Part B—Roadway Safety Management Process

B.1. PURPOSE OF PART B

Part B presents procedures and information useful in monitoring and reducing crash frequency on existing roadway networks. Collectively, the chapters in Part B are the roadway safety management process.

The six steps of the roadway safety management process are:

- *Chapter 4, Network Screening*—Reviewing a transportation network to identify and rank sites based on the potential for reducing average crash frequency.
- *Chapter 5, Diagnosis*—Evaluating crash data, historic site data, and field conditions to identify crash patterns.
- *Chapter 6, Select Countermeasures*—Identifying factors that may contribute to crashes at a site, and selecting possible countermeasures to reduce the average crash frequency.
- *Chapter 7, Economic Appraisal*—Evaluating the benefits and costs of the possible countermeasures, and identifying individual projects that are cost-effective or economically justified.
- *Chapter 8, Prioritize Projects*—Evaluating economically justified improvements at specific sites, and across multiple sites, to identify a set of improvement projects to meet objectives such as cost, mobility, or environmental impacts.
- *Chapter 9, Safety Effectiveness Evaluation*—Evaluating effectiveness of a countermeasure at one site or multiple sites in reducing crash frequency or severity.

Part B chapters can be used sequentially as a process, or they can be selected and applied individually to respond to the specific problem or project under investigation.

The benefits of implementing a roadway safety management process include the following:

- A systematic and repeatable process for identifying opportunities to reduce crashes and for identifying potential countermeasures resulting in a prioritized list of cost-effective safety countermeasures;
- A quantitative and systematic process that addresses a broad range of roadway safety conditions and tradeoffs;
- The opportunity to leverage funding and coordinate improvements with other planned infrastructure improvement programs;
- Comprehensive methods that consider traffic volume, collision data, traffic operations, roadway geometry, and user expectations; and
- The opportunity to use a proactive process to increase the effectiveness of countermeasures intended to reduce crash frequency.

There is no such thing as absolute safety. There is risk in all highway transportation. A universal objective is to reduce the number and severity of crashes within the limits of available resources, science, technology, and legislatively mandated priorities. The material in Part B is one resource for information and methodologies that are used in efforts to reduce crashes on existing roadway networks. Applying these methods does not guarantee that crashes will decrease across all sites; the methods are a set of tools available for use in conjunction with sound engineering judgment.

B.2. PART B AND THE PROJECT DEVELOPMENT PROCESS

Figure B-1 illustrates how the various chapters in Part B align with the traditional elements of the project development process introduced in Chapter 1. The chapters in Part B are applicable to the entire process; in several cases, individual chapters can be used in multiple stages of the project development process. For example,

- *System Planning*—Chapters 4, 7, and 8 present methods to identify locations within a network with potential for a change in crash frequency. Projects can then be programmed based on economic benefits of crash reduction. These improvements can be integrated into long-range transportation plans and roadway capital improvement programs.
- *Project Planning*—As jurisdictions are considering alternative improvements and specifying project solutions, the diagnosis (Chapter 5), countermeasure selection (Chapter 6), and economic appraisal (Chapter 7) methods presented in Part B provide performance measures to support integrating crash analysis into a project alternatives analysis.
- *Preliminary Design, Final Design, and Construction*—Countermeasure selection (Chapter 6) and Economic Appraisal (Chapter 7) procedures can also support the design process. These chapters provide information that could be used to compare various aspects of a design to identify the alternative with the lowest expected crash frequency and cost.
- *Operations and Maintenance*—Safety Effectiveness Evaluation (Chapter 9) procedures can be integrated into a community's operations and maintenance procedures to continually evaluate the effectiveness of investments. In addition, Diagnosis (Chapter 5), Selecting Countermeasures (Chapter 6), and Economic Appraisal (Chapter 7) procedures can be evaluated as part of ongoing overall highway safety system management.

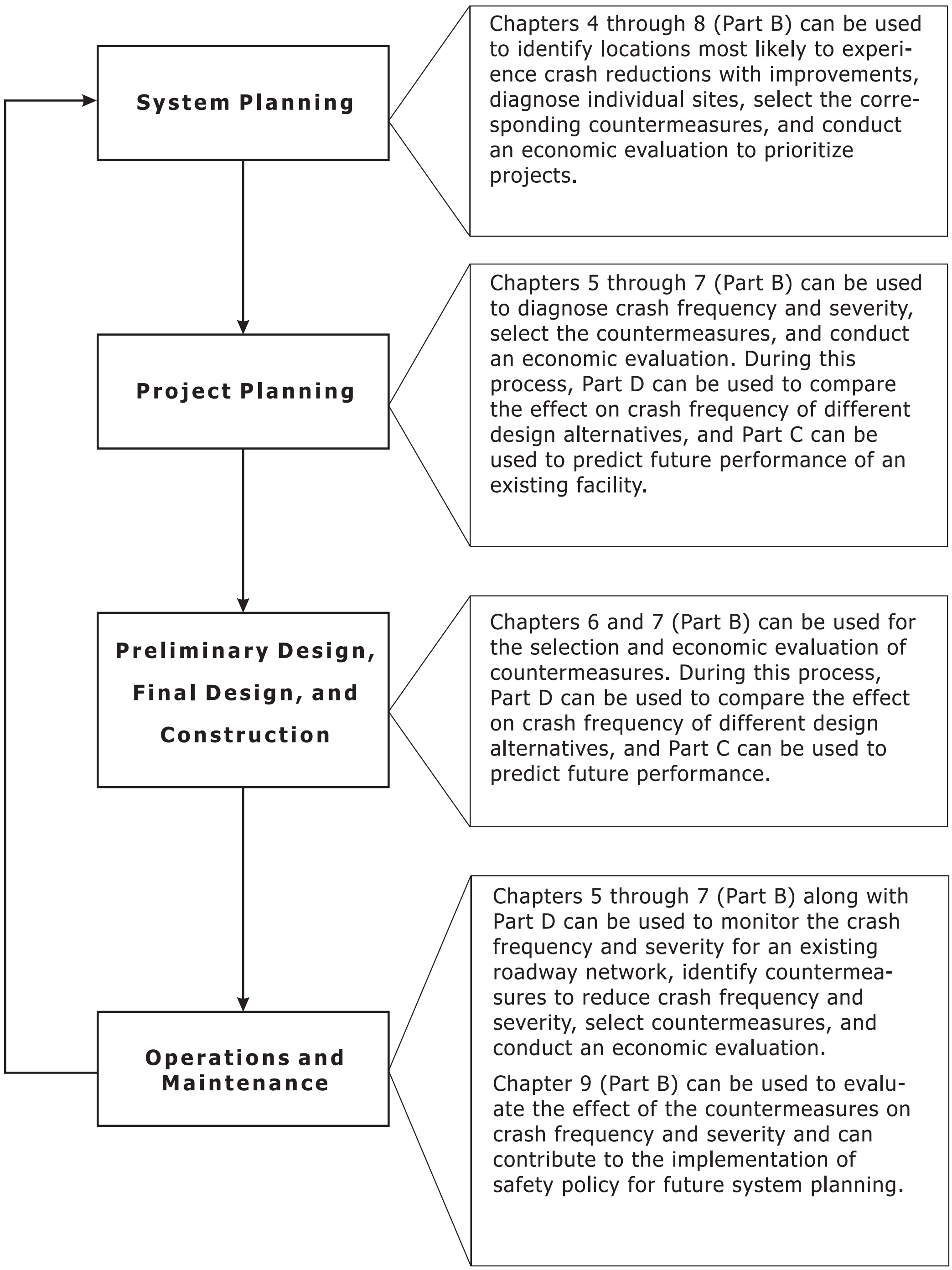

Figure B-1. The Project Development Process

B.3. APPLYING PART B

Chapter 4 presents a variety of crash performance measures and screening methods for assessing historic crash data on a roadway system and identifying sites which may respond to a countermeasure. As described in Chapter 4, there are strengths and weaknesses to each of the performance measures and screening methods that may influence which sites are identified. Therefore, in practice it may be useful to use multiple performance measures or multiple screening methods, or both, to identify possible sites for further evaluation.

Chapters 5 and 6 present information to assist with reviewing crash history and site conditions to identify a crash pattern at a particular site and identify potential countermeasures. While the HSM presents these as distinct activities, in practice they may be iterative. For example, evaluating and identifying possible crash-contributing factors (Chapter 6) may reveal the need for additional site investigation in order to confirm an original assessment (Chapter 5).

The final activity in Chapter 6 is selecting a countermeasure. Part D presents countermeasures and, when available, their corresponding Crash Modification Factors (CMFs). The CMFs presented in Part D have satisfied the screening criteria developed for the HSM, as described in Part D—Introduction and Applications Guidance. There are three types of information related to the effects of treatments:

1. a quantitative value representing the change in expected crashes (i.e., a CMF);

2. an explanation of a trend (i.e., change in crash frequency or severity) due to the treatment, but no quantitative information; and,

3. an explanation that information is not currently available.

Chapters 7 and 8 present information necessary for economically evaluating and prioritizing potential countermeasures at any one site or at multiple sites. In Chapter 7, the expected reduction in average crash frequency is calculated and converted to a monetary value or cost-effectiveness ratio. Chapter 8 presents prioritization methods to select financially optimal sets of projects. Because of the complexity of the methods, most projects require application of software to optimize a series of potential treatments.

Chapter 9 presents information on how to evaluate the effectiveness of treatments. This chapter will provide procedures for:

- Evaluating a single project to document the change in crash frequency resulting from that project;
- Evaluating a group of similar projects to document the change in crash frequency resulting from those projects;
- Evaluating a group of similar projects for the specific purpose of quantifying a countermeasure CMF; and
- Assessing the overall change in crash frequency resulting from specific types of projects or countermeasures in comparison to their costs.

Knowing the effectiveness of the program or project will provide information suitable to evaluate success of a program or project, and subsequently support policy and programming decisions related to improving roadway safety.

B.4. RELATIONSHIP TO PARTS A, C, AND D OF THE *HIGHWAY SAFETY MANUAL*

Part A provides introductory and fundamental knowledge for application of the HSM. An overview of Human Factors (Chapter 2) is presented to support engineering assessments in Parts B and C. Chapter 3 presents fundamentals for the methods and procedures in the HSM. Concepts from Chapter 3 that are applied in Part B include: expected average crashes, safety estimation, regression to the mean and regression-to-the-mean bias, and Empirical Bayes methods.

Part C of the HSM introduces techniques for estimating crash frequency of facilities being modified through an alternatives analysis or design process. Specifically, Chapters 10–12 present a predictive method for two-lane rural highways, multilane rural highways, and urban and suburban arterials, respectively. The predictive method in Part C is a proactive tool for estimating the expected change in crash frequency on a facility due to different design concepts. he material in Part C can be applied to the Part B methods as part of the procedures to estimate the crash reduction expected with implementation of potential countermeasures.

Finally, Part D consists of crash modification factors that can be applied in Chapters 4, 6, 7, and 8. The crash modification factors are used to estimate the potential crash reduction as the result of implementing a countermeasure(s). The crash reduction estimate can be converted into a monetary value and compared to the cost of the improvement and the cost associated with operational or geometric performance measures (e.g., delay, right-of-way).

B.5. SUMMARY

The roadway safety management process provides information for system planning; project planning; and near-term design, operations, and maintenance of a transportation system. The activities within the roadway safety management process provide:

- Awareness of sites that could benefit from treatments to reduce crash frequency or severity (Chapter 4, Network Screening);
- Understanding crash patterns and countermeasure(s) most likely to reduce crash frequency (Chapter 5, Diagnosis; Chapter 6, Select Countermeasures) at a site;
- Estimating the economic benefit associated with a particular treatment (Chapter 7, Economic Appraisal);
- Developing an optimized list of projects to improve (Chapter 8, Prioritize Projects); and
- Assessing the effectiveness of a countermeasure to reduce crash frequency (Chapter 9, Safety Effectiveness Evaluation).

The activities within the roadway safety management process can be conducted independently or they can be integrated into a cyclical process for monitoring a transportation network.

Chapter 4—Network Screening

4.1. INTRODUCTION

Network screening is a process for reviewing a transportation network to identify and rank sites from most likely to least likely to realize a reduction in crash frequency with implementation of a countermeasure. Those sites identified as most likely to realize a reduction in crash frequency are studied in more detail to identify crash patterns, contributing factors, and appropriate countermeasures. Network screening can also be used to formulate and implement a policy, such as prioritizing the replacement of non-standard guardrail statewide at sites with a high number of run-off-the-road crashes.

As shown in Figure 4-1, network screening is the first activity undertaken in a cyclical Roadway Safety Management Process outlined in Part B. Any one of the steps in the Roadway Safety Management Process can be conducted in isolation; however, the overall process is shown here for context. This chapter explains the steps of the network screening process, the performance measures of network screening, and the methods for conducting the screening.

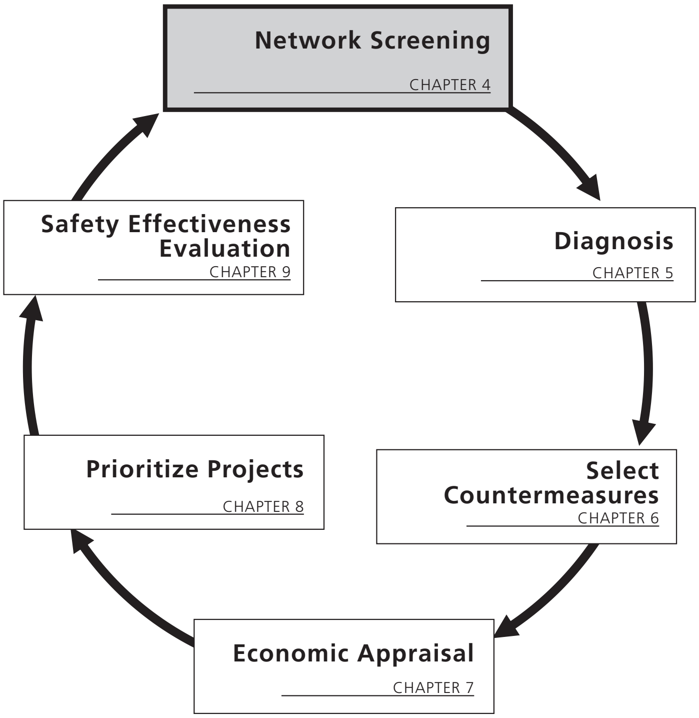

Figure 4-1. Roadway Safety Management Process

4.2. NETWORK SCREENING PROCESS

There are five major steps in network screening as shown in Figure 4-2:

1. *Establish Focus*—Identify the purpose or intended outcome of the network screening analysis. This decision will influence data needs, the selection of performance measures and the screening methods that can be applied.

2. *Identify Network and Establish Reference Populations*—Specify the type of sites or facilities being screened (i.e., segments, intersections, at-grade rail crossings) and identify groupings of similar sites or facilities.

3. *Select Performance Measures*—There are a variety of performance measures available to evaluate the potential to reduce crash frequency at a site. In this step, the performance measure is selected as a function of the screening focus and the data and analytical tools available.

4. *Select Screening Method*—There are three principle screening methods described in this chapter (i.e., ranking, sliding window, and peak searching). The advantages and disadvantages of each are described in order to help identify the most appropriate method for a given situation.

5. *Screen and Evaluate Results*—The final step in the process is to conduct the screening analysis and evaluate results.

The following sections explain each of the five major steps in more detail.

4.2.1. STEP 1—Establish the Focus of Network Screening

The first step in network screening is to establish the focus of the analysis (Figure 4-2). Network screening can be conducted and focused on one or both of the following:

1. Identify and rank sites where improvements have potential to reduce the number of crashes.

2. Evaluate a network to identify sites with a particular crash type or severity in order to formulate and implement a policy (e.g., identify sites with a high number of run-off-the-road crashes to prioritize the replacement of non-standard guardrail statewide).

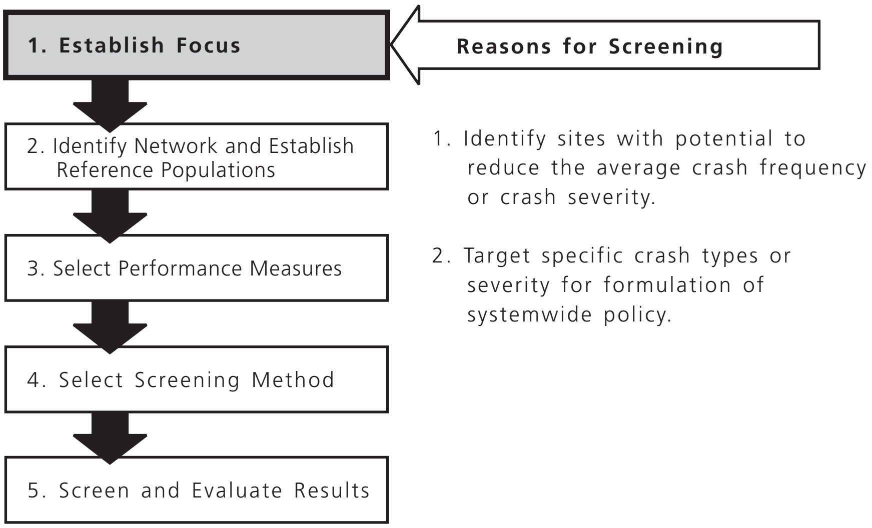

Figure 4-2. The Network Screening Process—Step 1, Establish Focus

If network screening is being applied to identify sites where modifications could reduce the number of crashes, the performance measures are applied to all sites. Based on the results of the analysis, those sites that show potential for improvement are identified for additional analysis. This analysis is similar to a typical "black spot" analysis conducted by a jurisdiction to identify the "high crash locations."

A transportation network can also be evaluated to identify sites that have potential to benefit from a specific program (e.g., increased enforcement) or countermeasure (e.g., a guardrail implementation program). An analysis such as this might identify locations with a high proportion or average frequency of a specific crash type or severity. In this case, a subset of the sites is studied.

Determining the Network Screening Focus

Question

A State DOT has received a grant of funds for installing rumble strips on rural two-lane highways. How could State DOT staff screen their network to identify the best sites for installing the rumble strips?

Answer

State DOT staff would want to identify those sites that can possibly be improved by installing rumble strips. Therefore, assuming run-off-the-road crashes respond to rumble strips, staff would select a method that provides a ranking of sites with more run-off-the-road crashes than expected for sites with similar characteristics. The State DOT analysis would focus on only a subset of the total crash database—run-off-the-road crashes.

If, on the other hand, the State DOT had applied a screening process and ranked all of their two-lane rural highways, this would not reveal which of the sites would specifically benefit from installing rumble strips.

There are many specific activities that could define the focus of a network screening process. The following are hypothetical examples of what could be the focus of network screening:

- An agency desires to identify projects for a Capital Improvement Program (CIP) or other established funding sources. In this case, all sites would be screened.
- An agency has identified a specific crash type of concern and desires to implement a systemwide program to reduce that type of crash. In this case all sites would be screened to identify those with more of the specific crashes than expected.
- An agency has identified sites within a sub-area or along a corridor that are candidates for further safety analysis. Only the sites on the corridor would be screened.
- An agency has received funding to apply a program or countermeasure(s) systemwide to improve safety (e.g., automated enforcement). Network screening would be conducted at all signalized intersections, a subset of the whole transportation system.

4.2.2. STEP 2—Identify the Network and Establish Reference Populations

The focus of the network screening process established in Step 1 forms the basis for the second step in the network screening process, which includes identifying the network elements to be screened and organizing these elements into reference populations (Figure 4-3). Examples of roadway network elements that can be screened include intersections, roadway segments, facilities, ramps, ramp terminal intersections, and at-grade rail crossings.

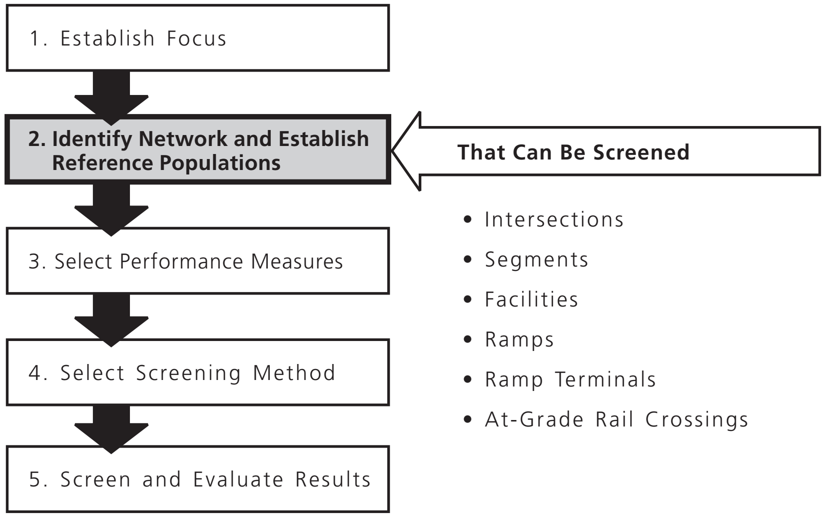

Figure 4-3. The Network Screening Process—Step 2, Identify Network and Establish Reference Populations

A reference population is a grouping of sites with similar characteristics (e.g., four-legged signalized intersections, two-lane rural highways). Ultimately, prioritization of individual sites is made within a reference population. In some cases, the performance measures allow comparisons across reference populations. The characteristics used to establish reference populations for intersections and roadway segments are identified in the following sections.

