avoid:

The selections of CMFs that are not consistent with the conditions of the particular site of interest or the specific target crash type(s) will result in inaccurate estimated average crash frequencies. It is also important to understand that the application of multiple CMFs will not always have a cumulative effect on the estimated average crash frequency. The CMF Clearinghouse FAQ titled "How can I apply multiple CMFs" provides additional information and clarification (see http://www.cmfclearinghouse.org/faqs.cfm#q4).

Alternative Analysis Approaches:

This analysis focused on injury crashes only and did not consider total crashes. Extending the analysis to other crash types or to crash severity levels could provide additional insights. As previously noted, the use of a relative comparison of CMFs is an additional analysis that can be conducted with the available data. In addition, alternative evaluations could include an economic appraisal such as the benefit/cost ratio or a prioritization evaluation that uses an incremental benefit/cost ratio.

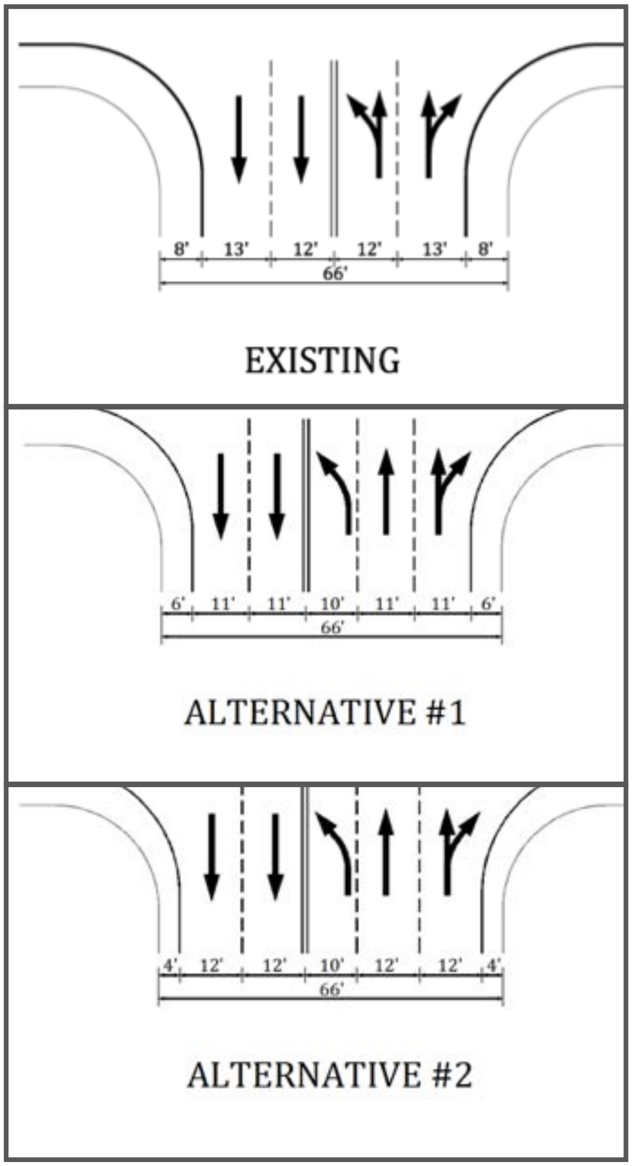
For this study, the city did not have current AADT information. It is feasible, however, that a reasonably accurate traffic volume estimate could be developed based on a combination of traffic volumes from prior years, development trends in the region, and use of comparison sites for volume estimation purposes. As the project shifts from the alternative analysis to the design phase, the analyst will assemble more detailed site-specific data including additional road characteristics. At that time, additional analysis procedures that incorporate CMFs, SPFs, or both can strengthen the overall analysis.

3.2 Predicting Crash Frequency for Alternative Intersection Turn Lane Options at Four-lane Rural Undivided Highways

PROBLEM OVERVIEW	
Safety Assessment Method: SPF with CMF Adjustment	
Project Phase: **Alternative Analysis**	Project Type: **2R**
Related Task: **Alternative Selection**	**Calculation Method:** ☐ **Hand Calculated** ☒ **Tool Based** *Hand calculated example for Alternative #1 included in Guide appendix.*
Comments: This example problem demonstrates how to conduct a safety assessment for an alternative intersection design for a rural, multilane highway and compare the estimated safety improvement to the existing configuration.	
LEVEL OF ANALYSIS	
Basic Intermediate Advanced	
Note: See table 3 for a full definition of Project Type designations.	

PROBLEM DESCRIPTION

A transportation analyst is finalizing the alternative evaluations for a four-lane undivided rural highway. The corridor has a two-way, stop-controlled intersection with a design speed of 50 mph and relatively little skew. Since about as many vehicles turn into the intersection as turn out of the intersection, the AADT is approximately 30,000 vpd on the major road (upstream and downstream of the intersection) and 5000 vpd on the minor road. The analyst is considering a low-cost redesign option that could be implemented within the currently proposed pavement limits. The change would apply to the roadway cross section that is designed to have 12-ft. inside lane widths, 13-ft. outside lanes, and 8-ft. paved shoulder widths. The analyst wants to identify a prospective lane configuration that will contribute to reducing the number of crashes at this intersection. He has identified two candidate left-turn lane alternatives to evaluate. The **Project Type** is *2R* and the **Related Task** is *Alternative Selection* for this effort. **How can the analyst compare the estimated crash frequency with Alternative #1, Alternative #2, and the existing configuration?**



Summary of Available Data:

The segment length that is influenced by the intersection can be assumed to extend approximately 1,000 ft. upstream and 1,000 ft. downstream of the intersection (measured from the intersection center line). This results in a total segment length of approximately 0.38 miles (or two approach segments of 0.19 miles each). Site features include:

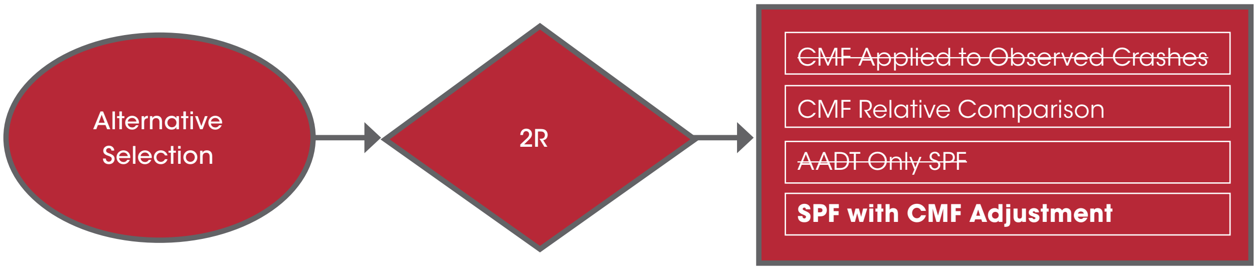
- No street lights.
- No automated speed enforcement.
- Side slopes 1:7 or flatter.

The schematic depicts the existing and two potential alternative lane configurations. As noted previously, the corridor is a four-lane rural, multilane, undivided highway with a two-way stop control (on the minor legs). At this time, historical crash data is not available for the existing intersection.

ANALYSIS

Selecting Appropriate Safety Assessment Method(s):

The analyst can first review the potential safety assessment methods shown in Table 8. The Alternative Selection task and the 2R project type are associated with two basic and two intermediate methods. For this assessment, the analyst intends to compare the number of estimated crashes for two alternative intersection lane configurations and contrast these values to the number of estimated crashes for the current intersection approach. Since a CMF-based method enables the specific consideration of a change in road characteristics, the safety assessment methods that use CMFs are applicable for this analysis. Traffic volume information is also available for the major and minor road, and so a safety assessment method that is volume-based can be used. Based on these considerations, the AADT-Only SPF method can be eliminated from further consideration since it does not directly capture changes in road characteristics. As previously noted, the historical (observed) crash data is not currently available for this location, so the CMF Applied to Observed Crashes method should also be eliminated.



The two remaining safety assessment methods include *CMF Relative Comparison* and *SPF with CMF Adjustment.* The analyst may elect to use one or both of these methods. The ability to directly incorporate the traffic volume into the analysis, however, strengthens the evaluation, so the analyst elects to use the SPF-based method. Because the data requirements are not substantially different for the *CMF Relative Comparison* option, this method could be an effective way to narrow down candidate lane and shoulder width options and to calculate a simple estimate of the effect for changing each of the individual road characteristics before conducting the more complicated intermediate safety assessments.

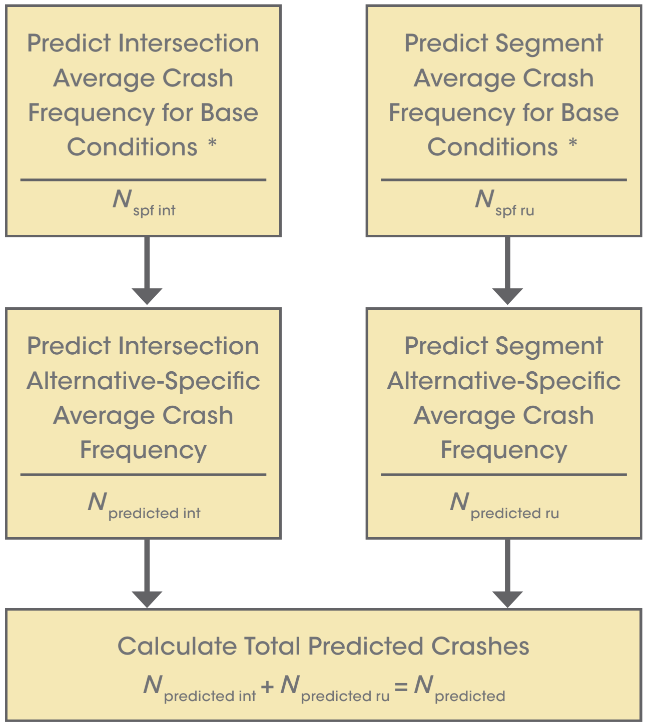
Linkage to the HSM:

The HSM can be used to estimate the number of predicted crashes for a rural, multilane highway by applying the procedures introduced in HSM Chapter 11 (pp. 11-1 to 11-71). By determining the predicted total and the fatal and injury crashes for the varying shoulder and lane width scenarios, the analyst can calculate the predicted crash reduction percentage for the alternative intersection approach configurations. The HSM provides manual calculations, but a spreadsheet tool is available and can be used to simplify this analysis.

Detailed Analysis:

To use the HSM predictive method, the analyst evaluates the intersection-related crashes (e.g., angle or turning crashes) separately from segment-related crashes (e.g., run-off-road) and then adds the crashes for each to compute the combined number of crashes for the roadway segment that overlaps an intersection.

This will provide the number of predicted crashes (estimated for a type of facility). The predictive equations (SPFs) can be locally derived, or the analyst can use the HSM equations. If the analyst uses the SPFs from the HSM, the SPFs will need to be calibrated for local conditions, where possible. To perform a relative comparison between two options for the same location, the procedure outlined in the HSM can be used and a calibration value of 1.0 assumed.



*Intersection base condition:
No turn lanes (HSM p.11-20)

Segment base conditions:
6′ shoulders & lanes ≥ 12′ (HSM p. 11-14)

The analyst would like to evaluate the estimated reduction in crashes associated with two prospective alternative lane and shoulder width configurations for an intersection approach. The following analysis provides detailed information for the tool-based evaluation for Alternative #1. The analyst conducted a similar analysis for Alternative #2 (results only shown for this scenario). Alternative #1 hand calculations are included in the Appendix.

This example uses the rural undivided multilane predictive procedures located in Chapter 11 of the HSM.

The following steps provide the calculations based on using the self-calculating HSM "Smart Spreadsheets" available for download at: http://www.highwaysafetymanual.org/Pages/tools_sub.aspx#4. For this example problem, the analyst should use the "HSM prediction rural multilane" spreadsheet tool.

STEP 1: Input the known data for each of the alternatives stated. Both intersection and segment data should be input as follows:

Intersection Input Data:

For intersection analysis, input data in the top section (Worksheet 2A) of the tab named "Rural Multilane Intersection." The **existing design** input data is shown as follows:

Worksheet 2A – General Information and Input Data for Rural Multilane Highway Intersections			
General Information		**Location Information**	
Analyst	PDP Analyst	Roadway	Example 4-lane undivided Rural Highway
Agency or Company	--	Section	Example minor road with stop control
Date Performed	--	Jurisdiction	Anywhere, USA
		Analysis Year	2015
Input Data		**Base Conditions**	**Site Conditions**
Intersection type (3ST, 4ST, 4SG)		--	4ST
$AADT_{major}$ (veh/day)	$AADT_{MAX}$ = 78,300 (veh/day)	--	30,000
$AADT_{minor}$ (veh/day)	$AADT_{MAX}$ = 7,400 (veh/day)	--	5,000
Intersection skew angle (degrees)		0	0
Number of non-STOP-controlled approaches with left-turn lanes (0, 1, 2)		0	0
Number of non-STOP-controlled approaches with right-turn lanes (0, 1, 2, 3, or 4)		0	0
Intersection lighting (present/not present)		Not Present	Not Present
Calibration Factor, C_i		1.00	1.00

The color coding indicates data that must be typed (yellow) and data that can be selected from pull-down lists (blue). For **Alternative #1**, the number of non-stop-controlled turn-lanes should be changed to two as shown in the red circle in the following graphic:

Worksheet 2A – General Information and Input Data for Rural Multilane Highway Intersections			
General Information		**Location Information**	
Analyst	PDP Analyst	Roadway	Example 4-lane undivided Rural Highway
Agency or Company	--	Section	Example minor road with stop control
Date Performed	--	Jurisdiction	Anywhere, USA
		Analysis Year	2015
Input Data		**Base Conditions**	**Site Conditions**
Intersection type (3ST, 4ST, 4SG)		--	4ST
$AADT_{major}$ (veh/day)	$AADT_{MAX}$ = 78,300 (veh/day)	--	30,000
$AADT_{minor}$ (veh/day)	$AADT_{MAX}$ = 7,400 (veh/day)	--	5,000
Intersection skew angle (degrees)		0	0
Number of non-STOP-controlled approaches with left-turn lanes (0, 1, 2)		0	2
Number of non-STOP-controlled approaches with right-turn lanes (0, 1, 2, 3, or 4)		0	0
Intersection lighting (present/not present)		Not Present	Not Present
Calibration Factor, C_i		1.00	1.00

Segment Input Data:

For segment analysis, input data in the top section (Worksheet 1A) of the "Rural Undivided Multilane Seg" tab. The existing design input data is shown as follows:

Worksheet 1A – General Information and Input Data for Rural Multilane Roadway Segments			
General Information		**Location Information**	
Analyst	PDP Analyst	Roadway	Example 4-lane undivided Rural Highway
Agency or Company	--	Section	1.0-1.38
Date Performed	--	Jurisdiction	Anywhere, USA
		Analysis Year	2015
Input Data		**Base Conditions**	**Site Conditions**
Roadway type (divided / undivided)		Undivided	Undivided
Length of segment, L (mi)		–	0.38
AADT (veh/day)	$AADT_{MAX}$ = 33,200 (veh/day)	–	30,000
Lane width (ft)		12	12
Shoulder width (ft) - right shoulder width for divided		6	8
Shoulder type - right shoulder type for divided		Paved	Paved
Median width (ft) - for divided only		30	Not Applicable
Side Slopes - for undivided only		1:7 or flatter	1:7 or Flatter
Lighting (present/not present)		Not Present	Not Present
Auto speed enforcement (present/not present)		Not Present	Not Present
Calibration Factor, C_r		1.00	1.00

Note that the segment length is 0.19 miles. Since the AADT does not change from one side of the intersection to the other, this calculation can either be performed as two individual segments 0.19 miles long (and then the results would be added), or a segment of 0.38 miles can be used that extends the entire length of the study section (as demonstrated in this input example).

The **Alternative #1** input data for the segment is demonstrated in the following graphic:

Worksheet 1A – General Information and Input Data for Rural Multilane Roadway Segments			
General Information		**Location Information**	
Analyst	PDP Analyst	Roadway	Example 4-lane undivided Rural Highway
Agency or Company	--	Section	1.0-1.38
Date Performed	--	Jurisdiction	Anywhere, USA
		Analysis Year	2015
Input Data		**Base Conditions**	**Site Conditions**
Roadway type (divided / undivided)		Undivided	Undivided
Length of segment, L (mi)		–	0.38
AADT (veh/day)	$AADT_{MAX}$ = 33,200 (veh/day)		30,000
Lane width (ft)		12	11
Shoulder width (ft) - right shoulder width for divided		6	6
Shoulder type - right shoulder type for divided		Paved	Paved
Median width (ft) - for divided only		30	Not Applicablepplicable
Side Slopes - for undivided only		1:7 or flatter	1:7 or Flatter
Lighting (present/not present)		Not Present	Not Present
Auto speed enforcement (present/not present)		Not Present	Not Present
Calibration Factor, Cr		1.00	1.00

STEP 2: Following input in Step 1, the spreadsheet tools automatically calculated the predicted number of crashes. To review example results for the intersection calculations, see the CMF results for **Alternative #1** (shown in Worksheet 2B) and predicted number of crashes (Worksheet 2C):

Worksheet 2B – Crash Modification Factors for Rural Multilane Highway Intersections					
(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	CMF for Intersection Skew Angle (CMF 1i)	CMF for Left-Turn Lanes (CMF 2i)	CMF for Left-Turn Lanes (CMF 3i)	CMF for Left-Turn Lanes (CMF 4i)	Combined CMF (CMF COMB)
	from Equations 11-18 or 11-20 and 11-19 or 11-21	from Table 11-22	from Table 11-23	from Equation 11-22	(2)*(3)*(4)*(5)
Total	1.00	0.52	1.00	1.00	0.52
Fatal and Injury (FI)	1.00	0.42	1.00	1.00	0.42
Note: The 4-leg Signalized Intersection (4SG) models do not have base conditions and so can only be used for estimation purposes. As a result, there are not CMFs provided for the 4SG condition.					

Worksheet 2C – Intersection Crashes for Rural Multilane Highway Intersections								
(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients			N spf int	Overdispersion Parameter, k	Combined CMFs	Calibration Factor, Ci	Predicted average crash frequency, N predicted int
	from Table 11-7 or 11-8			from Equation 11-11 or 11-12	from Table 11-7 or 11-8	from (6) of Worksheet 2B		(3)*(5)*(6)
	a	b	c or d (4SG)					
Total	-10.008	0.848	0.448	12.803	0.494	0.52	1.00	6.658
Fatal and Injury (FI)	-11.554	0.888	0.525	7.940	0.742	0.42	1.00	3.335
Fatal and Injury[a] (FI[a])	-10.734	0.828	0.412	3.709	0.655	0.42	1.00	1.558
Property Damage Only (PDO)	--	--	--	--	--	--	--	$(7)_{TOTAL} - (7)_{FI}$ 3.323
NOTE: [a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.								

Summary results are shown in Worksheet 2E. The intersection analysis results for **Alternative #1** are shown below. The shaded region identifies the summary data used in Step 3.

Worksheet 2E – Summary Results for Rural Multilane Highway Intersections	
(1)	**(2)**
Crash Severity Level	**Predicted average crash frequency (crashes / year)**
	(7) from Worksheet 2C
Total	6.66
Fatal and Injury (FI)	3.33
Fatal and Injury[a] (FI[a])	1.56
Property Damage Only (PDO)	3.32
NOTE: [a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.	

Similarly, the Alternative #1 spreadsheet results for segment calculations (Worksheets 1B, 1C, and 1E) are shown as:

Worksheet 1B (b) – Crash Modification Factors for Rural Multilane Undivided Roadway Segments					
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
CMF for Lane Width	CMF for Shoulder Width	CMF for Side Slopes	CMF for Lighting	CMF for Automated Speed Enforcement	Combined CMF
CMF 1ru	CMF 2ru	CMF 3ru	CMF 4ru	CMF 5ru	CMF comb
from Equation 11-13	from Equation 11-14	from Table 11-14	from Equation 11-15	from Section 11.7.1	(1)*(2)*(3)*(4)*(5)
1.01	1.00	1.00	1.00	1.00	1.01

Worksheet 1C (b) – Roadway Segment Crashes for Rural Multilane Undivided Roadway Segments									
(1)	**(2)**			**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Crash Severity Level	**SPF Coefficients**			**N spf rs(u)**	**Overdispersion Parameter, k**	**Combined CMFs**	Calibration Factor, Cr	**Predicted average crash frequency, N**
	from Table 11-3			from Equation 11-7	from Equation 11-8	(6) from Worksheet 1B (b)		(3)*(5)*(6)
	a	b	c					
Total	-9.653	1.176	1.675	4.494	0.493	1.01	1.00	4.543
Fatal and Injury (FI)	-9.410	1.094	1.796	2.461	0.437	1.01	1.00	2.487
Fatal and Injury[a] (FI[a])	-8.577	0.938	2.003	1.133	0.355	1.01	1.00	1.146
Property Damage Only (PDO)	--	--	--	--	--	--	--	$(7)_{TOTAL} - (7)_{FI}$ 2.055
NOTE: [a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.								

Worksheet 1E – Summary Results for Rural Multilane Roadway Segments			
(1)	(2)	(3)	(4)
Crash Severity Level	Predicted average crash frequency (crashes / year)	Roadway segment length (mi)	Crash rate (crashes/mi/year)
	(7) from Worksheet 1C (a) or (b)		(2)/(3)
Total	4.54	0.4	12.0
Fatal and Injury (FI)	2.49	0.4	6.5
Fatal and Injury[a] (FI[a])	1.15	0.4	3.0
Property Damage Only (PDO)	2.06	0.4	5.4
NOTE: [a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.			

STEP 3: Summarize the total number of crashes.

This activity can be performed manually or summarized on the "Rural Multilane Site Total" sheet (note that the analyst will need to customize this table to link to individual worksheets as needed). The Alternative #2 results are also depicted in the table. The results are summarized as follows:

	Total Crashes per Year			FI Crashes per Year		
Alternative	Intersection Crashes	Segment Crashes	Predicted Crashes	Intersection Crashes	Segment Crashes	Predicted Crashes
Existing	12.80	4.34	17.14 (say 18)	7.94	2.37	10.31 (say 11)
Alternative #1	6.66	4.54	11.20 (say 12)	3.33	2.49	5.82 (say 6)
Alternative #2	6.66	4.68	11.33 (say 12)	3.33	2.56	5.89 (say 6)
Comparison of Existing and Alternative #1 Predicted Crash Reductions						
Difference	12.80 – 6.66 = 6.14	4.34 – 4.54 = -0.20	17.14 – 11.20 = 5.94 (say 6)	7.94 – 3.33 = 4.61	2.37 – 2.49 = -0.12	10.31 – 5.82 = 4.49 (say 5)
Percent Reduction	48.0%	-4.6%	35%	58.1%	-5.06%	43%
Comparison of Existing and Alternative #2 Predicted Crash Reductions						
Difference	12.80 – 6.66 = 6.14	4.34 – 4.68 = -0.34	17.14 – 11.33 = 5.81 (say 6)	7.94 – 3.33 = 4.61	2.37 – 2.56 = -0.19	10.31 – 5.89 = 4.42 (say 5)
Percent Reduction	48.0%	-7.8%	35%	58.1%	-8.02%	43%
Note: FI = fatality and injury						

The spreadsheet values do not include any rounding errors as would be expected when performing hand calculations. As a result, these numbers should be similar but may not exactly match predicted crashes calculated manually.

FINDINGS

Interpreting the Results:

Based solely on an evaluation of the predicted number of crashes, a road with the characteristics described for the existing design configuration can be expected to experience approximately 18 crashes per year, of which about 11 would involve an injury. For locations where a left-turn lane is added with standard-use lanes of 11-ft. wide and shoulder widths of 6-ft. wide (Alternative #1), the total number of predicted crashes per year reduces to approximately 12 with 6 involving an injury. In contrast, an approach with a left-turn lane, standard-use lane widths of 12-ft., but shoulder widths of 4-ft. (Alternative #2) similarly results in 12 predicted crashes with 6 involving an injury.

For the conditions outlined in this problem, the addition of a left-turn lane provides added value as it can be expected to result in a reduction of approximately 35 percent in the total number of crashes and approximately a 43 percent reduction in FI crashes. The two alternatives considered provide very similar results, and so the analyst can conclude that either Alternative #1 or Alternative #2, if constructed, will result in the predicted crash reductions.

These calculations are based only on predicted crash performance, but do not consider potential operational issues. For example, vehicles positioned in the narrow 10-ft. left-turn lane as shown for both alternatives may encroach on the adjacent travel lane.

While this example focused on left-turn lane options, it is advisable for an analyst to conduct similar safety assessments for right-turn treatments.

Possible Errors to Avoid:

The HSM procedures require the analyst to understand how the SPFs and CMFs equate to the base conditions associated with the procedure. Incorrect use of these values can introduce erroneous results. This example compared the crash predictions, and so the use of a calibration factor with a value of 1.0 can be used for comparison purposes. If the analyst would like to record findings as crash frequency instead of percent reduction in the number of crashes, calibrated SPFs with known calibration factors should be used for the analysis. A more detailed analysis during the design phase would provide additional useful information about predicted crashes.