Intersection Reference Populations

Potential characteristics that can be used to establish reference populations for intersections include:

- Traffic control (e.g., signalized, two-way or four-way stop control, yield control, roundabout);
- Number of approaches (e.g., three-leg or four-leg intersections);
- Cross-section (e.g., number of through lanes and turning lanes);
- Functional classification (e.g., arterial, collector, local);
- Area type (e.g., urban, suburban, rural);
- Traffic volume ranges (e.g., total entering volume (TEV), peak hour volumes, average annual daily traffic (AADT)); or
- Terrain (e.g., flat, rolling, mountainous).

The characteristics that define a reference population may vary depending on the amount of detail known about each intersection, the purpose of the network screening, the size of the network being screened, and the performance measure selected. Similar groupings are also applied if ramp terminal intersections or at-grade rail crossings, or both, are being screened.

Establishing Reference Populations for Intersection Screening

The following table provides an example of data for several intersections within a network that have been sorted by functional classification and traffic control. These reference populations may be appropriate for an agency that has received funding to apply red-light-running cameras or other countermeasure(s) systemwide to improve safety at signalized intersections. As such, the last grouping of sites would not be studied since they are not signalized.

Example Intersection Reference Populations Defined by Functional Classification and Traffic Control

Reference Population	Segment ID	Street Type 1	Street Type 2	Traffic Control	Fatal	Injury	PDO	Total	Exposure Range (TEV/Average Annual Day)
Arterial-Arterial Signalized Intersections	3	Arterial	Arterial	Signal	0	41	59	100	55,000 to 70,000
	4	Arterial	Arterial	Signal	0	50	90	140	55,000 to 70,000
	10	Arterial	Arterial	Signal	0	28	39	67	55,000 to 70,000
Arterial-Collector Signalized Intersections	33	Arterial	Collector	Signal	0	21	52	73	30,000 to 55,000
	12	Arterial	Collector	Signal	0	40	51	91	30,000 to 55,000
	23	Arterial	Collector	Signal	0	52	73	125	30,000 to 55,000
Collector-Local All-Way Stop Intersections	22	Collector	Local	All-way Stop	1	39	100	140	10,000 to 15,000
	26	Collector	Local	All-way Stop	0	20	47	67	10,000 to 15,000

Segment Reference Populations

A roadway segment is a portion of a facility that has a consistent roadway cross-section and is defined by two endpoints. These endpoints can be two intersections, on- or off-ramps, a change in roadway cross-section, mile markers or mile posts, or a change in any of the roadway characteristics listed below.

Potential characteristics that can be used to define reference populations for roadway segments include:

- Number of lanes per direction;
- Access density (e.g., driveway and intersection spacing);
- Traffic volumes ranges (e.g., TEV, peak hour volumes, AADT);
- Median type or width, or both;
- Operating speed or posted speed;
- Adjacent land use (e.g., urban, suburban, rural);
- Terrain (e.g., flat, rolling, mountainous); and
- Functional classification (e.g., arterial, collector, local).

Other more detailed example roadway segment reference populations are: four-lane cross-section with raised concrete median; five-lane cross-section with a two-way, left-turn lane; or rural two-lane highway in mountainous terrain. If ramps are being screened, groupings similar to these are also applied.

Establishing Reference Populations for Segment Screening

Example:
The following table provides data for several roadway segments within a network. The segments have been sorted by median type and cross-section. These reference populations may be appropriate for an agency that desires to implement a systemwide program to employ access management techniques in order to potentially reduce the number of left-turn crashes along roadway segments.

Example Reference Populations for Segments

Reference Population	Segment ID	Cross-Section (lanes per direction)	Median Type	Segment Length (miles)
4-Lane Divided Roadways	A	2	Divided	0.60
	B	2	Divided	0.40
	C	2	Divided	0.90
5-Lane Roadway with Two-Way Left-Turn Lane	D	2	TWLTL	0.35
	E	2	TWLTL	0.55
	F	2	TWLTL	0.80

4.2.3. STEP 3—Select Network Screening Performance Measures

The third step in the network screening process is to select one or several performance measures to be used in evaluating the potential to reduce the number of crashes or crash severity at a site (Figure 4-4). Just as intersection traffic operations analysis can be measured as a function of vehicle delay, queue length, or a volume-to-capacity ratio, intersection safety can be quantitatively measured in terms of average crash frequency, expected average crash frequency, a critical crash rate, or several other performance measures. In network screening, using multiple performance measures to evaluate each site may improve the level of confidence in the results.

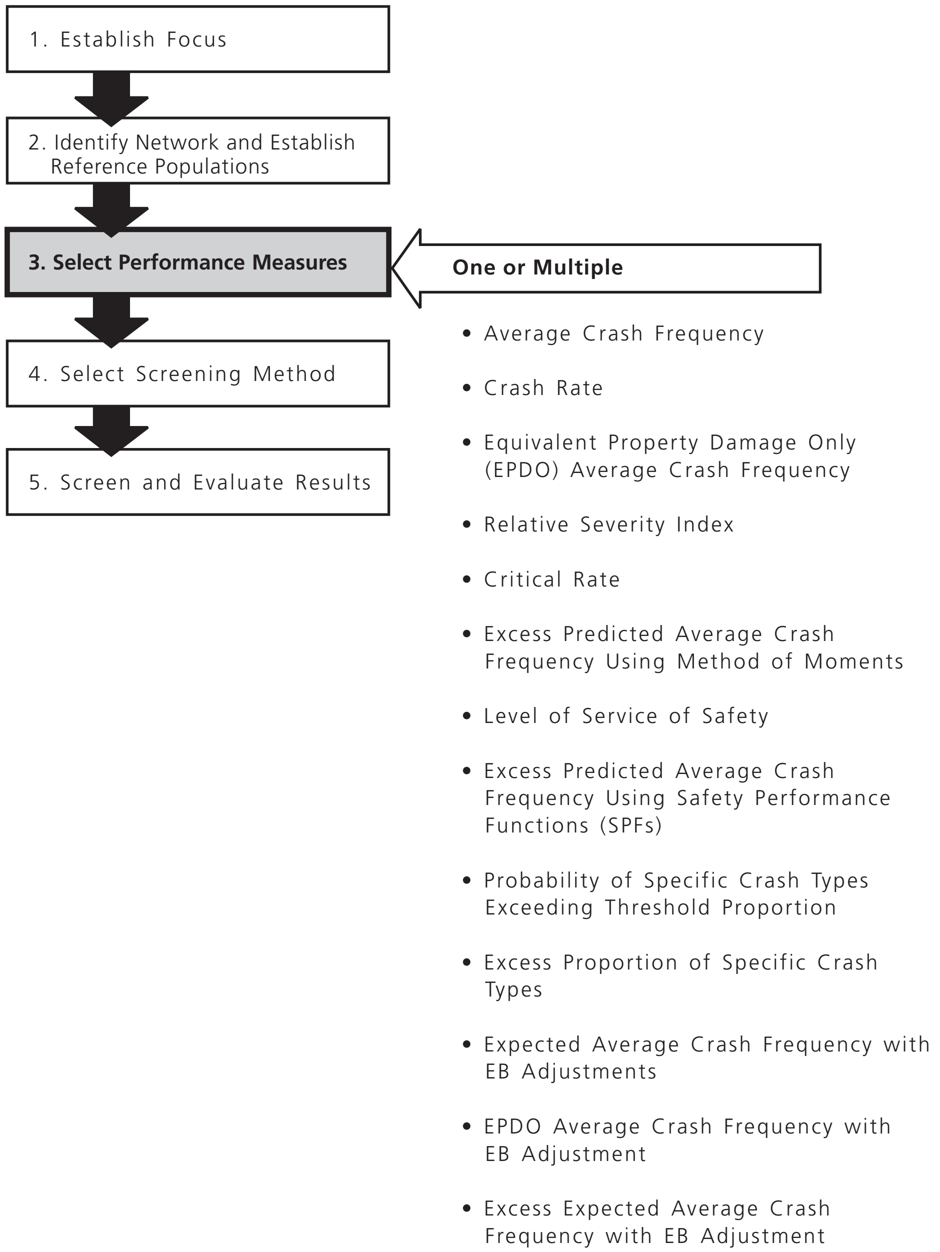

Figure 4-4. The Network Screening Process—Step 3, Select Performance Measures

Key Criteria for Selecting Performance Measures

The key considerations in selecting performance measures are: data availability, regression-to-the-mean bias, and how the performance threshold is established. This section describes each of these concepts. A more detailed description of the performance measures with supporting equations and example calculations is provided in Section 4.4.

Data and Input Availability

Typical data required for the screening analysis includes the facility information for establishing reference populations, crash data, traffic volume data, and, in some cases, safety performance functions. The amount of data and inputs that are available limits the number of performance measures that can be used. If traffic volume data is not available or cost prohibitive to collect, fewer performance measures are available for ranking sites. If traffic volumes are collected or made available, but calibrated safety performance functions and overdispersion parameters are not, the network could be prioritized using a different set of performance measures. Table 4-1 summarizes the data and inputs needed for each performance measure.

Table 4-1. Summary of Data Needs for Performance Measures

	Data and Inputs				
Performance Measure	**Crash Data**	**Roadway Information for Categorization**	**Traffic Volume[a]**	**Calibrated Safety Performance Function and Overdispersion Parameter**	**Other**
Average Crash Frequency	X	X			
Crash Rate	X	X	X		
Equivalent Property Damage Only (EPDO) Average Crash Frequency	X	X			EPDO Weighting Factors
Relative Severity Index	X	X			Relative Severity Indices
Critical Rate	X	X	X		
Excess Predicted Average Crash Frequency Using Method of Moments[b]	X	X	X		
Level of Service of Safety	X	X	X	X	
Excess Predicted Average Crash Frequency Using Safety Performance Functions (SPFs)	X	X	X	X	
Probability of Specific Crash Types Exceeding Threshold Proportion	X	X			
Excess Proportion of Specific Crash Types	X	X			
Expected Average Crash Frequency with EB Adjustment	X	X	X	X	
Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment	X	X	X	X	EPDO Weighting Factors
Excess Expected Average Crash Frequency with EB Adjustment	X	X	X	X	

[a] Traffic volume could be AADT, ADT, or peak hour volumes.
[b] The Method of Moments consists of adjusting a site's observed crash frequency based on the variance in the crash data and average crash counts for the site's reference population. Traffic volume is needed to apply Method of Moments to establish the reference populations based on ranges of traffic volumes as well as site geometric characteristics.

Regression-to-the-Mean Bias

Crash frequencies naturally fluctuate up and down over time at any given site. As a result, a short-term average crash frequency may vary significantly from the long-term average crash frequency. The randomness of crash occurrence indicates that short-term crash frequencies alone are not a reliable estimator of long-term crash frequency. If a three-year period of crashes were to be used as the sample to estimate crash frequency, it would be difficult to know if this three-year period represents a high, average, or low crash frequency at the site compared to previous years.

When a period with a comparatively high crash frequency is observed, it is statistically probable that a lower crash frequency will be observed in the following period (7). This tendency is known as regression-to-the-mean (RTM), and also applies to the statistical probability that a comparatively low crash frequency period will be followed by a higher crash frequency period.

Failure to account for the effects of RTM introduces the potential for “RTM bias”, also known as “selection bias”. RTM bias occurs when sites are selected for treatment based on short-term trends in observed crash frequency. For example, a site is selected for treatment based on a high observed crash frequency during a very short period of time (e.g., two years). However, the site’s long-term crash frequency may actually be substantially lower and therefore the treatment may have been more cost-effective at an alternate site.

Performance Threshold

A performance threshold value provides a reference point for comparison of performance measure scores within a reference population. Sites can be grouped based on whether the estimated performance measure score for each site is greater than or less than the threshold value. Those sites with a performance measure score less than the threshold value can be studied in further detail to determine if reduction in crash frequency or severity is possible.

The method for determining a threshold performance value is dependent on the performance measure selected. The threshold performance value can be a subjectively assumed value, or calculated as part of the performance measure methodology. For example, threshold values are estimated based on: the average of the observed crash frequency for the reference population, an appropriate safety performance function, or Empirical Bayes methods. Table 4-2 summarizes whether or not each of the performance measures accounts for regression-to-the-mean bias or estimates a performance threshold, or both. The performance measures are presented in relative order of complexity, from least to most complex. Typically, the methods that require more data and address RTM bias produce more reliable performance threshold values.

Table 4-2. Stability of Performance Measures

Performance Measure	Accounts for RTM Bias	Method Estimates a Performance Threshold
Average Crash Frequency	No	No
Crash Rate	No	No
Equivalent Property Damage Only (EPDO) Average Crash Frequency	No	No
Relative Severity Index	No	Yes
Critical Rate	Considers data variance but does not account for RTM bias	Yes
Excess Predicted Average Crash Frequency Using Method of Moments	Considers data variance but does not account for RTM bias	Yes
Level of Service of Safety	Considers data variance but does not account for RTM bias	Expected average crash frequency plus/minus 1.5 standard deviations
Excess Expected Average Crash Frequency Using SPFs	No	Predicted average crash frequency at the site
Probability of Specific Crash Types Exceeding Threshold Proportion	Considers data variance; not effected by RTM Bias	Yes
Excess Proportions of Specific Crash Types	Considers data variance; not effected by RTM Bias	Yes
Expected Average Crash Frequency with EB Adjustments	Yes	Expected average crash frequency at the site
Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment	Yes	Expected average crash frequency at the site
Excess Expected Average Crash Frequency with EB Adjustments	Yes	Expected average crash frequency per year at the site

Definition of Performance Measures

This section defines the performance measures in the HSM and the strengths and limitations of each measure. The following definitions, in combination with Tables 4-1 and 4-2, provide guidance on selecting performance measures. The procedures to apply each performance measures are presented in detail in Section 4.4.

Average Crash Frequency

The site with the greatest number of total crashes or the greatest number of crashes of a particular crash severity or type, in a given time period, is given the highest rank. The site with the second highest number of crashes in total or of a particular crash severity or type, in the same time period, is ranked second, and so on. The strengths and limitations of the Average Crash Frequency performance measure include the following:

Strengths	Limitations
Simple	Does not account for RTM bias
	Does not estimate a threshold to indicate sites experiencing more crashes than predicted for sites with similar characteristics
	Does not account for traffic volume
	Will not identify low-volume collision sites where simple cost-effective mitigating countermeasures could be easily applied

Crash Rate

The crash rate performance measure normalizes the frequency of crashes with the exposure, measured by traffic volume. When calculating a crash rate, traffic volumes are reported as million entering vehicles (MEV) per intersection for the study period. Roadway segment traffic volumes are measured as vehicle-miles traveled (VMT) for the study period. The exposure on roadway segments is often measured per million VMT.

The strengths and limitations of the Crash Rate performance measure include the following:

Strengths	Limitations
Simple	Does not account for RTM bias
Could be modified to account for severity if an EPDO or RSI-based crash count is used	Does not identify a threshold to indicate sites experiencing more crashes than predicted for sites with similar characteristics
	Comparisons cannot be made across sites with significantly different traffic volumes
	Will mistakenly prioritize low volume, low collision sites

Equivalent Property Damage Only (EPDO) Average Crash Frequency

The Equivalent Property Damage Only (EPDO) Average Crash Frequency performance measure assigns weighting factors to crashes by severity (fatal, injury, property damage only) to develop a combined frequency and severity score per site. The weighting factors are often calculated relative to Property Damage Only (PDO) crash costs. The crash costs by severity are summarized yielding an EPDO value. Although some agencies have developed weighting methods based on measures other than costs, crash costs are used consistently in the HSM to demonstrate use of the performance measure.

Crash costs include direct and indirect costs. Direct costs could include: ambulance service, police and fire services, property damage, or insurance. Indirect costs include the value society would place on pain and suffering or loss of life associated with the crash.

The strengths and limitations of the EPDO Average Crash Frequency performance measure include the following:

Strengths	Limitations
Simple	Does not account for RTM bias
Considers crash severity	Does not identify a threshold to indicate sites experiencing more crashes than predicted for sites with similar characteristics
	Does not account for traffic volume
	May overemphasize locations with a low frequency of severe crashes depending on weighting factors used

Relative Severity Index

Monetary crash costs are assigned to each crash type and the total cost of all crashes is calculated for each site. An average crash cost per site is then compared to an overall average crash cost for the site's reference population. The overall average crash cost is an average of the total costs at all sites in the reference population. The resulting Relative Severity Index (RSI) performance measure shows whether a site is experiencing higher crash costs than the average for other sites with similar characteristics.

The strengths and limitations of the RSI performance measure include the following:

Strengths	Limitations
Simple	Does not account for RTM bias
Considers collision type and crash severity	May overemphasize locations with a small number of severe crashes depending on weighting factors used
	Does not account for traffic volume
	Will mistakenly prioritize low-volume, low-collision sites

Critical Rate

The observed crash rate at each site is compared to a calculated critical crash rate that is unique to each site. The critical crash rate is a threshold value that allows for a relative comparison among sites with similar characteristics. Sites that exceed their respective critical rate are flagged for further review. The critical crash rate depends on the average crash rate at similar sites, traffic volume, and a statistical constant that represents a desired level of significance.

The strengths and limitations of the Critical Rate performance measure include the following:

Strengths	Limitations
Reduces exaggerated effect of sites with low volumes	Does not account for RTM bias
Considers variance in crash data	
Establishes a threshold for comparison	

Excess Predicted Average Crash Frequency Using Method of Moments

A site's observed average crash frequency is adjusted based on the variance in the crash data and average crash frequency for the site's reference population (4). The adjusted observed average crash frequency for the site is compared to the average crash frequency for the reference population. This comparison yields the potential for improvement which can serve as a measure for ranking sites.

The strengths and limitations of the Excess Predicted Average Crash Frequency Using Method of Moments performance measure include the following:

Strengths	Limitations
Establishes a threshold of predicted performance for a site	Does not account for RTM bias
Considers variance in crash data	Does not account for traffic volume
Allows sites of all types to be ranked in one list	Some sites may be identified for further study because of unusually low frequency of non-target crash types
Method concepts are similar to Empirical Bayes methods	Ranking results are influenced by reference populations; sites near boundaries of reference populations may be over-emphasized

Level of Service of Safety (LOSS)
Sites are ranked according to a qualitative assessment in which the observed crash count is compared to a predicted average crash frequency for the reference population under consideration (1,4,5). Each site is placed into one of four LOSS classifications, depending on the degree to which the observed average crash frequency is different than predicted average crash frequency. The predicted average crash frequency for sites with similar characteristics is predicted from an SPF calibrated to local conditions.

The strengths and limitations of the LOSS performance measure include the following:

Strengths	Limitations
Considers variance in crash data	Effects of RTM bias may still be present in the results
Accounts for volume	
Establishes a threshold for measuring potential to reduce crash frequency	

Excess Predicted Average Crash Frequency Using Safety Performance Functions (SPFs)
The site's observed average crash frequency is compared to a predicted average crash frequency from an SPF. The difference between the observed and predicted crash frequencies is the excess predicted crash frequency using SPFs. When the excess predicted average crash frequency is greater than zero, a site experiences more crashes than predicted. When the excess predicted average crash frequency value is less than zero, a site experiences fewer crashes than predicted.

The strengths and limitations of the Excess Predicted Average Crash Frequency Using SPFs performance measure include the following:

Strengths	Limitations
Accounts for traffic volume	Effects of RTM bias may still be present in the results
Estimates a threshold for comparison	

Probability of Specific Crash Types Exceeding Threshold Proportion
Sites are prioritized based on the probability that the true proportion, p_i, of a particular crash type or severity (e.g., long-term predicted proportion) is greater than the threshold proportion, p^*_i (6). A threshold proportion (p^*_i) is selected for each population, typically based on the proportion of the target crash type or severity in the reference population. This method can also be applied as a diagnostic tool to identify crash patterns at an intersection or on a roadway segment (Chapter 5).

The following summarizes the strengths and limitations of the Probability of Specific Crash Types Exceeding Threshold Proportion performance measure:

Strengths	Limitations
Can also be used as a diagnostic tool (Chapter 5)	Does not account for traffic volume
Considers variance in data	Some sites may be identified for further study because of unusually low frequency of non-target crash types
Not affected by RTM Bias	

Excess Proportions of Specific Crash Types

This performance measure is very similar to the Probability of Specific Crash Types Exceeding Threshold Proportion performance measure except that sites are prioritized based on the excess proportion. The excess proportion is the difference between the observed proportion of a specific collision type or severity and the threshold proportion from the reference population. A threshold proportion (p^*_i) is selected for each population, typically based on the proportion of the target crash type or severity in the reference population. The largest excess value represents the most potential for reduction in average crash frequency. This method can also be applied as a diagnostic tool to identify crash patterns at an intersection or on a roadway segment (Chapter 5).

The strengths and limitations of the Excess Proportions of Specific Crash Types performance measure include the following:

Strengths	Limitations
Can also be used as a diagnostic tool	Does not account for traffic volume
Considers variance in data	Some sites may be identified for further study because of unusually low frequency of non-target crash types
Not effected by RTM Bias	

Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment

The observed average crash frequency and the predicted average crash frequency from an SPF are weighted together using the EB method to calculate an expected average crash frequency that accounts for RTM bias. Part C, Introduction and Applications Guidance provides a detailed presentation of the EB method. Sites are ranked from high to low based on the expected average crash frequency.

The following summarizes the strengths and limitations of the Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment performance measure:

Strengths	Limitations
Accounts for RTM bias	Requires SPFs calibrated to local conditions

Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment

Crashes by severity are predicted using the EB procedure. Part C, Introduction and Applications Guidance provides a detailed presentation of the EB method. The expected crashes by severity are converted to EPDO crashes using the EPDO procedure. The resulting EPDO values are ranked. The EPDO Average Crash Frequency with EB Adjustments measure accounts for RTM bias and traffic volume.

The following summarizes the strengths and limitations of the EPDO Average Crash Frequency with EB Adjustment performance measure:

Strengths	Limitations
Accounts for RTM bias	May overemphasize locations with a small number of severe crashes depending on weighting factors used
Considers crash severity	

Excess Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment

The observed average crash frequency and the predicted crash frequency from an SPF are weighted together using the EB method to calculate an expected average crash frequency. The resulting expected average crash frequency is compared to the predicted average crash frequency from a SPF. The difference between the EB adjusted average crash frequency and the predicted average crash frequency from an SPF is the excess expected average crash frequency.

When the excess expected crash frequency value is greater than zero, a site experiences more crashes than expected. When the excess expected crash frequency value is less than zero, a site experiences fewer crashes than expected.

The following summarizes the strengths and limitations of the Excess Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment performance measure:

Strengths	Limitations
Accounts for RTM bias	Requires SPFs calibrated to local conditions
Identifies a threshold to indicate sites experiencing more crashes than expected for sites with similar characteristics	

4.2.4. STEP 4—Select Screening Method

The fourth step in the network screening process is to select a network screening method (Figure 4-5). In a network screening process, the selected performance measure would be applied to all sites under consideration using a screening method. In the HSM, there are three types of three categories of screening methods:

- Segments (e.g., roadway segment or ramp) are screened using either sliding window or peak searching methods.
- Nodes (e.g., intersections or ramp terminal intersections) are screened using simple ranking method.
- Facilities (combination of nodes and segments) are screened using a combination of segment and node screening methods.

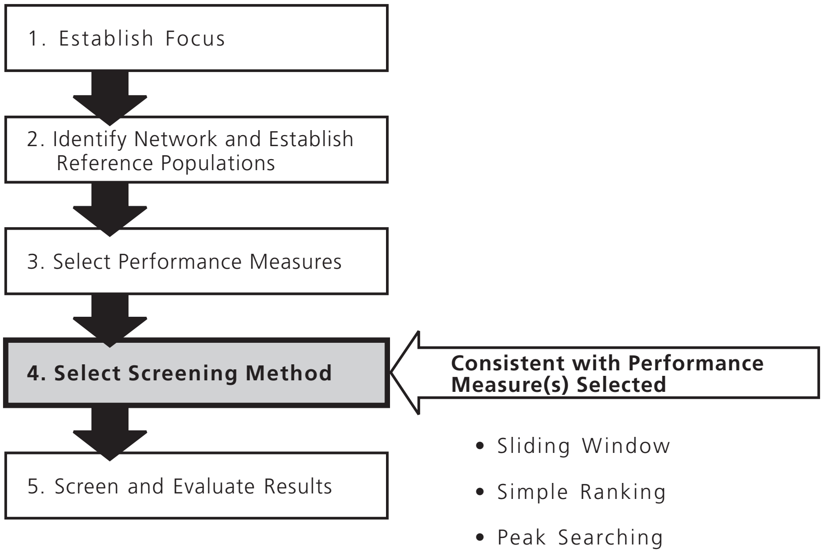

Figure 4-5. Network Screening Process—Step 4, Select Screening Method

Segment Screening Methods

Screening roadway segments and ramps requires identifying the location within the roadway segment or ramp that is most likely to benefit from a countermeasure intended to result in a reduction in crash frequency or severity. The location (i.e., subsegment) within a segment that shows the most potential for improvement is used to specify the critical crash frequency of the entire segment and subsequently select segments for further investigation. Having an understanding of what portion of the roadway segment controls the segment's critical crash frequency will make it easier and more efficient to identify effective countermeasures. Sliding window and peak searching methods can be used to identify the location within the segment which is likely to benefit from a countermeasure. The simple ranking method can also be applied to segments, but unlike sliding window and peak searching methods, performance measures are calculated for the entire length (typically 0.1 mi) of the segment.

Sliding Window Method

In the sliding window method a window of a specified length is conceptually moved along the road segment from beginning to end in increments of a specified size. The performance measure chosen to screen the segment is applied to each position of the window, and the results of the analysis are recorded for each window. A window pertains to a given segment if at least some portion of the window is within the boundaries of the segment. From all the windows that pertain to a given segment, the window that shows the most potential for reduction in crash frequency out of the whole segment is identified and is used to represent the potential for reduction in crash frequency of the whole segment. After all segments are ranked according to the respective highest subsegment value, those segments with the greatest potential for reduction in crash frequency or severity are studied in detail to identify potential countermeasures.

Windows will bridge two or more contiguous roadway segments in the sliding window method. Each window is moved forward incrementally until it reaches the end of a contiguous set of roadway segments. Discontinuities in contiguous roadway segments may occur as a result of discontinuities in route type, mileposts or routes, site characteristics, etc. When the window nears the end of a contiguous set of roadway segments, the window length remains the same, while the increment length is adjusted so that the last window is positioned at the end of the roadway segment.

In some instances, the lengths of roadway segments may be less than the typical window length, and the roadway segments may not be part of a contiguous set of roadway segments. In these instances, the window length (typically 0.10-mi windows) equals the length of the roadway segment.

Sliding Window Method

Question

Segment A in the urban four-lane divided arterial reference population will be screened by the "Excess Predicted Average Crash Frequency Using SPFs" performance measure. Segment A is 0.60 mi long.

If the sliding window method is used to study this segment with a window of 0.30-mi and 0.10-mi increment, how many times will the performance measure be applied on Segment A?

The following table shows the results for each window. Which subsegment would define the potential for reduction in crash frequency or severity of the entire segment?

Example Application of Sliding Window Method

Subsegment	Window Position	Excess Predicted Average Crash Frequency
A1	0.00 to 0.30 mi	1.20
A2	0.10 to 0.40 mi	0.80
A3	0.20 to 0.50 mi	1.10
A4	0.30 to 0.60 mi	1.90

Answer

As shown in the table, there are four 0.30 subsegments (i.e., window positions) on Segment A.

Subsegment 4 from 0.30 mi to 0.60 mi has a potential for reducing the average crash frequency by 1.90 crashes. This subsegment would be used to define the total segment crash frequency because this is the highest potential for reduction in crash frequency or severity of all four windows. Therefore, Segment A would be ranked and compared to other segments.

Peak Searching Method

In the peak searching method, each individual roadway segment is subdivided into windows of similar length, potentially growing incrementally in length until the length of the window equals the length of the entire roadway segment. The windows do not span multiple roadway segments. For each window, the chosen performance measure is calculated. Based upon the statistical precision of the performance measure, the window with the maximum value of the performance measure within a roadway segment is used to rank the potential for reduction in crashes of that site (i.e., whole roadway segment) relative to the other sites being screened.

The first step in the peak searching method is to divide a given roadway segment (or ramp) into 0.1-mi windows. The windows do not overlap, with the possible exception that the last window may overlap with the previous. If the segment is less than 0.1 mi in length, then the segment length equals the window length. The performance measure is then calculated for each window, and the results are subjected to precision testing. If the performance measure calculation for at least one subsegment satisfies the desired precision level, the segment is ranked based upon the maximum performance measure from all of the windows that meet the desired precision level. If none of the performance measures for the initial 0.1-mi windows are found to have the desired precision, the length of each window is incrementally moved forward; growing the windows to a length of 0.2 mi. The calculations are performed again to assess the precision of the performance measures. The methodology continues in this fashion until a maximum performance measure with the desired precision is found or the window length equals the site length.

The precision of the performance measure is assessed by calculating the coefficient of variation (CV) of the performance measure.

$$Coefficient\ of\ Variation\ (CV) = \frac{\sqrt{Var(Performance\ Measure)}}{Performance\ Measure} \tag{4-1}$$

A large CV indicates a low level of precision in the estimate, and a small CV indicates a high level of precision in the estimate. The calculated CV is compared to a specified limiting CV. If the calculated CV is less than or equal to the CV limiting value, the performance measure meets the desired precision level, and the performance measure for a given window can potentially be considered for use in ranking the segment. If the calculated CV is greater than the CV limiting value, the window is automatically removed from further consideration in potentially ranking the segment based upon the value of the performance measure.

There is no specific CV value that is appropriate for all network screening applications. However, by adjusting the CV value the user can vary the number of sites identified by network screening as candidates for further investigation. An appropriate initial or default value for the CV is 0.5.

Peak Searching Method

Question

Segment B, in an urban four-lane divided arterial reference population, will be screened using the Excess Expected Average Crash Frequency performance measure. Segment B is 0.47 mi long. The CV limiting value is assumed to be 0.25. If the peak searching method is used to study this segment, how is the methodology applied and how is the segment potentially ranked relative to other sites considered in the screening?

Answer

Iteration #1

The following table shows the results of the first iteration. In the first iteration, the site is divided into 0.1-mi windows. For each window, the performance measure is calculated along with the CV.

The variance is given as:

$$VAR_B = \frac{(5.2-5.7)^2+(7.8-5.7)^2+(1.1-5.7)^2+(6.5-5.7)^2+(7.8-5.7)^2}{(5-1)} = 7.7$$

The Coefficient of Variation for Segment B1 is calculated using Equation 4-1 as shown below:

$$CV_{B1} = \frac{\sqrt{7.7}}{5.7} = 0.53$$

Example Application of Expected Average Crash Frequency with Empirical Bayes Adjustment (Iteration #1)

Subsegment	Window Position	Excess Expected Average Crash Frequency	Coefficient of Variation (CV)
B1	0.00 to 0.10 mi	5.2	0.53
B2	0.10 to 0.20 mi	7.8	0.36
B3	0.20 to 0.30 mi	1.1	2.53
B4	0.30 to 0.40 mi	6.5	0.43
B5	0.37 to 0.47 mi	7.8	0.36
	Average	5.7	—

Because none of the calculated CVs are less than the CV limiting value, none of the windows meet the screening criterion, so a second iteration of the calculations is required.

Iteration #2

The following shows the results of the second iteration. In the second iteration, the site is analyzed using 0.2-mi windows. For each window, the performance measure is calculated along with the CV.

Example Application of Expected Average Crash Frequency with Empirical Bayes Adjustment (Iteration #2)

Subsegment	Window Position	Excess Expected Average Crash Frequency	Coefficient of Variation (CV)
B1	0.00 to 0.20 mi	6.50	0.25
B2	0.10 to 0.30 mi	4.45	0.36
B3	0.20 to 0.40 mi	3.80	0.42
B4	0.27 to 0.47 mi	7.15	0.22
	Average	5.5	—

In this second iteration, the CVs for subsegments B1 and B4 are less than or equal to the CV limiting value of 0.25. Segment B would be ranked based upon the maximum value of the performance measures calculated for subsegments B1 and B4. In this instance, Segment B would be ranked and compared to other segments according to the 7.15 Excess Expected Crash Frequency calculated for subsegment B4.

If during Iteration 2, none of the calculated CVs were less than the CV limiting value, a third iteration would have been necessary with 0.3-mi window lengths, and so on, until the final window length considered would be equal to the segment length of 0.47 mi.

Simple Ranking Method

A simple ranking method can be applied to nodes and segments. In this method, the performance measures are calculated for all of the sites under consideration, and the results are ordered from high to low. The simplicity of this method is the greatest strength. However, for segments, the results are not as reliable as the other segment screening methods.

Node-Based Screening

Node-based screening focuses on intersections, ramp terminal intersections, and at-grade rail crossings. A simple ranking method may be applied whereby the performance measures are calculated for each site, and the results are ordered from high to low. The outcome is a list showing each site and the value of the selected performance measure. All of the performance measures can be used with simple ranking for node-based screening.

A variation of the peak searching method can be applied to intersections. In this variation, the precision test is applied to determine which performance measure to rank upon. Only intersection-related crashes are included in the node-based screening analyses.

Facility Screening

A facility is a length of highway composed of connected roadway segments and intersections. When screening facilities, the connected roadway segments are recommended to be approximately 5 to 10 mi in length. This length provides for more stable results.

Table 4-3 summarizes the performance measures that are consistent with the screening methods.

Table 4-3. Performance Measure Consistency with Screening Methods

	Segments			Nodes	Facilities
Performance Measure	**Simple Ranking**	**Sliding Window**	**Peak Searching**	**Simple Ranking**	**Simple Ranking**
Average Crash Frequency	Yes	Yes	No	Yes	Yes
Crash Rate	Yes	Yes	No	Yes	Yes
Equivalent Property Damage Only (EPDO) Average Crash Frequency	Yes	Yes	No	Yes	Yes
Relative Severity Index	Yes	Yes	No	Yes	No
Critical Crash Rate	Yes	Yes	No	Yes	Yes
Excess Predicted Average Crash Frequency Using Method of Moments	Yes	Yes	No	Yes	No
Level of Service of Safety	Yes	Yes	No	Yes	No
Excess Predicted Average Crash Frequency Using SPFs	Yes	Yes	No	Yes	No
Probability of Specific Crash Types Exceeding Threshold Proportion	Yes	Yes	No	Yes	No
Excess Proportions of Specific Crash Types	Yes	Yes	No	Yes	No
Expected Average Crash Frequency with EB Adjustments	Yes	Yes	Yes	Yes	No
Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment	Yes	Yes	Yes	Yes	No
Excess Expected Average Crash Frequency with EB Adjustments	Yes	Yes	Yes	Yes	No

4.2.5. STEP 5—Screen and Evaluate Results

The performance measure and the screening method are applied to one or more of the segments, nodes, or facilities according to the methods outlined in Steps 3 and 4. Conceptually, for each segment or node under consideration, the selected performance measure is calculated and recorded (see Figure 4-6). Results can be recorded in a table or on maps as appropriate or feasible.

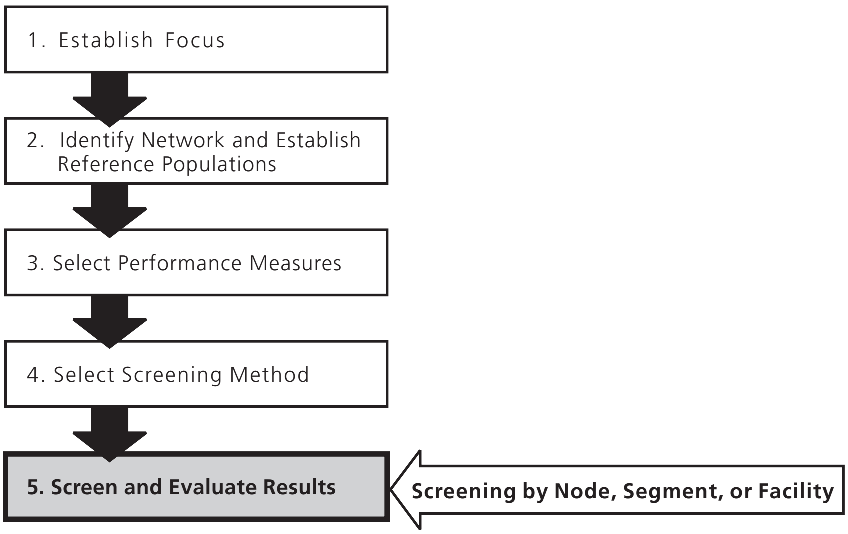

Figure 4-6. Optional Methods for Network Screening

The results of the screening analysis will be a list of sites ordered according to the selected performance measure. Those sites higher on the list are considered most likely to benefit from countermeasures intended to reduce crash frequency. Further study of these sites will indicate what kinds of improvements are likely to be most effective (see Chapters 5, 6, and 7).

In general, it can be useful to apply multiple performance measures to the same data set. In doing so, some sites will repeatedly be at the high or low end of the resulting list. Sites that repeatedly appear at the higher end of the list could become the focus of more detailed site investigations, while those that appear at the low end of the list could be ruled out for needing further investigation. Differences in the rankings produced by the various performance measures will become most evident at sites which are ranked in the middle of the list.

4.3. SUMMARY

This chapter explains the five steps of the network screening process, illustrated in Figure 4-7, that can be applied with one of three screening methods for conducting network screening. The results of the analysis are used to determine the sites that are studied in further detail. The objective of studying these sites in more detail is to identify crash patterns and the appropriate countermeasures to reduce the number of crashes; these activities are discussed in Chapters 5, 6, and 7.

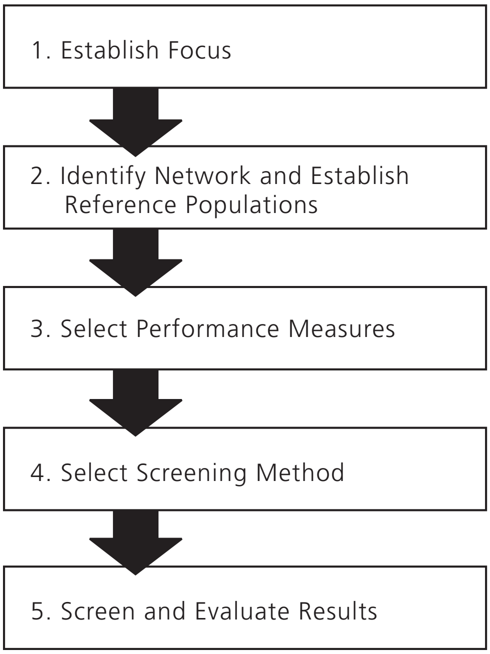

Figure 4-7. Network Screening Process

When selecting a performance measure and screening method, there are three key considerations. The first is related to the data that is available or can be collected for the study. It is recognized that this is often the greatest constraint; therefore, methods are outlined in the chapter that do not require a significant amount of data.

The second and third considerations relate to the performance of the methodology results. The most accurate study methodologies provide for the ability to: 1) account for regression-to-the-mean bias, and 2) estimate a threshold level of performance in terms of crash frequency or crash severity. These methods can be trusted with a greater level of confidence than those methods that do not.

Section 4.4 provides a detailed overview of the procedure for calculating each of the performance measures in this chapter. The section also provides step-by-step sample applications for each method applied to intersections. These same steps can be used on ramp terminal intersections and at-grade rail crossings. Section 4.4 also provides step-by-step sample applications demonstrating use of the peak searching and sliding window methods to roadway segments. The same steps can be applied to ramps.

4.4. PERFORMANCE MEASURE METHODS AND SAMPLE APPLICATIONS

4.4.1. Intersection Performance Measure Sample Data

The following sections provide sample data to be used to demonstrate application of each performance measure.

Sample Situation

A roadway agency is undertaking an effort to improve safety on their highway network. They are screening twenty intersections to identify sites with potential for reducing the crash frequency.

The Facts

- All of the intersections have four approaches and are in rural areas;
- Thirteen are signalized intersections and 7 are unsignalized (two-way stop controlled) intersections;
- Major and Minor Street AADT volumes are provided in Table 4-4;
- A summary of crash data over the same three years as the traffic volumes is shown in Table 4-5; and
- Three years of detailed intersection crash data is shown in Table 4-6.

Assumptions

- The roadway agency has locally calibrated Safety Performance Functions (SPFs) and associated overdispersion parameters for the study intersections. Predicted average crash frequency from an SPF is provided in Table 4-6 for the sample intersections.
- The roadway agency supports use of FHWA crash costs by severity and type.

Intersection Characteristics and Crash Data

Tables 4-4 and 4-5 summarize the intersection characteristics and crash data.