Alternative Analysis Approaches:

A common method for evaluating design alternatives is to use CMF comparisons that do not directly consider traffic volume. This approach is less reliable than the predictive methods, but can be used to evaluate alternatives when an SPF is not available for the condition or when a simple comparison between two alternatives is all that is needed.

If the project progresses to the design stage, and should the historical (observed) crash data become available at that time, the analyst could use the advanced safety assessment method to further evaluate existing conditions and future designs with minor changes. Future configurations that include major changes are not suitable for the SPF with CMF Weighted with Observed Crashes method as the observed crashes would no longer be representative of the new configuration.

3.3 Calculating Expected Crashes for Rural Two-Lane Highways

PROBLEM OVERVIEW	
Safety Assessment Method: SPF with CMF Weighted with Observed Crashes	
Project Phase: **Alternative Analysis**	Project Type: **3R**
Related Task: **Alternative Selection**	**Calculation Method:** ☐ **Hand Calculated** ☒ **Tool Based**
Comments: This example problem demonstrates how to use the IHSDM to calculate the expected number of crashes for alternative cross-section geometric options for a rural two-lane highway.	

LEVEL OF ANALYSIS

Basic — Intermediate — Advanced

Note: See table 3 for a full definition of Project Type designations.
Source: This example problem is based on a case study for Arizona SR 264 Burnside Junction to Summit posted at http://www.fhwa.dot.gov/design/pbpd/case_studies.cfm.

PROBLEM DESCRIPTION

As part of a 34.5-mile long, two-lane rural highway reconstruction project to enhance a developing freight route, a transportation agency would like to evaluate the estimated safety implications of two alternative designs. The current two-lane rural highway has intermittent right- and left-turning lanes and infrequent passing lanes. The existing horizontal and vertical geometry information has been acquired using a survey and was confirmed against the original as-built plans. As part of the project, the transportation agency has included the geometric information into a civil design software package. The two alternatives currently under consideration are defined as Alternative A and Alternative B.

Alternative A – Widen Existing Roadway to 34-ft.

The purpose of Alternative A is to widen the existing roadway to 34-ft. to provide 5-ft. shoulders by widening the existing 1-ft. shoulders to 5-ft. shoulders. The existing travel lane width would remain 12 ft. The improvements would include adding center line and shoulder rumble strips, flattening side slopes, installing guardrail, extending drainage structures, and providing delineators and recessed pavement markers.

Alternative B – Widen Existing Roadway to 40-ft.

The purpose of Alternative B is to widen the existing roadway to 40-ft. to provide full-width shoulders. The proposed improvements would widen the existing 1-ft. shoulders to 8-ft. shoulders. The existing travel lane width would remain 12-ft. The improvements would include adding center line and shoulder rumble strips, flattening side slopes, installing guardrail, extending drainage structures, and providing delineators and recessed pavement markers.

The **Project Type** is *3R* and the Related Task is Alternative Selection. How can the analyst estimate the difference in the average annual crash reduction for a 5-ft. shoulder compared to that of an 8-ft. shoulder over a 20-year period?

Summary of Available Data:

The 2010 AADT, 4-year crash counts, and the manner of collision are provided in the following tables. The first table also shows projected AADT values for the design year 2036.

AADT (vpd)		
Mile Post (MP)	**2010 AADT**	**2036 Projected AADT**
MP 441.02-MP 446.18	5,010	9,900
MP 446.18-MP 446.91	6,429	12,150
MP 446.91-MP 448.37	5,199	7,350
MP 448.37-MP 475.50	4,102	5,400
Note: AADT = average annual daily traffic, vpd = vehicles per day		

Crash Data (2007-2010)	
Crash Severity	**Number of Crashes**
Fatal	6
Incapacitating Injury	3
Non-Incapacitating Injury	1
Possible Injury	24
No Injury (PDO)	22
Total Crashes	56
Note: PDO = property damage only	

Manner of Collision (2007-2010)	
Manner of Collision	**Number of Crashes**
Head On	2
Left Turn	3
Rear End	13
Angle (Other than Left Turn)	5
Sideswipe (Opposite Direction)	2
Sideswipe (Same Direction)	4
Single Vehicle	27
Total Crashes	56

The following table shows the road characteristics for the various configurations. For informational purposes, the table shows the base conditions associated with a rural two-lane highway in the HSM. Notable variations from the base conditions include the shoulder width, roadside hazard rating, and center line rumble strips.

Road Characteristics (Existing and Proposed) for the Rural Two-Lane, Two Way Road

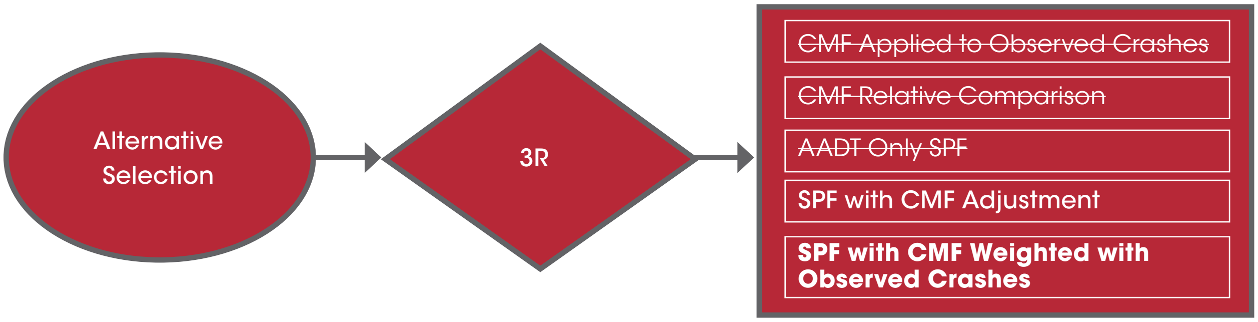
Roadway Element	Existing	Alternative A	Alternative B	HSM Base Condition
Lane width (ft)	12	12	12	12
Shoulder width (ft)	1	5	8	6
Shoulder type	Paved	Paved	Paved	Paved
Roadside hazard rating	Varies (6 or 7 most frequent)	Varies (1 or 2 most frequent)	Varies (1 or 2 most frequent)	3
Driveway Density	Per survey	Per survey	Per survey	≤ 5 per mile
Horizontal curves: length, radius, and presence or absence of spiral transitions	Per best fit alignment	Per best fit alignment (match existing)	Per best fit alignment (match existing)	None
Horizontal curves: Superelevation	Per as-builts & survey	Per as-builts & survey (match existing)	Per as-builts & survey (match existing)	None
Grades	Per as-builts & survey	Per as-builts & survey (match existing)	Per as-builts & survey (match existing)	≤ 3%
Center line rumble strips	None	Present	Present	None
Passing lanes	Per survey	Per survey (match existing)	Per survey (match existing)	None
Two-way left-turn lanes	Per survey	Per survey (match existing)	Per survey (match existing)	None
Lighting	Present at Intersection	Present at Intersection (match existing)	Present at Intersection (match existing)	None
Automated speed enforcement	None	None	None	None

HSM = Highway Safety Manual.

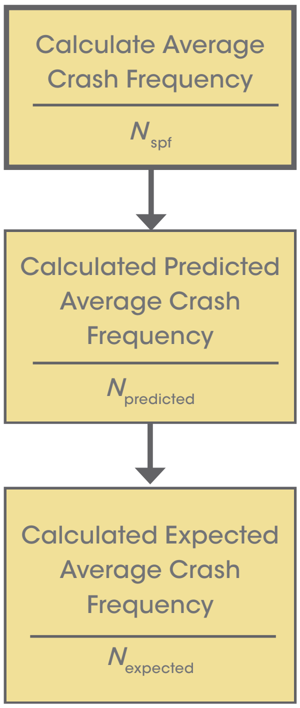
ANALYSIS

Selecting Appropriate Safety Assessment Method(s):

The analyst can first inspect Table 8 to identify potential safety assessment methods for a 3R project type and the alternative selection task (see Table 3 for a full definition of the 3R project type). Five potential methods (two basic, two intermediate, and one advanced) may be considered for this analysis. Because the alternatives require comparisons of varying geometric characteristics, an assessment method that includes CMFs is appropriate (thus eliminating the AADT-Only SPF). The study corridor is lengthy (almost 35 miles long) and the traffic volume and road characteristics vary throughout the corridor. Because the analyst would like to verify that the increase in traffic volume is considered in the analysis, the two basic methods are eliminated from consideration.



The remaining two potential safety assessment methods use procedures specific to the HSM. The *SPF with CMF Adjustment* can be used to evaluate the predicted number of crashes along a corridor with similar characteristics to the study site. The *SPF with CMF Weighted with Observed Crashes* includes the crash history so that the safety assessment includes consideration of the recent crash history at the location. Both of these safety assessment methods can be used.



To help select the method, the analyst reviews the length of the corridor and the varying road characteristic information and notes that the alignment information is already included in a civil design software package. The proposed analysis is impractical to conduct using hand calculations. Both of the methods can be performed, however, using the HSM "Smart Spreadsheets" and the FHWA IHSDM analysis software. The IHSDM has an added benefit in that it can directly import road characteristic data from a civil design software program with little to no additional manual entry. The selection of IHSDM, therefore, will enable the use of an advanced safety assessment method while also streamlining the analysis process. The web address to acquire this free software tool is provided in the "Detailed Analysis" section of this problem.

Linkage to the HSM:

The HSM can be used to estimate the number of predicted crashes for a rural, two-lane highway by applying the procedures introduced in HSM Chapter 10 (pp. 10-1 to 10-74). By determining predicted crashes, the analyst can estimate how many crashes may be expected for a specific road type with varying road conditions (in this case the curve radii and traffic volumes). Once the predicted number of crashes is known, the expected number of crashes for a specific site can be calculated by applying the Empirical Bayes Method summarized in HSM, Part C (Volume 2), pp. A-15 to A-23.

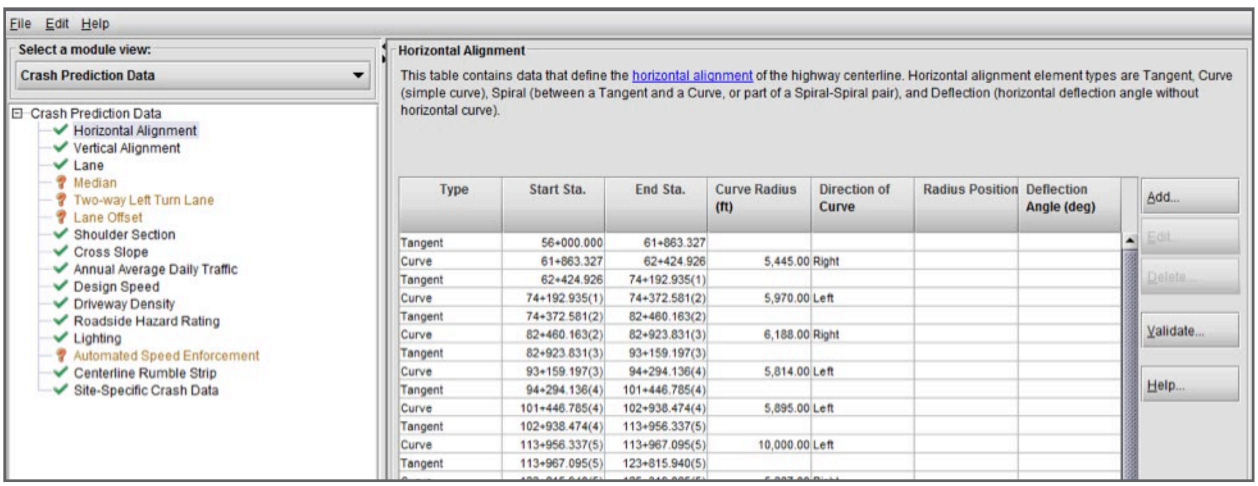
Detailed Analysis:

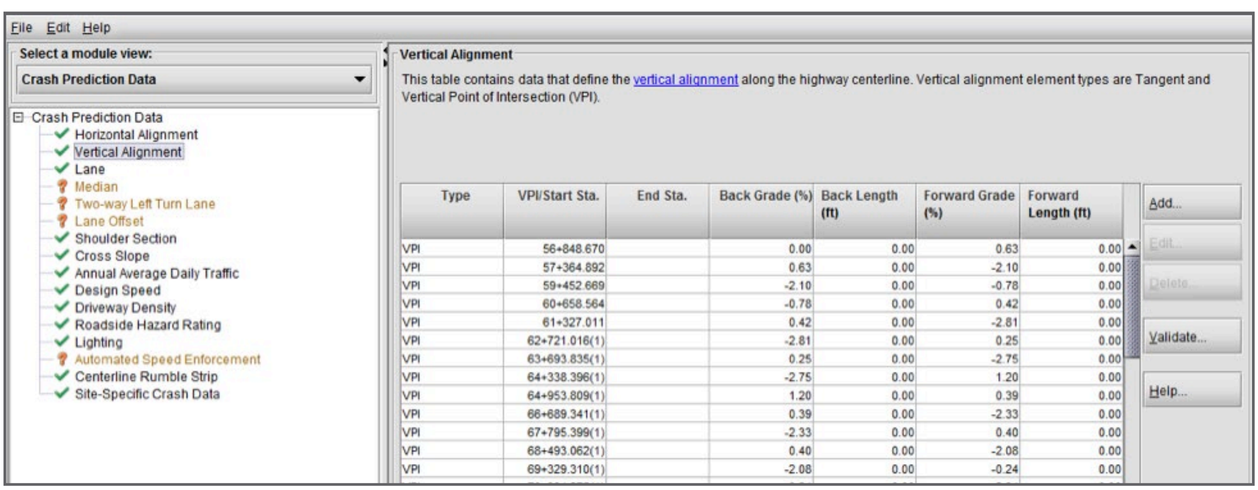
The IHSDM analysis software can be used to calculate the expected average crash counts for the existing conditions and the given alternatives for the 20-year study period. If a State has calibrated the SPF contained in the HSM or has developed its own SPF that has a similar equation format (functional form) as the HSM equation, these values can be directly inserted into the IHSDM.

To calculate the expected average crash frequency for the existing conditions and the proposed alternatives, download the IHSDM analysis software. This product can be downloaded free of charge at http://www.ihsdm.org. Two training courses are available through the Federal Highway Administration's National Highway Institute for those that would like to learn more about how to use the software (http://www.nhi.fhwa.dot.gov/training/course_search.aspx?tab=0&key=IHSDM&res=1).

STEP 1: Input (or import) the vertical and horizontal roadway alignments into IHSDM.

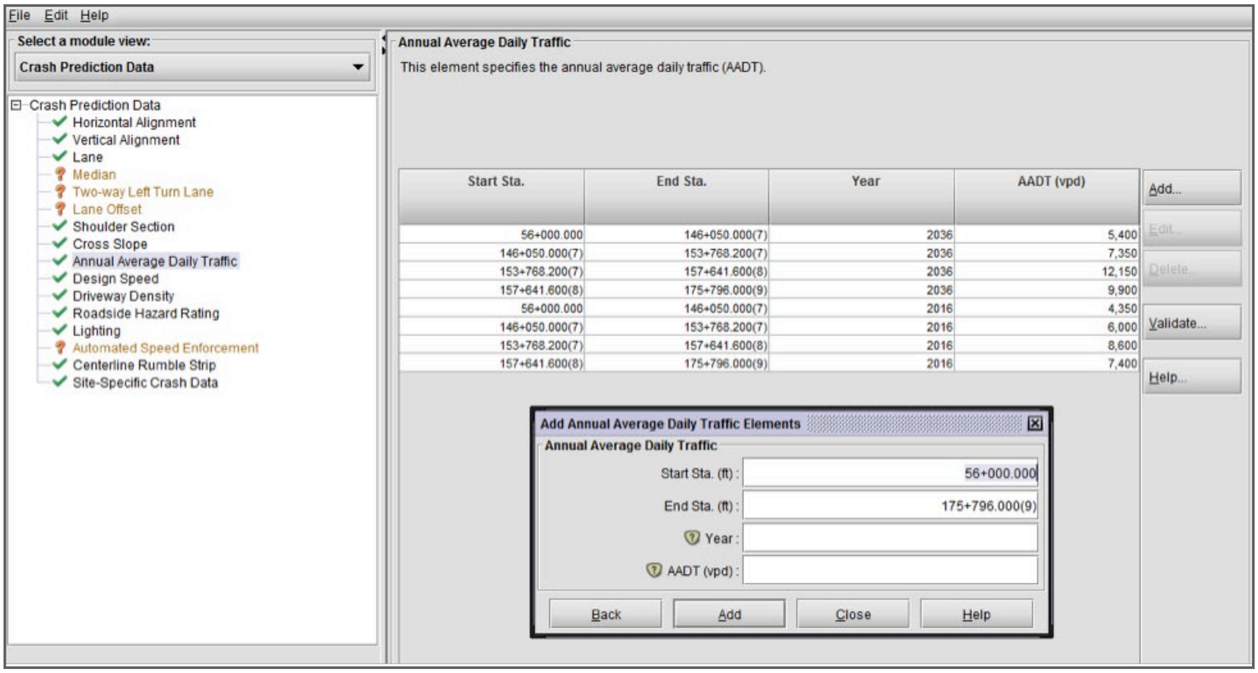
The following figures are screen shots of what the alignments should look like following input into IHSDM.



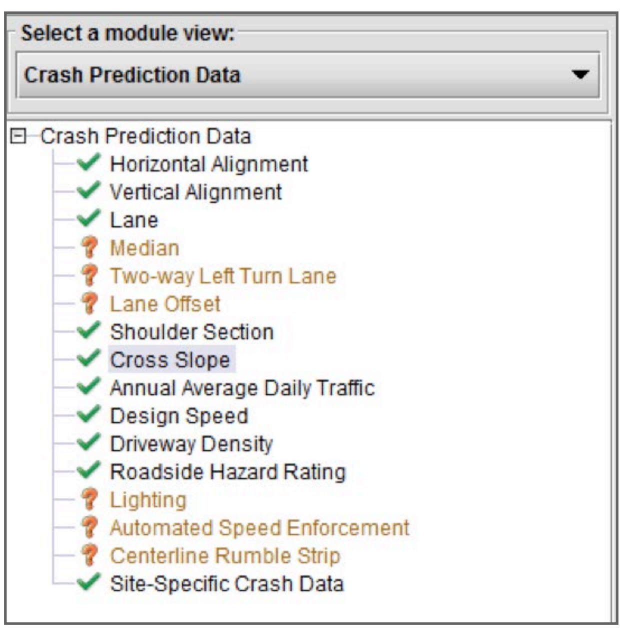


STEP 2: Input all remaining crash prediction data for the existing conditions.

Like the alignment data, all other data is entered using the roadway stationing. The following figure shows what the input data for AADT looks like.



The following figure shows all data that must be entered before running the Crash Prediction Module. Items with a green check show that required data was entered. An orange question mark represents data for which default values are being used because the analyst did not provide site specific information. A red "X" will appear by the data set if the required data is missing. This process of creating or importing a new highway must be followed for each alternative.



STEP 3: Run the crash prediction analysis within IHSDM.

IHSDM has the ability to create a summary, report, raw results, graphs, and spreadsheets of the analysis. The following table shows a summary of the results for expected crashes based on output from the IHSDM software analysis.

2016-2036 Expected Total Number of Crashes			
Crash Severity Levels	**Existing Conditions** **1-ft. Shoulder**	**Alternative A** **5-ft. Shoulders**	**Alternative B** **8-ft. Shoulders**
Total	636.38	531.58	504.16
Fatal and Injury	283.40	230.45	216.80
Property Damage Only	352.98	301.13	287.36
Reduction in Total Crashes	NA	104.80 (say 105)	132.22 (say 133)

2016-2036 Expected Average Annual Crash Frequency			
Crash Severity Levels	**Existing Conditions** **1-ft. Shoulder**	**Alternative A** **5-ft. Shoulders**	**Alternative B** **8-ft. Shoulders**
Total	31.82	26.58	25.21
Fatal and Injury	14.17	11.52	10.84
Property Damage Only	17.65	15.05	14.37
Reduction in Total Crashes	NA	5.24 (say 6)	6.61 (say 7)

FINDINGS

Interpreting the Results:

The proposed improvements for alternatives A and B respectively reduce the expected number of crashes compared to the existing conditions by 105 and 133 crashes, respectively, projected over a 20-year period. Alternatives A and B have an annual average crash reduction of 6 and 7 crashes per year, respectively. Based on the predictive method analysis, Alternative B, with the 8-ft. shoulder, will have an average annual reduction of between one and two more crashes per year than Alternative A, with a 5-ft. shoulder. This information on safety performance could then be considered alongside other project criteria.

Possible Errors to Avoid:

The analyst should confirm that data is entered (or imported) and used correctly in the IHDSM analysis software. IHSDM only takes into account those SPFs and CMFs associated with the HSM or that have been input (as previously indicated). The HSM procedures and the IHSDM are updated periodically with the most recent safety knowledge. Before starting an analysis, it is a good idea to confirm that you are always using the most recent version of the IHSDM software. As noted in the "Detailed Analysis" section of this problem, the IHSDM software and information about using the software can be found at the web address http://www.ihsdm.org.

Alternative Analysis Approaches:

The expectation to include traffic volume as well as changes in road characteristics narrowed down the suitable analysis tools to those that used SPFs with CMFs. This analysis could also have used the HSM spreadsheets presented in Problem 3.2. In addition, the findings from this analysis can be used as input into an economic appraisal such as a benefit/cost ratio or prioritization method such as incremental benefit/cost ratio.

3.4 Calculating Expected Crashes for Urban Freeway Ramps

PROBLEM OVERVIEW	
Safety Assessment Method: **SPF with CMF Weighted with Observed Crashes**	
Project Phase: **Alternative Analysis**	Project Type: **4R**
Related Task: **Interchange Justification Request**	**Calculation Method:** ☐ **Hand Calculated** ☒ **Tool Based** *Hand calculated example included in Guide appendix.*
Comments: This example problem demonstrates how to estimate the expected number of crashes for an urban freeway loop ramp.	
LEVEL OF ANALYSIS	
Basic Intermediate Advanced	
Note: See table 3 for a full definition of Project Type designations.	

PROBLEM DESCRIPTION

A State DOT is examining a 0.5-mile long urban freeway connector (loop) ramp to evaluate whether changes are needed for possible removal, improvement, or replacement due to recurring congestion. As part of this analysis, the DOT is conducting a safety assessment to determine whether the loop ramp has more crashes than would be expected for similar ramps. The **Project Type** is *4R* and the **Related Task** is to document analysis for a potential *Interchange Justification Request*. **How can the analyst predict the estimated number of crashes for this interchange freeway loop ramp for a 3-year study period between 2013 and 2015 while directly considering the AADT in the analysis?**

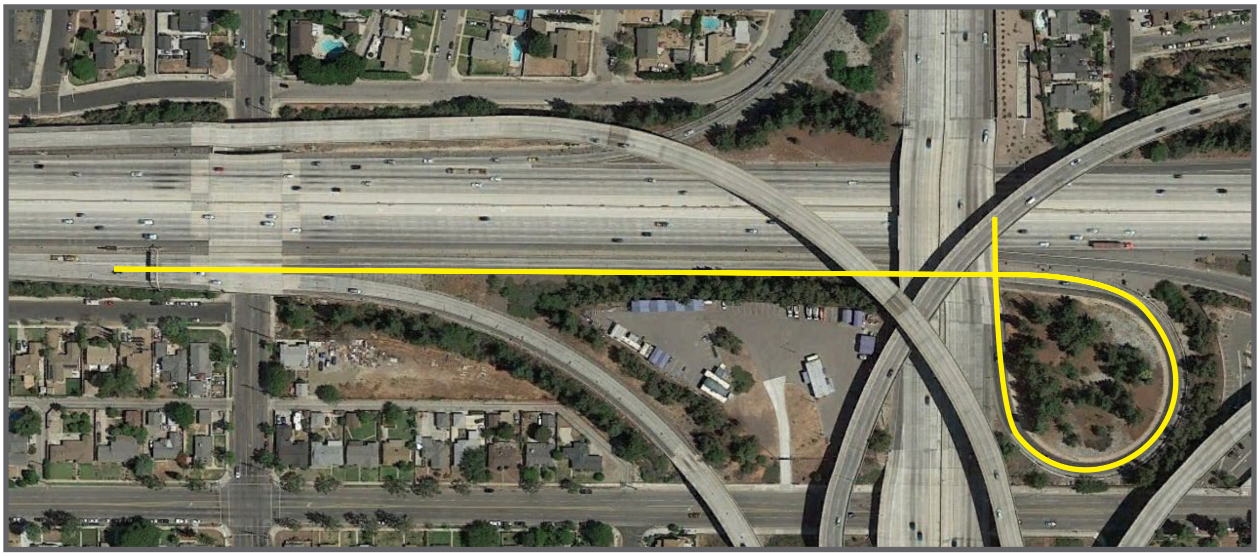
Summary of Available Data:

In 2013, the ramp had an AADT of 9,800 vpd. Other ramp characteristics are summarized as follows:

- One through lane.
- Ramp length = 0.5 miles.
- Average traffic speed on the freeway of 65 mph.