Table 4-4. Intersection Traffic Volumes and Crash Data Summary

Intersections	Traffic Control	Number of Approaches	Major AADT	Minor AADT	Crash Data		
					Total Year 1	Total Year 2	Total Year 3
1	Signal	4	30,100	4,800	9	8	5
2	TWSC	4	12,000	1,200	9	11	15
3	TWSC	4	18,000	800	9	8	6
4	Signal	4	11,200	10,900	8	2	3
5	Signal	4	30,700	18,400	3	7	5
6	Signal	4	31,500	3,600	6	1	2
7	TWSC	4	21,000	1,000	11	9	14
8	Signal	4	23,800	22,300	2	4	3
9	Signal	4	47,000	8,500	15	12	10
10	TWSC	4	15,000	1,500	7	6	4
11	Signal	4	42,000	1,950	12	15	11
12	Signal	4	46,000	18,500	10	14	8
13	Signal	4	11,400	11,400	4	1	1
14	Signal	4	24,800	21,200	5	3	2
15	TWSC	4	26,000	500	6	3	8
16	Signal	4	12,400	7,300	7	11	3
17	TWSC	4	14,400	3,200	4	4	5
18	Signal	4	17,600	4,500	2	10	7
19	TWSC	4	15,400	2,500	5	2	4
20	Signal	4	54,500	5,600	4	2	2

Table 4-5. Intersection Detailed Crash Data Summary (3 Years)

		Crash Severity			Crash Type							
Intersections	Total	Fatal	Injury	PDO	Rear-End	Sideswipe/ Overtaking	Right Angle	Ped	Bike	Head-On	Fixed Object	Other
1	22	0	6	16	11	4	4	0	0	0	1	2
2	35	2	23	10	4	2	21	0	2	5	0	1
3	23	0	13	10	11	5	2	1	0	0	4	0
4	13	0	5	8	7	2	3	0	0	0	1	0
5	15	0	4	11	9	4	2	0	0	0	0	0
6	9	0	2	7	3	2	3	0	0	0	1	0
7	34	1	17	16	19	7	5	0	0	0	3	0
8	9	0	2	7	4	3	1	0	0	0	0	1
9	37	0	22	15	14	4	17	2	0	0	0	0
10	17	0	7	10	9	4	2	0	0	0	1	1
11	38	1	19	18	6	5	23	0	0	4	0	0
12	32	0	15	17	12	2	14	1	0	2	0	1
13	6	0	2	4	3	1	2	0	0	0	0	0
14	10	0	5	5	5	1	1	1	0	0	1	1
15	17	1	4	12	9	4	1	0	0	0	1	2
16	21	0	11	10	8	4	7	0	0	0	1	1
17	13	1	5	7	6	2	2	0	0	1	0	2
18	19	0	8	11	8	7	3	0	0	0	0	1
19	11	1	5	5	5	4	0	1	0	0	0	1
20	8	0	3	5	2	3	2	0	0	0	1	0

Table 4-6. Estimated Predicted Average Crash Frequency from an SPF

Intersection	Year	AADT Major Street	AADT Minor Street	Predicted Average Crash Frequency from an SPF	Average 3-Year Predicted Crash Frequency from an SPF
2	1	12,000	1,200	1.7	1.7
	2	12,200	1,200	1.7	
	3	12,900	1,300	1.8	
3	1	18,000	800	2.1	2.2
	2	18,900	800	2.2	
	3	19,100	800	2.2	
7	1	21,000	1,000	2.5	2.6
	2	21,400	1,000	2.5	
	3	22,500	1,100	2.7	
10	1	15,000	1,500	2.1	2.2
	2	15,800	1,600	2.2	
	3	15,900	1,600	2.2	
15	1	26,000	500	2.5	2.3
	2	26,500	300	2.2	
	3	27,800	200	2.1	
17	1	14,400	3,200	2.5	2.6
	2	15,100	3,400	2.6	
	3	15,300	3,400	2.6	
19	1	15,400	2,500	2.4	2.5
	2	15,700	2,500	2.5	
	3	16,500	2,600	2.6	

4.4.2. Intersection Performance Measure Methods

The following sections provide step-by-step procedures for applying the performance measures described in Section 4.2.3, which provides guidance for selecting an appropriate performance measure.

4.4.2.1. Average Crash Frequency

Applying the Crash Frequency performance measure produces a simple ranking of sites according to total crashes or crashes by type or severity, or both. This method can be used to select an initial group of sites with high crash frequency for further analysis.

Data Needs

- Crash data by location

Strengths and Limitations

The strengths and limitations of the Crash Frequency performance measure include the following:

Strengths	Limitations
Simple	Does not account for RTM bias
	Does not estimate a threshold to indicate sites experiencing more crashes than predicted for sites with similar characteristics
	Does not account for traffic volume
	Will not identify low-volume collision sites where simple cost-effective mitigating countermeasures could be easily applied

Procedure

STEP 1—Sum Crashes for Each Location *Average Crash Frequency*

1 2

Count the number of crashes that occurred at each intersection.

STEP 2—Rank Locations *Average Crash Frequency*

1 2

The intersections can be ranked in descending order by the number of one or more of the following: total crashes, fatal and injury crashes, or PDO crashes.

Ranking of the 20 sample intersections is shown in the table. Column A shows the ranking by total crashes, Column B is the ranking by fatal and injury crashes, and Column C is the ranking by property damage-only crashes.

As shown in the table, ranking based on crash severity may lead to one intersection achieving a different rank depending on the ranking priority. The rank of Intersection 1 demonstrates this variation.

Column A		Column B		Column C	
Intersection	**Total Crashes**	**Intersection**	**Fatal and Injury**	**Intersection**	**PDO Crashes**
11	38	2	25	11	18
9	37	9	22	12	17
2	35	11	20	1	16
7	34	7	18	7	16
12	32	12	15	9	15
3	23	3	13	15	12
1	22	16	11	5	11
16	21	18	8	18	11
18	19	10	7	2	10
10	17	1	6	3	10
15	17	17	6	10	10
5	15	19	6	16	10
4	13	4	5	4	8
17	13	14	5	6	7
19	11	15	5	8	7
14	10	5	4	17	7
6	9	20	3	14	5
8	9	6	2	19	5
20	8	8	2	20	5
13	6	13	2	13	4

4.4.2.2. Crash Rate

The crash rate performance measure normalizes the number of crashes relative to exposure (traffic volume) by dividing the total number of crashes by the traffic volume. The traffic volume includes the total number of vehicles entering the intersection, measured as million entering vehicles (MEV).

Data Needs

- Crashes by location
- Traffic Volume

Strengths and Limitations

The strengths and limitations of the Crash Rate performance measure include the following:

Strengths	Limitations
Simple	Does not account for RTM bias
Could be modified to account for severity if an EPDO or RSI-based crash count is used	Does not identify a threshold to indicate sites experiencing more crashes than predicted for sites with similar characteristics
	Comparisons cannot be made across sites with significantly different traffic volumes
	Will mistakenly prioritize low-volume, low-collision sites

Procedure

The following outlines the assumptions and procedure for ranking sites according to the crash rate method. The calculations for Intersection 7 are used throughout the remaining sample problems to highlight how to apply each method.

STEP 1—Calculate MEV *Crash Rate*

1 2 3

Calculate the million entering vehicles for all 3 years. Use Equation 4-2 to calculate the exposure in terms of million entering vehicles (MEV) at an intersection.

$$MEV = \frac{TEV}{1{,}000{,}000} \times (n) \times (365) \tag{4-2}$$

Where:

MEV = Million entering vehicles

TEV = Total entering vehicles per day

n = Number of years of crash data

Total Entering Vehicles

This table summarizes the total entering volume (TEV) for all sample intersections. The TEV is a sum of the major and minor street AADT found in Table 4-4.

TEV is converted to MEV as shown in the following equation for Intersection 7:

$$MEV = \left(\frac{22{,}000}{1{,}000{,}000}\right) \times (3) \times (365) = 24.1$$

Total Entering Vehicles

Intersection	TEV/day	MEV
1	34900	38.2
2	13200	14.5
3	18800	20.6
4	22100	24.2
5	49100	53.8
6	35100	38.4
7	22000	24.1
8	46100	50.5
9	55500	60.8
10	16500	18.1
11	43950	48.1
12	64500	70.6
13	22800	25.0
14	46000	50.4
15	26500	29.0
16	19700	21.6
17	17600	19.3
18	22100	24.2
19	17900	19.6
20	60100	65.8

STEP 2—Calculate the Crash Rate ***Crash Rate***

1 **2** 3

Calculate the crash rate for each intersection by dividing the total number of crashes by MEV for the 3-year study period as shown in Equation 4-3.

$$R_i = \frac{N_{\text{observed},\, i\,(\text{total})}}{MEV_i} \tag{4-3}$$

Where:

R_i = Observed crash rate at intersection i

$N_{\text{observed},i(\text{total})}$ = Total observed crashes at intersection i

MEV_i = Million entering vehicles at intersection i

Below is the crash rate calculation for Intersection 7. The total number of crashes for each intersection is summarized in Table 4-5.

$$\text{Crash Rate} = \frac{34}{24.1} = 1.4 \ \ [\text{crashes/MEV}]$$

Step 3—Rank Intersections *Crash Rate*

1 2 3

Rank the intersections based on their crash rates.

This table summarizes the results from applying the crash rate method.

Ranking Based on Crash Rates

Intersection	Crash Rate
2	2.4
7	1.4
3	1.1
16	1.0
10	0.9
11	0.8
18	0.8
17	0.7
9	0.6
15	0.6
1	0.6
19	0.6
4	0.5
12	0.5
5	0.3
13	0.2
6	0.2
14	0.2
8	0.2
20	0.1

4.4.2.3. Equivalent Property Damage Only (EPDO) Average Crash Frequency

The Equivalent Property Damage Only (EPDO) Average Crash Frequency performance measure assigns weighting factors to crashes by severity to develop a single combined frequency and severity score per location. The weighting factors are calculated relative to Property Damage Only (PDO) crashes. To screen the network, sites are ranked from the highest to the lowest score. Those sites with the highest scores are evaluated in more detail to identify issues and potential countermeasures.

This method is heavily influenced by the weighting factors for fatal and injury crashes. A large weighting factor for fatal crashes has the potential to rank sites with one fatal crash and a small number of injury or PDO crashes, or both, above sites with no fatal crashes and a relatively high number of injury or PDO crashes, or both. In some applications, fatal and injury crashes are combined into one category of Fatal/Injury (FI) crashes to avoid overemphasizing fatal crashes. Fatal crashes are tragic events; however, the fact that they are fatal is often the outcome of factors (or a combination of factors) that is out of the control of the engineer and planner.

Data Needs

- Crash data by severity and location
- Severity weighting factors
- Crash costs by crash severity

Strengths and Limitations

The strengths and limitations of the EPDO Average Crash Frequency performance measure include the following:

Strengths	Limitations
Simple	Does not account for RTM bias
Considers crash severity	Does not identify a threshold to indicate sites experiencing more crashes than predicted for sites with similar characteristics
	Does not account for traffic volume
	May overemphasize locations with a low frequency of severe crashes depending on weighting factors used

Procedure for Applying the EPDO Average Crash Frequency Performance Measure

Societal crash costs are used to calculate the EPDO weights. State and local jurisdictions often have accepted societal crash costs by type or severity, or both. When available, locally developed crash cost data is preferred. If local information is not available, national crash cost data is available from the Federal Highway Administration (FHWA). In order to improve acceptance of study results that use monetary values, it is important that monetary values be reviewed and endorsed by the jurisdiction in which the study is being conducted.

The FHWA report *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*, prepared in October 2005, documented mean comprehensive societal costs by severity as listed in Table 4-7 (rounded to the nearest hundred dollars) (2). As of December 2008, this was the most recent FHWA crash cost information, although these costs represent 2001 values.

Appendix 4A includes a summary of crash costs and outlines a process to update monetary values to current year values.

Table 4-7. Societal Crash Cost Assumptions

Severity	Comprehensive Crash Cost (2001 Dollars)
Fatal (K)	$4,008,900
Injury Crashes (A/B/C)	$82,600
PDO (O)	$7,400

Source: *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*, FHWA-HRT-05-051, October 2005

The values in Table 4-7 were published in the FHWA study. A combined disabling (A), evident (B), and possible (C) injury crash cost was provided by FHWA to develop an average injury (A/B/C) cost. Injury crashes could also be subdivided into disabling injury, evident injury, and possible injury crashes depending on the amount of detail in the crash data and crash costs available for analysis.

STEP 1—Calculate EDPO Weights ***Equivalent Property Damage Only (EPDO) Average Crash Frequency***

1 2 **3**

Calculate the EPDO weights for fatal, injury, and PDO crashes. The fatal and injury weights are calculated using Equation 4-4. The cost of a fatal or injury crash is divided by the cost of a PDO crash, respectively. Weighting factors developed from local crash cost data typically result in the most accurate results. If local information is not available, nationwide crash cost data is available from the Federal Highway Administration (FHWA). Appendix 4A provides more information on the national data available.

The weighting factors are calculated as follows:

$$f_{y(\text{weight})} = \frac{CC_y}{CC_{PDO}} \tag{4-4}$$

Where:

$f_{y(\text{weight})}$ = Weighting factor based on crash severity, y

CC_y = Crash cost for crash severity, y

CC_{PDO} = Crash cost for PDO crash severity

As shown, a sample calculation for the injury (A/B/C) EPDO weight ($f_{inj(\text{weight})}$) is:

$$f_{inj(\text{weight})} = \frac{\$82,600}{\$7,400} = 11$$

Therefore, the weighting factors for all crash severities are shown in the following table:

Sample EPDO Weights

Severity	Cost	Weight
Fatal (K)	$4,008,900	542
Injury (A/B/C)	$82,600	11
PDO (O)	$7,400	1

STEP 2—Calculate EPDO Scores ***Equivalent Property Damage Only (EPDO) Average Crash Frequency***

1 2 3

For each intersection, multiply the EPDO weights by the corresponding number of fatal, injury, and PDO crashes as shown in Equation 4-5. The frequency of PDO, Injury, and Fatal crashes is based on the number of crashes, not the number of injuries per crash.

$$Total\ EPDO\ Score = f_{k(\text{weight})}(N_{\text{observed},i(F)}) + f_{inj(\text{weight})}(N_{\text{observed},i(I)}) + f_{PDO(\text{weight})}(N_{\text{observed},i(PDO)}) \tag{4-5}$$

Where:

$f_{k(\text{weight})}$ = Fatal Crash Weight

$N_{\text{observed},i(F)}$ = Number of Fatal Crashes per intersection, i

$f_{inj(\text{weight})}$ = Injury Crash Weight

$N_{\text{observed},i(I)}$ = Number of Injury Crashes per intersection, i

$f_{PDO(\text{weight})}$ = PDO Crash Weight

$N_{\text{observed},i(PDO)}$ = Number of PDO Crashes per intersection, i

STEP 3—Rank Locations ***Equivalent Property Damage Only (EPDO) Average Crash Frequency***

1 2 3

The intersections can be ranked in descending order by the EPDO score.

As shown, the calculation of EPDO Score for Intersection 7 is

Total EPDO $Score_7$ = (542 × 1) + (11 × 17) + (1 × 16) = 745

The number of fatal, injury, and PDO crashes for each intersection were shown in the example box in Section 4.4.2.1. The table below summarizes the EPDO score.

The calculation is repeated for each intersection.

The ranking for the 20 intersections is based on EPDO method. The results of calculations for Intersection 7 are highlighted.

Sample EPDO Ranking

Intersection	EPDO Score
2	1347
11	769
7	745
17	604
19	602
15	598
9	257
12	182
3	153
16	131
18	99
10	87
1	82
4	63
14	60
5	55
20	38
6	29
8	29
13	26

4.4.2.4. Relative Severity Index (RSI)

Jurisdiction-specific societal crash costs are developed and assigned to crashes by crash type and location. These societal crash costs make up a relative severity index. Relative Severity Index (RSI) crash costs are assigned to each crash at each site based on the crash type. An average RSI crash cost is calculated for each site and for each population. Sites are ranked based on their average RSI cost and are also compared to the average RSI cost for their respective population.

Data Needs

- Crashes by type and location
- RSI Crash Costs

Strengths and Limitations

The strengths and limitations of the RSI performance measure include the following:

Strengths	Limitations
Simple	Does not account for RTM bias
Considers collision type and crash severity	May overemphasize locations with a small number of severe crashes depending on weighting factors used
	Does not account for traffic volume
	Will mistakenly prioritize low-volume, low-collision sites

Procedure

The RSI costs listed in Table 4-8 are used to calculate the average RSI cost for each intersection and the average RSI cost for each population. The values shown represent 2001 dollar values and are rounded to the nearest hundred dollars. Appendix 4A provides a method for updating crash costs to current year values.

Table 4-8. Crash Cost Estimates by Crash Type

Crash Type	Crash Cost (2001 Dollars)
Rear-End, Signalized Intersection	$26,700
Rear-End, Unsignalized Intersection	$13,200
Sideswipe/Overtaking	$34,000
Angle, Signalized Intersection	$47,300
Angle, Unsignalized Intersection	$61,100
Pedestrian/Bike at an Intersection	$158,900
Head-On, Signalized Intersection	$24,100
Head-On, Unsignalized Intersection	$47,500
Fixed Object	$94,700
Other/Undefined	$55,100

Source: *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*, FHWA-HRT-05-051, October 2005

STEP 1—Calculate RSI Costs per Crash Type ***Relative Severity Index (RSI)***

1 2 3 4

For each intersection, multiply the observed average crash frequency for each crash type by their respective RSI crash cost.

The RSI crash cost per crash type is calculated for each location under consideration. The following example contains the detailed summary of the crashes by type at each intersection.

This table summarizes the number of crashes by crash type at Intersection 7 over the last three years and the corresponding RSI costs for each crash type.

Intersection 7 Relative Severity Index Costs

Intersection 7	Number of Observed Crashes	Crash Costs	RSI Costs
Rear-End, Unsignalized Intersection	19	$13,200	$250,800
Sideswipe Crashes, Unsignalized Intersection	7	$34,000	$238,000
Angle Crashes, Unsignalized Intersection	5	$61,100	$305,500
Fixed Object Crashes, Unsignalized Intersection	3	$94,700	$284,100
Total RSI Cost for Intersection 7			$1,078,400

Note: Crash types that were not reported to have occurred at Intersection 7 were omitted from the table; the RSI value for these crash types is zero.

STEP 2—Calculate Average RSI Cost for Each Intersection

Relative Severity Index (RSI)

1 2 3 4

Sum the RSI crash costs for all crash types and divide by the total number of crashes at the intersection to arrive at an average RSI value for each intersection.

$$\overline{RSI_i} = \frac{\sum_{j=1}^{n} RSI_j}{N_{\text{observed},i}} \quad (4\text{-}6)$$

Where:

$\overline{RSI_i}$ = Average RSI cost for the intersection, i

RSI_j = RSI cost for each crash type, j

$N_{\text{observed},i}$ = Number of observed crashes at the site i

The RSI calculation for Intersection 7 is as follows:

$$\overline{RSI_7} = \frac{\$1,078,400}{34} = \$31,700$$

STEP 3—Calculate the Average RSI Cost for Each Population

Relative Severity Index (RSI)

1 2 3 4

Calculate the average RSI cost for the population (the control group) by summing the total RSI costs for each site and dividing by the total number of crashes within the population.

$$\overline{RSI}_{av(\text{control})} = \frac{\sum_{i=1}^{n} RSI_i}{\sum_{i=1}^{n} N_{\text{observed},i}} \tag{4-7}$$

Where:

$\overline{RSI}_{av(\text{control})}$ = Average RSI cost for the reference population (control group)

RSI_i = Total RSI cost at site *i*

$N_{\text{observed},i}$ = number of observed crashes at site *i*

In this sample problem, Intersection 7 is in the unsignalized intersection population. Therefore, illustrated below is the calculation for the average RSI cost for the unsignalized intersection population.

The average RSI cost for the population ($\overline{RSI}_p$) is calculated using Table 4-8. The following table summarizes the information needed to calculate the average RSI cost for the population:

Unsignalized Intersection	Rear-End	Sideswipe	Angle	Ped/Bike	Head-On	Fixed Object	Other	Total
Number of Crashes over Three Years								
2	4	2	21	2	5	0	1	35
3	11	5	2	1	0	4	0	23
7	19	7	5	0	0	3	0	34
10	9	4	2	0	0	1	1	17
15	9	4	1	0	0	1	2	17
17	6	2	2	0	1	0	2	13
19	5	4	0	1	0	0	1	11
Total Crashes in Unsignalized Intersection Population								150
RSI Crash Costs per Crash Type								
2	$52,800	$68,000	$1,283,100	$317,800	$237,500	$0	$55,100	$2,014,300
3	$145,200	$170,000	$122,200	$158,900	$0	$378,800	$0	$975,100
7	$250,800	$238,000	$305,500	$0	$0	$284,100	$0	$1,078,400
10	$118,800	$136,000	$122,200	$0	$0	$94,700	$55,100	$526,800
15	$118,800	$136,000	$61,100	$0	$0	$94,700	$110,200	$520,800
17	$79,200	$68,000	$122,200	$0	$47,500	$0	$110,200	$427,100
19	$66,000	$136,000	$0	$158,900	$0	$0	$55,100	$416,000
Sum of Total RSI Costs for Unsignalized Intersections								$5,958,500
Average RSI Cost for Unsignalized Intersections ($5,958,500/150)								$39,700

STEP 4—Rank Locations and Compare ***Relative Severity Index (RSI)***

1 2 3 **4**

The average RSI costs are calculated by dividing the RSI crash cost for each intersection by the number of crashes for the same intersection. The average RSI cost per intersection is also compared to the average RSI cost for its respective population.

The following table shows the intersection ranking for all 20 intersections based on their average RSI costs. The RSI costs for Intersection 7 would be compared to the average RSI cost for the unsignalized intersection population. In this instance, the average RSI cost for Intersection 7 ($31,700) is less than the average RSI cost for all unsignalized intersections ($39,700 from calculations in Step 3).

Ranking Based on Average RSI Cost per Intersection

Intersection	Average RSI Cost[a]	Exceeds RSI_p
2	$57,600	X
14	$52,400	X
6	$48,900	X
9	$44,100	X
20	$43,100	X
3	$42,400	X
4	$42,000	X
12	$41,000	X
11	$39,900	X
16	$39,500	
19	$37,800	
1	$37,400	
13	$34,800	
8	$34,600	
18	$34,100	
17	$32,900	
7	$31,700	
5	$31,400	
10	$31,000	
15	$30,600	

[a]Average RSI Costs per Intersection are rounded to the nearest $100.

4.4.2.5. Critical Rate

The observed crash rate at each site is compared to a calculated critical crash rate that is unique to each site. Sites that exceed their respective critical rate are flagged for further review. The critical crash rate depends on the average crash rate at similar sites, traffic volume, and a statistical constant that represents a desired confidence level.

Data Needs

- Crashes by location
- Traffic Volume

Strengths and Limitations

The strengths and limitations of the performance measure include the following:

Strengths	Limitations
Reduces exaggerated effect of sites with low volumes	Does not account for RTM bias
Considers variance in crash data	
Establishes a threshold for comparison	

Procedure

The following outlines the assumptions and procedure for applying the critical rate method. The calculations for Intersection 7 are used throughout the sample problems to highlight how to apply each method.