- Segment type is a ramp connector.
- Two horizontal curves with the following characteristics:
    - *Horizontal curve #1: radius = 11,460 ft, curve length = 0.04 mi, begins 0.26 mi from start of ramp (in direction of travel).*
    - *Horizontal curve #2: radius = 150 ft, curve length = 0.12 mi., begins 0.34 mi from start of ramp (in direction of travel).*
- Lane width = 13 ft.
- Right shoulder width = 10 ft.
- Left shoulder width = 7 ft.
- No lane adds or drops by taper.
- Roadside barrier on right side:
    - *Barrier #1: 0.06 mi long positioned 11 ft. from edge of traveled way to barrier face.*
    - *Barrier #2: 0.05 mi long positioned 11 ft. from edge of traveled way to barrier face.*
- Roadside barrier on left side:
    - *Barrier #1: 0.02 mi long positioned 8 ft. from edge of traveled way to barrier face.*
    - *Barrier #2: 0.05 mi long positioned 8 ft. from edge of traveled way to barrier face.*
    - *Barrier #3: 0.10 mi long positioned 8 ft. from edge of traveled way to barrier face.*
- Ramp entrance and exit not present in the study section.

The following aerial photograph depicts the ramp configuration (center line highlighted with yellow).



Source: ©2015 Google Earth

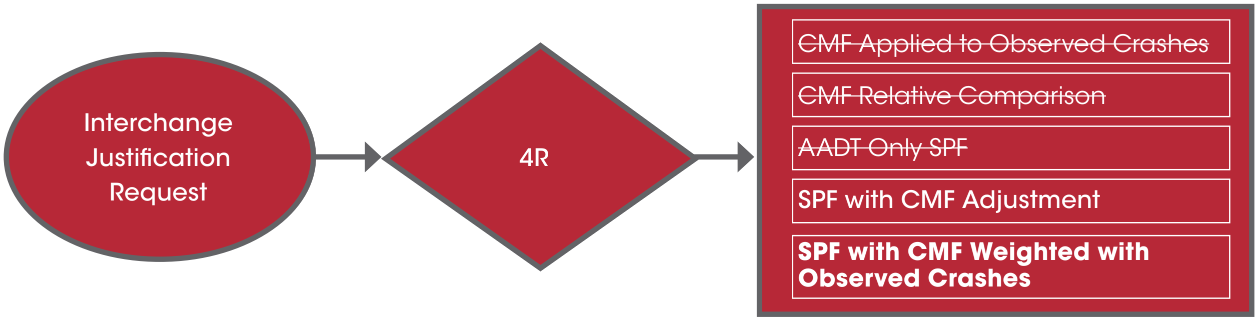
Crash data for the corridor during the study period is summarized in the following table. The small number of observed crashes at this location provides information about observed crash frequency. For this example, the observed crash information is available for estimating future safety performance. The small crash frequencies observed would not be useful for identifying prospective countermeasures.

Year	Property Damage Only Crashes		Fatal and Injury Crashes	
	Multiple-vehicle	Single-vehicle	Multiple-vehicle	Single-vehicle
2013	0	1	0	1
2014	1	0	0	0
2015	0	1	0	0

ANALYSIS

Selecting Appropriate Safety Assessment Method(s):

The analyst can evaluate the candidate safety assessment methods shown in Table 8. The *Interchange Justification Request* task and the 4R project type are associated with five potential safety assessment methods: two basic, two intermediate, and one advanced. Because the goal is to comprehensively assess the varying ramp geometric features and calculate the estimated number of crashes, an assessment method that includes CMFs is appropriate (thus eliminating the *AADT-Only SPF*). The analyst would like to verify the influence of traffic volume over the three-year study period. This requires a volume-based approach (i.e. methods that use an SPF). The two basic methods should therefore be eliminated from consideration as they do not include traffic volume in the analysis.

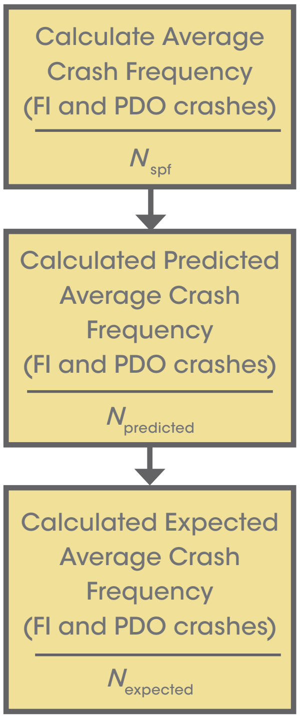


The remaining two potential safety assessment methods use procedures specific to the HSM. The SPF with CMF Adjustment can be used to evaluate the predicted number of crashes along a corridor with similar characteristics to the study site. The *SPF with CMF Weighted with Observed Crashes* includes the crash history so that the safety assessment includes consideration of the recent crash history at the location. Both of these safety assessment methods can be used, but the site-specific emphasis provides additional confidence that the calculated numbers reflect the expected number of crashes for the specific study site. For this reason, the analyst selects the *SPF with CMF Weighted with Observed Crashes* method.

The analyst has the following three available options for performing the analysis for this method:

- Perform the analysis using hand calculations (see Appendix for this example).
- Conduct the assessment using the self-calculating "Smart Spreadsheet" tool known as ISATe.
- Use the FHWA software tool IHSDM.

The choice between the two automated tools is simply a preference issue as they both correspond to the HSM approach for this analysis. For this assessment, the analyst selected ISATe. The web address to acquire this free software tool is provided in the "Detailed Analysis" section of this problem.



Linkage to the HSM:

The 2014 HSM Supplement can be used to estimate the number of expected crashes for a freeway or a ramp. The procedure for ramps is introduced in HSM Chapter 19 (pp. 19-1 to 19-152). By determining predicted crashes, the analyst can estimate how many crashes may be estimated for a specific ramp with varying road conditions (in this case multiple horizontal curves and varying barrier to the right and left). Once the predicted number of crashes is known, the expected number of crashes for a specific site can be calculated by applying the Empirical Bayes Method summarized in the 2014 HSM Supplement, pp. B-14 to B-30.

Detailed Analysis:

As previously indicated, the analyst has selected the advanced method for an *SPF with CMF Weighted with Observed Crashes*. This assessment is for a specific location with a known crash history and so the procedure calculates the expected number of crashes. Because the ramp's cross-sectional characteristics are consistent along its entire length, the ramp can be modeled as one segment.

To calculate the expected average crash frequency for the existing ramp location, the analyst has decided to use ISATe, a free software self-calculating spreadsheet tool. This product can be downloaded free of charge at http://www.highwaysafetymanual.org/Pages/tools_sub.aspx. The following steps summarize the process for performing the calculations to evaluate the expected crashes.

STEP 1: Enter known data.

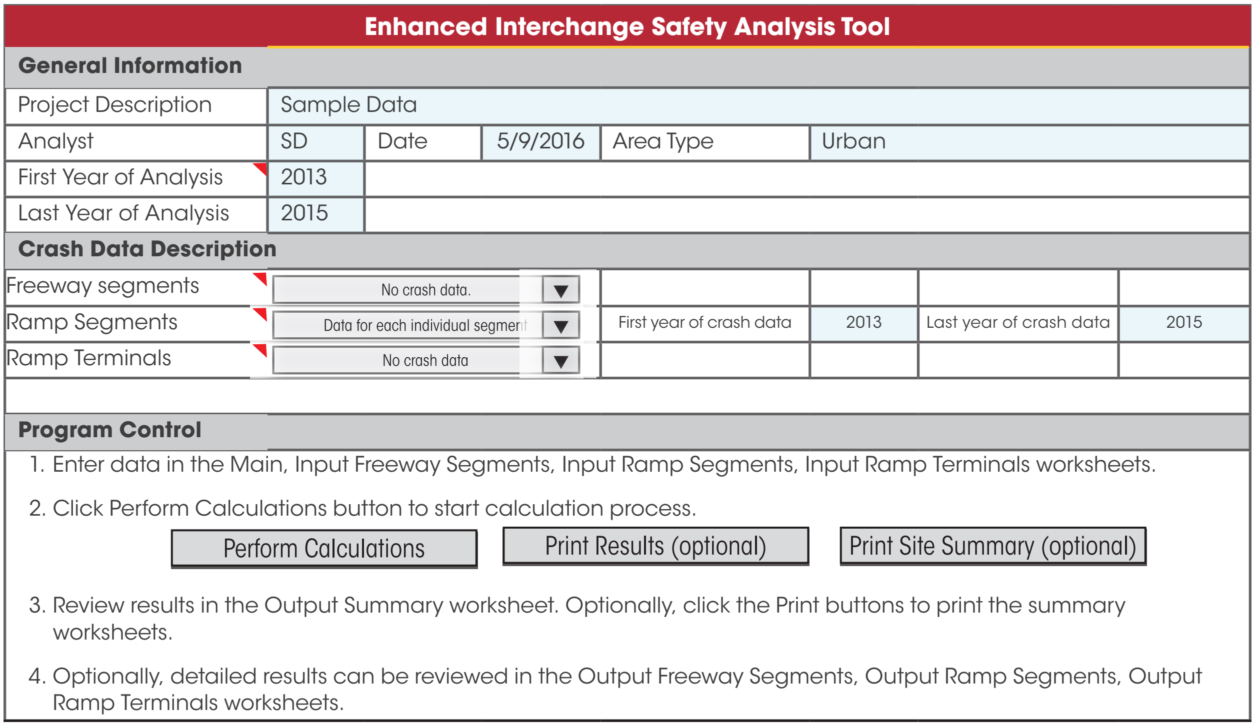
The analyst enters the geometry, traffic, and crash data into the ISATe program. The analysis is conducted by automating the calculations using the program and reviewing the results. ISATe provides the analyst with expected crash frequencies for the ramp and also outputs CMF values to help the analyst identify roadway characteristics that could be changed to reduce crash frequency.

STEP 2: Divide the ramp into homogeneous segments.

The beginning and ending of the ramp are defined as the gore nose where the ramp joins each freeway mainline. This particular ramp does not need to be divided into segments because its cross-sectional characteristics are consistent throughout its length, and ISATe can model a ramp with up to five horizontal curves along its length.

STEP 3: Specify analysis period, analysis type, and area type in the ISATe "Main" worksheet.

For this analysis, the time period of interest is defined as the years 2013-2015. Crash data are available, so the empirical Bayes analysis procedure that is built into ISATe will be used. The area type is specified as urban.



Enhanced Interchange Safety Analysis Tool

General Information						
Project Description	Sample Data					
Analyst	SD	Date	5/9/2016	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	2013	Last year of crash data	2015	
Ramp Terminals	No crash data					
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.

Perform Calculations | Print Results (optional) | Print Site Summary (optional)

3. Review results in the Output Summary worksheet. 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.

STEP 4: Enter input data into the ISATe "Input Ramp Segments" worksheet.

This worksheet contains two columns to describe each ramp segment (for the crash period and the study period) and rows for each input data element. In this example problem, the crash period and the study period are the same time period, and no potential modifications to this ramp are being considered, so the input data for the crash period and the study period are the same. For some analyses (e.g., if a projection of future crash counts is desired), a study period in the future can be specified, while the crash period always must be in the past.

As shown in the aerial photo, the loop ramp is a single-lane ramp with two horizontal curves. The first curve is gradual (radius = 11,460 ft) and is located under the freeway mainline bridge. The second curve is sharp (radius = 150 ft) and is located in the southeast quadrant of the interchange.

Input Worksheet for Ramp Segments			
Clear / Echo Input Values (View results in Column CJ) / Check Input Values (View results in Advisory Messages)		Segment 1	
		Crash Period	**Study Period**
Basic Roadway Data			
Number of through lanes (n):		1	1
Ramp segment description:			
Segment length (L), mi:		0.5	0.5
Average traffic speed on the freeway (V_{frwy}), mi/h:		65	65
Segment type (ramp or collector-distributor road):		Connector	Connector
Type of control at crossroad ramp terminal:			
Alignment Data			
Horizontal Curve Data	**See notes**		
1	Horizontal curve?:	In Seg.	In Seg.
	Curve radius (R_1), ft:	11460	11460
	Length of curve (L_{c1}), mi:	0.04	0.04
	Length of curve in segment ($L_{c1,seg}$), mi:	0.04	0.04
	Ramp-mile of beginning of curve in direction of travel (X_1), mi:	0.26	0.26
2	Horizontal curve?:	In Seg.	In Seg.
	Curve radius (R_2), ft:	150	150
	Length of curve (L_{c2}), mi:	0.12	0.12
	Length of curve in segment ($L_{c2,seg}$), mi:	0.12	0.12
	Ramp-mile of beginning of curve in direction of travel (X_2), mi:	0.34	0.34
3	Horizontal curve?:	No	No

Cross section data and roadside data are entered as shown. The analyst should input specific information for a total of five barrier sections – three located on the left side of the ramp (in the direction of travel) and two located on the right side of the ramp.

The analyst should next enter ramp access and traffic data. These data include the presence and lengths of ramp entrances or exits on each segment, and presence of weaving sections. The analyst provides traffic volumes for the years 2013, and ISATe uses the same traffic volume for the years 2014 and 2015.

Crash data are entered and broken down by crash type, severity, and year.

Cross Section Data			
Lane width (W_l), ft:		13	13
Right shoulder width (W_{rs}), ft:		10	10
Left shoulder width (W_{ls}), ft:		7	7
Presence of lane add or lane drop by taper:		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:		Yes	Yes
1	Length of barrier ($L_{rb,1}$), mi:	0.06	0.06
	Distance from edge of traveled way to barrier face ($W_{off,r,1}$), ft:	11	11
2	Length of barrier ($L_{rb,2}$), mi:	0.05	0.05
	Distance from edge of traveled way to barrier face ($W_{off,r,2}$), ft:	11	11
3	Length of barrier ($L_{rb,3}$), mi:		
	Distance from edge of traveled way to barrier face ($W_{off,r,3}$), ft:		
4	Length of barrier ($L_{rb,4}$), mi:		
	Distance from edge of traveled way to barrier face ($W_{off,r,4}$), ft:		
5	Length of barrier ($L_{rb,5}$), mi:		
	Distance from edge of traveled way to barrier face ($W_{off,r,5}$), ft:		
Presence of barrier on left side of roadway:		Yes	Yes
1	Length of barrier ($L_{lb,1}$), mi:	0.02	0.02
	Distance from edge of traveled way to barrier face ($W_{off,l,1}$), ft:	8	8
2	Length of barrier ($L_{lb,2}$), mi:	0.05	0.05
	Distance from edge of traveled way to barrier face ($W_{off,l,2}$), ft:	8	8
3	Length of barrier ($L_{lb,3}$), mi:	0.1	0.1
	Distance from edge of traveled way to barrier face ($W_{off,l,3}$), ft:	8	8
4	Length of barrier ($L_{lb,4}$), mi:		
	Distance from edge of traveled way to barrier face ($W_{off,l,4}$), ft:		
5	Length of barrier ($L_{lb,5}$), mi:		
	Distance from edge of traveled way to barrier face ($W_{off,l,5}$), ft:		

Ramp Access Data	See Note		
Ramp Entrance	Ramp entrance in segment? (If yes, indicate type.):	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
	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: (enter data only for those years for which it is available, leave other years blank)	2013	9800
	2014	
	2015	

Crash Data	Year	Segment Crashes
Count of Fatal and Injury (FI) Crashes by Year		
Multiple-vehicle crashes ($N_{o,w,n,mv,fi}$)	2013	0
	2014	0
	2015	0
	2016	
	2017	
Single-vehicle crashes ($N_{o,w,n,sv,fi}$)	2013	1
	2014	0
	2015	0
	2016	
	2017	
Count of Property Damage Only (PDO) Crashes by Year		
Multiple-vehicle crashes ($N_{o,w,n,mv,pdo}$)	2013	0
	2014	1
	2015	0
	2016	
	2017	
Single-vehicle crashes ($N_{o,w,n,sv,pdo}$)	2013	1
	2014	0
	2015	1
	2016	
	2017	

Once all input data are entered into the "Input Ramp Segments" worksheet, the analyst should click the "Check Input Values" button to verify that no illogical or erroneous data values were entered.

STEP 5: Perform the analysis calculations.

The analyst clicks the "Perform Calculations" button on the "Main" worksheet of ISATe to initiate calculations.

STEP 6: Review the calculation results.

ISATe provides a summary of the calculation results on the "Output Summary" worksheet. In this example problem, the freeway facility of interest consists of one ramp segment. ISATe can also be used to analyze a facility that consists of a combination of mainline segments, ramp segments, and crossroad ramp terminals.

For the entire analysis period (2013-2015), the ramp is expected to experience about nine crashes, of which about six will be PDO. These values are equivalent to expected crash frequencies of about three crashes per year, of which about two will be PDO.

Output Summary

General Information

Project description:	Sample Data				
Analyst:	JAB	Date:	5/9/2016	Area Type:	Urban
First year of analysis:	2013				
Last year of analysis:	2105				

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?	Yes	First year of crash data:	2013
	Project-level crash data available?	No	Last year of crash data:	2015
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:	8.5	0.1	0.2	1.3	1.7	5.3
Estimated average crash freq. during Study Period, crashes/yr:	2.8	0.0	0.1	0.4	0.6	1.8

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:	1	8.5	0.1	0.2	1.3	1.7	5.3
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	2.8	0.0	0.1	0.4	0.6	1.8
	2014	2.8	0.0	0.1	0.4	0.6	1.8
	2015	2.8	0.0	0.1	0.4	0.6	1.8

FINDINGS

Interpreting the Results:

By using the ISATe spreadsheet program to evaluate the loop ramp, the analyst estimates that the expected crash frequency is about three crashes per year. Over the entire analysis period, this equates to about nine crashes. These computed numbers are consistent with the observed crash counts. The analyst can conduct similar analyses on other loop ramps and compare the values for this location to assess whether they are notably higher than those for similar locations.

Possible Errors to Avoid:

It is possible for the analyst to enter erroneous input data or to enter values that are illogical when compared across several input elements. For example, a roadside barrier lateral offset cannot be located closer to the travel lane than the width of the shoulder. The ISATe program contains many data validation mechanisms to minimize this possibility, and a checking feature is also available by clicking the "Check Input Values" button on the input data worksheets.

Alternative Analysis Approaches:

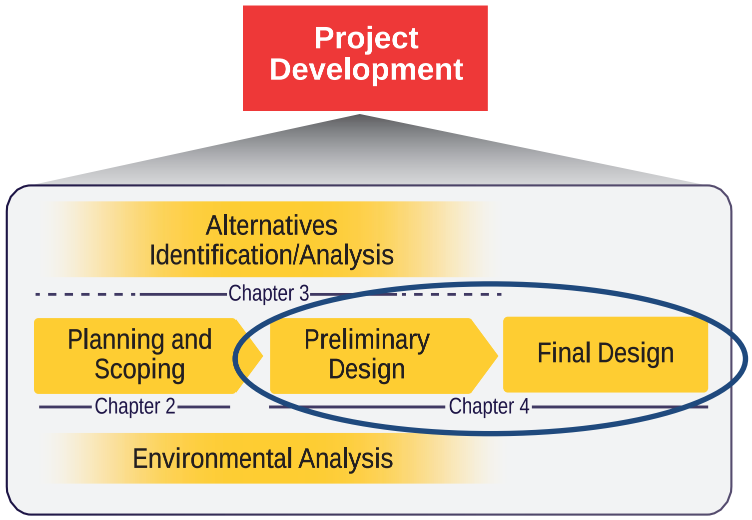
This analysis can also be performed by hand-calculating the ramp safety prediction methodology described in Chapter 19 of the HSM (see Appendix item A-3.4). Due to the extensive nature of the calculations, however, the hand-calculated method is time consuming and can be cumbersome due to the large number of equations included in the methodology.

The FHWA software tool IHSDM, however, could also be used to conduct this analysis. The crash module for the IHSDM includes a "site-based analysis tool" that can be used without having to include the detailed horizontal and vertical alignment and cross-section data noted in Example Problem 3.3. The selection of ISATe versus IHSDM is a matter of personal preference since both of these free tools perform the same analysis. The IHSDM software is available for download at http://www.ihsdm.org.

CHAPTER 4: Preliminary and Final Design Applications

The preliminary and final design phases are clearly defined for most jurisdictions, yet key elements of these two phases can differ for each transportation agency. This Guide, therefore, combines the preliminary and final design into a single chapter.

During the design phase, design decisions must be refined and finalized prior to construction. In general, safety assessments in the design phase focus on documenting design decisions, including those that require exceptions to the design standards, and calculating the estimated number of crashes that can be anticipated for the final facility design.



NOTE: Elements of ongoing life cycle activities are incorporated into Chapters 2 and 4 as appropriate.

Figure 6. The Project Development Cycle and Corresponding Design Chapters

This chapter provides information to help select safety assessment methods suitable for addressing questions about safety performance that arise during these preliminary and final design activities based upon the related task and project type. This Guide describes the design tasks in four general categories:

- Selecting specific design elements and their dimensions,
- Design exceptions,
- Value engineering, and
- Establishing the work zone transportation management plan.

Selecting specific design elements and their dimensions is a critical design activity for all elements of the project. The objective of the safety assessment in this task is to compare the estimated safety performance for the alternative dimensions or elements. This safety assessment information can then be used to help inform the final facility design process.

Design exceptions are needed on National Highway System roadways when controlling criteria are not met. States may also require documentation of deviations from their own design criteria on or off the National Highway System. The objective of safety assessment in this task is to estimate how the design exception impacts safety performance and to identify and evaluate potential strategies for mitigating the impact. The goal of this task is to quantify the design exception and potential mitigation strategies so that corridor safety performance is not adversely affected.

On certain projects, **value engineering** provides recommendations for providing needed functions, optimizing value and quality, and reducing the time to develop and deliver the project (23 CFR 627). The objective of safety assessment in this task is to quantify safety performance so that it can be weighed with other project considerations.

Establishing the work zone transportation management plan enables efficient construction of a project without compromising safety or operations. The objective of safety assessment in this task, as it relates to safety performance, is to compare the safety impacts of the various traffic control strategies considered during development of the transportation management plan.

Table 8 identifies the seven assessment methods applicable to the preliminary and final design tasks and their safety performance related analysis objective. The check marks in Table 8 suggest suitable safety assessment methods for each related task and objective and, in some cases, are distinguished by project type. In this context, the term "suitable" means that the method generally has the capability to address the safety performance related analysis objective with the data typically available for the related task and project type.

The following example questions demonstrate the type of questions the analyst may develop at the beginning of the safety assessment. These questions are based on the example problems included in this chapter.

1. How can the analyst estimate the annual number of crashes for this new facility?
2. How does the analyst calculate the estimated number of crashes for each roundabout?
3. How can the analyst estimate how the change in roadway geometry may affect the number of total and fatal and injury (FI) crashes?

Table 9 highlights that the level of predictive reliability generally increases moving from basic to advanced methods. At the same time, the required resources for the analysis also will increase. In some cases, it may not be feasible to fully implement the preferred safety assessment method due to limitations in site information, crash data, traffic volume, or similar information. As an example, the Basic safety assessment method for a *CMF Applied to Observed Crashes* cannot be executed if historic crash data is not available. Consequently, the approach for selecting a safety assessment method for alternatives evaluation and identification is graphically depicted as follows.

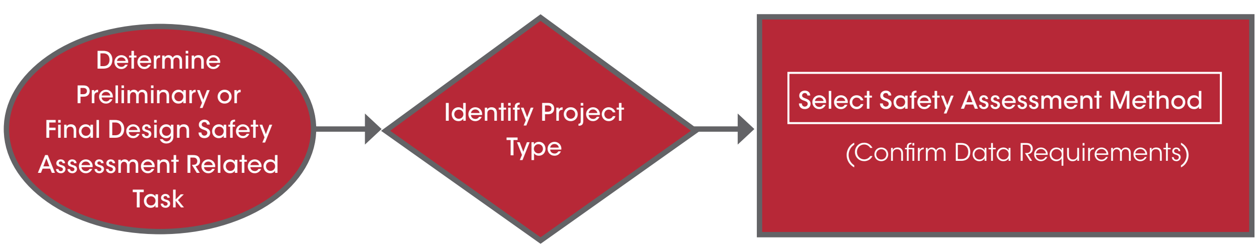


Table 9. Preliminary and Final Design Safety Assessment Objective

Related Task	Objective	Project Type	Basic				Intermediate		Advanced
			Site Evaluation or Audit	Historical Crash Data Evaluation	CMF Applied to Observed Crashes	CMF Relative Comparison	AADT Only SPF	SPF with CMF Adjustment	SPF with CMF Weighted with Observed Crashes
			Observed Crashes				Predicted Crashes		Expected Crashes
Safety Assessments:	Increasing Level of Predictive Relaibility →								
Selecting specific design elements and their dimensions	To compare safety impacts of alternative dimensions	2R	✓	✓	✓	✓			
		3R, 4R	✓	✓	✓	✓ [8]	✓	✓	✓
		NL				✓	✓	✓ [5]	
Design Exception	To estimate design exception impacts on safety performance and to identify and evaluate strategies for mitigation	3R, 4R			✓	✓	✓	✓ [7]	✓
		NL					✓	✓	
Value Engineering	To quantify safety performance so that it can be weighed with other project considerations	4R			✓	✓	✓ [6]	✓	✓
		NL					✓	✓	
Establishing the Work Zone Transportation Management Plan	To compare safety impacts of traffic control strategies	2R	✓			✓			
		3R, 4R							
		NL							
Data Requirements:	Increasing Level of Resources Needed (Staff, Analysis, Time, etc.) →								
Road Type[1]			✓		✓	✓	✓	✓	✓
Road Characteristics[2]			✓		✓	✓		✓	✓
Traffic Volume (vpd)[3]							✓	✓	✓
Observed Crash Data[4]				✓		✓			✓

[1]Road Type refers to rural two-lane highway, rural multi-lane highway, urban freeway, etc. [2] Road Characteristics includes physical features such as lane widths, access density, etc. [3] Traffic Volume is the ADT or AADT in vehicles per day. [4] Observed Crash Data represents the historic crash data at the study site for a period of more than 1 year (preferably 3 to 5 years). [5] See Example Problem 4.1. [6] See Example Problem 4.2. [7] See Example Problem 4.3. [8] See Example Problem 5.3.