Assumptions

Calculations in the following steps were conducted using a P-value of 1.645 which corresponds to a 95 percent confidence level. Other possible confidence levels, based on a Poisson distribution and one-tailed standard normal random variable, are shown in Table 4-9.

Table 4-9. Confidence Levels and P Values for Use in Critical Rate Method

Confidence Level	P_c—Value
85 percent	1.036
90 percent	1.282
95 percent	1.645
99 percent	2.326
99.5 percent	2.576

Source: *Road Safety Manual*, PIARC Technical Committee on Road Safety, 2003, p. 113

STEP 1—Calculate MEV for Each Intersection ***Critical Rate***

1 2 3 4 5

Calculate the volume in terms of million entering vehicles for all 3 years. Equation 4-8 is used to calculate the million entering vehicles (MEV) at an intersection.

$$MEV = \left(\frac{TEV}{1{,}000{,}000}\right) \times (n) \times (365) \tag{4-8}$$

Where:

MEV = Million entering vehicles

TEV = Total entering vehicles per day

n = Number of years of crash data

Shown below is the calculation for the MEV of Intersection 7. The TEV is found in Table 4-4.

$$MEV = \left(\frac{22{,}000}{1{,}000{,}000}\right) \times (3) \times (365) = 24.1$$

STEP 2—Calculate the Crash Rate for Each Intersection ***Critical Rate***

1 **2** 3 4 5

Calculate the crash rate for each intersection by dividing the number of crashes by MEV, as shown in Equation 4-9.

$$R_i = \frac{N_{\text{observed},i(\text{total})}}{MEV_i} \tag{4-9}$$

Where:

R_i = Observed crash rate at intersection i

$N_{\text{observed},i(\text{total})}$ = Total observed crashes at intersection i

MEV_i = Million entering vehicles at intersection i

Below is the crash rate calculation for Intersection 7. The total number of crashes for each intersection is summarized in Table 4-5, and the MEV is noted in Step 1.

$$R_i = \frac{34}{24.1} = 1.41 \text{ [crashes/MEV]}$$

STEP 3—Calculate Weighted Average Crash Rate per Population ***Critical Rate***

1 2 **3** 4 5

Divide the network into reference populations based on operational or geometric differences and calculate a weighted average crash rate for each population weighted by traffic volume using Equation 4-10.

$$R_a = \frac{\sum_{i=1} (TEV_i \times R_i)}{\sum_{i=1} (TEV_i)} \tag{4-10}$$

Where:

R_a = Weighted average crash rate for reference population

R_i = Observed crash rate at site i

TEV_i = Total entering vehicles per day for intersection i

For this sample problem, the populations are two-way, stop-controlled intersections (TWSC) and intersections controlled by traffic signals as summarized in the following table:

Two-Way Stop Controlled	Crash Rate	Weighted Average Crash Rate
2	2.42	
3	1.12	
7	1.41	
10	0.94	1.03
15	0.59	
17	0.67	
19	0.56	
Signalized	**Crash Rate**	**Weighted Average Crash Rate**
1	0.58	
4	0.54	
5	0.28	
6	0.23	
8	0.18	
9	0.61	
11	0.79	0.42
12	0.45	
13	0.24	
14	0.20	
16	0.97	
18	0.79	
20	0.12	

STEP 4—Calculate Critical Crash Rate for Each Intersection ***Critical Rate***

1 2 **4** 3 5

Calculate a critical crash rate for each intersection using Equation 4-11.

$$R_{c,i} = R_a + \left[P \times \sqrt{\frac{R_a}{MEV_i}} \right] + \left[\frac{1}{(2 \times (MEV_i))} \right] \tag{4-11}$$

Where:

$R_{c,i}$ = Critical crash rate for intersection i

R_a = Weighted average crash rate for reference population

P = P-value for corresponding confidence level

MEV_i = Million entering vehicles for intersection i

For Intersection 7, the calculation of the critical crash rate is:

$$R_{c,7} = 1.03 + \left[1.645 \times \sqrt{\left(\frac{1.03}{24.1}\right)}\right] + \left[\frac{1}{(2 \times (24.1))}\right] = 1.40 \text{ [crashes/MEV]}$$

STEP 5—Compare Observed Crash Rate with Critical Crash Rate *Critical Rate*

1 2 3 4 5

Observed crash rates are compared with critical crash rates. Any intersection with an observed crash rate greater than the corresponding critical crash rate is flagged for further review.

The critical crash rate for Intersection 7 is compared to the observed crash rate for Intersection 7 to determine if further review of Intersection 7 is warranted.

Critical Crash Rate for Intersection 7 = 1.40 [crashes/MEV]

Observed Crash Rate for Intersection 7 = 1.41 [crashes/MEV]

Since 1.41 > 1.40, Intersection 7 is identified for further review.

The following table summarizes the results for all 20 intersections being screened by the roadway agency.

Critical Rate Method Results

Intersection	Observed Crash Rate (crashes/MEV)	Critical Crash Rate (crashes/MEV)	Identified for Further Review
1	0.58	0.60	
2	2.42	1.51	X
3	1.12	1.43	
4	0.54	0.66	
5	0.28	0.57	
6	0.23	0.60	
7	1.41	1.40	X
8	0.18	0.58	
9	0.61	0.56	X
10	0.94	1.45	
11	0.79	0.58	X
12	0.45	0.55	
13	0.24	0.65	
14	0.20	0.58	
15	0.59	1.36	
16	0.97	0.67	X
17	0.67	1.44	
18	0.79	0.66	X
19	0.56	1.44	
20	0.12	0.56	

4.4.2.6. Excess Predicted Average Crash Frequency Using Method of Moments

In the method of moments, a site's observed crash frequency is adjusted to partially account for regression to the mean. The adjusted observed average crash frequency is compared to the average crash frequency for the reference population to determine the potential for improvement (PI). The potential for improvement of all reference populations (e.g., signalized four-legged intersections, unsignalized three-legged intersections, urban, and rural, etc.) are combined into one ranking list as a basic multiple-facility network screening tool.

Data Needs

- Crashes by location
- Multiple reference populations

Strengths and Limitations

The strengths and limitations of the performance measure include the following:

Strengths	Limitations
Establishes a threshold of predicted performance for a site	Effects of RTM bias may still be present in the results
Considers variance in crash data	Does not account for traffic volume
Allows sites of all types to be ranked in one list	Some sites may be identified for further study because of unusually low frequency of non-target crash types
Method concepts are similar to Empirical Bayes methods	Ranking results are influenced by reference populations; sites near boundaries of reference populations may be over-emphasized

Procedure

The following outlines the procedure for ranking intersections using the Method of Moments. The calculations for Intersection 7 are used throughout the sample problems to highlight how to apply each method.

STEP 1—Establish Reference Populations *Excess Predicted Average Crash Frequency Using Method of Moments*

1 2 3 4 5 6

Organize historical crash data of the study period based upon factors such as facility type, location, or other defining characteristics.

The intersections from Table 4-4 have been organized into two reference populations, as shown in the first table for two-way stop controlled intersections and in the second table for signalized intersections.

TWSC Reference Population

Intersection ID	Traffic Control	Number of Approaches	Urban/ Rural	Total Crashes	Average Observed Crash Frequency
2	TWSC	4	U	35	11.7
3	TWSC	4	U	23	7.7
7	TWSC	4	U	34	11.3
10	TWSC	4	U	17	5.7
15	TWSC	4	U	17	5.7
17	TWSC	4	U	13	4.3
19	TWSC	4	U	11	3.7
Sum				150	50.1

Signalized Reference Population

Intersection ID	Traffic Control	Number of Approaches	Urban/ Rural	Total Crashes	Average Observed Crash Frequency
1	Signal	4	U	22	7.3
4	Signal	4	U	13	4.3
5	Signal	4	U	15	5.0
6	Signal	4	U	9	3.0
8	Signal	4	U	9	3.0
9	Signal	4	U	37	12.3
11	Signal	4	U	38	12.7
12	Signal	4	U	32	10.7
13	Signal	4	U	6	2.0
14	Signal	4	U	10	3.3
16	Signal	4	U	21	7.0
18	Signal	4	U	19	6.3
20	Signal	4	U	8	2.7
Sum				239	79.6

STEP 2—Calculate Average Crash Frequency per Reference Population

Excess Predicted Average Crash Frequency Using Method of Moments

1 **2** 3 4 5 6

Sum the average annual observed crash frequency for each site in the reference population and divide by the number of sites.

$$N_{\text{observed } rp} = \frac{\sum_{i=1}^{n} N_{\text{observed},i}}{n_{\text{sites}}} \tag{4-12}$$

Where:

$N_{\text{observed } rp}$ = Average crash frequency, per reference population

$N_{\text{observed},i}$ = Observed crash frequency at site i

$n_{(\text{sites})}$ = Number of sites per reference population

Calculate the observed average crash frequency in the TWSC reference population:

$$N_{\text{observed},TWSC} = \frac{50}{7} = 7.1 \text{ [crashes per year]}$$

STEP 3—Calculate Crash Frequency Variance per Reference Population
Excess Predicted Average Crash Frequency Using Method of Moments

1 2 **3** 4 5 6

Use Equation 4-13 to calculate variance. Alternatively, variance can be more easily calculated with common spreadsheet programs.

$$Var(N) = \frac{\sum_{i=1}^{n} \left(N_{\text{observed},i} - N_{\text{observed},rp}\right)^{(2)}}{n_{\text{sites}} - 1} \tag{4-13}$$

Where:

$Var(N)$ = Variance

$N_{observed,rp}$ = Average crash frequency, per reference population

$N_{\text{observed},i}$ = Observed crash frequency per year at site i

n_{sites} = Number of sites per reference population

Calculate the crash frequency variance calculation for the TWSC reference population:

$$S_{TWSC}{}^{2} = \frac{112.8}{6} = 18.8$$

The variance for signal and TWSC reference populations is shown in the following table:

	Crash Frequency	
Reference Population	**Average**	**Variance**
Signal	6.1	10.5
TWSC	7.1	18.8

STEP 4—Calculate Adjusted Observed Crash Frequency per Site
Excess Predicted Average Crash Frequency Using Method of Moments

1 2 3 **4** 5 6

Using the variance and average crash frequency for a reference population, find the adjusted observed crash frequency for each site using Equation 4-14.

$$N_{\text{observed},i(adj)} = N_{\text{observed},i} + \frac{N_{\text{observed},rp}}{Var(N)} \times (N_{\text{observed},rp} - N_{\text{observed},i}) \tag{4-14}$$

Where:

$N_{observed,i(adj)}$ = Adjusted observed number of crashes per year, per site

$Var(N)$ = Variance (equivalent to the square of the standard deviation, s^2)

$N_{observed,i}$ = Observed average crash frequency per year at site i

$N_{observed,rp}$ = Average crash frequency, per reference population

As shown, calculate the adjusted observed average crash frequency for Intersection 7:

$$N_{observed,7(adj)} = 11.3 + \frac{7.1}{10.5} \times (7.1 - 11.3) = 8.5 \text{ [crashes per year]}$$

STEP 5—Calculate Potential for Improvement per Site ***Excess Predicted Average Crash Frequency Using Method of Moments***

1 2 3 **5** 4 6

Subtract the average crash frequency per reference population from the adjusted observed average crash frequency per site.

$$PI_i = N_{observed,i(adj)} - N_{observed,rp} \tag{4-15}$$

Where:

PI_i = Potential for Improvement per site

$N_{observed,i(adj)}$ = Adjusted observed average crash frequency per year, per site

$N_{observed,rp}$ = Average crash frequency, per reference population

As shown below, calculate the potential for improvement for Intersection 7:

$PI_7 = 8.5 - 7.1 = 1.4$ [crashes per year]

STEP 6—Rank Sites According to PI ***Excess Predicted Average Crash Frequency Using Method of Moments***

1 2 3 4 5 **6**

Rank all sites from highest to lowest PI value. A negative PI value is not only possible but indicates a low potential for crash reduction.

The PI rankings along with each site's adjusted observed crash frequency are as follows:

Intersections	Observed Average Crash Frequency	Adjusted Observed Crash Frequency	PI
11	12.7	9.8	3.6
9	12.3	9.6	3.4
12	10.7	8.6	2.5
2	11.7	8.6	1.4
7	11.3	8.5	1.4
1	7.3	6.8	0.7
16	7.0	6.6	0.5
3	7.7	7.3	0.2
18	6.3	6.2	0.1
10	5.7	6.7	–0.5
15	5.7	6.7	–0.5
5	5.0	5.5	–0.6
17	4.3	6.3	–0.9
4	4.3	5.1	–1.0
19	3.7	6.0	–1.1
14	3.3	4.6	–1.5
6	3.0	4.4	–1.7
8	3.0	4.4	–1.7
20	2.7	4.2	–1.9
13	2.0	3.8	–2.3

4.4.2.7. Level of Service of Safety (LOSS)

Sites are ranked by comparing their observed average crash frequency to the predicted average crash frequency for the entire population under consideration (1,4,5). The degree of deviation from the predicted average crash frequency is divided into four LOSS classes. Each site is assigned a LOSS based on the difference between the observed average crash frequency and the predicted average crash frequency for the study group. Sites with poor LOSS are flagged for further study.

Data Needs

- Crash data by location (recommended period of 3 to 5 Years)
- Calibrated Safety Performance Function (SPF) and overdispersion parameter
- Traffic volume

Strengths and Limitations

The strengths and limitations of the performance measure include the following:

Strengths	Limitations
Considers variance in crash data	Effects of RTM bias may still be present in the results
Accounts for volume	
Establishes a threshold for measuring crash frequency	

Procedure

The following sections outline the assumptions and procedure for ranking the intersections using the LOSS performance measure.

Sample Problem Assumptions

The calculations for Intersection 7 are used throughout the sample problem to demonstrate how to apply each method.

The Sample problems provided in this section are intended to demonstrate calculation of the performance measures, not the predictive method. Therefore, simplified predicted average crash frequency for the TWSC intersection population were developed using the predictive method outlined in Part C and are provided in Table 4-6 for use in sample problems.

The simplified estimates assume a calibration factor of 1.0, meaning that there are assumed to be no differences between the local conditions and the base conditions of the jurisdictions used to develop the base SPF model. It is also assumed that all CMFs are 1.0, meaning there are no individual geometric design and traffic control features that vary from those conditions assumed in the base model. These assumptions are to simplify this example and are rarely valid for application of the predictive method to actual field conditions.

STEP 1—Estimate Predicted Average Crash Frequency Using an SPF *Level of Service of Safety (LOSS)*

1 2 3 4 5

Use the predictive method and SPFs outlined in Part C to estimate the average crash frequency. The predicted average crash frequency is summarized in Table 4-10:

Table 4-10. Estimated Predicted Average Crash Frequency from an SPF

Intersection	Year	AADT		Predicted Average Crash Frequency from an SPF	Average 3-Year Expected Crash Frequency from an SPF
		Major Street	Minor Street		
2	1	12,000	1,200	1.7	1.7
	2	12,200	1,200	1.7	
	3	12,900	1,300	1.8	
3	1	18,000	800	2.1	2.2
	2	18,900	800	2.2	
	3	19,100	800	2.2	
7	1	21,000	1,000	2.5	2.6
	2	21,400	1,000	2.5	
	3	22,500	1,100	2.7	
10	1	15,000	1,500	2.1	2.2
	2	15,800	1,600	2.2	
	3	15,900	1,600	2.2	
15	1	26,000	500	2.5	2.3
	2	26,500	300	2.2	
	3	27,800	200	2.1	
17	1	14,400	3,200	2.5	2.6
	2	15,100	3,400	2.6	
	3	15,300	3,400	2.6	
19	1	15,400	2,500	2.4	2.5
	2	15,700	2,500	2.5	
	3	16,500	2,600	2.6	

STEP 2—Calculate Standard Deviation *Level of Service of Safety (LOSS)*

1 **2** 3 4 5

Calculate the standard deviation of the predicted crashes. Equation 4-16 is used to calculate the standard deviation. This estimate of standard deviation is valid since the SPF assumes a negative binomial distribution of crash counts.

$$\sigma = \sqrt{k + N_{\text{predicted}}{}^{2}} \tag{4-16}$$

Where:

σ = Standard deviation

k = Overdispersion parameter of the SPF

$N_{\text{predicted}}$ = Predicted average crash frequency from the SPF

As shown, the standard deviation calculations for Intersection 7 are

$$\sigma = \sqrt{0.40 \times 2.6^2} = 1.6$$

The standard deviation calculation is performed for each intersection. The standard deviation for the TWSC intersections is summarized in the following table:

Intersection	Average Observed Crash Frequency	Predicted Average Crash Frequency from an SPF	Standard Deviation
2	11.7	1.7	1.1
3	7.7	2.2	1.4
7	11.3	2.6	1.6
10	5.7	2.2	1.4
15	5.7	2.3	1.5
17	4.3	2.6	1.6
19	3.7	2.5	1.6

STEP 3—Calculate Limits for LOSS Categories ***Level of Service of Safety (LOSS)***

1 2 **3** 4 5

Calculate the limits for the four LOSS categories for each intersection using the equations summarized in Table 4-11.

Table 4-11. LOSS Categories

LOSS	Condition	Description
I	$\sigma < N_{observed} < (N - 1.5 \times (\sigma))$	Indicates a low potential for crash reduction
II	$(N - 1.5 \times (\sigma)) \leq N_{observed} < N$	Indicates low to moderate potential for crash reduction
III	$N \leq N_{observed}\ (N + 1.5 \times (\sigma))$	Indicates moderate to high potential for crash reduction
IV	$N_{observed} \geq (N + 1.5 \times (\sigma))$	Indicates a high potential for crash reduction

This sample calculation for Intersection 7 demonstrates the upper limit calculation for LOSS III.

$N + 1.5 \times (\sigma) = 2.6 + 1.5 \times (1.6) = 5.0$

A similar pattern is followed for the other LOSS limits.

The values for this calculation are provided in the following table:

LOSS Limits for Intersection 7

Intersection	LOSS I Limits	LOSS II Limits	LOSS III Upper Limit	LOSS IV Limits
7	0 to 0.2	0.2 to 2.6	2.6 to 5.0	≥ 5.0

STEP 4—Compare Observed Crashes to LOSS Limits *Level of Service of Safety (LOSS)*

1 2 3 **4** 5

Compare the total observed crash frequency at each intersection, N_o, to the limits of the four LOSS categories. Assign a LOSS to each intersection based on the category in which the total observed crash frequency falls.

Given that an average of 11.3 crashes were observed per year at Intersection 7 and the LOSS IV limits are 5.0 crashes per year, Intersection 7 is categorized as Level IV.

STEP 5—Rank Intersections *Level of Service of Safety (LOSS)*

1 2 3 4 **5**

List the intersections based on their LOSS for total crashes.

The following table summarizes the TWSC reference population intersection ranking based on LOSS:

Intersection LOSS Ranking

Intersection	LOSS
2	IV
3	IV
7	IV
10	IV
15	IV
17	III
19	III

4.4.2.8. Excess Predicted Average Crash Frequency Using SPFs

Locations are ranked in descending order based on the excess crash frequency or the excess predicted crash frequency of a particular collision type or crash severity.

Data Needs

- Crash data by location

Strengths and Limitations

The strengths and limitations of the performance measure include the following:

Strengths	Limitations
Accounts for traffic volume	Effects of RTM bias may still be present in the results
Estimates a threshold for comparison	

Procedure

The following sections outline the assumptions and procedure for ranking intersections using the Excess Predicted Crash Frequency using SPFs performance measure.

Sample Problem Assumptions

The Sample problems provided in this section are intended to demonstrate calculation of the performance measures, not predictive method. Therefore, simplified predicted average crash frequency for the TWSC intersection population were developed using predictive method outlined in Part C and are provided in Table 4-6 for use in sample problems.

The simplified estimates assume a calibration factor of 1.0, meaning that there are assumed to be no differences between the local conditions and the base conditions of the jurisdictions used to develop the SPF. It is also assumed that all CMFs are 1.0, meaning there are no individual geometric design and traffic control features that vary from those conditions assumed in the SPF. These assumptions are for theoretical application and are rarely valid for application of Part C predictive method to actual field conditions.

STEP 1—Summarize Crash History ***Excess Predicted Average Crash Frequency Using SPFs***

1 2 3 4

Tabulate the number of crashes by type and severity at each site for each reference population being screened.

The reference population for TWSC intersections is shown as an example in the following table:

TWSC Reference Population

Intersection	Year	AADT Major Street	AADT Minor Street	Observed Number of Crashes	Average Observed Crash Frequency
2	1	12,000	1,200	9	11.7
	2	12,200	1,200	11	
	3	12,900	1,300	15	
3	1	18,000	800	9	7.7
	2	18,900	800	8	
	3	19,100	800	6	
7	1	21,000	1,000	11	11.3
	2	21,400	1,000	9	
	3	22,500	1,100	14	
10	1	15,000	1,500	7	5.7
	2	15,800	1,600	6	
	3	15,900	1,600	4	
15	1	26,000	500	6	5.7
	2	26,500	300	3	
	3	27,800	200	8	
17	1	14,400	3,200	4	4.3
	2	15,100	3,400	4	
	3	15,300	3,400	5	
19	1	15,400	2,500	5	3.7
	2	15,700	2,500	2	
	3	16,500	2,600	4	

STEP 2—Calculate Predicted Average Crash Frequency from an SPF ***Excess Predicted Average Crash Frequency Using SPFs***

1 **2** 3 4

Using the predictive method in Part C, calculate the predicted average crash frequency, $N_{\text{predicted},n}$, for each year, n, where $n = 1,2,\ldots,Y$. Refer to Part C—Introduction and Applications Guidance for a detailed overview of the method to calculate the predicted average crash frequency. The example provided here is simplified to emphasize calculation of the performance measure, not the predictive method.