Note: Project type definitions are as follows: R2 = resurfacing existing facilities. R3 = major rehabilitation of an existing facility. R4 = major retrofit construction efforts. NL = highway construction at a new location. See Table 3 for a full definition of each Project Type. ✓= suitable safety assessment method. ADT = average daily traffic. AADT = annual average daily traffic. CMF = crash modification factor. SPF = safety performance function. vpd = vehicles per day.

This chapter provides examples that demonstrate the selection process for the preliminary and final design safety assessment methods. These examples are simplified, hypothetical problems intended to illustrate the thorough process for selecting a method and demonstrate how to apply the method to answer the associated safety-based question.

4.1 Predicting Crashes for a New Urban Multilane Arterial

PROBLEM OVERVIEW	
Safety Assessment Method: SPF with CMF Adjustment	
Project Phase: **Preliminary & Final Design**	Project Type: **NL**
Related Task: **Selecting Specific Design Elements and Their Dimensions**	**Calculation Method:** ☐ **Hand Calculated** ☒ **Tool Based**
Comments: This example problem demonstrates how to calculate the predicted number of crashes for a four-lane urban arterial following the construction of a median and the addition of lighting and auto speed enforcement.	
LEVEL OF ANALYSIS	

Note: See table 3 for a full definition of Project Type designations.

PROBLEM DESCRIPTION

As part of an expansion effort, a city will be constructing a new four-lane urban arterial. The analyst has been asked to estimate the number of crashes that could occur annually on this facility. The new corridor will be 1-mile long and will only have four minor residential driveways. Other characteristics of the road include a 20-ft. wide median, street lighting, and automated speed enforcement. The **Project Type** is NL and the **Related Task** is *Selecting Specific Design Elements and Their Dimensions*. How can the analyst estimate the annual number of crashes for this new facility?

Summary of Available Data:

The predicted AADT (for the major approach) is 28,000 vpd, and there are four minor residential driveways. Additional road information is as follows:

- No on-street parking.
- No roadside fixed objects closer than 30 ft.
- Posted speed limit of 40 mph.
- Regional *Highway Safety Manual* (HSM) urban arterial segment safety performance function (SPF) calibration factor of 1.05.
- Because it is new construction, there is no available crash history.

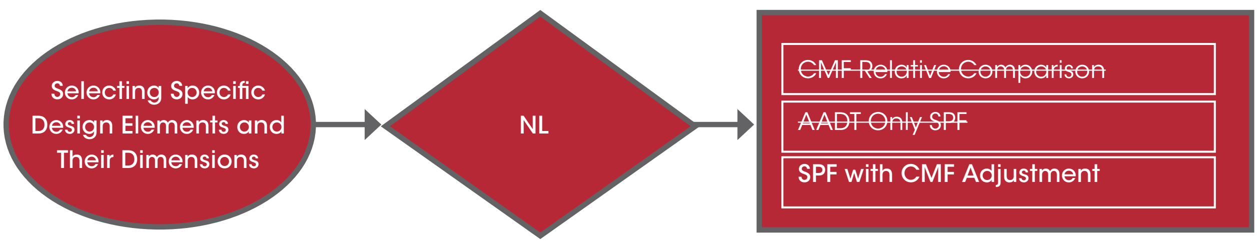
ANALYSIS

Selecting Appropriate Safety Assessment Method(s):

The analyst can review the applicable safety assessment methods summarized in Table 9. The Selecting Specific Design Elements and Their Dimensions project task for a NL project type is associated with three safety assessment methods (one basic and two intermediate). The CMF-based methods are needed to evaluate the influence of unique geometric characteristics, so the analyst eliminates the *AADT-Only SPF* option. The *CMF Relative Comparison* method can help the analyst better understand the influence of each individual design feature (for which a CMF is available), but does not provide a way to estimate the overall predicted corridor number of crashes and so this method is also eliminated from consideration. The selected safety assessment method, therefore, is the *SPF with CMF Adjustment*.

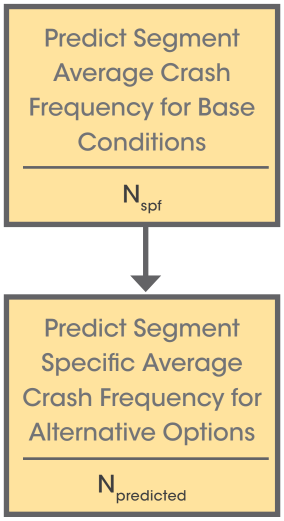
Linkage to the HSM:

The HSM can be used to estimate the number of predicted crashes for an urban or suburban arterial by applying the procedures introduced in HSM Chapter 12 (pp. 12-1 to 12-122). By determining predicted crashes, the analyst can estimate how many crashes are anticipated for a specific road type with varying road conditions.



Detailed Analysis:

For the *SPF with CMF Adjustment* safety assessment method, the analyst can use the SPF from the HSM for a divided segment. This evaluation can be performed using hand calculations (see Appendix A-4.1) or by using the free self-calculating spreadsheets or FHWA IHSDM tool. For a single location, the spreadsheets can be easily applied. For more complex corridors, IHSDM is the recommended method.



The following steps provide the calculations based on using the HSM "Smart Spreadsheets" available for download at: http://www.highwaysafetymanual.org/Pages/tools_sub.aspx#4. For this example problem, the analyst should use the "HSM prediction urban and suburban arterial" spreadsheet tool.

As noted in the "Summary of Available Data" section, the SPFs from the HSM have been previously calibrated to the region and have a calibration value of 1.05.

STEP 1: Input the known data for the proposed design.

The analyst should input the data for the study segment.

Segment Input Data:

For segment analysis, input data in the top section (Worksheet 1A) of the "Segment 1" tab. The proposed design input data is shown as follows:

Worksheet 1A - General Information and Input Data for Urban and Suburban Roadway Segments			
General Information		Location Information	
Analyst Agency or Company Date Performed	ABC City 05/10/16	Roadway Roadway Section Jurisdiction Analysis Year	2015
Input Data		Base Conditions	Site Conditions
Roadway type (2U, 3T, 4U, 4D, ST)		--	4D
Length of segment, L (mi)		--	1
AADT (veh/day)	$AADT_{MAX}$ =66,000 (veh/day)	--	28,000
Type of on-street parking (none/parallel/angle)		None	None
Proportion of curb length with on-street parking		--	0
Median width (ft) - for divided only		15	20
Lighting (present / not present)		Not Present	Present
Auto speed enforcement (present / not present)		Not Present	Present
Major commercial driveways (number)		--	0
Minor commercial driveways (number)		--	0
Major industrial / institutional driveways (number)		--	0
Minor industrial / institutional driveways (number)		--	0
Major residential driveways (number)		--	0
Minor residential driveways (number)		--	4
Other driveways (number)		--	0
Speed Category		--	Posted Speed Greater than 30 mph
Roadside fixed object density (fixed objects / mi)		0	0
Offset to roadside fixed objects (ft) [If greater than 30 or Not Present, input 30]		30	30
Calibration Factor, Cr		1.00	1.05

STEP 2: Following input in Step 1, review the predicted number of crashes automatically calculated by the spreadsheet tool see Worksheet 1L below).

Worksheet 1L - Summary Results for Urban and Suburban Roadway Segments			
(1)	(2)	(3)	(4)
Crash Severity Level	Predicted average crash frequency, $N_{predicted\ rs}$ (crashes/year) (Total) from Worksheet 1K	Roadway Segment Length, L (mi)	Crash Rate (crashes/mil/year) (2)/(3)
Total	5.3	1.00	5.3
Fatal and injury (FI)	1.5	1.00	1.5
Property damage only (PDO)	3.8	1.00	3.8

Additional information related to crash type by severity is also calculated and can be reviewed in the spreadsheet tool.

STEP 3: Summarize Findings.

The analyst's ultimate goal is to calculate the estimated number of crashes predicted for the road constructed on the new location. In addition to the total number of crashes, crash severity information is important to note. The following table summarizes these results.

Roadway Improvement Scenario	Predicted Number Fatal and Injury Crashes	Predicted Number of Total Crashes	Predicted Number of Property Damage Only Crashes
Urban Arterial with median, lighting, and automated enforcement	1.5 (say 2)	5.3 (say 6)	5.3 – 1.5 = 3.8 (say 4)

FINDINGS

Interpreting the Results:

Based on an evaluation of the predicted number of crashes, an urban four-lane arterial with a 30-ft. median, four minor driveways, street lighting, and automated enforcement is estimated to have approximately six total crashes per year, of which 2 crashes are fatal and injury crashes, for a 1-mile segment of road.

The city may want to consider alternative configurations (e.g., wider versus narrower medians, the effects of on-street parking, etc.) to ultimately identify the optimal design that meets the needs of the corridor, fulfills access requirements for adjacent properties, and minimizes crashes while also considering cost effective roadway elements.

Possible Errors to Avoid:

The HSM procedures require the analyst to understand how all SPFs and CMFs equate to the base conditions associated with the procedure. Incorrect use of these values can introduce erroneous results.

Alternative Analysis Approaches:

While the *SPF with CMF Adjustment* safety assessment method provides predicted crash information for the total length of road segment, selection of individual road features could be incrementally considered using the CMF Relative Comparison approach. For example, a preliminary analysis to evaluate varying the median width by a simple comparison of the CMF values can enable the analyst to narrow down the design options prior to applying the more complex (i.e., more data intensive) SPF method.

4.2 Calculating Predicted Crash Frequency for Proposed Two-Lane Roundabout

PROBLEM OVERVIEW	
Safety Assessment Method: AADT-Only SPF	
Project Phase: **Preliminary & Final Design**	Project Type: **4R**
Related Task: **Safety Input for Value Engineering Assessment**	**Calculation Method:** ☒ **Hand Calculated** ☐ **Tool Based**
Comments: This example problem demonstrates how to consider the number of crashes as one input into the value engineering process. For this case, the problem evaluates three proposed roundabouts (four-leg, two-circulating lanes) that are located within the larger project boundaries.	
LEVEL OF ANALYSIS	
Basic — Intermediate — Advanced	
Note: See table 3 for a full definition of Project Type designations.	

PROBLEM DESCRIPTION

A city is reconstructing a corridor that includes several at-grade intersections. As part of the larger project, the city is documenting value engineering decisions related to the improvements. Within the corridor are three at-grade intersections that the city is designing to be converted to multilane roundabouts. Their analyst has been asked to calculate the estimated number of crashes for each roundabout so that this information can be used as input into the overall value engineering decisions. The **Project Type** is *4R* and the **Related Task** is Value Engineering. How does the analyst calculate the estimated number of crashes for each roundabout?

Summary of Available Data:

The following table shows the predicted AADT values for the design year. For design consistency purposes, the geometric design will be similar for each proposed roundabout.

Roundabout	Average Annual Daily Traffic (vehicles per day)
1	12,700
2	33,150
3	26,000

Other information includes:

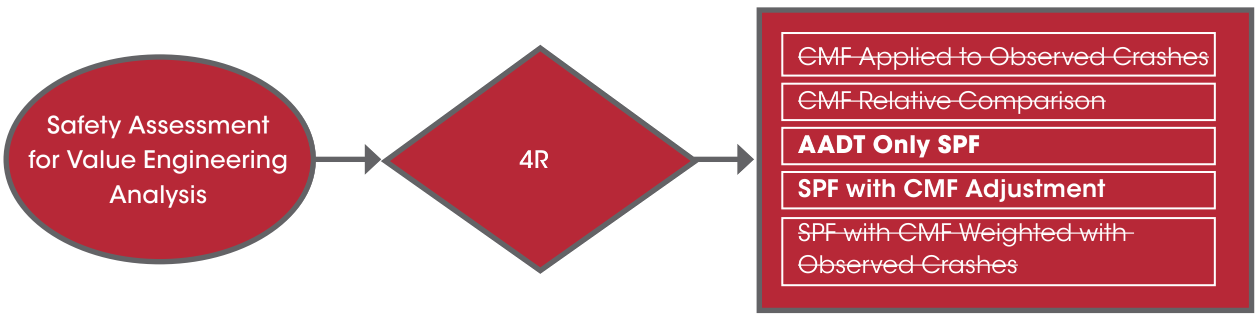
- Two circulating lanes.
- Four intersection legs.
- Regional calibration factor of 0.89 for total crashes and 0.93 for fatal and injury crashes (based on SPFs included in NCHRP Report 672).

- Due to the substantially modified corridor design, available corridor crash history will not be representative of future design conditions.

ANALYSIS

Selecting Appropriate Safety Assessment Method(s):

The analyst can review Table 9 to identify potential safety assessment methods for this effort. For a *4R* project and the *Safety Assessment for Value Engineering Analysis* related task, five candidate safety assessment methods are available: two basic methods, two intermediate, and one advanced. The analyst notes that the crash conditions prior to corridor reconstruction represent a substantially different configuration than those shown in the design plans and so concludes that safety assessment methods based on historical (observed) crashes can be eliminated. The evaluation of a *CMF Relative Comparison* option would potentially provide valuable information if there were geometric differences between the three proposed roundabouts, but all three have consistent designs, and so the analyst eliminates this assessment method from consideration.



The final two candidate safety assessment methods are the *AADT-Only SPF* and the *SPF with CMF Adjustment* options. The analyst reviews candidate SPFs for these two prospective procedures and discovers that the 2010 HSM did not yet include an SPF for roundabouts; however, *NCHRP Report 672* does have SPFs for roundabouts and, as previously indicated, the city has already calibrated these to local conditions. As a result, the analyst selects the *AADT-Only SPF* option.

Linkage to the HSM:

The application of an SPF is similar to predictive methods presented in Volume 2 (Part C) of the HSM; however, the roundabout SPFs provided in *NCHRP Report 672* (p. 5-23) are not included in the HSM.

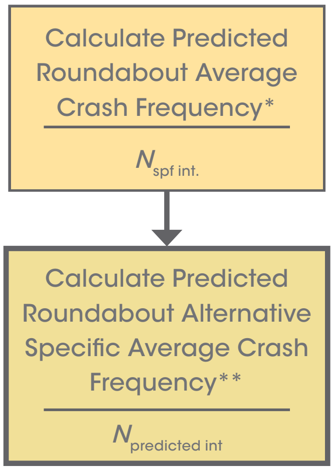
Detailed Analysis:

The crash prediction models in the NCHRP Report 672 only require the use of entering AADT and geometric configuration (number of legs and circulating lanes) to calculate the estimated total number of crashes at the roundabout. As previously indicated, the city uses the SPFs from *NCHRP Report 672 – Roundabouts: An Informational Guide*, which have been calibrated for local conditions (C_{Total} = 0.89, C_{FI} = 0.93). The following steps summarize the calculations for estimating the number of crashes for each roundabout.

STEP 1: Calculate the predicted average total crash frequency and fatal and injury (FI) frequency for the roundabout (N_{SPF}).

The *NCHRP Report 672* equations for a roundabout with four legs and two circulating lanes are used for this calculation. The base conditions associated with the SPF require entering AADT values from 2000 to 35,000 vpd for the "Total Crash" equation and AADT values from 2000 to 37,000 for the "FI Crash" equation. All three of the study roundabouts meet these criteria. Note: KAB and FI crashes are assumed to be equivalent terms for the purpose of this analysis

Calculations	Notes
Unadjusted Total Crashes per year:	
$N_{spf\ int\ (Total)}=0.0038 \times AADT^{0.7490}$	NCHRP Report 672, Exhibit 5-19, p. 5-23 (4-leg and 2 circulating lanes)
$N_{spf\ int\ (Total)}=0.0038 \times (12{,}700^{0.7490})=4.50$	SPF Total Crashes -- #1 (AADT = 12,700 vpd)
$N_{spf\ int\ (Total)}=0.0038 \times (33{,}150^{0.7490})=9.24$	SPF Total Crashes -- #2 (AADT = 33,150 vpd)
$N_{spf\ int\ (Total)}=0.0038 \times (26{,}000^{0.7490})=7.70$	SPF Total Crashes -- #3 (AADT = 26,000 vpd)
Unadjusted Fatal + Injury (FI) Crashes per year:	
$N_{spf\ int\ (FI)}=0.0013 \times AADT^{0.5923}$	NCHRP Report 672, Exhibit 5-20, p. 5-23 (4-leg and 2 circulating lanes)
$N_{spf\ int\ (FI)}=0.0013 \times (12{,}700^{0.5923})=0.35$	FI Crashes: Roundabout #1 (AADT = 12,700 vpd)
$N_{spf\ int\ (FI)}=0.0013 \times (33{,}150^{0.5923})=0.62$	FI Crashes: Roundabout #2 (AADT = 33,150 vpd)
$N_{spf\ int\ (FI)}=0.0013 \times (26{,}000^{0.5923})=0.54$	FI Crashes: Roundabout #3 (AADT = 26,000 vpd)
Definitions	
$N_{spf\ int\ (Total)}$= average total crash frequency for intersection-related crashes $N_{spf\ int\ (FI)}$= average fatal and injury crash frequency for intersection-related crashes $AADT_{entering}$= entering (largest) AADT (vehicles per day) AADT = average annual daily traffic, FI = fatal and injury, NCHRP = National Cooperative Highway Research Program, SPF = safety performance function, vpd = vehicles per day	



* Roundabout SPF does not include CMFs (see NCHRP Report 672, Ch. 5)

**Local Calibration for the NCHRP Report 672 SPFs resulted in calibration factors of 0.89 for total crashes and 0.93 for fatal and injury crashes

STEP 2: Calculate the predicted average crash frequency for each roundabout ($N_{predicted}$).

The predicted average crash frequency for each option can be calculated using HSM Equation C-1, p. C-4 of HSM Volume 2:

$$N_{predicted}=N_{spf} \times (CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{yx}) \times C_x$$

Where: CMF = crash modification factor/function and C = calibration factor for SPF

For the *NCHRP Report 672* equations, companion CMFs are not available, so this equation is reduced to the following (effectively assigning a value of 1.0 to each CMF value):

$$N_{predicted}=N_{spf} \times C_x$$

As previously indicated, the SPF calibration factor for the local region has a total crash value of $C_{Total} = 0.89$ and a fatal and injury value of $C_{FI} = 0.93$.

Calculations	Notes
$N_{predicted\ int} = N_{spf\ int} \times C$	Reduced HSM equation
Adjusted Total Crashes per Year	
$N_{predicted\ int\ (Roundabout\ \#1\text{-}Total)} = 4.50 \times 0.89 = 4.01$	Predicted Total Crashes -- #1
$N_{predicted\ int\ (Roundabout\ \#2\text{-}Total)} = 9.24 \times 0.89 = 8.22$	Predicted Total Crashes -- #2
$N_{predicted\ int\ (Roundabout\ \#3\text{-}Total)} = 7.70 \times 0.89 = 6.85$	Predicted Total Crashes -- #3
Adjusted FI Crashes per Year	
$N_{predicted\ int\ (Roundabout\ \#1\text{-}FI)} = 0.35 \times 0.93 = 0.33$	Predicted FI Crashes -- #1
$N_{predicted\ int\ (Roundabout\ \#2\text{-}FI)} = 0.62 \times 0.93 = 0.58$	Predicted FI Crashes -- #2
$N_{predicted\ int\ (Roundabout\ \#3\text{-}FI)} = 0.54 \times 0.93 = 0.50$	Predicted FI Crashes -- #3
Definitions: FI = fatal and injury. HSM = Highway Safety Manual.	

STEP 3: Summarize the findings.

Location	Predicted FI Crashes per Year	Predicted Total Crashes per Year
Roundabout #1	0.3 (say 1)	4.0 (say 5)
Roundabout #2	0.6 (say 1)	8.2 (say 9)
Roundabout #3	0.5 (say 1)	6.9 (say 7)

FINDINGS

Interpreting the Results:

Based on the results calculated using the model found in *NCHRP Report 672 – Roundabouts: An Informational Guide*, the analyst noted that the predicted number of crashes is substantially based on the entering traffic volume at the roundabout location. For all three roundabouts, however, the predicted number of FI crash per year is less than one. These estimates are an important input into the overall value engineering assessment. The city has elected to maintain consistent roundabout geometry for all three intersection locations and so the higher volume roundabout (in this case #2) is predicted to have more total crashes each year than the other two locations. An important aspect of value engineering is the incremental improvement of features.

Possible Errors to Avoid:

It is important to confirm that, when selecting a model to predict crashes, the SPF and its associated base conditions are appropriate for the studied transportation facility. For this example, the AADT values should be consistent with those used to develop the *NCHRP Report 672* (Section 5-4).

Another potential error is the expectation that using the more advanced method will provide better results. For this analysis, the corridor prior to redesign is not similar to the modified corridor and intersection configuration. Consequently, the historical (observed) crashes should not be used in the evaluation for a completely different "after" intersection configuration.

Alternative Analysis Approaches:

The HSM also has CMFs that can be used to predict crashes for converting a two-way, stop-controlled intersection or signalized intersection to a roundabout. As noted previously, Part C (Volume 2) of the HSM does not contain an SPF for roundabouts. If the installation of a roundabout is being considered as one of the alternatives, however, the predicted number of crashes can be calculated by using the SPF for the existing conditions and then applying the appropriate CMF from HSM Part D (Volume 3).

4.3 Documenting a Design Decision for a Sharp Horizontal Curve on a Rural Two-Lane Highway

PROBLEM OVERVIEW

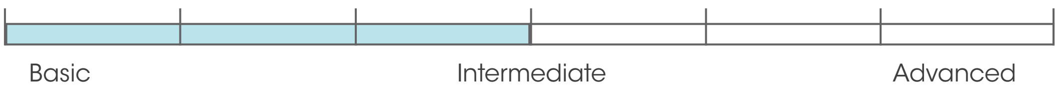
Safety Assessment Method: **SPF with CMF Adjustment**

Project Phase: **Preliminary & Final Design**	Project Type: **4R**
Related Task: **Design Exception**	**Calculation Method:** ☐ **Hand Calculated** ☒ **Tool Based** *Hand calculated example included in Guide appendix.*

Comments:

This example problem demonstrates how to evaluate the effect a design decision can have on the estimated number of crashes for a rural two-lane, two-way highway horizontal curve re-alignment project.

LEVEL OF ANALYSIS



Note: See table 3 for a full definition of Project Type designations.

PROBLEM DESCRIPTION

A two-lane highway that runs parallel to a river is experiencing failure of the embankment on the south side of the road. To avoid a complete failure due to a landslide, designers are planning to shift the roadway to the north. This will cause a sharper curvature along the section just prior to an at-grade rail crossing. The proposed new design results in a horizontal curve, with a 250 ft. radius, which is shorter than the minimum recommended curve radius (for e=6 percent, curve radius= 340 ft.) for its existing design speed of 35 mph, as set forth by *A Policy on Geometric Design of Highways and Streets* by the American Association of State Highway and Transportation Officials (AASHTO). Over the most recent 5-year period, there have been approximately 30 crashes in the vicinity of this 0.5-mile segment.

The **Project Type** is *4R* and the **Related Task** is to evaluate a *Design Exception*. **How can the analyst estimate how the change in roadway geometry may affect the number of crashes (Total and FI)?**

Summary of Available Data:

To perform this evaluation, the analyst must know the existing and proposed roadway geometry. The roadway curve geometry is summarized as follows:

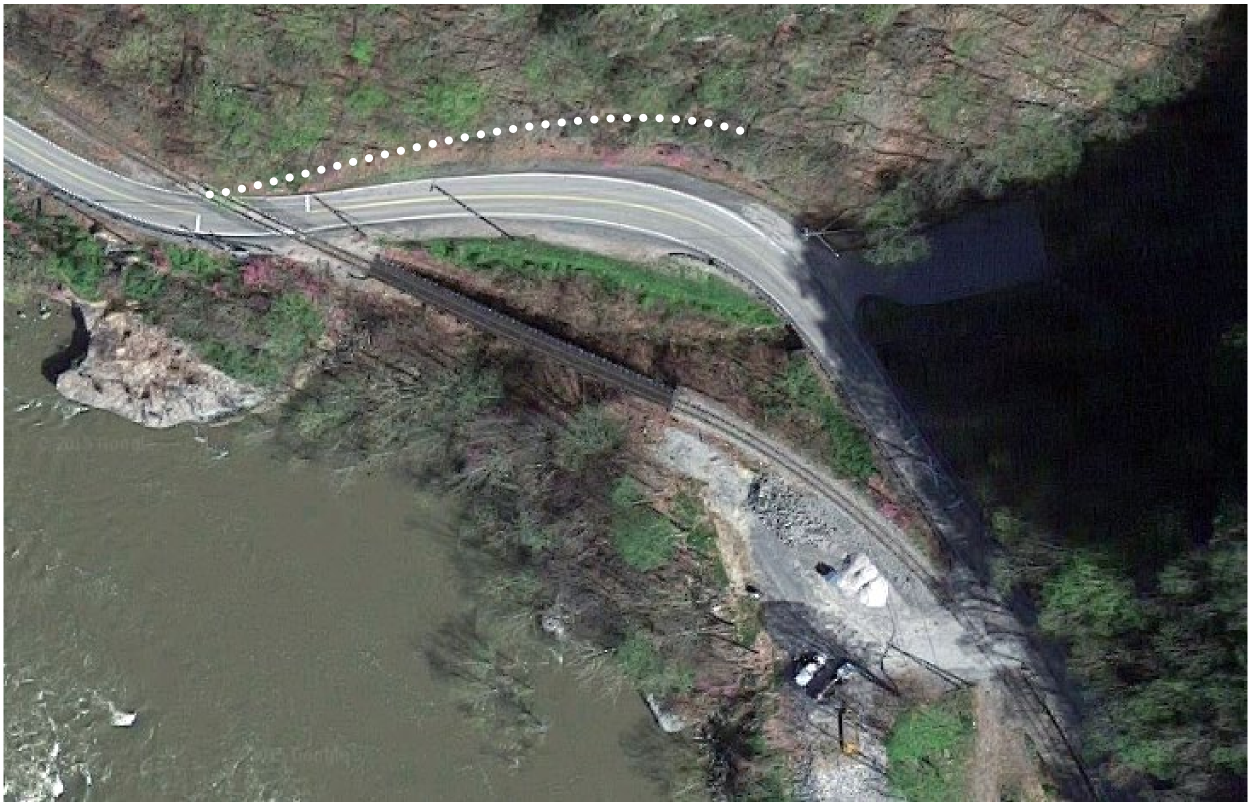
Geometric Element (ft.)	Existing	Proposed
Curve Length	200	230
Curve Radius	380	250

In addition, the corridor has the following characteristics:

- Existing and future curve will have constant curve radius without any transitional spiral curves.
- AADT=11,000 vpd.

- Segment length= 0.5 miles.
- Detailed crash data is not currently available.
- Using the SPF from the HSM, the regional calibration factor for rural two-lane highways is C = 0.97.

The existing configuration with the proposed curve superimposed is shown in the following graphic.



Source: ©2015 Google Earth

Aerial View of the Horizontal Curve

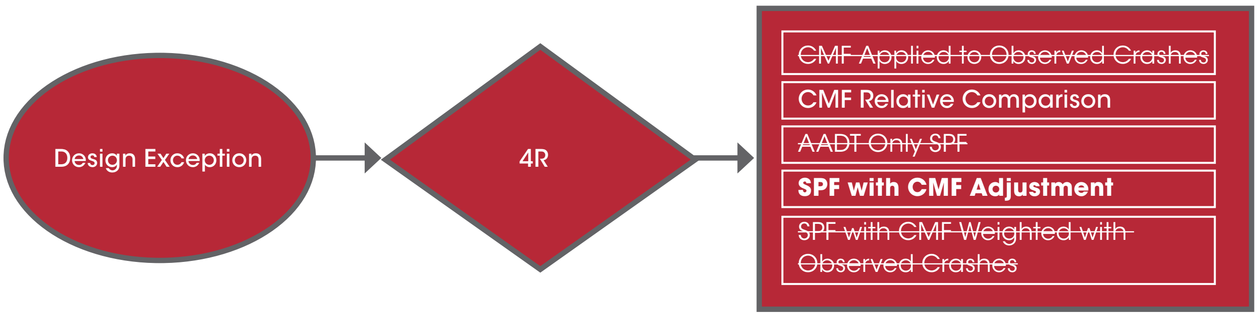
Source: ©Google Streetview

Google StreetView of the Existing Conditions along the Horizontal Curve

ANALYSIS

Selecting Appropriate Safety Assessment Method(s):

The analyst can review Table 9 to identify suitable safety assessment methods for evaluating a 4R project type that requires a design exception. There are five candidate safety assessment methods: two basic, two intermediate, and one advanced. The specific goal of the analyst is to assess whether the alternative curve design will result in a larger number of total or fatal injury crashes based on a change in the horizontal curve geometry. This design-based evaluation requires the use of a CMF-based procedure, so the *AADT-Only SPF* method can be eliminated. In addition, the historical (observed) crash detailed information is not available and so the two methods that rely on observed crashes can also be eliminated (i.e. *CMF Applied to Observed Crashes* and *SPF with CMF Weighted with Observed Crashes*).



The two remaining safety assessment methods are the *CMF Relative Comparison* method and the SPF with *CMF Adjustment* method. Either of these two methods will provide useful information, but the analyst would like to estimate the number of additional crashes, and the relative comparison approach provides the percentage of additional crashes. For this reason, the analyst ultimately selects the *SPF with CMF Adjustment* for the subsequent evaluation.

Linkage to the HSM:

The HSM can be used to estimate the number of predicted crashes for a rural, two-lane highway by applying the procedures introduced in HSM Chapter 10 (pp. 10-1 to 10-74). By determining predicted crashes, the analyst can estimate how many crashes may be expected for a specific road type with varying road conditions (in this case the curve radii and curve length). The HSM provides manual calculations, but a spreadsheet tool is available and can be used to simplify this analysis.

Detailed Analysis:

This example demonstrates how to use the HSM to estimate the likely effect of designing curves with radii less than the recommended minimum values in AASHTO's *A Policy on Geometric Design of Highways and Streets*.

The rural two-lane predictive method is located in Chapter 10 of the HSM. The following steps provide the calculations based on using the HSM "Smart Spreadsheets" available for download at: http://www.highwaysafetymanual.org/Pages/tools_sub.aspx#4. For this example problem, the analyst should use the "HSM prediction rural two lane" spreadsheet tool. Example hand calculations are included in the Guide Appendix (see A-4.3).

STEP 1: Input the known data for the roadway segment.

Segment Input Data:

For segment analysis, input data in the top section (Worksheet 1A) of the "Segment 1" tab. The Existing Condition input data is shown as follows:

Worksheet 1A - General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments						
General Information		Location Information				
Analyst Agency or Company Date Performed	**Analyst**	Roadway Roadway Section Jurisdiction Analysis Year	SH 111 MP 0.0 to MP 0.5 Study Site 2015			
Input Data		Base Conditions	Site Conditions			
Length of segment, L (mi)		--	0.5			
AADT (veh/day)	$AADT_{MAX}$ = 17,800 (veh/day)	--	11,000			
Lane width (ft)		12	12			
Shoulder width (ft)		6	Right Shld:	6	Left Shld:	6
Shoulder type		Paved	Right Shld:	Paved	Left Shld:	Paved
Length of horizontal curve (mi)		0	0.038			
Radius of curvature (ft)		0	380			
Spiral transition curve (present/not present)		Not Present	Not Present			
Superelevation variance (ft/ft)		< 0.01	0			
Grade (%)		0	0			
Driveway density (driveways/mile)		5	5			
Centerline rumble strips (present/not present)		Not Present	Not Present			
Passing lanes [present (1 lane)/present (2 lane)/not present)]		Not Present	Not Present			
Two-way left-turn lane (present/not present)		Not Present	Not Present			
Roadside hazard rating (1-7 scale)		3	3			
Segment lighting (present/not present)		Not Present	Not Present			
Auto speed enforcement (present/not present)		Not Present	Not Present			
Calibration Factor, Cr		1	0.97			

The applicable input data for the segment of the proposed alternative curve section is demonstrated in the following graphic.

Worksheet 1A - General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments						
General Information			**Location Information**			
Analyst Agency or Company Date Performed	**Analyst**		Roadway Roadway Section Jurisdiction Analysis Year	SH 111 MP 0.0 to MP 0.5 Study Site 2015		
Input Data			**Base Conditions**	**Site Conditions**		
Length of segment, L (mi)			--	0.5		
AADT (veh/day)		$AADT_{MAX}$ =17,800 (veh/day)	--	11,000		
Lane width (ft)			12	12		
Shoulder width (ft)			6	Right Shld:	6	Left Shld: 6
Shoulder type			Paved	Right Shld:	Paved	Left Shld: Paved
Length of horizontal curve (mi)			0	0.044		
Radius of curvature (ft)			0	250		
Spiral transition curve (present/not present)			Not Present	Not Present		
Superelevation variance (ft/ft)			< 0.01	0		
Grade (%)			0	0		
Driveway density (driveways/mile)			5	5		
Centerline rumble strips (present/not present)			Not Present	Not Present		
Passing lanes [present (1 lane)/present (2 lane)/not present)]			Not Present	Not Present		
Two-way left-turn lane (present/not present)			Not Present	Not Present		
Roadside hazard rating (1-7 scale)			3	3		
Segment lighting (present/not present)			Not Present	Not Present		
Auto speed enforcement (present/not present)			Not Present	Not Present		
Calibration Factor, Cr			1	0.97		

STEP 2: Following input in Step 1, the spreadsheet tools automatically calculate the predicted number of crashes. The following tables show the results for the exiting condition and the proposed alternative.

Existing:

Worksheet 1B - Crash Modification Factors for Rural Two-Lane Two-Way Roadway Segments						
(1)	(2)	(3)	(4)	(5)	(6)	(7)
CMF for Lane Width	CMF for Shoulder Width and Type	CMF for Horizontal Curves	CMF for Super-elevation	CMF for Grades	CMF for Driveway Density	CMF for Centerline Rumble Strips
CMF 1r	*CMF 2r*	*CMF 3r*	*CMF 4r*	*CMR 5r*	*CMF 6r*	*CMF 7r*
from Equation 10-11	from Equation 10-12	from Equation 10-13	from Equations 10-14, 10-15, or 10-16	from Table 10-11	from Equation 10-17	from Section 10.7.1
1.00	1.00	4.58	1.00	1.00	1.00	1.00

Worksheet 1E - Summary Results for Rural Two-Lane Two-Way Roadway Segments				
(1)	(2)	(3)	(4)	(5)
Crash Severity Level	Crash Severity Distribution (proportion)	Predicted Average Crash Frequency (crashes/year)	Roadway Segment Length (mi)	Crash Rate (crashes/mi/year)
	(4) from Worksheet 1C	(8) from Worksheet 1C		(3)/(4)
Total	1.000	6.53	0.5	13.1
Fatal and Injury (FI)	0.321	2.10	0.5	4.2
Property Damage Only (PDO)	0.679	4.44	0.5	8.9

Proposed:

Worksheet 1B - Crash Modification Factors for Rural Two-Lane Two-Way Roadway Segments						
(1)	(2)	(3)	(4)	(5)	(6)	(7)
CMF for Lane Width	CMF for Shoulder Width and Type	CMF for Horizontal Curves	CMF for Super-elevation	CMF for Grades	CMF for Driveway Density	CMF for Centerline Rumble Strips
CMF 1r	*CMF 2r*	*CMF 3r*	*CMF 4r*	*CMR 5r*	*CMF 6r*	*CMF 7r*
from Equation 10-11	from Equation 10-12	from Equation 10-13	from Equations 10-14, 10-15, or 10-16	from Table 10-11	from Equation 10-17	from Section 10.7.1
1.00	1.00	5.70	1.00	1.00	1.00	1.00

Worksheet 1E - Summary Results for Rural Two-Lane Two-Way Roadway Segments				
(1)	(2)	(3)	(4)	(5)
Crash Severity Level	Crash Severity Distribution (proportion)	Predicted Average Crash Frequency (crashes/year)	Roadway Segment Length (mi)	Crash Rate (crashes/mi/year)
	(4) from Worksheet 1C	(8) from Worksheet 1C		(3)/(4)
Total	1.000	8.13	0.5	16.3
Fatal and Injury (FI)	0.321	2.61	0.5	5.2
Property Damage Only (PDO)	0.679	5.52	0.5	11.0

STEP 3: Summarize the results for predicted crashes.

Configurations	Total Predicted Crashes per Year	Fatal and Injury Crashes per Year
Existing Horizontal Curve Section (R = 380 ft)	6.53 (say 7)	2.10 (say 3)
Alternative Horizontal Curve Section (R = 250 ft)	8.13 (say 9)	2.61 (say 3)
Increase in Predicted Number of Crashes due to Design Exception	8.13 - 6.53 = 1.60 (say 2)	2.61 – 2.10 = 0.51 (say 1 FI crash every 2 years)
Percent Increase in Predicted Number of Crashes due to Design Exception	1.60/6.53×100%=24.5% (say 25%)	0.51/2.10×100%=24.3% (say 25%)

FINDINGS

Interpreting the Results:

The construction of a sharper horizontal curve at this location will result in approximately two more crashes per year with an additional fatal or injury crash predicted to occur approximately once every 2 years. These changes correspond to an increase in crashes of approximately 25 percent at the 0.5-mile section. The large percentage relative to the very small frequency can lead to an overstatement of the site conditions. The actual total number of crashes is expected to increase from 7 to 9 crashes per year. If deemed necessary, it may be feasible to "offset" this increase in crashes. The DOT may elect to acquire detailed crash data and evaluate whether additional safety treatments may help mitigate this increase in crashes. These treatments could include, for example, additional signing and marking.

Possible Errors to Avoid:

The HSM recommends using engineering judgment to assess whether combined CMFs reasonably represent an estimated crash frequency. Analysts should be cautious to only multiply CMFs that correspond to the correct baseline conditions and appropriate crash types and severity. The CMF Clearinghouse FAQ titled "How can I apply multiple CMFs" provides additional information and clarification (see http://www.cmfclearinghouse.org/faqs.cfm#q4).

Alternative Analysis Approaches:

If data are available, a detailed evaluation of observed crash severity could help to offer additional insights regarding corridor operations. In addition, the use of the CMF Relative Comparison approach, as noted during the safety assessment method selection, may be a convenient tool for quickly considering how varying site features may ultimately influence the percent increase or decrease in crashes for a candidate safety treatment.

CHAPTER 5. Urban Street Continuous Case Study

Safety assessment methods can be incorporated into all phases of the project development process. To demonstrate how an agency could continue to assess safety throughout the various project stages, the following urban street case study, referred to as a continuous case study, provides example problems that answer the following questions:

- **How can the analyst estimate which, if any, of the road segments or intersections have more crashes than expected for a facility of this type?** (Planning and Scoping)
- **How can the analyst compare the estimated crash frequency for the existing configuration to Option #1, Option #2, and Option #3?** (Alternative Analysis)
- **How can the analyst estimate the annual percent reduction in crashes for installing a left-turn lane contrasted to installing a right-turn lane at Intersection #1?** (Preliminary and Final Design)

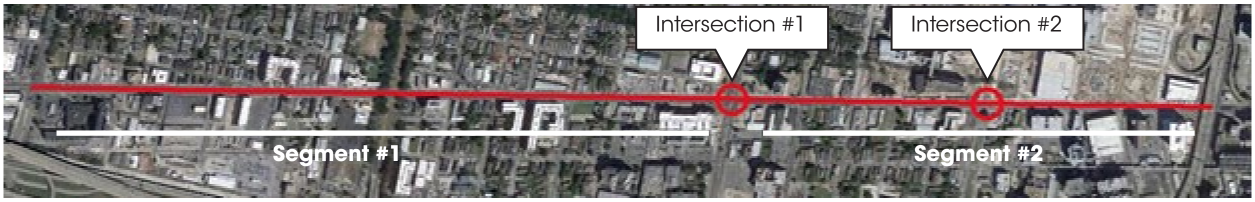
The detailed calculations for these questions are summarized in Sections 5.1, 5.2, and 5.3.

5.1 Urban Street Continuous Case Study – Planning and Scoping

PROBLEM OVERVIEW	
Safety Assessment Method: **SPF with CMF Weighted with Observed Crashes**	
Project Phase: **Planning & Scoping**	Project Type: **3R**
Related Task: **Establish Project Purpose and Need**	**Calculation Method:** ☐ **Hand Calculated** ☒ **Tool Based**
Comments: This example problem demonstrates how to estimate the number of expected crashes for an urban arterial and calculate excess crash conditions.	
LEVEL OF ANALYSIS	
Basic — Intermediate — Advanced	
Note: See table 3 for a full definition of Project Type designations.	

PROBLEM DESCRIPTION

As part of planning and scoping activities, a transportation agency has identified an urban street targeted for renovation that experiences multiple-vehicle crashes involving vehicles turning left. The specific section of the urban street includes two segments and two signalized intersections. The street has a narrow divided median but does not have any left-turn lanes. The section is 1.85 miles in length and passes through a community that consists of commercial development near multiple-family residential dwellings, as shown on the aerial photo. The associated **Project Type** is a 3R project and the **Related Task** is to *Establish Project Purpose and Need*. **How can the analyst estimate which, if any, of the road segments or intersections have more crashes than expected for a facility of this type?**



Source: ©Google Earth

Summary of Available Data:

Segment Data

The existing urban corridor has the following segment characteristics:

- Roadway is a four-lane divided urban arterial with parallel parking along the entire corridor.
- Adjacent land use is commercial / industrial.
- Median width = 10 ft.
- Street lights present along corridor.
- No automated speed enforcement.
- Posted speed limit = 40 mph.
- Estimated number of roadside fixed objects = 100 per mile.
- Typical offset to roadside fixed objects = 10 ft.

Characteristics unique to each segment are summarized in the following table:

Roadway Segment Characteristic	Segment 1	Segment 2
Segment Length (miles)	1.1	0.75
Annual average daily traffic (vehicles per day) *[3-year average value]*	13,300	11,500
Commercial driveway count	1 major, 17 minor	3 major, 7 minor
Industrial/institutional driveway count	2 major, 0 minor	2 major, 0 minor
Residential driveway count	1 major, 0 minor	0
Other driveway count	0	0

Note: For the purposes of this example, a major driveway is assumed to have a minimum of 10 vehicles per hour during the peak periods.

Segment crashes for the 3-year study period are shown as follows:

Crash Type/ Location	Observed Crash Frequency (crashes/yr)			3-Year Average for Observed Crash Frequency (crashes/yr)
	Year 1	Year 2	Year 3	
Multiple-vehicle non-driveway				
Segment 1	5	7	6	6
Segment 2	2	1	3	2
Single-vehicle				
Segment 1	3	3	3	3
Segment 2	2	4	0	2
Multiple-vehicle driveway-related				
Segment 1	1	3	2	2
Segment 2	2	1	0	1

Intersection Data

The two public intersections located along the corridor have the following common characteristics:

- Each intersection is a four-leg signalized intersection with permissive phasing on all approaches and no turn lanes.
- Street lights present.
- Right-turn-on-red permitted for all approaches.
- Intersection red-light cameras are not present.
- Sum of pedestrian crossings per hour = 10.
- Maximum number of lanes crossed by pedestrian = 4.
- Number of bus stops within 1000 ft. = 2.

Characteristics unique to each intersection are summarized in the following table:

Signalized Intersection Characteristic	Intersection 1	Intersection 2
Major-road annual average daily traffic (vehicles per day) [3-year average value]	13,300	11,500
Minor-road annual average daily traffic (vehicles per day) [3-year average value]	8,800	9,600
Number of Bus Stops within 1,000 ft. of the Intersection	11	7
Schools within 1000 ft. of the Intersection	Present	Not present
Number of Alcohol Sales Establishments within 1,000 ft. of the Intersection	0	1

Intersection crashes for the 3-year study period are shown as follows:

Crash Type/ Location	Observed Crash Frequency (crashes/yr)			3-Year Average for Observed Crash Frequency (crashes/yr)
	Year 1	Year 2	Year 3	
Multiple-vehicle				
Intersection 1	3	2	4	3
Intersection 2	2	2	2	2
Single-vehicle				
Intersection 1	0	1	2	1
Intersection 2	0	0	0	0

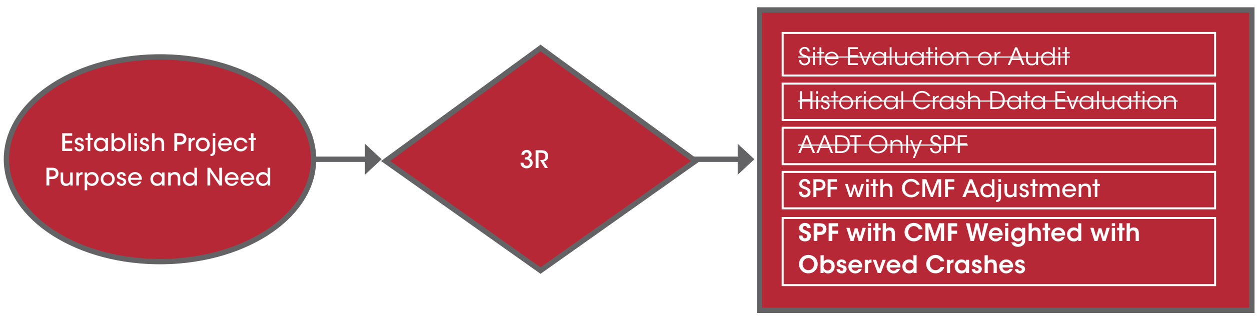
ANALYSIS

Selecting Appropriate Safety Assessment Method(s):

The analyst can first inspect Table 5 to identify potential safety assessment methods for a 3R project type and the Establish Project Purpose and Need task. Five potential methods may be considered for this analysis: two basic, two intermediate, and one advanced. Because the goal of this analysis is to assess whether the corridor experiences more crashes than would be expected for a facility of this type, a *Site Evaluation or Audit* would not provide this type of crash-specific information. The analyst plans to use the safety performance functions (SPF) from the *Highway Safety Manual* (HSM) for this assessment, so the *AADT-Only SPF* method can be removed from consideration. The *Historical Crash*

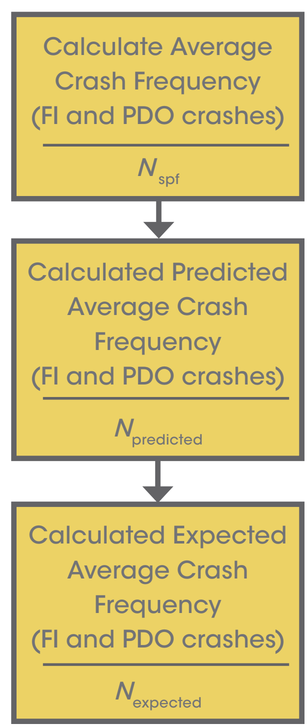
Data Evaluation can be used to identify the type and location of crashes at the site, but does not provide information related to the number of crashes that could be expected at a similar facility and so this method is also removed from consideration. The two remaining methods can be used for the analysis.

The transportation agency noted the possibility that left-turn maneuvers may be an issue, and so the analyst selects the *SPF with CMF Weighted with Observed Crashes* option for this evaluation. This method enables subsequent evaluation of roadway characteristics, if needed, as the project development process progresses while also considering the crash history for the study corridor. The *SPF with CMF Adjustment* method, though not selected, is also a viable safety assessment method for this evaluation because it does allow the calculation of predicted crashes for similar facility types that could then be compared to the observed crashes.



The *SPF with CMF Weighted with Observed Crashes* method results in expected crash information and can be used for estimating the future performance of an existing facility or the future impact of minor geometric changes to an existing road (see Table 1). To most effectively use this approach, an agency should calibrate the SPF for its local jurisdiction. A calibration factor of 1.0 can be used if this information is not available, but the results will not be refined to local conditions. The results can, however, be used for comparative purposes.

After the expected number of crashes is calculated, a variety of analysis approaches can be used to then evaluate whether the corridor is over-represented by crashes. For this assessment, the analyst will calculate the excess expected average crash frequency by comparing the number of expected crashes (unique to the study corridor) to the predicted number of crashes (representing roads with similar characteristics to the study corridor).



Linkage to the HSM:

The HSM can be used to estimate the number of predicted crashes for an urban and suburban arterial by applying the procedures introduced in HSM Chapter 12 (pp. 12-1 to 12-122). By determining predicted crashes, the analyst can estimate how many crashes may be estimated for a specific road type with varying road conditions. Once the predicted number of crashes is known, the expected number of crashes for a specific site can be calculated by applying the Empirical Bayes Method summarized in HSM, Part C (Volume 2), pp. A-15 to A-23.

To further evaluate the calculated number of expected crashes, the analyst can then assess the various safety assessment performance measures summarized in Table 6 (based on HSM Table 4-1, p. 4-8). Because the selected *Advanced* safety assessment method (*SPF with CMF Weighted with Observed Crashes*) will result in the number of expected crashes, the analyst selects the excess expected crash frequency method to assess whether the crashes for the corridor exceed what can be typically estimated for a similar corridor. Additional information about this procedure is located in HSM Chapter 4 (p. 4-75 to 4-78).

Detailed Analysis:

The expected average crash frequency for the corridor segments and intersections can be calculated using the HSM "Smart Spreadsheets" available for download at: http://www.highwaysafetymanual.org/Pages/tools_sub.aspx#4. For this example problem, the analyst can use the "HSM prediction urban and rural arterials" spreadsheet tool.

STEP 1: Input the data for each segment and intersection into the spreadsheet tool.

The following graphic shows a representation of Worksheet 1A for Segment #1. This roadway segment worksheet includes input information similar to that shown in the HSM worksheet (see HSM p. 12-108). Segment #2 data is similarly input into a worksheet (not shown).