The predicted average crash frequency from SPFs are summarized for the TWSC intersections for a three-year period in the following table:

SPF Predicted Average Crash Frequency

Intersection	Year	Predicted Average Crash Frequency from SPF (Total)	Predicted Average Crash Frequency from an SPF (FI)	Predicted Average Crash Frequency from an SPF (PDO)	Average 3-Year Predicted Crash Frequency from SPF
	1	1.7	0.6	1.1	
2	2	1.7	0.6	1.1	1.7
	3	1.8	0.7	1.1	
	1	2.1	0.8	1.3	
3	2	2.2	0.8	1.4	2.2
	3	2.2	0.9	1.4	
	1	2.5	1.0	1.6	
7	2	2.5	1.0	1.6	2.6
	3	2.7	1.1	1.7	
	1	2.1	0.8	1.3	
10	2	2.2	0.9	1.4	2.2
	3	2.2	0.9	1.4	
	1	2.5	1.0	1.6	
15	2	2.2	0.9	1.4	2.3
	3	2.1	0.8	1.3	
	1	2.5	1.0	1.5	
17	2	2.6	1.0	1.6	2.6
	3	2.6	1.0	1.6	
	1	2.4	1.0	1.5	
19	2	2.5	1.0	1.5	2.5
	3	2.6	1.0	1.6	

STEP 3—Calculate Excess Predicted Average Crash Frequency ***Excess Predicted Average Crash Frequency Using SPFs***

1 2 **3** 4

For each intersection the excess predicted average crash frequency is based upon the average of all years of data. The excess is calculated as the difference in the observed average crash frequency and the predicted average crash frequency from an SPF.

$$Excess(N) = \overline{N_{\text{observed},i}} - \overline{N_{\text{predicted},i}} \tag{4-17}$$

Where:

$\overline{N_{\text{observed},i}}$ = Observed average crash frequency for site i

$\overline{N_{\text{predicted},i}}$ = Predicted average crash frequency from SPF for site.

Shown below is the predicted excess crash frequency calculation for Intersection 7:

$Excess_{(TWSC)} = 11.3 - 2.6 = 8.7$ [crashes per year]

The following table shows the excess expected average crash frequency for the TWSC reference population:

Excess Predicted Average Crash Frequency for TWSC Population

Intersection	Observed Average Crash Frequency	Predicted Average Crash Frequency from an SPF	Excess Predicted Average Crash Frequency
2	11.7	1.7	10.0
3	7.7	2.2	5.5
7	11.3	2.6	8.7
10	5.7	2.2	3.5
15	5.7	2.3	3.4
17	4.3	2.6	1.7
19	3.7	2.5	1.2

STEP 4—Rank Sites ***Excess Predicted Average Crash Frequency Using SPFs***

1 2 3 **4**

Rank all sites in each reference population according to the excess predicted average crash frequency.

The following table ranks the TWSC intersections according to the excess predicted average crash frequency:

Ranking of TWSC Population Based on Excess Predicted Average Crash Frequency from an SPF

Intersection	Excess Predicted Average Crash Frequency
2	10.0
7	8.7
3	5.5
10	3.5
15	3.4
17	1.7
19	1.2

4.4.2.9. Probability of Specific Crash Types Exceeding Threshold Proportion

Sites are prioritized based on the probability that the true proportion, p_i, of a particular crash type or severity (e.g., long-term predicted proportion) is greater than the threshold proportion, p^*_i (6). A threshold proportion (p^*_i) is identified for each crash type.

Data Needs

- Crash data by type and location

Strengths and Limitations

The strengths and limitations of the Probability of Specific Crash Types Exceeding Threshold Proportion performance measure include the following:

Strengths	Limitations
Can also be used as a diagnostic tool (Chapter 5)	Does not account for traffic volume
Considers variance in data	Some sites may be identified for further study because of unusually low frequency of non-target crash types
Not effected by RTM Bias	

Procedure

Organize sites into reference populations and screen to identify those that have a high proportion of a specified collision type or crash severity.

The sample intersections are to be screened for a high proportion of angle crashes. Prior to beginning the method, the 20 intersections are organized into two subcategories (i.e., reference populations): (1) TWSC intersections and (2) signalized intersections.

STEP 1—Calculate Observed Proportions ***Probability of Specific Crash Types Exceeding Threshold Proportion***

1	2	3	4	5	6

A. Determine which collision type or crash severity to target and calculate observed proportion of target collision type or crash severity for each site.

B. Identify the frequency of the collision type or crash severity of interest and the total observed crashes of all types and severity during the study period at each site.

C. Calculate the observed proportion of the collision type or crash severity of interest for each site that has experienced two or more crashes of the target collision type or crash severity using Equation 4-18.

$$p_i = \frac{N_{\text{observed},i}}{N_{\text{observed},i(\text{total})}} \tag{4-18}$$

Where:

p_i = Observed proportion at site i

$N_{\text{observed},i}$ = Number of observed target crashes at site i

$N_{\text{observed},i(\text{total})}$ = Total number of crashes at site i

Shown below is the calculation for angle crashes for Intersection 7. The values used in the calculation are found in Table 4-5.

$$p_i = \frac{5}{34} = 0.15$$

STEP 2—Estimate a Threshold Proportion ***Probability of Specific Crash Types Exceeding Threshold Proportion***

1	2	3	4	5	6

Select the threshold proportion of crashes, p^*_i, for a specific collision type. A useful default starting point is the proportion of target crashes in the reference population under consideration. For example, if considering rear-end crashes, it would be the observed average rear-end crash frequency experienced at all sites in the reference population divided by the total observed average crash frequency at all sites in the reference population. The proportion of a specific crash type in the entire population is calculated using Equation 4-19.

$$p^*_i = \frac{\sum N_{\text{observed},i}}{\sum N_{\text{observed},i(\text{total})}} \tag{4-19}$$

Where:

p^*_i = Threshold proportion

$\sum N_{\text{observed},i}$ = Sum of observed target crash frequency within the population

$\sum N_{\text{observed},i(\text{total})}$ = Sum of total observed crash frequency within the population

Below is the calculation for threshold proportion of angle collisions for TWSC intersections.

$$p^*_i = \frac{33}{150} = 0.22$$

The following table summarizes the threshold proportions for the reference populations:

Estimated Threshold Proportion of Angle Collisions

Reference Population	Angle Crashes	Total Crashes	Observed Threshold Proportion (p^*_i)
TWSC	33	150	0.22
Traffic Signals	82	239	0.34

STEP 3—Calculate Sample Variance ***Probability of Specific Crash Types Exceeding Threshold Proportion***

1 2 **3** 4 5 6

Calculate the sample variance (s^2) for each subcategory. The sample variance is different than population variance. Population variance is commonly used in statistics and many software tools and spreadsheets use the population variance formula as the default variance formula.

For this method, be sure to calculate the sample variance using Equation 4-20:

$$Var(N) = \left(\frac{1}{n_{\text{sites}} - 1}\right) \times \left[\sum_{i=1}^{n}\left(\frac{N_{\text{observed},i}^2 - N_{\text{observed},i}}{N_{\text{observed},i(\text{total})}^2 - N_{\text{observed},i(\text{total})}}\right) - \left(\frac{1}{n_{\text{sites}}}\right) \times \left(\sum_{i=1}^{n}\frac{N_{\text{observed},i}}{N_{\text{observed},i(\text{total})}}\right)^2\right] \tag{4-20}$$

for $N_{\text{observed},i(\text{total})} \geq 2$

Where:

n_{sites} = Total number of sites being analyzed

$N_{\text{observed},i}$ = Observed target crashes for a site i

$N_{\text{observed},i(\text{total})}$ = Total number of crashes for a site i

The following table summarizes the calculations for the two-way stop-controlled subcategory. TWSC sites 15 and 19 were removed from the variance calculation because fewer than two angle crashes were reported over the study period.

Sample Variance Calculation

TWSC	Angle Crashes ($N_{\text{observed},i}$)	$(N_{\text{observed},i})^2$	Total Crashes ($N_{\text{observed},i(\text{total})}$)	$(N_{\text{observed},i(\text{total})})^2$	n	TWSC Variance
2	21	441	35	1225		
7	5	25	34	1156		
3	2	4	23	529	5	0.037
10	2	4	17	289		
17	2	4	13	169		

STEP 4—Calculate Alpha and Beta Parameters ***Probability of Specific Crash Types Exceeding Threshold Proportion***

1 2 3 **4** 5 6

Calculate the sample mean proportion of target crashes by type or severity for all sites under consideration using Equation 4-21.

$$\overline{p_i^*} = \frac{\sum p_i}{n_{\text{sites}}}, N_{\text{observed},i} \geq 2 \tag{4-21}$$

Where:

n_{sites} = Total number of sites being analyzed

$\overline{p^*_i}$ = Mean proportion of target crash types

p_i = Observed proportion

Calculate Alpha (α) and Beta (ß) for each subcategory using Equations 4-22 and 4-23.

$$\alpha = \frac{\overline{p^*_i}^2 - \overline{p^*_i}^3 - s^2(\overline{p^*_i})}{Var(N)} \tag{4-22}$$

$$\beta = \frac{\alpha}{\overline{p^*_i}} - \alpha \tag{4-23}$$

Where:

$Var(N)$ = Variance (equivalent to the square of the standard deviation, s^2)

$\overline{p^*_i}$ = Mean proportion of target crash types

The calculation for the two-way stop-controlled subcategory is:

$$\alpha = \frac{0.22^2 - 0.22^3 - 0.037 \times 0.22}{0.037} = 0.80$$

$$\beta = \frac{0.80}{0.22} - 0.80 = 2.84$$

The following table shows the numerical values used in the equations and summarizes the alpha and beta calculations for the TWSC intersections:

Alpha and Beta Calculations

Subcategories	s^2	$\overline{p^*_i}$	α	ß
TWSC	0.034	0.22	0.91	3.2

STEP 5—Calculate the Probability ***Probability of Specific Crash Types Exceeding Threshold Proportion***

1 2 3 4 5 6

Using a "betadist" spreadsheet function, calculate the probability for each intersection as shown in Equation 4-24.

$$p\left(\frac{p_i > p_i^*}{N_{\text{observed},i}, N_{\text{observed},i(\text{total})}}\right) = 1 - betadist(p_i^*, \alpha + N_{\text{observed},i}, \beta + N_{\text{observed},i(\text{total})} - N_{\text{observed},i}) \tag{4-24}$$

Where:

p^*_i = Threshold proportion

p_i = Observed proportion

$N_{\text{observed},i}$ = Observed target crashes for a site i

$N_{\text{observed},i(\text{total})}$ = Total number of crashes for a site i

The probability calculation for Intersection 7 is:

$$p\left(\frac{p_i > p_i^*}{N_{\text{observed},i}, N_{\text{observed},i(\text{total})}}\right) = 1 - betadist(0.22, 0.80 + 5, 2.84 + 34 - 5)$$

The following table summarizes the probability calculation for Intersection 7:

Probability Calculations

TWSC	Angle Crashes ($N_{\text{observed},i}$)	Total Crashes ($N_{\text{observed},i(\text{total})}$)	p_i	p^*_i	α	ß	Probability
7	5	34	0.15	0.22	0.80	2.84	0.13

For Intersection 7, the resulting probability is interpreted as "There is a 13 percent chance that the long-term expected proportion of angle crashes at Intersection 7 is actually greater than the long-term expected proportion for TWSC intersections." Therefore, in this case, with such a small probability, there is limited need of additional study of Intersection 7 with regards to angle crashes.

STEP 6—Rank Locations ***Probability of Specific Crash Types Exceeding Threshold Proportion***

1 2 3 4 5 6

Rank the intersections based on the probability of angle crashes occurring at the intersection.

The TWSC intersection population is ranked based on the Probability of Specific Crash Types Exceeding Threshold Proportion Performance Measure as shown in the following table:

Ranking Based on Probability of Specific Crash Types Exceeding Threshold Proportion Performance Measure

Intersections	Probability
2	1.00
11	0.99
9	0.81
12	0.71
16	0.36
6	0.35
13	0.35
20	0.26
17	0.25
4	0.20
7	0.13
10	0.13
5	0.08
1	0.08
18	0.07
3	0.04

4.4.2.10 Excess Proportion of Specific Crash Types

Sites are evaluated to quantify the extent to which a specific crash type is overrepresented compared to other crash types at a location. The sites are ranked based on excess proportion, which is the difference between the true proportion, p_i, and the threshold proportion, p^*_i. The excess is calculated for a site if the probability that a site's long-term observed proportion is higher than the threshold proportion, p^*_i, exceeds a certain limiting probability (e.g., 90 percent).

Data Needs

- Crash data by type and location

Strengths and Limitations

The strengths and limitations of the Excess Proportions of Specific Crash Types Proportion performance measure include the following:

Strengths	Limitations
Can also be used as a diagnostic tool	Does not account for traffic volume.
Considers variance in data	Some sites may be identified for further study because of unusually low frequency of non-target crash types
Not effected by RTM Bias	

Procedure

Calculation of the excess proportion follows the same procedure outlined in Steps 1 through 5 of the Probability of Specific Crash Types Exceeding Threshold Proportions method. Therefore, the procedure outlined in this section builds on the previous method and applies results of sample calculations shown above in the example table of Step 6.

For the sample situation, the limiting probability is selected to be 60 percent. The selection of a limiting probability can vary depending on the probabilities of each specific crash types exceeding a threshold proportion. For example, if many sites have high probability, the limiting probability can be correspondingly higher in order to limit the number of sites to a reasonable study size. In this example, a 60 percent limiting probability results in four sites that will be evaluated based on the Excess Proportions performance measure.

STEP 6—Calculate the Excess Proportion ***Excess Proportion of Specific Crash Types***

1 2 3 4 **6** 7

Calculate the difference between the true observed proportion and the threshold proportion for each site using Equation 4-25:

$$p_{diff} = p_i - p_i^* \quad (4\text{-}25)$$

Where:

p^*_i = Threshold proportion

p_i = Observed proportion

STEP 7—Rank Locations ***Excess Proportion of Specific Crash Types***

1 2 3 4 5 6 **7**

Rank locations in descending order by the value of Pdiff. The greater the difference between the observed and threshold proportion, the greater the likelihood that the site will benefit from a countermeasure targeted at the collision type under consideration.

The four intersections that met the limiting probability of 60 percent are ranked in the following table:

Ranking Based on Excess Proportion

Intersections	Probability	Observed Proportion	Threshold Proportion	Excess Proportion
2	1.00	0.60	0.22	0.38
11	0.99	0.61	0.34	0.27
9	0.81	0.46	0.34	0.12
12	0.71	0.44	0.34	0.10

4.4.2.11. Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment

The Empirical Bayes (EB) method is applied in the estimation of expected average crash frequency. The EB method, as implemented in this chapter, is implemented in a slightly more sophisticated manner than in Part C, Appendix A. The version of the EB method implemented here uses yearly correction factors for consistency with network screening applications in the SafetyAnalyst software tools.

Data Needs

- Crash data by severity and location
- Traffic volume
- Basic site characteristics (i.e., roadway cross-section, intersection control, etc.)
- Calibrated Safety Performance Functions (SPFs) and overdispersion parameters

Strengths and Limitations

The strengths and limitations of the Expected Average Crash Frequency with EB Adjustment performance measure include the following:

Strengths	Limitations
Accounts for RTM bias	Requires SPFs calibrated to local conditions

Procedure

The following sample problem outlines the assumptions and procedure for ranking intersections based on the expected average crash frequency with Empirical Bayes adjustments. The calculations for Intersection 7 are used throughout the sample problems to highlight how to apply each method.

Sample Problem Assumptions

The sample problems provided in this section are intended to demonstrate calculation of the performance measures, not predictive method. Therefore, simplified predicted average crash frequency for the TWSC intersection population were developed using predictive method outlined in Part C and are provided in Table 4-6 for use in sample problems.

The simplified estimates assume a calibration factor of 1.0, meaning that there are assumed to be no differences between the local conditions and the base conditions of the jurisdictions used to develop the SPF. It is also assumed that all CMFs are 1.0, meaning there are no individual geometric design and traffic control features that vary from those conditions assumed in the base model. These assumptions are for theoretical application and are rarely valid for application of the Part C predictive method to actual field conditions.

STEP 1—Calculate the Predicted Average Crash Frequency from an SPF

Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment

1 2 3 4 5 6 7

Using the predictive method in Part C calculate the predicted average crash frequency, $N_{\text{predicted},n}$, for each year, n, where $n = 1,2,\ldots,Y$. Refer to Part C—Introduction and Applications Guidance for a detailed overview of the method to calculate the predicted average crash frequency. The example provided here is simplified to emphasize calculation of the performance measure, not predictive method.

In the following steps this prediction will be adjusted using an annual correction factor and an Empirical Bayes weight. These adjustments will account for annual fluctuations in crash occurrence due to variability in roadway conditions and other similar factors; they will also incorporate the historical crash data specific to the site.

STEP 2—Calculate Annual Correction Factor

Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment

1 **2** 3 4 5 6 7

Calculate the annual correction factor (C_n) at each intersection for each year and each severity (i.e., total and *FI*).

The annual correction factor is predicted average crash frequency from an SPF for year n divided by the predicted average crash frequency from an SPF for year 1. This factor is intended to capture the effect that annual variations in traffic, weather, and vehicle mix have on crash occurrences. (3)

$$C_{n(\text{total})} = \frac{N_{\text{predicted},n(\text{total})}}{N_{\text{predicted},1(\text{total})}} \quad \text{and} \quad C_{n(FI)} = \frac{N_{\text{predicted},n(FI)}}{N_{\text{predicted},1(FI)}} \tag{4-26}$$

Where:

$C_{n(\text{total})}$ = Annual correction factor for total crashes

$C_{n(FI)}$ = Annual correction factor for fatal or injury crashes, or both

$N_{\text{predicted},\,n(\text{total})}$ = Predicted number of total crashes for year n

$N_{\text{predicted},1(FI)}$ = Predicted number of fatal or injury crashes, or both, for year n

Shown below is the calculation for Intersection 7 based on the annual correction factor for year 3. The predicted crashes shown in the equation are the result of Step 1 and are summarized in the table that follows.

$$C_{3(\text{total})} = \frac{2.7}{2.5} = 1.1$$

$$C_{3(FI)} = \frac{1.1}{1.0} = 1.1$$

This calculation is repeated for each year and each intersection. The following table summarizes the annual correction factor calculations for the TWSC intersections:

Annual Correction Factors for all TWSC Intersections

Intersection	Year	Predicted Average Crash Frequency from SPF (total)	Predicted Average Crash Frequency from SPF (FI)	Correction Factor (total)	Correction Factor (FI)
2	1	1.7	0.6	1.0	1.0
	2	1.7	0.6	1.0	1.0
	3	1.8	0.7	1.1	1.2
3	1	2.1	0.8	1.0	1.0
	2	2.2	0.8	1.0	1.0
	3	2.2	0.9	1.0	1.1
7	1	2.5	1.0	1.0	1.0
	2	2.5	1.0	1.0	1.0
	3	2.7	1.1	1.1	1.1
10	1	2.1	0.8	1.0	1.0
	2	2.2	0.9	1.0	1.1
	3	2.2	0.9	1.0	1.1
15	1	2.5	1.0	1.0	1.0
	2	2.2	0.9	0.9	0.9
	3	2.1	0.8	0.8	0.8
17	1	2.5	1.0	1.0	1.0
	2	2.6	1.0	1.0	1.0
	3	2.6	1.0	1.0	1.0
	1	2.4	1.0	1.0	1.0
19	2	2.5	1.0	1.0	1.0
	3	2.6	1.0	1.1	1.0

STEP 3—Calculate Weighted Adjustment

Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment

1 2 **3** 4 5 6 7

Calculate the weighted adjustment, w, for each intersection and each severity (i.e., total and *FI*). The weighted adjustment accounts for the reliability of the safety performance function that is applied. Crash estimates produced using Safety Performance Functions with overdispersion parameters that are low (which indicates higher reliability) have a larger weighted adjustment. Larger weighting factors place a heavier reliance on the SPF estimate.

$$w_{\text{total}} = \frac{1}{1 + k_{\text{total}} \times \sum_{n=1}^{N} N_{\text{predicted},n(\text{total})}} \quad \text{and} \quad w_{FI} = \frac{1}{1 + k_{FI} \times \sum_{n=1}^{N} N_{\text{predicted},n(FI)}} \tag{4-27}$$

Where:

w = Empirical Bayes weight

k = Overdispersion parameter of the SPF

$N_{\text{predicted},\,n(\text{total})}$ = Predicted average total crash frequency from an SPF in year n

$N_{\text{predicted},\,n(FI)}$ = Predicted average fatal and injury crash frequency from an SPF in year n

Shown below is the weighted adjustment calculation for total and fatal/injury crashes for Intersection 7.

The sum of the predicted crashes (7.7 and 3.1) is the result of summing the annual predicted crashes summarized in Step 2 for Intersection 7.

$$w_{\text{total}} = \frac{1}{(1+(0.49\times 7.7))} = 0.2$$

$$w_{FI} = \frac{1}{(1+(0.74\times 3.1))} = 0.3$$

The calculated weights for the TWSC intersections are summarized in the following table:

Weighted Adjustments for TWSC Intersections

Intersection	w_{total}	w_{FI}
2	0.3	0.4
3	0.2	0.4
7	0.2	0.3
10	0.2	0.3
15	0.2	0.3
17	0.2	0.3
19	0.2	0.3

STEP 4—Calculate First Year EB-adjusted Expected Average Crash Frequency

Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment

1 2 3 **4** 5 6 7

Calculate the base EB-adjusted expected average crash frequency for year 1, $N_{\text{expected},1}$ using Equations 4-28 and 4-29.

This stage of the method integrates the observed crash frequency with the predicted average crash frequency from an SPF. The larger the weighting factor, the greater the reliance on the SPF to estimate the long-term predicted average crash frequency per year at the site. The observed crash frequency on the roadway segments is represented in the equations below as $N_{\text{observed},n}$.

$$N_{\text{expected},1(\text{total})} = w_{\text{total}} \times N_{\text{predicted},1(\text{total})} + (1 - w_{\text{total}}) \times \left(\frac{\sum_{n=1}^{N} N_{\text{observed},y(\text{total})}}{\sum_{n=1}^{N} C_{n(\text{total})}} \right) \quad (4\text{-}28)$$

and

$$N_{\text{expected},1(FI)} = w_{FI} \times N_{\text{predicted},1(FI)} + (1 - w_{FI}) \times \left(\frac{\sum_{n=1}^{N} N_{\text{observed},y(FI)}}{\sum_{n=1}^{N} C_{n(FI)}} \right) \quad (4\text{-}29)$$

Where:

$N_{expected,1}$ = EB-adjusted estimated average crash frequency for year 1

w = Weight

$N_{predicted,i(total)}$ = Estimated average crash frequency for year 1 for the intersection

$N_{observed,n}$ = Observed crash frequency at the intersection

C_n = Annual correction factor for the intersection

n = year

Shown below is the total and fatal/injury calculation for Intersection 7.

These calculations are based on information presented in Steps 2 and 3.

$$N_{expected,1(total)} = 0.2 \times (2.5) + (1 - 0.2) \times \frac{34}{3.1} = 9.3$$

$$N_{expected,1(FI)} = 0.3 \times (1.0) + (1 - 0.3) \times \frac{18}{3.1} = 4.4$$

STEP 5—Calculate Final Year EB-adjusted Expected Average Crash Frequency

Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment

1 2 3 **5** 4 6 7

Calculate the EB-adjusted expected number of fatal and injury crashes and total crashes for the final year (in this example, the final year is year 3).

$$N_{expected,n(total)} = N_{expected,1(total)} \times C_{n(total)} \quad (4\text{-}30)$$

$$N_{expected,n(FI)} = N_{expected,1(FI)} \times C_{n(FI)} \quad (4\text{-}31)$$

Where:

$N_{expected,n}$ = EB-adjusted expected average crash frequency for final year

$N_{expected,1}$ = EB-adjusted expected average crash frequency for year 1

C_n = Annual correction factor for year, n

Shown below are the calculations for Intersection 7.

$$N_{expected,3(total)} = 9.3 \times (1.1) = 10.2$$

$$N_{expected,3(FI)} = 4.4 \times (1.1) = 4.8$$

$$N_{expected,3(PDO)} = N_{expected,3(total)} - N_{expected,3(FI)}$$

The following table summarizes the calculations for Intersection 7:

Year 3—EB-Adjusted Expected Average Crash Frequency[a]

	Fatal and/or Injury Crashes			Total Crashes			PDO Crashes
Intersection	$N_{E,1(FI)}$	$C_{3(FI)}$	$N_{E,3(FI)}$	$N_{E,1(total)}$	$C_{3(total)}$	$N_{E,3(total)}$	$N_{E,3(PDO)}$
7	4.4	1.1	4.8	9.3	1.1	10.2	5.4

[a] *E* = "expected" in the variables presented in this table

STEP 6—Calculate the Variance of the EB-Adjusted Average Crash Frequency (Optional)
Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment

1 2 3 4 5 **6** 7

When using the peak searching method (or an equivalent method for intersections), calculate the variance of the EB-adjusted expected number of crashes for year n. Equation 4-32 is applicable to roadway segments and ramps, and Equation 4-33 is applicable to intersections.

$$Var(N_{\text{expected},n})_{\text{roadways}} = N_{\text{expected},n} \times \left(\frac{(1-w)}{L}\right) \times \frac{C_n}{\sum_{n=1}^{N} C_n} \tag{4-32}$$

$$Var\left(N_{\text{expected},n}\right)_{\text{intersections}} = N_{\text{expected},n} \times (1-w) \times \frac{C_n}{\sum_{n=1}^{n} C_n} \tag{4-33}$$

Shown below are the variation calculations for Year 3 at Intersection 7.

$$Var(N_{\text{expected},3(\text{total})})_{\text{intersections}} = 10.2 \times (1-0.2) \times \frac{1.1}{3.1} = 2.9$$

The following table summarizes the calculations for Year 3 at Intersection 7:

Year 3—Variance of EB-Adjusted Expected Average Crash Frequency

Intersection	Variance
2	2.1
3	1.4
7	2.9
10	1.1
15	1.0
17	1.0
19	1.0

STEP 7—Rank Sites ***Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment***

1 2 3 4 5 6 7

Rank the intersections based on the EB-adjusted expected average crash frequency for the final year in the analysis, as calculated in Step 5.

This table summarizes the ranking based on EB-Adjusted Crash Frequency for the TWSC Intersections.

EB-Adjusted Expected Average Crash Frequency Ranking

Intersection	EB-Adjusted Average Crash Frequency
7	10.2
2	9.6
3	6.1
10	4.5
15	4.3
17	3.9
19	3.7

4.4.2.12. Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment

Equivalent Property Damage Only (EPDO) Method assigns weighting factors to crashes by severity to develop a single combined frequency and severity score per location. The weighting factors are calculated relative to Property Damage Only (PDO) crashes. To screen the network, sites are ranked from the highest to the lowest score. Those sites with the highest scores are evaluated in more detail to identify issues and potential countermeasures.

The frequency of PDO, Injury, and Fatal crashes is based on the number of crashes, not the number of injuries per crash.

Data Needs

- Crashes by severity and location
- Severity weighting factors
- Traffic volume on major and minor street approaches
- Basic site characteristics (i.e., roadway cross-section, intersection control, etc.)
- Calibrated safety performance functions (SPFs) and overdispersion parameters

Strengths and Limitations

The strengths and limitations of the performance measure include the following:

Strengths	Limitations
Accounts for RTM bias	May overemphasize locations with a small number of severe crashes depending on weighting factors used
Considers crash severity	

Assumptions

The societal crash costs listed in Table 4-12 are used to calculate the EPDO weights.

Table 4-12. Societal Crash Cost Assumptions

Severity	Cost
Fatal (K)	$4,008,900
Injury Crashes (A/B/C)	$82,600
PDO (O)	$7,400

Source: *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*, FHWA-HRT-05-051, October 2005

Sample Problem Assumptions

The Sample problems provided in this section are intended to demonstrate calculation of the performance measures, not predictive method. Therefore, simplified predicted average crash frequency for the TWSC intersection population were developed using predictive method outlined in Part C and are provided in Table 4-6 for use in sample problems.

The simplified estimates assume a calibration factor of 1.0, meaning that there are assumed to be no differences between the local conditions and the base conditions of the jurisdictions used to develop the base SPF model. It is also assumed that all CMFs are 1.0, meaning there are no individual geometric design and traffic control features that vary from those conditions assumed in the base model. These assumptions are for theoretical application and are rarely valid for application of predictive method to actual field conditions.

STEP 1—Calculate Weighting Factors for Crash Severity

Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment

1	2	3	4	5	6	7	8	9	10

Calculate the EPDO weights for fatal, injury, and PDO crashes. The fatal and injury weights are calculated using Equation 4-34. The cost of a fatal or injury crash is divided by the cost of a PDO crash, respectively. Weighting factors developed from local crash cost data typically result in the most accurate results. If local information is not available, nationwide crash cost data is available from the Federal Highway Administration (FHWA). Appendix 4A provides information on the national data available and a method for updating crash costs to current dollar values.

The weighting factors are calculated as follows:

$$f_{y(\text{weight})} = \frac{CC_y}{CC_{PDO}} \tag{4-34}$$

Where:

$f_{y(\text{weight})}$ = EPDO weighting factor based on crash severity, y;

CC_y = Crash cost for crash severity, y; and,

CC_{PDO} = Crash cost for PDO crash severity.

Incapacitating (A), evident (B), and possible (C) injury crash costs developed by FHWA were combined to develop an average injury (A/B/C) cost. Below is a sample calculation for the injury (A/B/C) EPDO weight (W_I):

$$f_{inj(\text{weight})} = \frac{\$82{,}600}{\$7{,}400} = 11$$

Therefore, the EPDO weighting factors for all crash severities are shown in the following table:

Example EPDO Weights

Severity	Cost	Weight
Fatal (K)	$4,008,900	542
Injury (A/B/C)	$82,600	11
PDO (O)	$7,400	1

STEP 2—Calculate Predicted Average Crash Frequency from an SPF

Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment

1 **2** 3 4 5 6 7 8 9 10

Using the predictive method in Part C, calculate the predicted average crash frequency, $N_{\text{predicted},n}$, for each year, n, where $n = 1, 2, \ldots, N$. Refer to Part C—Introduction and Applications Guidance for a detailed overview of the method to calculate the predicted average crash frequency. The example provided here is simplified to emphasize calculation of the performance measure, not the predictive method. The predicted average crash frequency from SPFs is summarized for the TWSC intersections for a three-year period in Table 4-13.

Calculations will have to be made for both total and Fatal/Injury crashes, or for Fatal/Injury and Property Damage Only crashes. This example calculates total and Fatal/Injury crashes, from which Property Damage Only crashes are derived.

Table 4-13. Estimated Predicted Average Crash Frequency from an SPF

Intersection	Year	AADT		Predicted Average Crash Frequency from an SPF	Average 3-Year Predicted Crash Frequency from an SPF
		Major Street	Minor Street		
	1	12,000	1,200	1.7	
2	2	12,200	1,200	1.7	1.7
	3	12,900	1,300	1.8	
	1	18,000	800	2.1	
3	2	18,900	800	2.2	2.2
	3	19,100	800	2.2	
	1	21,000	1,000	2.5	
7	2	21,400	1,000	2.5	2.6
	3	22,500	1,100	2.7	
	1	15,000	1,500	2.1	
10	2	15,800	1,600	2.2	2.2
	3	15,900	1,600	2.2	
	1	26,000	500	2.5	
15	2	26,500	300	2.2	2.3
	3	27,800	200	2.1	
	1	14,400	3,200	2.5	
17	2	15,100	3,400	2.6	2.6
	3	15,300	3,400	2.6	
	1	15,400	2,500	2.4	
19	2	15,700	2,500	2.5	2.5
	3	16,500	2,600	2.6	

STEP 3—Calculate Annual Correction Factors

Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment

1 2 **3** 4 5 6 7 8 9 10

Calculate the annual correction factors (C_n) at each intersection for each year and each severity using Equation 4-35.

The annual correction factor is predicted average crash frequency from an SPF for year *y* divided by the predicted average crash frequency from an SPF for year 1. This factor is intended to capture the effect that annual variations in traffic, weather, and vehicle mix have on crash occurrences (3).

$$C_{n(\text{total})} = \frac{N_{\text{predicted},n(\text{total})}}{N_{\text{predicted},n(\text{total})}} \quad \text{and} \quad C_{n(FI)} = \frac{N_{\text{predicted},n(FI)}}{N_{\text{predicted},1(FI)}} \tag{4-35}$$

Where:

$C_{n(\text{total})}$ = Annual correction factor for total crashes

$C_{n(FI)}$ = Annual correction factor for fatal and/or injury crashes

$N_{\text{predicted},n(\text{total})}$ = Predicted number of total crashes for year, *n*

$N_{\text{predicted},1(\text{total})}$ = Predicted number of total crashes for year 1

$N_{\text{predicted},n(FI)}$ = Predicted number of fatal and/or injury crashes for year, *n*

$N_{\text{predicted},1(FI)}$ = Predicted number of fatal and/or injury crashes for year 1

Shown below is the calculation for Intersection 7 based on the yearly correction factor for year 3. The predicted crashes shown in the equation are the result of Step 2.

$$C_{3(\text{total})} = \frac{2.7}{2.5} = 1.1 \qquad C_{3(FI)} = \frac{1.1}{1.0} = 1.1$$

The annual correction factors for all TWSC intersections are summarized in the following table:

Annual Correction Factors for all TWSC Intersections

Intersection	Year	Predicted Average Crash Frequency from an SPF (total)	Predicted Average Crash Frequency from an SPF (*FI*)	Correction Factor (total)	Correction Factor (*FI*)
	1	1.7	0.6	1.0	1.0
2	2	1.7	0.6	1.0	1.0
	3	1.8	0.7	1.1	1.2
	1	2.1	0.8	1.0	1.0
3	2	2.2	0.8	1.0	1.0
	3	2.2	0.9	1.0	1.1
	1	2.5	1.0	1.0	1.0
7	2	2.5	1.0	1.0	1.0
	3	2.7	1.1	1.1	1.1
	1	2.1	0.8	1.0	1.0
10	2	2.2	0.9	1.0	1.1
	3	2.2	0.9	1.0	1.1
	1	2.5	1.0	1.0	1.0
15	2	2.2	0.9	0.9	0.9
	3	2.1	0.8	0.8	0.8
	1	2.5	1.0	1.0	1.0
17	2	2.6	1.0	1.0	1.0
	3	2.6	1.0	1.0	1.0
	1	2.4	1.0	1.0	1.0
19	2	2.5	1.0	1.0	1.0
	3	2.6	1.0	1.1	1.0

STEP 4—Calculate Weighted Adjustment

Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment

1 2 3 **4** 5 6 7 8 9 10

Calculate the weighted adjustment, *w*, for each intersection and each severity. The weighted adjustment accounts for the reliability of the safety performance function that is applied. Crash estimates produced using safety performance functions with overdispersion parameters that are low (which indicates higher reliability) have a larger weighted adjustment. Larger weighting factors place a heavier reliance on the SPF to predict the long-term predicted average crash frequency per year at a site. The weighted adjustments are calculated using Equation 4-36.

$$w_{\text{total}} = \frac{1}{1 + k_{\text{total}} \times \sum_{n=1}^{N} N_{\text{predicted},n(\text{total})}} \quad \text{and} \quad w_{FI} = \frac{1}{1 + k_{FI} \times \sum_{n=1}^{N} N_{\text{predicted},n(FI)}} \tag{4-36}$$

Where:

w = Empirical Bayes weight

n = years

k = Overdispersion parameter of the SPF

$N_{\text{predicted},n}$ = Predicted average crash frequency from an SPF in year n

Shown below is the weighted adjustment calculation for fatal/injury and total crashes for Intersection 7.

The overdispersion parameters shown below are found in Part C along with the SPFs. The sum of the predicted crashes (7.7 and 3.1) is the result of summing the annual predicted crashes for Intersection 7 summarized in Step 3.

$$w_{\text{total}} = \frac{1}{1 + (0.49 \times 7.7))} = 0.2$$

$$w_{FI} = \frac{1}{1 + (0.74 \times 3.1))} = 0.3$$

The total and *FI* weights are summarized for the TWSC intersections in Step 5.

STEP 5—Calculate First Year EB-adjusted Expected Average Crash Frequency

Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment

1 2 3 4 **5** 6 7 8 9 10

Calculate the base EB-adjusted expected average crash frequency for year 1, $N_{E,1}$.

This stage of the method integrates the observed crash frequency with the predicted average crash frequency from an SPF. The larger the weighting factor, the greater the reliance on the SPF to estimate the long-term expected average crash frequency per year at the site. The observed crash frequency, $N_{\text{observed},y}$, on the roadway segments is represented in Equations 4-37 and 4-38 below.

$$N_{\text{expected},1(\text{total})} = w_{\text{total}} \times N_{\text{predicted},1(\text{total})} + (1 - w_{\text{total}}) \times \left(\frac{\sum_{n=1}^{N} N_{\text{observed},n(\text{total})}}{\sum_{n=1}^{N} C_{n(\text{total})}} \right) \tag{4-37}$$

and

$$N_{\text{expected},1(FI)} = w_{FI} \times N_{\text{predicted},1(FI)} + (1 - w_{FI}) \times \left(\frac{\sum_{n=1}^{N} N_{\text{observed},n(FI)}}{\sum_{n=1}^{N} C_{n(FI)}} \right) \tag{4-38}$$

Where:

$N_{\text{expected},1}$ = EB-adjusted expected average crash frequency for year 1

w = Weight

$N_{\text{predicted},1}$ = Predicted average crash frequency for year 1

$N_{\text{observed},n}$ = Observed average crash frequency at the intersection

C_n = Annual correction factor for the intersection

n = years

Shown below is the total crash calculation for Intersection 7.

$$N_{\text{expected},1(\text{total})} = 0.2 \times (2.5) + (1 - 0.2) \times \left(\frac{34}{3.1}\right) = 9.3$$

The following table summarizes the calculations for total crashes at Intersection 7.

Year 1—EB-Adjusted Number of Total Crashes

Intersection	$N_{\text{predicted},1(\text{total})}$	$w_{(\text{total})}$	$N_{\text{observed},n(\text{total})}$ (All Years)	Sum of Total Correction Factors ($C_1 + C_2 + C_3$)	$N_{\text{expected},1(\text{total})}$
7	2.5	0.2	34	3.1	9.3

The EB-adjusted expected average crash frequency calculations for all TWSC intersections are summarized in Step 6.

STEP 6—Calculate Final Year EB-adjusted Average Crash Frequency

Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment

1 2 3 4 5 **6** 7 8 9 10

Calculate the EB-adjusted expected number of fatal and injury crashes and total crashes for the final year. Total and fatal and injury EB-adjusted expected average crash frequency for the final year is calculated using Equations 4-39 and 4-40, respectively.

$$N_{\text{expected},n(\text{total})} = N_{\text{expected},1(\text{total})} \times C_{n(\text{total})} \tag{4-39}$$

$$N_{\text{expected},n(\text{FI})} = N_{\text{expected},1(FI)} \times C_{n(FI)} \tag{4-40}$$

Where:

$N_{\text{expected},,n}$ = EB-adjusted expected average crash frequency for final year, n (the final year of analysis in this sample problem is $n = 3$).

$N_{\text{expected},1}$ = EB-adjusted expected average crash frequency for first year, $n = 1$

C_n = Annual correction factor for year, n

Shown below are the calculations for Intersection 7. The annual correction factors shown below are summarized in Step 3 and the EB-adjusted crashes for Year 1 are values from Step 4.

$N_{\text{expected,3(total)}} = 9.3 \times (1.1) = 10.2$

$N_{\text{expected,3}(FI)} = 4.4 \times (1.1) = 4.8$

$N_{\text{expected,3}(PDO)} = 10.2 - 4.8 = 5.4$

The calculation of $N_{\text{expected,3}(PDO)}$ is based on the difference between the Total and FI expected average crash frequency. The following table summarizes the results of Steps 4 through 6, including the EB-adjusted expected average crash frequency for all TWSC intersections:

EB-Adjusted Expected Average Crash Frequency for TWSC Intersections

Intersection	Year	Observed Number of Crashes (total)	Predicted Average Crash Frequency from an SPF (total)	Weight (total)	Weight (*FI*)	EB-Adjusted Expected Average Crash Frequency (total)	EB-Adjusted Expected Average Crash Frequency (*FI*)	EB-Adjusted Expected Average Crash Frequency (*PDO*)
	1	9.0	1.7			8.7	4.9	3.8
2	2	11.0	1.7	0.3	0.4	8.7	4.9	3.8
	3	15.0	1.8			9.6	5.8	3.8
	1	9.0	2.1			6.1	3.0	3.1
3	2	8.0	2.2	0.2	0.4	6.1	3.0	3.1
	3	6.0	2.2			6.1	3.3	2.8
	1	11.0	2.5			9.3	4.3	5.0
7	2	9.0	2.5	0.2	0.3	9.3	4.3	5.0
	3	14.0	2.7			10.2	4.8	5.4
	1	7.0	2.1			4.5	1.7	2.8
10	2	6.0	2.2	0.2	0.3	4.7	1.9	2.8
	3	4.0	2.2			4.5	1.9	2.6
	1	6.0	2.5			5.4	1.6	3.8
15	2	3.0	2.2	0.2	0.3	4.8	1.4	3.4
	3	8.0	2.1			4.3	1.3	3.0
	1	4.0	2.5			3.9	1.7	2.2
17	2	4.0	2.6	0.2	0.3	4.1	1.7	2.4
	3	5.0	2.6			3.9	1.7	2.2
	1	5.0	2.4			3.4	1.7	1.7
19	2	2.0	2.5	0.2	0.3	3.5	1.7	1.8
	3	4.0	2.6			3.7	1.7	2.0

STEP 7—Calculate the Proportion of Fatal and Injury Crashes
Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment

1 2 3 4 5 6 **7** 8 9 10

Equations 4-41 and 4-42 are used to identify the proportion of fatal crashes with respect to all non-PDO crashes in the reference population and injury crashes with respect to all non-PDO crashes in the reference population.

$$P_F = \frac{\sum N_{\text{observed},(F)}}{\sum N_{\text{observed},(FI)}} \tag{4-41}$$

$$P_I = \frac{\sum N_{\text{observed},(I)}}{\sum N_{\text{observed},(FI)}} \tag{4-42}$$

Where:

$N_{\text{observed},(F)}$ = Observed number of fatal crashes from the reference population;

$N_{\text{observed},(I)}$ = Observed number of injury crashes from the reference population;

$N_{\text{observed},(FI)}$ = Observed number of fatal-and-injury crashes from the reference population;

P_F = Proportion of observed number of fatal crashes out of FI crashes from the reference population;

P_I = Proportion of observed number of injury crashes out of FI crashes from the reference population.