Worksheet 1A - General Information and Input Data for Urban and Suburban Roadway Segments			
General Information		Location Information	
Analyst Agency or Company Date Performed	ABC DOT 06/15/16	Roadway Roadway Section Jurisdiction Analysis Year	Urban Corridor - Segment #1 MP 1.0 to MP 2.1 Small Town, USA 2015
Input Data		Base Conditions	Site Conditions
Roadway type (2U, 3T, 4U, 4D, ST)		--	4D
Length of segment, L (mi)		--	1.1
AADT (veh/day)	$AADT_{MAX}$ = 66,000 (veh/day)	--	13,300
Type of on-street parking (none/parallel/angle)		None	Parallel (Comm/Ind)
Proportion of curb length with on-street parking		--	1
Median width (ft) - for divided only		15	10
Lighting (present / not present)		Not Present	Present
Auto speed enforcement (present / not present)		Not Present	Not Present
Major commercial driveways (number)		--	1
Minor commercial driveways (number)		--	17
Major industrial / institutional driveways (number)		--	2
Minor industrial / institutional driveways (number)		--	0
Major residential driveways (number)		--	1
Minor residential driveways (number)		--	0
Other driveways (number)		--	0
Speed Category		--	Posted Speed Greater than 30 mph
Roadside fixed object density (fixed objects / mi)		0	100
Offset to roadside fixed objects (ft) [If greater than 30 or Not Present, input 30]		30	10
Calibration Factor, Cr		1.00	1.00

Data for each of the study intersections can then be input into Worksheet 2A (see HSM p. 12-113). The following graphic depicts a representation of the Intersection #1 worksheet. Intersection #2 data is similarly included into a worksheet (not shown).

Workseet 1L - General Information and Input Data for Urban and Suburban Arterial Intersections			
General Information		**Location Information**	
Analyst Agency or Company Date Performed	ABC DOT 06/15/16	Roadway Intersection Jurisdiction Analysis Year	Urban Corridor Intersection #1 Small Town, USA 2015
Input Data		**Base Conditions**	**Site Conditions**
Intersection type (3ST, 3SG, 4ST, 4SG)		–	4SG
$AADT_{MAJOR}$ (veh/day)	$AADT_{MAX}$ = 67,700 (veh/day)	–	13,300
$AADT_{MINOR}$ (veh/day)	$AADT_{MAX}$ = 33,400 (veh/day)	–	8,800
Intersection lighting (present/not present)		Not Present	Present
Calibration factor, C_i		1.00	1.00
Data for unsignalized intersections only:		–	–
Number of major-road approaches with left-turn lanes (0,1,2)		0	0
Number of major-road approaches with right-turn lanes (0,1,2)		0	0
Data for signalized intersections only:		–	–
Number of approaches with left-turn lanes (0,1,2,3,4) [for 3SG, use maximum value of 3]		0	0
Number of approaches with right-turn lanes (0,1,2,3,4) [for 3SG, use maximum value of 3]		0	0
Number of approaches with left-turn signal phasing [for 3SG, use maximum value of 3]		–	0
Type of left-turn signal phasing for Leg #1		Permissive	Permissive
Type of left-turn signal phasing for Leg #2		–	Permissive
Type of left-turn signal phasing for Leg #3		–	Permissive
Type of left-turn signal phasing for Leg #4 (if applicable)		–	Permissive
Number of approaches with right-turn-on-red prohibited [for 3SG, use maximum value of 3]		0	0
Intersection red light cameras (present/not present)		Not Present	Not Present
Sum of all pedestrian crossing volumes (PedVol) – Signalized intersections only			10
Maximum number of lanes crossed by a pedestrian (n_{lanesx})		–	4
Number of bus stops within 300 m (1,000 ft) of the intersection		0	2
Schools within 300 m (1,000 ft) of the intersection (present/not present)		Not Present	Present
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection		0	0

STEP 2: Tabulate the predicted crash frequency for each segment and intersection.

The following graphics show representations of Worksheet 1L (see HSM p. 12-113) for Segment #1 and Worksheet 2L (see HSM p. 12-117) for Intersection #1. The analyst developed similar summaries (not shown) for Segment #2 and Intersection #2.

Segment #1 Summary Results:

General Information and Input Data for Urban and Suburban Arterial Intersections			
Crash Severity Level	Predicted Average Crash Frequency $N_{predicted\ rs}$ (crashes/year) (Total) from Worksheet 1K	Roadway Segment Length, L(mi)	Crash Rate (crashes/mi/year) (2)/(3)
Total	5.8	1.10	5.3
Fatal and injury (FI)	1.6	1.10	1.5
Property damage only (PDO)	4.2	1.10	3.8

Intersection #1 Summary Results:

Summary Results for Urban and Suburban Arterial Intersections	
1	2
Crash Severity Level	Predicted Average Crash Frequency $N_{predicted\ int}$ (crashes/year) (Total) from Worksheet 2K
Total	3.6
Fatal and injury (FI)	1.2
Property damage only (PDO)	2.4

STEP 3: Calculate the expected number of crashes for each segment and intersection.

The "Urban Site Total" worksheet tab in the spreadsheet can be used to summarize the predicted and observed crashes, apply the weighted adjustment factor, and calculate the expected average crash frequency. The summary results are depicted in the following representations for Worksheet 3A (see HSM p. 12-118). The highlighted values represent the historical crash data.

Worksheet 3A - Predicted Crashes by Severity and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials							
1	2	3	4	5	6	7	8
Collision Type/Site Type	Predicted Average Crash Frequency			Observed Crashes $N_{predicted}$ (crashes/year)	Overdispersion Parameter, k	Weighted Adjustment, w	Expected Average Crash Frequency
	$N_{predicted}$ (TOTAL)	$N_{predicted}$ (FI)	$N_{predicted}$ (PDO)			Equation A 5 from Part C Appendix	Equation A 4 from Part C Appendix
ROADWAY SEGMENTS							
Multiple-vehicle non-driveway							
Segment 1	3.931	1.137	2.795	6	1.320	0.162	5.666
Segment 2	2.199	0.643	1.557	2	1.320	0.256	2.051
Single-vehicle							
Segment 1	1.231	0.194	1.037	3	0.860	0.486	2.141
Segment 2	0.784	0.120	0.664	2	0.860	0.597	1.274
Multiple-vehicle driveway-related							
Segment 1	0.546	0.155	0.391	2	1.390	0.568	1.174
Segment 2	0.372	0.106	0.266	1	1.390	0.659	0.586
INTERSECTIONS							
Multiple-vehicle							
Intersection 1	3.208	1.007	2.201	3	0.390	0.444	3.092
Intersection 2	2.801	0.864	1.937	2	0.390	0.478	2.383
Single-vehicle							
Intersection 1	0.248	0.073	0.175	1	0.360	0.918	0.310
Intersection 2	0.230	0.071	0.159	0	0.360	0.924	0.212
COMBINED (sum of column)	15.551	4.369	11.182	22	–	–	18.889

STEP 4: Calculate the excess crashes by segment or intersection.

Based on the weighting of the observed and predicted crashes in Step 3, the analyst can calculate the excess expected average crash frequency to identify corridor segments or intersections with more than the expected number of crashes. Computing this measure requires the tabulation of the following quantities:

- Predicted average crash frequency (crashes/year).
- Expected average crash frequency (crashes/year).
- Excess value.

The excess value is calculated by subtracting the predicted average crash frequency from the expected average crash frequency. The following table summarizes the total crash statistics using this approach.

Crash Type / Site Type	Predicted Average Crash Frequency (crashes/yr)	Expected Average Crash Frequency (crashes/yr)	Excess Calculated as Expected minus Predicted (crashes/yr)
Multiple-vehicle non-driveway			
Segment 1	3.9	5.7	1.8
Segment 2	2.2	2.1	-0.1
Single-vehicle			
Segment 1	1.2	2.1	0.9
Segment 2	0.8	1.3	0.5
Multiple-vehicle driveway-related			
Segment 1	0.6	1.2	0.6
Segment 2	0.4	0.6	0.2
Multiple-vehicle			
Intersection 1	3.2	3.1	-0.1
Intersection 2	2.8	2.4	-0.4
Single-vehicle			
Intersection 1	0.2	0.3	0.1
Intersection 2	0.2	0.2	0.0
Corridor Total	15.6	18.9	3.3

FINDINGS

Interpreting the Results:

Based on the excess expected average crash frequencies calculated in Step 4, the largest excess of crashes is found to occur on Segment 1. The overall street section is found to experience 3 to 4 more crashes per year than would be predicted for a similar facility.

Possible Errors to Avoid:

The study location does not have left-turn lanes present but does include a 10-ft. median. This physical constraint requires the analyst to assume a segment roadway type that is a four-lane divided arterial (4D). Similarly, the parallel parking along the entire corridor length requires a value of 1 for the proportion of curb length with on-street parking. Because the curb length does not extend into the intersections, the total corridor length should not be used for determining this proportion value.

Alternative Analysis Approaches:

During the selection of the appropriate safety assessment method, the analyst also identified the *SPF with CMF Adjustment* as a candidate assessment method to consider. Because this method is classified as an *Intermediate* safety assessment method, the procedure results in predicted crashes for a facility type. The use of this alternative analysis method would require a safety assessment performance measure (see Table 6) other than the excess expected average crash value. The companion performance measure procedure to use with predicted crashes that will address the analyst's question of over-represented locations is the *Excess Predicted Average Crash Frequency* using SPFs noted in the performance measures table.

5.2 Urban Street Continuous Case Study – Alternatives Analysis

PROBLEM OVERVIEW	
Safety Assessment Method: SPF with CMF Adjustment	
Project Phase: **Alternatives Analysis**	Project Type: **3R**
Related Task: **Alternative Selection**	**Calculation Method:** ☐ **Hand Calculated** ☒ **Tool Based**
Comments: This example problem demonstrates how to estimate the number of predicted crashes for alternative design options	
LEVEL OF ANALYSIS	
Basic — Intermediate — Advanced (3 of 6 segments shaded)	
Note: See table 3 for a full definition of Project Type designations.	

PROBLEM DESCRIPTION

The analyst next conducted the alternative evaluations task for the improvement project for the four-lane divided urban arterial corridor identified in Section 5.1. After determining that the corridor does experience a higher-than-expected crash frequency, the analyst examined the crash predictions more closely to evaluate low-cost redesign options that could be implemented within the current right-of-way limits. The initial study identified Segment #1 as the section of road with the greatest number of expected crashes compared to predicted crashes, so the analyst is focused on alternatives that can be applied to that 1-mile segment.

The alternatives currently under consideration include:

- Option 1: Reduce on-street parking to 50 percent of the section's curb length.
- Option 2: Reduce the number of roadside objects to no more than 50 objects per mile.
- Option 3: Combine Option 1 and Option 2 (reduce on-street parking and remove roadside objects).

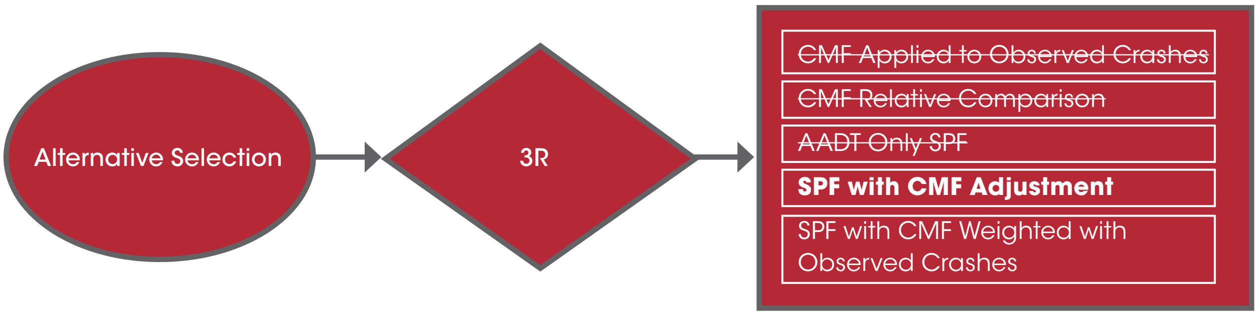
The **Project Type** is *3R* and the **Related Task** is *Alternative Selection*. **How can the analyst compare the estimated crash frequency for the existing configuration to Option #1, Option #2, and Option #3?**

Summary of Available Data:

The site data is the same as that presented in the Section 5.1 data summary. The modifications are expected to occur in 2 years, and at that time the AADT value is projected to increase moderately from the current 13,300 vpd value to 13,725 vpd.

ANALYSIS

The analyst can first review the potential safety assessment methods shown in Table 8. The Alternative Selection task and the 3R project type are associated with five safety assessment methods: two basic, two intermediate, and one advanced. For this evaluation, the analyst intends to compare the number of estimated crashes for three low-cost options and contrast these values to the number of crashes for the current segment. Since a CMF-based method enables the specific consideration of a change in road characteristics, the safety assessment methods that use CMFs are applicable for this analysis. Traffic volume information is also available, so a safety assessment method that is volume-based can be used. Based on these considerations, the *AADT-Only SPF* method, which does not directly capture changes in road characteristics, can be eliminated from further consideration. The analyst would like to incorporate both the calculations conducted for the initial assessment as well as the moderate increase in traffic volume. Consequently, the analyst eliminates the methods that do not use an SPF (i.e., *CMF Applied to Observed Crashes and CMF Relative Comparison*).

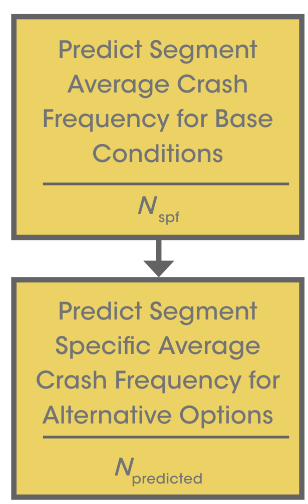


The two remaining safety assessment methods include *SPF with CMF Adjustment* and *SPF with CMF Weighted with Observed Crashes*. The analyst may elect to use one or both of these methods. Because the modifications can be expected to change the future number of crashes at the site, the analyst selects the *SPF with CMF Adjustment* method so that weighting with observed crashes for a modified roadway does not introduce unexpected biases. The *SPF with CMF Weighted with Observed Crashes* method can be used to evaluate the future impact of minor geometric changes to an existing road (per Table 1), but since the threshold of "minor geometric changes" can vary, the analyst elects not to use this particular method.

Ultimately, the analyst selects the *SPF with CMF Adjustment* method for the assessment. To use this analysis method most effectively, an agency should calibrate the SPF for its local jurisdiction. A calibration factor of 1.0 can be used if this information is not available, but the results will not be refined to location conditions. For the purposes of this assessment, the SPF method can be used for comparison.

Linkage to the HSM:

The HSM can be used to estimate the number of predicted crashes for an urban and suburban arterial by applying the procedures introduced in HSM Chapter 12 (pp. 12-1 to 12-122). By determining predicted crashes, the analyst can estimate how many crashes may be associated with a specific road type with varying road conditions. Once the predicted number of crashes is known, the analyst can compare the estimated safety performance of the varying options to identify optimal designs.



Detailed Analysis:

The predicted average crash frequency for the corridor segments and intersections can be calculated using the HSM "Smart Spreadsheets" available for download at: http://www.highwaysafetymanual.org/Pages/tools_sub.aspx#4. For this example problem, the analyst can use the "HSM prediction urban and rural arterials" spreadsheet tool.

STEP 1: Input the data for the study segment (referred to as Segment #1 in Section 5) into the spreadsheet tool.

This evaluation should use the future AADT value of 13,725 vpd. The following graphic shows a representation of Worksheet 1A for Segment #1, Option #3. This roadway segment worksheet includes input information similar to that shown in the HSM worksheet (see HSM p. 12-108). Information for existing Segment #1 conditions, Option 1, and Option 2 are similarly input into a worksheet (not shown).

General Information and Input Data for Urban and Suburban Roadway Segments			
General Information		Location Information	
Analyst Agency or Company Date Performed	ABC DOT 06/15/16	Roadway Intersection Jurisdiction Analysis Year	Urban Corridor-Segment #1 MP 1.0 to MP 2.1 Small Town, USA 2015
Input Data		Base Conditions	Site Conditions
Intersection type (2U, 3T, 4U, 4D, ST)		–	4D
Length of segment, L (mi)		–	1.1
AADT (veh/day)	$AADT_{MAX}$ = 66,000 (veh/day)	–	13,725
Type of on-street parking (none/parallel/angle)		None	Parallel (Comm/Ind)
Proportion of curb length with on-street parking		–	0.5
Median width (ft) - for divided only		15	10
Lighting (present / not present)		Not Present	Present
Auto speed enforcement (present / not present)		Not Present	Not Present
Major commercial driveways (number)		–	1
Minor commercial driveways (number)		–	17
Major industrial / institutional driveways (number)		–	2
Minor industrial / institutional driveways (number)		–	0
Major residential driveways (number)		–	1
Minor residential driveways (number)		–	0
Other driveways (number)		–	0
Speed Category		–	Posted Speed Greater than 30 mph
Roadside fixed object density (fixed objects / mi)		0	50
Offset to roadside fixed objects (ft) [If greater than 30 or Not Present, input 30]		30	10
Calibration Factor, Cr		1.00	1.00

STEP 2: Calculate the number of predicted crashes for the study year.

At the completion of Step 1, the spreadsheet tools automatically calculated the predicted number of crashes for the existing conditions and for the three candidate options. To review example results for the intersection calculations, see the summary results of the predicted crashes for Option 3 (shown in Worksheet 1L). The analyst calculated similar summary results (not shown) for the Existing configuration, Option 1, and Option 2 (using the AADT value of 13,725 vpd as previously noted).

Worksheet 1L - General Information and Input Data for Urban and Suburban Roadway Segments			
Crash Severity Level	Predicted Average Crash Frequency $N_{predicted\ rs}$ (crashes/year) (Total) from Worksheet 1K	Roadway Segment Length, L(mi)	Crash Rate (crashes/mi/year) (2)/(3)
Total	4.2	1.10	3.8
Fatal and injury (FI)	1.2	1.10	1.1
Property damage only (PDO)	3.0	1.10	2.8

STEP 3: Summarize Findings.

The analyst's ultimate goal is to assess how much the three options have the potential to reduce the number of crashes predicted for the study segment 2 years into the future (when the AADT is 13,725 vpd). In addition to the total number of predicted crashes, the crash severity information is important to note. The following table summarizes these results.

Roadway Improvement Scenario	Predicted Number of FI Crashes (crashes/yr)	Potential Reduction in FI Crashes (crashes/yr)	Percent Reduction in FI Crashes	Predicted Number of Total Crashes (crashes/yr)	Potential Reduction in Total Crashes (crashes/yr)	Percent Reduction in Total Crashes
Existing Configuration	1.7	N/A	N/A	6.1	N/A	N/A
Option 1 – Reduce on-street parking by 50%	1.3	1.7 – 1.3 = 0.4	23.5%	4.8	6.1 – 4.8 = 1.3	21.3%
Option 2 – Reduce the number of roadside objects to 50 per mile	1.5	1.7 – 1.5 = 0.2	11.8%	5.3	6.1 – 5.3 = 0.8	13.1%
Option 3 – Reduce on-street parking by 50% and reduce the number of roadside objects to 50 per mile	1.2	1.7 – 1.2 – 0.5	29.4%	4.2	6.1 – 4.2 = 1.9	31.1%
Note: N/A = not applicable.						

FINDINGS

Interpreting the Results:

Based solely on an evaluation of the predicted number of crashes, reducing the on-street parking to approximately 50 percent of the curb length (Option #1) results in a 21.3 percent total crash reduction. If the number of roadside objects is reduced to 50 per mile (from the current 100 per mile) and the road is not otherwise modified (Option #2), the reduction in total number of crashes can be estimated to be approximately 13.1 percent. For the alternative that reduces the on-street parking and the roadside object density (Option #3), the reduction in the total number of crashes can be similarly estimated as a 31.1 percent. The number of fatal and injury crashes for the existing roadway segment is equivalent to less than two per year. This value is based on SPFs that have not been calibrated to the region. For all three options, the reduction in the number of fatal and injury crashes is similar to the trend observed for total crashes with reductions of 23.5 percent , 11.8 percent, and 29.4 percent for Option 1, 2, and 3 respectively.

For the conditions outlined in this problem, the minor modifications to the corridor appear to result in modest crash reductions. The number of predicted crashes can be used as input into a cost benefit study to assess whether the investment is economically justified. The analyst should use caution when assessing the results of this analysis due to the small number of crashes (less than 10).

These calculations are based only on predicted crash performance, but do not consider potential operational issues. For example, limiting the on-street parking can potentially provide additional operational benefits to the adjacent travel lane.

Possible Errors to Avoid:

The HSM procedures require the analyst to understand how SPFs and CMFs equate to the base conditions associated with the procedure. Incorrect use of these values can introduce erroneous results. This example compared the crash predictions, so a calibration factor with a value of 1.0 can be used for comparison purposes. If the analyst would like to record findings as crash frequency instead of percent reduction in the number of crashes, calibrated SPFs with known calibration factors should be used for the analysis. A more detailed analysis during the design phase would provide additional useful information about predicted crashes.

Alternative Analysis Approaches:

A common method for evaluating design alternatives is to use CMF comparisons that do not directly consider traffic volume. This approach is less reliable than the predictive methods, but can be used to evaluate alternatives when an SPF is not available for the condition or when a simple comparison between two alternatives is all that is needed.

The analyst can also use the advanced safety assessment method to further evaluate existing conditions and future designs with minor changes. Future configurations that include major changes are not suitable for the *SPF with CMF Weighted with Observed Crashes* method as the observed crashes would no longer be representative of the new configuration.

5.3 Urban Street Continuous Case Study – Preliminary & Final Design

PROBLEM OVERVIEW	
Safety Assessment Method: **CMF Relative Comparison**	
Project Phase: **Preliminary & Final Design**	Project Type: **3R**
Related Task: **Selecting Specific Design Elements and Their Dimension**	**Calculation Method:** ☒ **Hand Calculated** ☐ **Tool Based**
Comments: This example problem demonstrates how to calculate the predicted number of crashes for alternative design options at an urban arterial.	
LEVEL OF ANALYSIS	
Basic / Intermediate / Advanced (Basic marked)	
Note: See table 3 for a full definition of Project Type designations.	

PROBLEM DESCRIPTION

This problem is based on the scenario for Segment #1 as shown in Section 5.2.

During the project development design phase, the transportation agency notified the analyst that on-street parking will be reduced by 50 percent for the entire corridor. This design change will result in complete removal of on-street parking at the intersection approaches for the corridor described in Section 5.1. The transportation agency intends to use the "recovered" space to make room for turn lanes at Intersection #1. The turn lanes will only be added on the primary corridor approaches (and not on the intersecting streets). The **Project Type** is *3R* and the **Related Task** is *Selecting Specific Design Elements and Their Dimensions*. **How can the analyst estimate the annual percentage reduction in crashes for installing a left-turn lane compared with the estimated reduction from installing a right-turn lane at Intersection #1?**

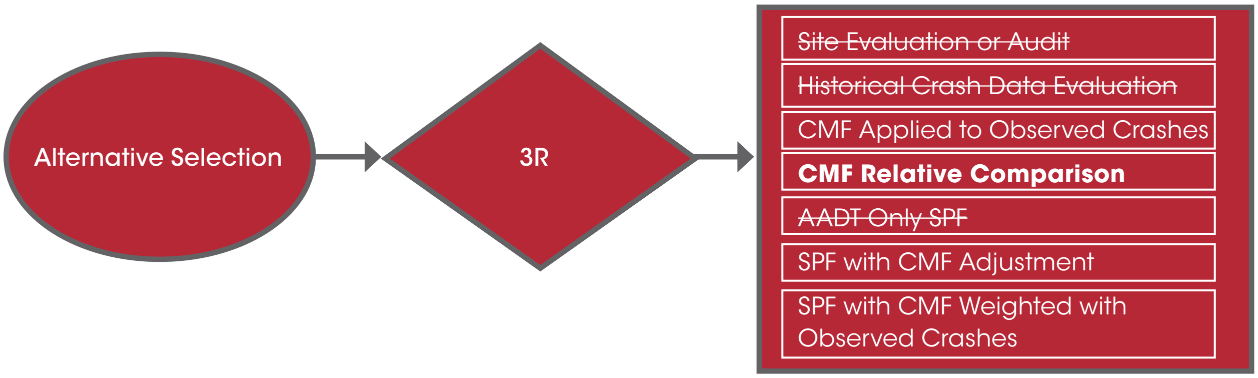
Summary of Available Data:

The site data is the same as that presented in the Section 5.1 data summary. Right-turn-on-red will continue to be permitted on all approaches.

ANALYSIS

Selecting Appropriate Safety Assessment Method(s)

The analyst can first review the potential safety assessment methods shown in Table 9. The *Selecting Specific Design Elements and Their Dimensions* task and the 3R project type are associated with all seven candidate safety assessment methods. For this evaluation, the analyst intends to compare the estimated percent reduction in crashes for the two turn-lane options, so a CMF-based method that considers varying geometric characteristics is needed. As a result, the analyst may eliminate the *Site Evaluation or Audit*, the *Historical Crash Data Evaluation*, and the *AADT-Only SPF* safety assessment methods from further consideration. The addition of a turn lane at Intersection #1 is a minor geometric change, so any of the remaining four methods should be suitable for the turn lane analysis. Because all four of the CMF-based methods should provide similar results for this comparison, the analyst selects the basic method that does not require extensive data – *CMF Relative Comparison*. The analyst could also have used one of the remaining SPF-based methods with minimal additional effort as a continuation of the previous calculations conducted, as illustrated in Sections 5.1 and 5.2.



Linkage to the HSM:

Chapter 12 (p. 12-24 to 12-26) and Chapter 14 (p. 14-23 to 14-26) of the HSM, as well as the FHWA-sponsored CMF Clearinghouse (www.cmfclearinghouse.org) collectively include a wide variety of CMFs for varying turn lane configurations. These CMF resources identify the base conditions and applicable site applications for the individual countermeasure of interest.

Detailed Analysis:

The *CMF Relative Comparison* safety assessment method can be used to compare potential countermeasures or treatments to identify the treatment most likely to have the greatest impact on reducing crashes. The only data requirement for this basic safety assessment method is the value for each CMF representing the candidate treatments for the same "before" characteristics and crash types.

To perform this assessment, the analyst reviews the CMF values for the two turn-lane options and compares their relative values. The information for the two CMFs is summarized in the following table. Recall that a CMF value less than 1.0 is associated with a larger reduction in future crashes when compared to a CMF with a value equal to 1.0 (assumed to have no real effect on reducing crashes). Based on this simple comparison, the analyst concludes that the recommended treatments, in order of priority, should be:

1. Install a left-turn lane at the signalized intersection (associated with a CMF value of 0.81 or an estimated 19 percent reduction in crashes).
2. Install a right-turn lane at the signalized intersection (associated with a CMF of 0.92 or an estimated 8 percent reduction in crashes for this treatment).

Proposed Treatment	CMF (S.E.)	Crash Type (Base Condition)	Crash Severity	Source
Install left-turn lane on two signalized intersection approaches	0.81 (0.13)	★★★ All crash types and roadway types	All	HSM Table 12-24, p. 12-43, HSM Table 14-12, p. 14-23, and CMF Clearinghouse at http://www.cmfclearinghouse.org/detail.cfm?facid=270#commentanchor
Install right-turn lane on two signalized intersection approaches	0.92 (0.03)	★★★★★ All crash types and rural roadway types	All	HSM Table 12-26, p. 12-44, HSM Table 14-15, p. 14-26, and CMF Clearinghouse at http://www.cmfclearinghouse.org/detail.cfm?facid=290#commentanchor

Note: ★ = CMF Clearinghouse Star Rating. CMF = crash modification factor. HSM = Highway Safety Manual. S.E. = standard error.

FINDINGS

Interpreting the Results:

Based on the relative comparison of CMFs method, the analyst concluded that the addition of a left-turn lane on the two major approaches for Intersection #1 is a more effective option for reducing crashes than adding a right-turn lane. This assessment is based on the historic crash performance of left-turn and right-turn lanes and their associated CMFs and does not account for design features such as length of turn lane or operational features including consideration of turning volumes. A comprehensive assessment that addresses these issues should be performed as well during the design phase of the project development process.

Possible Errors to Avoid:

A wide variety of CMF values are available for turn lanes. The selection of appropriate CMFs should include verification of appropriate base conditions, confirmation of consistent crash types between compared CMFs, and selection of higher quality CMFs based on small standard error values or higher star ratings (if using the CMF Clearinghouse). A common error associated with selection of CMFs is the selection of values that do not have applicable "before" conditions.

Alternative Analysis Approaches:

For this analysis, four candidate safety assessment methods emerged as viable options for the analysis. For the three methods that were not selected, the CMF value is multiplied by the observed or the predicted number of crashes. Though these techniques will result in numeric answers that generally represent the estimated reduction in crashes, they will all provide a similar answer to the analyst's question providing that the same CMF values are used for all of the evaluations. For this reason, any of the four CMF-based safety assessment methods is suitable for this analysis. The analyst selected the *CMF Relative Comparison* method based on the comparative nature of the question and recognized that, for this condition, this simple approach would provide similar findings as one of the more complex analysis methods and could be performed quickly with minimal data requirements.

Appendix. Alternative Calculations for Select Example Problems

A-3.2 Hand Calculated Example — Predicting Crash Frequency for Alternative Intersection Turn-lane Options at Four-Lane, Rural, Undivided Highways

PROBLEM OVERVIEW	
Safety Assessment Method: SPF with CMF Adjustment	
Project Phase: **Alternative Analysis**	Project Type: **2R**
Related Task: **Alternative Selection**	**Calculation Method:** ☒ **Hand Calculated** ☐ **Tool Based** *Tool based example included in Problem 3.2.*
Comments: This example problem demonstrates how to conduct a safety assessment for an alternative design for a rural, multilane highway and compare the estimated safety improvement to the existing configuration.	
LEVEL OF ANALYSIS	
Basic — Intermediate — Advanced (shaded: Basic to Intermediate)	
Note: See table 3 for a full definition of Project Type designations.	

Detailed Analysis:

This example demonstrates hand calculations for Problem 3.2 and Alternative #1. The full problem in Chapter 3 includes two alternative options. For this assessment, the analyst can use the *SPF with CMF Adjustment* method. This will provide the number of predicted crashes (estimated for a type of facility). The SPFs can be locally derived or the analyst can use the *Highway Safety Manual* (HSM) equations. If the analyst uses the safety performance functions (SPF) from the HSM, they should be calibrated for local conditions where possible. To perform a relative comparison between two options for the same location, this procedure can be used and a calibration value of 1.0 assumed.

This hand-calculated example uses the rural undivided multilane predictive procedures located in Chapter 11 of the HSM.

STEP 1: Calculate the predicted average total crash frequency and fatal and injury frequency for the intersection and major road segment base conditions (N_{SPF}).

Intersection Calculations ($N_{SPF\ int}$):

From the HSM, use the SPF equation for intersection-related crashes at undivided rural multi-lane highways to calculate the average intersection total crash frequency. This base condition SPF applies to the existing configuration as well as the alternative.

Calculations	Notes
Total Crashes:	
$N_{spf\ int\ (Total)}$=exp[-10.008 +(0.848 ×ln($AADT_{maj}$)) +(0.448×ln($AADT_{min}$))]	HSM Equation 11-11, p. 11-21 with 4ST Total (4-lane stop on minor) constants from HSM Table 11-7, p. 11-22
$N_{spf\ int\ (Total)}$=exp[-10.008+(0.848 ×ln(30,000)) +(0.448 ×ln(5,000))]=12.80	*Answer (Total Crashes)*
Fatal + Injury (FI) Crashes:	
$N_{spf\ int\ (Total)}$=exp[-11.554+(0.888×ln($AADT_{maj}$)) +(0.525×ln($AADT_{min}$))]	HSM Equation 11-11 with 4ST Fatal and injury constants from HSM Table 11-7, p. 11-22
$N_{spf\ int\ (FI)}$=exp[-11.554+(0.888 ×ln(30,000)) +(0.525 ×ln(5,000))]=7.94	*Answer (FI Crashes)*
Note: $N_{spf\ int\ (Total)}$= average total crash frequency for intersection-related crashes $N_{spf\ int\ (FI)}$= average fatal and injury crash frequency for intersection-related crashes $AADT_{maj}$= major road AADT (vehicles per day) $AADT_{min}$ = minor road AADT (vehicles per day) FI = Fatality and injury. HSM = Highway Safety Manual.	

Segment Calculations *($N_{SPF\ ru}$):*

The HSM equation for undivided roadway segments can be used to calculate the average segment crash frequency. This SPF applies to the existing design as well as the alternative intersection configuration. Recall that each approach segment is 0.19 miles for a total study length of 0.38 miles.

Calculations	Notes
Total Crashes:	
$N_{spf\ ru\ (Total)} = e^{(-9.653+(1.176 \times \ln(AADT))+\ln(L))}$	HSM Equation 11-7 with 4-lane total constants from HSM Table 11-3, p. 11-15
$N_{spf\ ru\ (Total)} = e^{(-9.653+(1.176 \times \ln(30{,}000))+\ln(0.19))} = 2.247$	Calculation for one major road approach segment
$N_{spf\ ru\ (Total)} = 2.247 \times 2 = 4.494$	*Answer including Both Approaches (0.38 mile segment)*
FI Crashes:	
$N_{spf\ ru\ (FI)} = e^{(-9.410+(1.094 \times \ln(AADT))+\ln(L))}$	HSM Equation 11-7 with 4-lane Fatal and injury constants from HSM Table 11-3, p. 11-15
$N_{spf\ ru\ (FI)} = e^{(-9.410+(1.094 \times \ln(30{,}000))+\ln(0.19))} = 1.230$	Calculation for one major road approach segment
$N_{spf\ ru\ (FI)} = 1.230 \times 2 = 2.460$	*Answer including Both Approaches (0.38 mile segment)*

Note:
$N_{spf\ ru\ (Total)}$ = average total crash frequency for rural undivided segment-related crashes
$N_{spf\ ru\ (FI)}$ = average fatal and injury crash frequency for rural undivided segment-related crashes
$AADT$ = annual average daily traffic for primary corridor (for this example, this is the same as the $AADT_{maj}$ used in the intersection-related calculations) (vehicles per day)
L = segment length (miles)
FI = Fatality and injury, HSM = Highway Safety Manual

STEP 2: Calculate the predicted average crash frequency for the segment and intersection unique design conditions ($N_{predicted}$).

The predicted average crash frequency (*Npredicted*) for each option can be calculated using the following equation (HSM Equation 11-1, p. 11-2):

$$N_{predicted} = N_{spf} \times (CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{yx}) \times C_x$$

Where: CMF = crash modification factor/function and C = calibration factor for SPF

[Notice that any countermeasure that matches base conditions will have a CMF value of 1.0 and does not change the value of $N_{predicted}$.]

Predicted Average Crash Frequency (N_{int}) for Intersections

The intersection-related CMFs that do not match base conditions are next included in the calculations. For this example, a calibration factor of 1.0 is assumed (assuming the HSM predictive equations are representative of local conditions). The required CMFs are:

Total Crashes	Fatal and Injury Crashes	Notes
Left-turn Lane CMF:		
CMF_{2i}=0.52	CMF_{2i}=0.42	Use HSM Table 11-22, p. 11-34 for left-turn lanes *(Alternative)*
Note: CMF = crash modification factor, $CMF2_i$ = left-turn lane CMF		

The predicted number of intersection-related crashes is then calculated by multiplying the CMFs and the calibration factor times the appropriate $N_{spf\ int}$ value.

Calculations	Notes
$N_{(predicted\ int} = N_{(spf\ int)} \times CMF_{2i} \times C_x$	Equations with turn lane CMF and the local calibration factor
Total Crashes:	
$N_{predicted\ int(Existing\text{-}Total} = 12.80 \times 1.0 \times 1.0 = 12.80$	Existing
$N_{predicted\ int(Alt\text{-}Total} = 12.80 \times 0.52 \times 1.0 = 6.66$	Alternative
FI Crashes:	
$N_{predicted\ int(Existing\text{-}Fi} = 7.94 \times 1.0 \times 1.0 = 7.94$	Existing
$N_{predicted\ int(Alt\text{-}Fi} = 7.94 \times 0.42 \times 1.0 = 3.33$	Alternative
Definitions:	
Note: C_x = Local calibration factor (can assume C_x=1.0 for this calculation because evaluation is based on relative comparisons) CMF = crash modification factor	

Segment Predicted Average Crash Frequency

The segment-related CMFs that do not match base conditions are next included in the calculations. These are the required CMFs:

Calculations	Notes
Lane Width CMFs:	
$CMF_{1ru} = (CMF_{RA} - 1.0) \times P_{RA} + 1.0$	HSM Equation 11-13, p. 11-26 with Table 11-11 values and default value of 0.27 for P_{RA}
$CMF_{1ru} = (1.00 - 1.0) \times 0.27 + 1.0 = 1.00$	≥ 12′ Lanes *(Existing)*
$CMF_{1ru} = (1.04 - 1.0) \times 0.27 + 1.0 = 1.01$	11′ Lanes *(Alternative)*
Shoulder Width CMFs:	
$CMF_{2ru} = (CMF_{WRA} \times CMF_{TRA} - 1.0) \times P_{RA} + 1.0$	HSM Equation 11-14, p. 11-27 with Table 11-12 and Table 11-13 values and default value of 0.27 for P_{RA}
$CMF_{2ru} = (0.87 \times 1.00 - 1.0) \times 0.27 + 1.0 = 0.96$	8′ paved shoulder *(Existing)*
$CMF_{2ru} = (1.00 \times 1.00 - 1.0) \times 0.27 + 1.0 = 1.00$	6′ paved shoulder *(Alternative)*
Note: CMF = crash modification factor CMF_{1ru} = Lane width CMF CMF_{2ru} = Shoulder width and type CMF CMF_{RA} = for segment-related crashes (run-off-the-road, head-on, sideswipe) CMF_{WRA} = for segment-related crashes based on shoulder width CMF_{TRA} = for segment-related crashes based on shoulder type P_{RA} = Proportion that segment-related crashes make up of all crashes (default is 0.27)	

The predicted number of segment-related crashes is then calculated by multiplying the CMFs and the calibration factor times the appropriate $N_{spf\ ru}$ value.

Calculations	Notes
$N_{predicted\ ru} = N_{spf\ ru} \times (CMF_{1ru} \times CMF_{2ru}) \times C$	Equations with lane and shoulder CMFs and the local calibration factor
Total Crashes:	
$N_{predicted\ ru(Existing\text{-}Total)} = 4.49 \times (1.0 \times 0.96) \times 1.0 = 4.31$	Existing
$N_{predicted\ ru(Alt\text{-}Total)} = 4.49 \times (1.01 \times 1.0) \times 1.0 = 4.53$	Alternative
Fatal and Injury Crashes:	
$N_{predicted\ ru(Existing\text{-}FI)} = 2.46 \times (1.0 \times 0.96) \times 1.0 = 2.36$	Existing
$N_{predicted\ ru(Alt\text{-}FI)} = 2.46 \times (1.01 \times 1.0) \times 1.0 = 2.48$	Alternative

STEP 3: Add the intersection and segment crashes per year to calculate the total and FI predicted crashes ***($N_{(predicted\ (Total))}$) and ($N_{(predicted\ (FI))}$) .***

	Total Crashes per Year			Fatal and Injury Crashes per Year		
Alternative	**Intersection Crashes**	**Segment Crashes**	**Predicted Crashes**	**Intersection Crashes**	**Segment Crashes**	**Predicted Crashes**
Existing	12.80	4.31	17.11 (say 18)	7.94	2.36	10.30 (say 11)
Alternative #1	6.66	4.53	11.19 (say 12)	3.33	2.48	5.81 (say 6)
Difference	6.14	-0.22	5.92 (say 6)	4.61	-0.12	4.49 (say 5)
Percent Reduction	48.0%	-5.1%	34.6% (say 34%)	58.1%	-5.1%	43.6% (say 43%)

Manual calculations are shown only for total crashes. Calculations for fatal and injury (FI) and property damage only (PDO) crashes are calculated in a similar manner. The hand calculations include rounded values. The self-calculating spreadsheets do not truncate the numbers and so rounding errors are not included. Consequently, the hand calculated results may have minor differences than the spreadsheet calculated values.

A-3.4 Hand Calculated Example — Calculating Expected Crashes for Urban Freeway Ramps

PROBLEM OVERVIEW	
Safety Assessment Method: SPF with CMF Weighted with Observed Crashes	
Project Phase: **Alternative Analysis**	Project Type: **4R**
Related Task: **Interchange Justification Request**	**Calculation Method:** ☒ **Hand Calculated** ☐ **Tool Based** *Tool based example included in Problem 3.4.*
Comments: This example problem demonstrates how to estimate the expected number of crashes for an urban freeway loop ramp.	
LEVEL OF ANALYSIS	
Basic — Intermediate — Advanced	
Note: See table 3 for a full definition of Project Type designations.	

Detailed Analysis:

This example demonstrates hand calculations for Problem 3.4. The full problem in Chapter 3 includes calculations that demonstrate the use of the free ISATe self-calculating "Smart Spreadsheet." For this assessment, the analyst can use the *SPF with CMF Weighted with Observed Crashes* method. This assessment is for a specific location with a known crash history, so the expected number of crashes can be calculated. Because the ramp's cross-sectional characteristics are consistent along its entire length, the ramp can be modeled as one segment.

The following steps summarize the process for performing hand calculations to evaluate the expected crashes.

STEP 1: Calculate the predicted average crash frequency, $N_{spf:}$

Multiple-vehicle crashes:

The HSM equations for multiple-vehicle FI and PDO crashes at freeway ramps are summarized as follows:

Calculations	Notes
Predicted Average Crash Frequency for Multiple-Vehicle Crash Types:	
$N_{spf,\ cds,\ 1,\ mv,\ fi} = 0.5 \times \exp(-2.997 + 0.524 \times \ln[0.001 \times 9800] + 0.0699[0.001 \times 9800])$ $N_{spf,\ cds,\ 1,\ mv,\ fi} = 0.164$ crashes/yr	HSM Equation 19-22, p. 19-31 with urban one-lane C-D road segment FI crash severity constants from HSM Table 19-7, p. 19-32. Approximately 0.164 FI multiple-vehicle crashes
$N_{spf,\ cds,\ 1,\ mv,\ pdo} = 0.5 \times \exp(-3.311 + 1.256 \times \ln[0.001 \times 9800] + 0[0.001 \times 9800])$ $N_{spf,\ cds,\ 1,\ mv,\ pdo} = 0.321$ crashes/yr	HSM Equation 19-22, p. 19-31 with urban one-lane C-D road segment PDO crash severity constants from HSM Table 19-7, p. 19-32. Approximately 0.321 PDO multiple-vehicle crashes

Note: HSM = Highway Safety Manual. PDO = property damage only.

Single-vehicle crashes:

The HSM equations for single-vehicle FI and PDO crashes at freeway ramps are summarized as follows:

Calculations	Notes
Predicted Average Crash Frequency for Single-Vehicle Crash Types:	
$N_{spf,\ cds,\ 1,\ sv,\ fi} = 0.5 \times \exp(-2.848 + 0.718 \times \ln[0.001 \times 9800])$ $N_{spf,\ cds,\ 1,\ sv,fi} = 0.149$ crashes/yr	HSM Equation 19-26, p. 19-34 with urban one-lane C-D road segment FI crash severity constants from HSM Table 19-10, p. 19-35. Approximately 0.149 FI single-vehicle crashes
$N_{spf,\ cds,\ 1,\ mv,\ pdo} = 0.5 \times \exp(-2.659 + 0.689 \times \ln[0.001 \times 9800])$ $N_{spf,\ cds,\ 1,\ mv,\ pdo} = 0.169$ crashes/yr	HSM Equation 19-26, p. 19-34 with urban one-lane C-D road segment PDO crash severity constants from HSM Table 19-10, p. 19-35. Approximately 0.169 PDO single-vehicle crashes

Note: FI = fatal and injury. HSM = Highway Safety Manual. PDO = property damage only.

__STEP 2:__ Apply the appropriate CMFs and calculate the predicted average crash frequency ***($N_{predicted}$)***

Calculate CMF values for any conditions that differ from the base conditions.

CMF for Horizontal Curve:

The horizontal curve CMF requires an average entry speed ($v_{ent,i}$), the radius for the entry curve *(R_i)*, the proportion of the segment length with the curve *($P_{c,\ i}$)*, and the number of horizontal curves in the segment *(m)*. To calculate this CMF value, the limited curve speed (curve with the sharpest radius) must first be identified.

Calculations	Notes
Limited Curve speed	
$v_{max,\ 1} = 0.324\times(32.2\times R_1)^{0.30}$ $v_{max,\ 2} = 0.324\times(32.2\times R_2)^{0.30}$	Limiting curve speed for horizontal curve [HSM equation 19-59, p. 19-67]
$v_{max,\ 1} = 0.324\times(32.2\times 11460)^{0.30}$ $v_{max,\ 1} = 151.35\ ft/s$ $v_{max,\ 2} = 0.324\times(32.2\times 150)^{0.30}$ $v_{max,\ 2} = 41.279\ ft/s$	Limiting curve speed for curve 1 and curve 2 are 151.35 ft/s and 41.27 ft/s, respectively
Average entry speed at curve 1	
If $1.47\times V_{frwy} \le v_{max,\ 1}$, then: $v_{ent,\ 1} = 1.47\times V_{frwy}$ As, $1.47\times V_{frwy} = 1.47\times 65 = 95.55 \le v_{max,\ 1}(= 155.35)$ $v_{ent,\ 1} = 1.47\times V_{frwy} = 1.47\times 65 = 95.55\ ft/s$	HSM equation 19-68, p.19-70
Average exit speed at curve 1	
$v_{ext,\ 1} = v_{ent,\ 1} \le v_{max,\ 1}$ $v_{ext,\ 1} = v_{ent,\ 1} \le v_{max,\ 1}(= 155.35)$ $v_{ext,\ 1} = 95.55\ ft/s$	HSM equation 19-70, p.19-70
Average entry speed at curve 2	
If $v_{ext,\ i-1} > v_{max,\ i}$, then: $v_{ent,\ i} = Max\begin{cases} v_{ext,\ i-1} - 0.034\times 5280\times(X_i - X_{i-1} - L_{c,\ i-1}) \\ 1.47\times V_{cdroad} \end{cases}$ As, $v_{ext,\ 1}(= 155.35) > v_{max,\ 2}(= 41.279)$, then: $v_{ent,\ 2} = Max\begin{cases} v_{ext,\ 1} - 0.034\times 5280\times(X_2 - X_1 - L_{c,\ 1}) \\ 1.47\times V_{cdroad} \end{cases}$ $= Max\begin{cases} 95.55 - 0.034\times 5280\times(0.34 - 0.26 - 0.04) \\ 1.47\times 40 \end{cases}$ $= Max\begin{cases} 88.369 \\ 58.800 \end{cases} = 88.369\ ft/s$	HSM equation 19-72, p.19-70 From HSM Table 19-42, p. 19-67, V_{cdroad}=40

Calculations	Notes
CMF for horizontal curve	
$CMF_{1,\ cds,\ 1,\ y,\ z} = 1.0 + a \times \frac{1000}{32.2} \times \left[\sum_{i=1}^{m} \left(\frac{v_{ent,i}}{R_i}\right)^2 \times P_{c,i}\right]$	HSM equation 19-33, p.19-47
$CMF_{1,\ cds,\ 1,\ mv,\ fi} = 1.0 + 0.779 \times \frac{1000}{32.2} \times \left[\left(\frac{95.55}{11460}\right)^2 \times \frac{0.04}{0.5} + \left(\frac{88.37}{150}\right)^2 \times \frac{0.12}{0.5}\right]$ $CMF_{1,\ cds,\ 1,\ mv,\ fi} = 3.015$ $CMF_{1,\ cds,\ 1,\ mv,\ pdo} = 1.0 + 0.545 \times \frac{1000}{32.2} \times \left[\left(\frac{95.55}{11460}\right)^2 \times \frac{0.04}{0.5} + \left(\frac{88.37}{150}\right)^2 \times \frac{0.12}{0.5}\right]$ $CMF_{1,\ cds,\ 1,\ mv,\ pdo} = 2.410$ $CMF_{1,\ cds,\ 1,\ sv,\ fi} = 1.0 + 2.406 \times \frac{1000}{32.2} \times \left[\left(\frac{95.55}{11460}\right)^2 \times \frac{0.04}{0.5} + \left(\frac{88.37}{150}\right)^2 \times \frac{0.12}{0.5}\right]$ $CMF_{1,\ cds,\ 1,\ sv,\ fi} = 7.224$ $CMF_{1,\ cds,\ 1,\ sv,\ pdo} = 1.0 + 3.136 \times \frac{1000}{32.2} \times \left[\left(\frac{95.55}{11460}\right)^2 \times \frac{0.04}{0.5} + \left(\frac{88.37}{150}\right)^2 \times \frac{0.12}{0.5}\right]$ $CMF_{1,\ cds,\ 1,\ sv,\ pdo} = 9.113$	

Note: HSM = Highway Safety Manual.

CMF for Lane Width:

Calculations	Notes
CMF for Lane Width	
$CMF_{2, w, x, y, fi} = \exp(a \times [W_1 - 14])$	HSM equation 19-34, p.19-48
$CMF_{2, cds, 1, mv, fi} = \exp(-0.0458 \times [13-14])$ $CMF_{2, cds, 1, mv, fi} = 1.047$ $CMF_{2, cds, 1, sv, fi} = \exp(-.0458 \times [13-14])$ $CMF_{2, cds, 1, sv, fi} = 1.047$ $CMF_{2, cds, 1, mv, pdo} = 1.000$ $CMF_{2, cds, 1, sv, pdo} = 1.000$	HSM Table 19-25, p.19-48

Note: CMF = crash modification factor. HSM = Highway Safety Manual.

CMF for Shoulder Width:

CMF for Right Shoulder Width	
$CMF_{3, w, x, y, z} = \exp(a \times [W_{rs} - 8])$	HSM equation 19-35, p.19-48
$CMF_{3, cds, 1, mv, fi} = \exp(-0.0539 \times [10-8])$ $CMF_{3, cds, 1, mv, fi} = 0.897$ $CMF_{3, cds, 1, mv, pdo} = \exp(-0.0259 \times [10-8])$ $CMF_{3, cds, 1, mv, pdo} = 0.949$ $CMF_{3, cds, 1, sv, fi} = \exp(-0.0539 \times [10-8])$ $CMF_{3, cds, 1, sv, fi} = 0.897$ $CMF_{3, cds, 1, sv, pdo} = \exp(-0.0259 \times [10-8])$ $CMF_{3, cds, 1, sv, pdo} = 0.949$	HSM Table 19-26, p.19-49

Note: CMF = crash modification factor. HSM = Highway Safety Manual.

CMF for Left Shoulder Width	
$CMF_{4,\ w,\ x,\ y,\ fi} = \exp(a \times [W_{ls}-4])$	HSM equation 19-36, p.19-49
$CMF_{4,\ cds,\ 1,\ mv,\ fi} = \exp(-0.0539 \times [7-4])$ $CMF_{4,\ cds,\ 1,\ mv,\ fi} = 0.851$ $CMF_{4,\ cds,\ 1,\ mv,\ pdo} = \exp(-0.0259 \times [7-4])$ $CMF_{4,\ cds,\ 1,\ mv,\ pdo} = 0.925$ $CMF_{4,\ cds,\ 1,\ sv,\ fi} = \exp(-0.0539 \times [7-4])$ $CMF_{4,\ cds,\ 1,\ sv,\ fi} = 0.851$ $CMF_{4,\ cds,\ 1,\ sv,\ pdo} = \exp(-0.0259 \times [7-4])$ $CMF_{4,\ cds,\ 1,\ sv,\ pdo} = 0.925$	HSM Table 19-27, p.19-49

Note: CMF = crash modification factor. HSM = Highway Safety Manual.

CMF for Roadside Barrier:

CMF for Right Side Barrier	
$$CMF_{5,\ w,\ x,\ y,\ z} = (1.0 - P_{rb})\times 1.0 + P_{rb}\times \exp\left(\frac{a}{W_{rcb}}\right)$$ $$W_{rcb} = \frac{\sum L_{rb,i}}{\sum \frac{L_{rb,i}}{W_{off,r,i} - W_{rs}}}$$	HSM equation 19-37, p.19-50 HSM equation 19-74, p.19-71
$$W_{rcb} = \frac{0.06 + 0.05}{\frac{0.06}{11-10} + \frac{0.05}{11-10}} = 1$$ $$CMF_{5,\ cds,\ 1,\ mv,\ fi} = \left(1.0 - \frac{0.11}{0.50}\right)\times 1.0 + \frac{0.11}{0.50}\times \exp\left(\frac{0.210}{1}\right)$$ $$CMF_{5,\ cds,\ 1,\ mv,\ fi} = 1.051$$ $$CMF_{5,\ cds,\ 1,\ mv,\ pdo} = \left(1.0 - \frac{0.11}{0.50}\right)\times 1.0 + \frac{0.11}{0.50}\times \exp\left(\frac{0.193}{1}\right)$$ $$CMF_{5,\ cds,\ 1,\ mv,\ pdo} = 1.047$$ $$CMF_{5,\ cds,\ 1,\ sv,\ fi} = \left(1.0 - \frac{0.11}{0.50}\right)\times 1.0 + \frac{0.11}{0.50}\times \exp\left(\frac{0.210}{1}\right)$$ $$CMF_{5,\ cds,\ 1,\ sv,\ fi} = 1.051$$ $$CMF_{5,\ cds,\ 1,\ sv,\ pdo} = \left(1.0 - \frac{0.11}{0.50}\right)\times 1.0 + \frac{0.11}{0.50}\times \exp\left(\frac{0.193}{1}\right)$$ $$CMF_{5,\ cds,\ 1,\ sv,\ pdo} = 1.047$$	HSM Table 19-28, p.19-50 HSM Table 19-28, p.19-50 HSM Table 19-28, p.19-50 HSM Table 19-28, p.19-50

Note: CMF = crash modification factor. HSM = Highway Safety Manual.

CMF for Left Side Barrier	
$CMF_{6,\ w,\ x,\ y,\ z} = (1.0 - P_{lb})\times 1.0 + P_{lb}\times \exp\left(\frac{a}{W_{lcb}}\right)$ $W_{rcb} = \frac{\sum L_{lb,i}}{\sum \frac{L_{lb,i}}{W_{off,l,i} - W_{ls}}}$	HSM equation 19-38, p.19-51 HSM equation 19-76, p.19-72
$W_{rcb} = \frac{0.02 + 0.05 + 0.10}{\frac{0.02}{8-7} + \frac{0.05}{8-7} + \frac{0.10}{8-7}} = 1$ $CMF_{6,\ cds,\ 1,\ mv,\ fi} = \left(1.0 - \frac{0.17}{0.50}\right)\times 1.0 + \frac{0.17}{0.50}\times \exp\left(\frac{0.210}{1}\right)$ $CMF_{6,\ cds,\ 1,\ mv,\ fi} = 1.079$ $CMF_{6,\ cds,\ 1,\ mv,\ pdo} = \left(1.0 - \frac{0.17}{0.50}\right)\times 1.0 + \frac{0.17}{0.50}\times \exp\left(\frac{0.193}{1}\right)$ $CMF_{6,\ cds,\ 1,\ mv,\ pdo} = 1.072$ $CMF_{6,\ cds,\ 1,\ sv,\ fi} = \left(1.0 - \frac{0.17}{0.50}\right)\times 1.0 + \frac{0.17}{0.50}\times \exp\left(\frac{0.210}{1}\right)$ $CMF_{6,\ cds,\ 1,\ sv,\ fi} = 1.079$ $CMF_{6,\ cds,\ 1,\ sv,\ pdo} = \left(1.0 - \frac{0.17}{0.50}\right)\times 1.0 + \frac{0.17}{0.50}\times \exp\left(\frac{0.193}{1}\right)$ $CMF_{6,\ cds,\ 1,\ sv,\ pdo} = 1.072$	HSM Table 19-29, p.19-51 HSM Table 19-29, p.19-51 HSM Table 19-29, p.19-51 HSM Table 19-29, p.19-51

Note: CMF = crash modification factor. HSM = Highway Safety Manual.

STEP 3: Calculate the predicted average crash frequency for the segment under unique design conditions ***($N_{predicted}$)***

Calculations	Notes
Multiple-vehicle crashes	
$N_{p*,\ cds,\ 1,\ mv,\ fi} = N_{spf,\ cds,\ 1,\ mv,\ fi} \times CMF_{1,\ cds,\ 1,\ mv,\ fi} \times CMF_{2,\ cds,\ 1,\ mv,\ fi} \times CMF_{3,\ cds,\ 1,\ mv,\ fi} \times CMF_{4,\ cds,\ 1,\ mv,\ fi} \times CMF_{5,\ cds,\ 1,\ mv,\ fi} \times CMF_{6,\ cds,\ 1,\ mv,\ fi}$	FI Crashes
$N_{p*,\ cds,\ 1,\ mv,\ fi} = 0.164 \times (3.015 \times 1.047 \times 0.897 \times 1.055 \times 1.05 \times 1.08) = 0.448$	
$N_{p*,\ cds,\ 1,\ mv,\ pdo} = N_{spf,\ cds,\ 1,\ mv,\ pdo} \times CMF_{1,\ cds,\ 1,\ mv,\ pdo} \times CMF_{2,\ cds,\ 1,\ mv,\ pdo} \times CMF_{3,\ cds,\ 1,\ mv,\ pdo} \times CMF_{4,\ cds,\ 1,\ mv,\ pdo} \times CMF_{5,\ cds,\ 1,\ mv,\ pdo} \times CMF_{6,\ cds,\ 1,\ mv,\ pdo}$	PDO Crashes
$N_{p*,\ cds,\ 1,\ mv,\ pdo} = 0.321 \times (2.409 \times 0.949 \times 1.000 \times 1.026 \times 1.05 \times 1.38) = 0.762$	
Single-vehicle crashes	
$N_{p*,\ cds,\ 1,\ sv,\ fi} = N_{spf,\ cds,\ 1,\ sv,\ fi} \times CMF_{1,\ cds,\ 1,\ sv,\ fi} \times CMF_{2,\ cds,\ 1,\ sv,\ fi} \times CMF_{3,\ cds,\ 1,\ sv,\ fi} \times CMF_{4,\ cds,\ 1,\ sv,\ fi} \times CMF_{5,\ cds,\ 1,\ sv,\ fi} \times CMF_{6,\ cds,\ 1,\ sv,\ fi}$	FI Crashes
$N_{p*,\ cds,\ 1,\ sv,\ fi} = 0.149 \times (7.224 \times 1.047 \times 0.897 \times 1.055 \times 1.05 \times 1.08) = 0.978$	
$N_{p*,\ cds,\ 1,\ sv,\ pdo} = N_{spf,\ cds,\ 1,\ sv,\ pdo} \times CMF_{1,\ cds,\ 1,\ sv,\ pdo} \times CMF_{2,\ cds,\ 1,\ sv,\ pdo} \times CMF_{3,\ cds,\ 1,\ sv,\ pdo} \times CMF_{4,\ cds,\ 1,\ sv,\ pdo} \times CMF_{5,\ cds,\ 1,\ sv,\ pdo} \times CMF_{6,\ cds,\ 1,\ sv,\ pdo}$	PDO Crashes
$N_{p*,\ cds,\ 1,\ sv,\ fi} = 0.169 \times (9.113 \times 0.949 \times 1.000 \times 1.026 \times 1.05 \times 1.38) = 1.516$	

Note: FI = fatal and injury. HSM = Highway Safety Manual. PDO = property damage only.

STEP 4: Calculate the expected crashes.

The next step is to evaluate the expected number of total crashes.

Overdispersion Factor	Weighting Factor	$N_{expected}$	Notes
$k_{cds,\ 1,\ mv,\ fi} = \frac{1}{K_{cds,\ 1,\ mv,\ fi} \times L_r} = \frac{1}{14.6 \times 0.5} = 0.137$	$w = \frac{1}{1 + k_{cds,\ 1,\ mv,\ fi} \times \sum_{all\ sites} N_{p*,\ cds,\ 1,\ mv,\ fi}} = \frac{1}{1 + 0.137 \times 0.448 \times 3} = 0.844$	$N_{expected} = w \times N_{predicted} + (1 - w) \times N_{observed} = 0.844 \times 0.448 + (1 - 0.844) \times 0 \times \left(\frac{1}{3}\right) = 0.378\ crashes/yr.$	HSM Equation 19-23 [p.19-32] HSM Equation B-5, B-6, B-7 [p. Appendix B-20]
$k_{cds,\ 1,\ mv,\ pdo} = \frac{1}{K_{cds,\ 1,\ mv,\ pdo} \times L_r} = \frac{1}{12.7 \times 0.5} = 0.157$	$w = \frac{1}{1 + k_{cds,\ 1,\ mv,\ pdo} \times \sum_{all\ sites} N_{p*,\ cds,\ 1,\ mv,\ pdo}} = \frac{1}{1 + 0.157 \times 0.762 \times 3} = 0.735$	$N_{expected} = w \times N_{predicted} + (1 - w) \times N_{observed} = 0.735 \times 0.762 + (1 - 0.735) \times 1 \times \left(\frac{1}{3}\right) = 0.649\ crashes/yr.$	HSM Equation 19-23 [pp.19-32] HSM Equation B-5, B-6, B-7 [p. Appendix B-20]
$k_{cds,\ 1,\ sv,\ fi} = \frac{1}{K_{cds,\ 1,\ sv,\ fi} \times L_r} = \frac{1}{7.91 \times 0.5} = 0.253$	$w = \frac{1}{1 + k_{cds,\ 1,\ sv,\ fi} \times \sum_{all\ sites} N_{p*,\ cds,\ 1,\ sv,\ fi}} = \frac{1}{1 + 0.253 \times 0.978 \times 3} = 0.574$	$N_{expected} = w \times N_{predicted} + (1 - w) \times N_{observed} = 0.574 \times 0.978 + (1 - 0.574) \times 1 \times (\frac{1}{3}) = 0.703\ crashes/yr.$	HSM Equation 19-27 [p.19-35] HSM Equation B-5, B-6, B-7 [p. Appendix B-20]
$k_{cds,\ 1EN,\ sv,\ pdo} = \frac{1}{K_{cds,\ 1,\ sv,\ pdo} \times L_r} = \frac{1}{9.77 \times 0.5} = 0.208$	$w = \frac{1}{1 + k_{cds,\ 1,\ sv,\ pdo} \times \sum_{all\ sites} N_{p*,\ cds,\ 1,\ sv,\ pdo}} = \frac{1}{1 + 0.208 \times 1.516 \times 3} = 0.518$	$N_{expected} = w \times N_{predicted} + (1 - w) \times N_{observed} = 0.518 \times 1.516 + (1 - 0.518) \times 2 \times \left(\frac{1}{3}\right) = 1.107\ crashes/yr.$	HSM Equation 19-27 [p.19-35] HSM Equation B-5, B-6, B-7 [p. Appendix B-20]

Note: HSM = Highway Safety Manual.

Summary table:

Total Crashes, All Severities:	
$N_{expected,\ mv,\ fi} = 0.378\ crashes/yr = 1.135\ crashes/\ 3yrs.$	Total number of multi-vehicle FI expected crashes (in 3 yrs.) is 1.135 crashes.
$N_{expected,\ mv,\ pdo} = 0.648\ crashes/yr = 1.946\ crashes/\ 3yrs.$	Total number of multi-vehicle PDO expected crashes (in 3 yrs.) is 1.946 crashes.
$N_{expected,\ sv,\ fi} = 0.706\ crashes/yr = 2.110\ crashes/\ 3yrs.$	Total number of single-vehicle FI expected crashes (in 3 yrs.) is 2.110 crashes.
$N_{expected,\ sv,\ pdo} = 1.107\ crashes/yr = 3.320\ crashes/\ 3yrs.$	Total number of single-vehicle PDO expected crashes (in 3 yrs.) is 3.320 crashes.
$N_{expected} = N_{expected,\ mv,\ fi} + N_{expected,\ mv,\ pdo} + N_{expected,\ sv,\ fi} + N_{expected,\ sv,\ pdo} = 8.512\ crashes/\ 3yrs.$	Total number of expected crashes (in 3 yrs.) is 8.512 crashes.

Note: FI = fatal and injury. PDO = property damage only.

A-4.1 Hand Calculated Example — Predicting Crashes for a New Urban Multilane Arterial

PROBLEM OVERVIEW	
Safety Assessment Method: SPF with CMF Adjustment	
Project Phase: **Preliminary & Final Design**	Project Type: **NL**
Related Task: **Selecting Specific Design Elements and Their Dimensions**	**Calculation Method:** ☒ **Hand Calculated** ☐ **Tool Based** *Tool based example included in Problem 4.1.*
Comments: This example problem demonstrates how to calculate the predicted number of crashes for a four-lane urban arterial following the construction of a median and the addition of lighting and auto speed enforcement.	
LEVEL OF ANALYSIS	
Basic — Intermediate — Advanced	
Note: See table 3 for a full definition of Project Type designations.	

Detailed Analysis:

The urban multilane predictive method is located in Chapter 12 of the HSM. The following steps summarize the manual calculation for the proposed configurations as described in Problem 4.1.

STEP 1: Calculate the predicted average crash frequency and fatal and injury frequency for the proposed road segment.

Segment Calculations ($N_{SPF\ RS}$):

Use the SPF equation in the HSM for segment-related crashes at divided urban multi-lane arterials to calculate crash frequency:

Calculations	Notes
$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$	HSM Equation 12-4, p. 12-5
Calculate Multiple-Vehicle Non-Driveway Collisions (N_{brmv}):	
$N_{brmv} = \exp\,(a + b \times \ln(AADT) + \ln(L))$	HSM Equation 12-10, p. 12-18
$N_{brmv(total)} = \exp(-12.34 + 1.36\times \ln(28{,}000) + \ln(1)) = 4.885$	HSM Table 12-10, p. 12-18 (for 4-lane divided (4D))
$N'_{brmv(FI)} = \exp(-12.76 + 1.28\times \ln(28{,}000) + \ln(1)) = 1.415$	HSM Equation 12-11, p. 12-20
$N'_{brmv(PDO)} = \exp(-12.81 + 1.38\times \ln(28{,}000) + \ln(1)) = 3.747$	HSM Equation 12-12, p. 12-20
$N_{brmv(FI)} = N_{brmv(\,total)} \times \left(\dfrac{N'_{brmv(FI)}}{N'_{brmv(FI)} + N'_{brmv(PDO)}}\right)$	
$N_{brmv(PDO)} = N_{brmv(total)} - N_{brmv(FI)}$	

Calculations	Notes
$N_{brmv(FI)} = 4.885\times\left(\frac{1.415}{1.415+3.747}\right) = 1.339$ $N_{brmv(PDO)} = 4.885 - 1.339 = 3.547$	

Calculations	Notes
Calculate Single Vehicle Related Crashes (N_{brsv}):	
$N_{brsv} = \exp\,(a + b\times\ln(AADT) + \ln(L))$	HSM Equation 12-13, p. 12-20
$N_{brsv(total)} = \exp(-5.05 + 0.47\times\ln(28{,}000) + \ln(1)) = 0.788$ $N'_{brsv(FI)} = \exp(-8.71 + 0.66\times\ln(28{,}000) + \ln(1)) = 0.142$ $N'_{brsv(PDO)} = \exp(-5.04 + 0.45\times\ln(28{,}000) + \ln(1)) = 0.649$ $N_{brsv(FI)} = N_{brsv(\,total)}\times\left(\frac{N'_{brsv(FI)}}{N'_{brsv(FI)} + N'_{brsv(PDO)}}\right)$ $N_{brsv(PDO)} = N_{brsv(total)} - N_{brsv(FI)}$	HSM Table 12-10, p. 12-18 (for 4D)
$N_{brsv(FI)} = 0.788\times\left(\frac{0.142}{0.142+0.649}\right) = 0.141$	HSM Equation 12-11, p. 12-20
$N_{brmv(PDO)} = 0.788 - 0.141 = 0.647$	HSM Equation 12-12, p. 12-20
Calculate Multiple-Vehicle Driveway-Related Collisions (N_{brdwy}):	
$N_{brdwy(total)} = \sum_{all\ driveway\ types} n_j \times N_j \times \left(\frac{AADT}{15{,}000}\right)^t$	HSM Equation 12-16, p. 12-22
$N_{brdwy(total)} = 4\times0.003\times\left(\frac{28000}{15{,}000}\right)^{1.106} = 0.024$ $N_{brdwy(FI)} = N_{brdwy(total)}\times f_{dwy}$ $N_{brdwy(PDO)} = N_{brdwy(total)} - N_{brdwy(FI)}$	HSM Table 12-7, p. 12-24 (for 4D)
$N_{brdwy(FI)} = 0.024\times0.284 = 0.007$ $N_{brdwy(PDO)} = 0.024 - 0.007 = 0.017$ $N_{spf\ rs} = 4.885 + 0.788 + 0.024 = 5.697$ crashes/year	
Definitions HSM = *Highway Safety Manual*. FI = Fatal + Injury Crashes. PDO = Property Damage Only.	

STEP 2: Calculate the Crash Modification Factors:

Calculations	Notes
CMF for Median Width (CMF_{3r}):	
$CMF_{3r} = 0.99$	Median width= 20'
CMF for Lighting (CMF_{4r}):	
$CMF_{4r} = 1 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ $CMF_{4r} = 1 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636) = 0.913$	HSM Equation 12-34, p. 12-42 HSM Table 12-23, p. 12-42 (4D)
CMF for Automated Speed Enforcement (CMF_{5r}):	
$CMF_{5r} = 0.95$	Automated Speed Enforcement Present per HSM, P. 12-43
Definitions CMF = crash modification factor, HSM = *Highway Safety Manual.*	

STEP 3: Calculate the predicted average crash frequency for the design conditions ***($N_{predicted}$)***.

The predicted average crash frequency ($N_{predicted}$) can be calculated using the following equations:

$$N_{br} = N_{spf} \times (CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r})$$

$$N_{predicted} = (N_{br} + N_{pedr} + N_{biker}) \times C_r$$

Calculations	Notes
$N_{br} = 5.697 \times (1.00 \times 1.00 \times 0.99 \times 0.91 \times 0.95) =$ 4.871 crashes/year	Proposed Design
$N_{pedr} = N_{br} \times f_{dwy}$ $N_{biker} = N_{br} \times f_{biker}$	HSM Equation 12-19, p. 12-27 HSM Equation 12-20, p. 12-27
$N_{pedr} = 4.871 \times 0.019 = 0.093$ $N_{biker} = 4.871 \times 0.005 = 0.024$ $N_{predicted} = (4.871 + 0.093 + 0.024) \times 1.05 =$ 5.237 crashes/year	HSM Table 12-8, p. 12-27 HSM Table 12-9, p. 12-28 5.237 total crashes/year for design configuration
Definitions HSM = *Highway Safety Manual.*	

Manual calculations are shown only for total crashes. Calculations for FI and PDO crashes are calculated in a similar manner. The hand calculations include rounded values. The self-calculating spreadsheets do not truncate the numbers and so rounding errors are not included. Consequently, the hand calculated results may have minor differences than the spreadsheet calculated values.

A-4.3 Hand Calculated Example — Documenting a Design Decision for a Sharp Horizontal Curve on a Rural Two-Lane Highway

PROBLEM OVERVIEW	
Safety Assessment Method: SPF with CMF Adjustment	
Project Phase: **Preliminary & Final Design**	Project Type: **4R**
Related Task: **Design Exception**	**Calculation Method:** ☒ **Hand Calculated** ☐ **Tool Based** *Tool based example included in Problem 4.3.*
Comments: This example problem demonstrates how to evaluate the effect a design decision can have on the estimated number of crashes for a rural two-lane, two-way highway horizontal curve re-alignment project.	
LEVEL OF ANALYSIS	
Basic Intermediate Advanced	
Note: See table 3 for a full definition of Project Type designations.	

Detailed Analysis:

The predictive methods for rural two-lane highways and curved roadway segments are located in Chapter 10 of the HSM. The following steps summarize the process for performing hand calculations to evaluate safety treatments that can be included in the preliminary or final design phases.

STEP 1: Calculate the average crash frequency for the rural two-lane road segments considering base conditions (N_{SPF}). This value represents the number of crashes for any rural two-lane highway with a similar traffic volume and only base conditions.

Segment Calculations ($N_{SPF\ RS}$):

Use the SPF equation from the HSM for rural two-lane undivided roadway segments to calculate the average segment crash frequency:

Calculations	Notes
Total Crashes:	
$N_{spf\ rs} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)}$	HSM Equation 10-6, p. 10-15
$N_{spf\ rs} = 11{,}000 \times 0.5 \times 365 \times 10^{-6} \times e^{(-0.312)} = 1.469$ crashes	Answer (Total Crashes)
Note: HSM = Highway Safety Manual	

STEP 2: Calculate predicted average crash frequency for the segment under unique design conditions ($N_{predicted}$). This value represents the number of crashes for any rural two-lane highway with a similar traffic volume and similar geometric characteristics.

To calculate the estimated CMF due to decreasing the curve radii, the designer must first estimate the CMF of installing a curve compared to a base condition of a straight section of road.

Calculations	Notes
Total Crashes, All Severities:	
$CMF = \frac{(1.55 \times L_C) + \left(\frac{80.2}{R}\right) - (0.012 \times S)}{(1.55 * L_C)}$	HSM Equation 10-13, p. 10-27
$CMF = \frac{\left(1.55 \times \frac{200}{5280}\right) + \left(\frac{80.2}{380}\right) - (0.012 \times 0)}{\left(1.55 \times \frac{200}{5280}\right)} = 4.58$	Length of curve (converted from feet to miles) – Calculates CMF for existing curve

Next calculate the CMF for the new curve using the same method.

Calculations	Notes
Total Crashes, All Severities:	
$CMF = \frac{(1.55 \times L_C) + \left(\frac{80.2}{R}\right) - (0.012 \times S)}{(155 \times L_C)}$	HSM Equation 10-13, p. 10-27
$CMF = \frac{\left(1.55 \times \frac{230}{5280}\right) + \left(\frac{80.2}{250}\right) - (0.012 \times 0)}{(1.55 \times 230/5280)} = 5.71$	Length of curve (converted from feet to miles) – Calculates CMF for proposed curve

The predicted average crash frequency ($\boldsymbol{N_{predicted}}$) can then be calculated using the following equation:

$$N_{predicted} = N_{spf\ rs} \times (CMF_{1x} \times CMF_{2x} \times \ldots\ldots\ldots \times CMF_{yx}) \times C_x$$

Calculations	Notes
$N_{predicted} = N_{spf} \times CMF_{1x} \times C_x$	Base Equations Using C_x = 0.97 as the local calibration factor
Total Crashes	
$N_{predicted}$ = 1.469×4.58×0.97=6.52	Answer (Total Crashes, Existing)
$N_{predicted}$ = 1.469×5.74×0.97=8.14	Answer (Total Crashes, Proposed)
Crash reduction=(6.52-8.14)/6.52 = -25%	Crash reduction

For more information:

Scale and Scope of Safety Assessment Methods in the Project Development Process, visit: http://safety.fhwa.dot.gov/

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