Shown below are the calculations for the TWSC intersection reference population.

$$P_F = \frac{6}{80} = 7.5\%$$

$$P_I = \frac{74}{80} = 92.5\%$$

STEP 8—Calculate the Weight of Fatal and Injury Crashes
Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment

1 2 3 4 5 6 7 **8** 9 10

Compared to PDO crashes the relative EPDO weight of fatal and injury crashes is calculated using Equation 4-43.

$$w_{EPDO,FI} = P_F \times f_{K(\text{weight})} + P_I \times f_{inj(\text{weight})} \tag{4-43}$$

Where:

$f_{inj(\text{weight})}$ = EPDO injury weighting factor;

$f_{K(\text{weight})}$ = EPDO fatal weighting factor;

P_F = Proportion of observed number of fatal crashes out of FI crashes from the reference population.

Shown below is the calculation for Intersection 7. The EPDO weights, $f_{K(\text{weight})}$ and W_I are summarized in Step 1.

$w_{EPDO,FI} = (0.075 \times 542) + (0.925 \times 11) = 50.8$

STEP 9—Calculate the Final Year EPDO Expected Average Crash Frequency

Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment

1 2 3 4 5 6 7 8 **9** 10

Equation 4-43 can be used to calculate the EPDO expected average crash frequency for the final year for which data exist for the site.

$$N_{\text{expected},3(EPDO)} = N_{\text{expected},n(PDO)} + w_{EPDO,FI} \times N_{\text{expected},n(FI)}$$

Shown below is the calculation for Intersection 7.

$N_{\text{expected},3(EPDO)} = 5.4 + 50.8 \times 4.8 = 249.2$

STEP 10—Rank Sites by EB-adjusted EPDO Score

Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment

1 2 3 4 5 6 7 8 9 **10**

Order the database from highest to lowest by EB-adjusted EPDO score. The highest EPDO score represents the greatest opportunity to reduce the number of crashes.

The following table summarizes the EB-Adjusted EPDO Ranking for the TWSC Intersections.

EB-Adjusted EPDO Ranking

Intersection	EB-Adjusted EPDO
2	298.4
7	249.2
3	170.4
10	99.1
17	88.6
19	88.4
15	69.0

4.4.2.13. Excess Expected Average Crash Frequency with EB Adjustments

The Empirical Bayes Method is applied to estimate expected crash frequency. Part C Introduction and Applications Guidance, explains how to apply the EB Method. Intersections are ranked based on the difference between the predicted estimates and EB-adjusted estimates for each intersection, the excess expected average crash frequency per year.

Data Needs

- Crash data by severity and location
- Traffic volume
- Basic site characteristics (i.e., roadway cross-section, intersection control)
- Calibrated Safety Performance Functions (SPFs) and overdispersion parameters

Strengths and Limitations

The strengths and limitations of the Excess Expected Average Crash Frequency with EB Adjustments performance measure include the following:

Strengths	Limitations
Accounts for RTM bias	None
Identifies a threshold to indicate sites experiencing more crashes than expected for sites with similar characteristics	

Procedure

The following sample problem outlines the assumptions and procedure for ranking seven TWSC intersections based on the expected crash frequency with Empirical Bayes adjustments. The calculations for Intersection 7 are used throughout the sample problems to highlight how to apply each method.

Table 4-14. Societal Crash Cost Assumptions

Crash Severity	Crash Cost
Combined Cost for Crashes with a Fatality or Injury, or Both (K/A/B/C)	$158,200
PDO (O)	$7,400

Source: *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*, FHWA-HRT-05-051, October 2005

As shown in Table 4-14, the crash cost that can be used to weigh the expected number of FI crashes is $158,200. The crash cost that can be used to weigh the expected number of PDO crashes is $7,400. More information on crash costs, including updating crash cost values to current year of study values, is provided in Appendix 4A.

Sample Problem Assumptions

The sample problems provided in this section are intended to demonstrate calculation of the performance measures, not predictive method. Therefore, simplified predicted average crash frequency for the TWSC intersection population were developed using predictive method outlined in Part C and are provided in Table 4-6 for use in sample problems.

The simplified estimates assume a calibration factor of 1.0, meaning that there are assumed to be no differences between the local conditions and the base conditions of the jurisdictions used to develop the SPF. It is also assumed that all CMFs are 1.0, meaning there are no individual geometric design and traffic control features that vary from those conditions assumed in the base model. These assumptions are for theoretical application and are rarely valid for application of the Part C predictive method to actual field conditions.

Calculation of this performance measure follows Steps 1–5 outlined for the Expected Average Crash Frequency with EB Adjustments performance measure.

The results of Steps 1, 4, and 5 that are used in calculations of the excess expected average crash frequency are summarized in the following table:

Summary of Performance Measure Calculations for Steps 1, 4, and 5

Intersection	Year	Observed Average Crash Frequency (*FI*)	Observed Average Crash Frequency (*PDO*)	SPF Predicted Average Crash Frequency (*FI*)	SPF Predicted Average Crash Frequency (*PDO*)	EB-Adjusted Expected Average Crash Frequency (*FI*)	EB-Adjusted Expected Average Crash Frequency (*PDO*)
2	1	8	1	0.6	1.1	4.9	3.8
	2	8	3	0.6	1.1	4.9	3.8
	3	9	6	0.7	1.1	5.8	3.8
3	1	8	1	0.8	1.3	3.0	3.1
	2	3	5	0.8	1.4	3.0	3.1
	3	2	4	0.9	1.4	3.3	2.8
7	1	5	6	1.0	1.6	4.3	5.0
	2	5	4	1.0	1.6	4.3	5.0
	3	8	6	1.1	1.7	4.8	5.4
10	1	4	3	0.8	1.3	1.7	2.8
	2	2	4	0.9	1.4	1.9	2.8
	3	1	3	0.9	1.4	1.9	2.6
15	1	1	5	1.0	1.6	1.6	3.8
	2	1	2	0.9	1.4	1.4	3.4
	3	3	5	0.8	1.3	1.3	3.0
17	1	2	2	1.0	1.5	1.7	2.2
	2	2	2	1.0	1.6	1.7	2.4
	3	2	3	1.0	1.6	1.7	2.2
19	1	3	2	1.0	1.5	1.7	1.7
	2	1	1	1.0	1.5	1.7	1.8
	3	2	2	1.0	1.6	1.7	2.0

STEP 6—Calculate the Excess Expected Average Crash Frequency

Excess Expected Average Crash Frequency with EB Adjustments

1 2 3 4 5 **6** 7 8

The difference between the predicted estimates and EB-adjusted estimates for each intersection is the excess as calculated by Equation 4-45.

$$Excess_y = (N_{\text{expected},n(PDO)} - N_{\text{predicted},n(PDO)}) + (N_{\text{expected},n(FI)} - N_{\text{predicted},n(FI)}) \quad (4\text{-}45)$$

Where:

$Excess_y$ = Excess expected crashes for year, n

$N_{\text{expected},n}$ = EB-adjusted expected average crash frequency for year, n

$N_{\text{predicted},n}$ = SPF predicted average crash frequency for year, n

Shown below is the calculation for Intersection 7.

$Excess_3$ = 5.4 – 1.7 + 4.8 – 1.1 = 7.4 [crashes per year]

The calculations for all TWSC intersections are summarized in Step 8.

STEP 7—Calculate Severity Weighted Excess (Optional)

Excess Expected Average Crash Frequency with EB Adjustments

1	2	3	4	5	6	7	8

Calculate the severity weighted EB-adjusted excess expected crash value in dollars.

$$Excess_{(sw)} = (N_{\text{expected},n(PDO)} - N_{\text{predicted},n(PDO)}) \times CC_{(PDO)} + (N_{\text{expected},n(FI)} - N_{\text{predicted},n(FI)}) \times CC_{(FI)} \quad (4\text{-}46)$$

Where:

$Excess_{(sw)}$ = Severity weighted EB-adjusted expected excess crash value

$CC_{(Y)}$ = Crash cost for crash severity, Y

Shown below is the calculation for Intersection 7.

$Excess_{(sw)}$ = (5.4 –1.7) × \$7.400 + (4.8 – 1.1) × \$158,200 = \$612,720

The calculations for all TWSC intersections are summarized in Step 8.

STEP 8—Rank Locations ***Excess Expected Average Crash Frequency with EB Adjustments***

1	2	3	4	5	6	7	8

Rank the intersections based on either EB-adjusted expected excess crashes calculated in Step 6 or based on EB-adjusted severity weighted excess crashes calculated in Step 7. The first table shows the ranking of TWSC intersections based on the EB-adjusted expected excess crashes calculated in Step 6. The intersection ranking shown in the second table is based on the EB-adjusted severity weighted excess crashes calculated in Step 7.

Rankings according to calculations are as follows:

EB-Adjusted Excess Expected Crash Ranking

Intersection	Excess
2	7.8
7	7.4
3	3.8
10	2.2
15	2.2
17	1.3
19	1.1

EB-Adjusted Severity Weighted Excess Crash Ranking

Intersection	$Excess_{(sw)}$ [a]
2	$826,800
7	$612,700
3	$390,000
10	$167,100
17	$115,200
19	$113,700
15	$91,700

[a] All $Excess_{(SW)}$ values rounded to the nearest hundred dollars.

4.4.3. Roadway Segments Performance Measure Sample Data

The Situation

A roadway agency is undertaking an effort to improve safety on their highway network. There are ten roadway segments from which the roadway agency wants to identify sites that will be studied in more detail because they show a potential for reducing the average crash frequency.

After reviewing the guidance in Section 4.2, the agency chooses to apply the sliding window method using the RSI performance measure to analyze each roadway segment. If desired, the agency could apply other performance measures or the peak searching method to compare results and confirm ranking.

The Facts

- The roadway segments are comprised of:
  - 1.2 mi of rural undivided two-lane roadway
  - 2.1 mi are undivided urban/suburban arterial with four lanes
  - 0.6 mi of divided urban/suburban two-lane roadway
- Segment characteristics and a three-year summary of crash data is in Table 4-15.
- Three years of detailed roadway segment crash data is shown in Table 4-16.

Assumptions

- The roadway agency has accepted the FHWA crash costs by severity and type as shown in Table 4-17.

Roadway Segment Characteristics and Crash Data

Tables 4-15 and 4-16 summarize the roadway segment characteristics and crash data.

Table 4-15. Roadway Segment Characteristics

Segments	Cross-Section (Number of Lanes)	Segment Length (miles)	AADT	Undivided/Divided	Crash Data		
					Total Year 1	Total Year 2	Total Year 3
1	2	0.80	9,000	U	16	15	14
2	2	0.40	15,000	U	12	14	10
3	4	0.50	20,000	D	6	9	5
4	4	0.50	19,200	D	7	5	1
5	4	0.35	22,000	D	18	16	15
6	4	0.30	25,000	D	14	12	10
7	4	0.45	26,000	D	12	11	13
8	2	0.20	10,000	U	2	1	3
9	2	0.25	14,000	U	3	2	1
10	2	0.15	15,000	U	1	2	1

Table 4-16. Roadway Segment Detail Crash Data Summary (3 Years)

Segment	Total	Crash Severity			Crash Type							
		Fatal	Injury	PDO	Rear-End	Angle	Head-On	Sideswipe	Pedestrian	Fixed Object	Rollover	Other
1	45	3	17	25	0	0	6	5	0	15	19	0
2	36	0	5	31	0	1	3	3	3	14	10	2
3	20	0	9	11	1	0	5	5	0	5	3	1
4	13	0	5	8	3	0	1	2	0	4	0	3
5	49	0	9	40	1	1	21	12	2	5	5	2
6	36	0	5	31	4	0	11	10	0	5	4	2
7	36	0	6	30	2	0	13	11	0	4	3	3
8	6	0	1	5	2	0	0	1	0	1	0	2
9	6	0	1	5	1	0	0	1	0	2	0	2
10	4	0	0	4	2	0	0	0	0	1	0	1

Table 4-17. Relative Severity Index Crash Costs

Crash Type	RSI Crash Costs
Rear-End, Non-Intersection	$30,100
Sideswipe/Overtaking	$34,000
Angle, Non-Intersection	$56,100
Pedestrian/Bike, Non-Intersection	$287,900
Head-On, Non-Intersection	$375,100
Rollover	$239,700
Fixed Object	$94,700
Other/Undefined	$55,100

Source: *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*, FHWA-HRT-05-051, October 2005

Sliding Window Procedure

The sliding window approach is one analysis method that can be applied when screening roadway segments. It consists of conceptually sliding a window of a specified length along the road segment in increments of a specified size. The method chosen to screen the segment is applied to each position of the window and the results of the analysis are recorded for each window. The window that shows the greatest potential for improvement is used to represent the total performance of the segment. After all segments are ranked according to the respective highest window value, those segments with the greatest potential for reduction in crash frequency or severity are studied in detail to identify potential countermeasures.

The following assumptions are used to apply the sliding window analysis technique in the roadway segment sample problems:

- Segment 1 extends from mile point 1.2 to 2.0
- The length of window in the sliding window analysis is 0.3 mi.
- The window slides in increments of 0.1 mi.

The name of the window subsegments and the limits of each subsegment are summarized in Table 4-18.

Table 4-18. Segment 1 Sliding Window Parameters

Window Subsegments	Beginning Limit (Mile Point)	Ending Limit (Mile Point)
1a	1.2	1.5
1b	1.3	1.6
1c	1.4	1.7
1d	1.5	1.8
1e	1.6	1.9
1f	1.7	2.0

The windows shown in Table 4-18 are the windows used to evaluate Segment 1 throughout the roadway segment sample problems. Therefore, whenever window subsegment 1a is referenced, it is the portion of Segment 1 that extends from mile point 1.2 to 1.5 and so forth.

Table 4-19 summarizes the crash data for each window subsegment within Segment 1. This data will be used throughout the roadway segment sample problems to illustrate how to apply each screening method.

Table 4-19. Segment 1 Crash Data per Sliding Window Subsegments

Window Subsegments	Total	Crash Severity			Crash Type			
		Fatal	Injury	PDO	Head-On	Sideswipe	Fixed Object	Rollover
1a	8	0	3	5	0	0	3	5
1b	8	0	4	4	1	1	3	3
1c	7	0	3	4	3	1	0	3
1d	11	2	3	6	1	2	5	3
1e	4	0	0	4	0	0	1	3
1f	7	1	4	2	1	1	3	2

When the sliding window approach is applied to a method, each segment is ranked based on the highest value found on that segment.

STEP 1—Calculate RSI Crash Costs per Crash Type ***Sliding Window Procedure***

1 2 3 4

For each window subsegment, multiply the average crash frequency for each crash type by their respective RSI crash type.

The following table summarizes the observed average crash frequency by crash type for each window subsegment over the last three years and the corresponding RSI crash costs for each crash type.

Crash Type Summary for Segment 1 Window Subsegments

Window Subsegments	Head-On	Sideswipe	Fixed Object	Rollover	Total[a]
Observed Average Crash Frequency					
1a	0	0	3	5	8
1b	1	1	3	3	8
1c	3	1	0	3	7
1d	1	2	5	3	11
1e	0	0	1	3	4
1f	1	1	3	2	7
RSI Crash Costs per Crash Type[b]					
1a	$0	$0	$284,100	$1,198,500	$1,482,600
1b	$375,100	$34,000	$284,100	$719,100	$1,412,300
1c	$1,125,300	$34,000	$0	$719,100	$1,878,400
1d	$375,100	$68,000	$473,500	$719,100	$1,635,700
1e	$0	$0	$94,700	$719,100	$813,800
1f	$375,100	$34,000	$284,100	$479,400	$1,172,600

[a] Crash types that were not reported to have occurred on Roadway Segment 1 were omitted from the table. The RSI costs for these crash types are zero.
[b] The values in this table are the result of multiplying the average crash frequency for each crash type by the corresponding RSI cost.

The calculation for Window Subsegment 1d is shown below.

Total RSI Cost = (1 × $375,100) + (2 × $34,000) + (5 × $94,700) + (3 × $239,700) = $1,635,700

STEP 2—Calculate Average RSI Cost per Subsegment *Sliding Window Procedure*

1 **2** 3 4

Sum the RSI costs for all crash types and divide by the total average crash frequency for the specific window subsegment as shown in Equation 4-47. The result is an Average RSI cost for each window subsegment.

$$\text{Average RSI Cost per Subsegment} = \frac{\text{Total RSI Cost}}{N_{observed,i(total)}} \tag{4-47}$$

Where:

$N_{observed,i(total)}$ = Total observed crashes at site, i

The calculation for Window Subsegment 1d is:

$$\text{Average RSI Cost} = \frac{\$1{,}635{,}700}{11} = \$148{,}700$$

The following table summarizes the Average RSI Crash Cost calculation for each window subsegment within Segment 1.

Average RSI Crash Cost per Window Subsegment

Window Subsegment	Total Number of Crashes	Total RSI Value	Average RSI Value
1a	8	$1,482,600	$185,300
1b	8	$1,412,300	$176,500
1c	7	$1,878,400	$268,300
1d	11	$1,635,700	$148,700
1e	4	$813,800	$203,500
1f	7	$1,172,600	$167,500

STEP 3—Calculate Average RSI Cost for the Population *Sliding Window Procedure*

1 2 **3** 4

Calculate the average RSI cost for the entire population by summing the total RSI costs for each site and dividing by the total average crash frequency within the population. In this sample problem, the population consists of Segment 1 and Segment 2. Preferably, there are more than two Segments within a population; however, for the purpose of illustrating the concept and maintaining brevity, this set of example problems only has two segments within the population.

The average RSI cost for the population ($\overline{RSI_p}$) is calculated using Equation 4-48.

$$\overline{RSI}_p = \frac{\sum_{i=1}^{n} RSI_i}{\sum_{i=1}^{n} N_{\text{observed},i}} \tag{4-48}$$

Where:

$\overline{RSI}_p$ = Average RSI cost for the population

RSI_i = RSI cost per site in the population

$N_{\text{observed},i}$ = Number of observed crashes in the population

The following example summarizes the information needed to calculate the average RSI cost for the population.

Average RSI Cost for Two-Lane Undivided Rural Highway Population

Roadway Segments	Angle	Head-On	Side-swipe	Pedestrian	Fixed Object	Rollover	Other	Total
				Average Crash Frequency Over Three Years				
1	0	6	5	0	15	19	0	45
2	1	3	3	3	14	10	2	36
				RSI Crash Costs per Crash Type				
1	$0	$2,250,600	$170,000	$0	$1,420,500	$4,554,300	$0	$8,395,400
2	$56,100	$1,125,300	$102,000	$863,700	$1,325,800	$2,397,000	$110,000	$5,979,900

Below is the average RSI cost calculation for the Rural Two-Lane Highway population. This can be used as a threshold for comparison of RSI cost of individual subsegments within a segment.

$$\overline{RSI}_p = \frac{\sum_{i=1}^{n} RSI_i}{\sum_{i=1}^{n} N_{\text{observed},i}} = \frac{\$8,395,400 + \$5,979,900}{45 + 36} = \$177,500$$

STEP 4—Rank Locations and Compare ***Sliding Window Procedure***

1 2 3 4

Steps 1 and 2 are repeated for each roadway segment and Step 3 is repeated for each population. The roadway segments are ranked using the highest average RSI cost calculated for each roadway segment. For example, Segment 1 would be ranked using the highest average RSI cost shown in Step 2 from Window Subsegment 1c ($268,300). The highest average RSI cost for each roadway segment is also compared to the average RSI cost for the entire population. This comparison indicates whether or not the roadway segment's average RSI cost is above or below the average value for similar locations.

4.5. REFERENCES

(1) Allery, B., J. Kononov. Level of Service of Safety. *In Transportation Research Record 1840.* TRB, National Research Council, Washington, DC, 2003, pp. 57–66.

(2) Council, F., E. Zaloshnja, T. Miller, and B. Persaud. *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries.* FHWA-HRT-05-051. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, October 2005.

(3) Hauer, E. *Observational Before-After Studies in Road Safety.* Pergamon Press Inc., Oxford, UK, 1997.

(4) Kononov, J. *Use of Direct Diagnostics and Pattern Recognition Methodologies in Identifying Locations with Potential for Accident Reductions.* Transportation Research Board Annual Meeting CD-ROM. TRB, National Research Council, Washington, DC, 2002.

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(6) Midwest Research Institute. *White Paper for Module 1—Network Screening.* Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2002. Available from http://www.safetyanalyst.org/whitepapers.

(7) Ogden, K. W. *Safer Roads: A Guide to Road Safety Engineering*. Ashgate, Farnham, Surrey, UK, 1996.

APPENDIX 4A—CRASH COST ESTIMATES

State and local jurisdictions often have accepted crash costs by crash severity and crash type. When available, these locally developed crash cost data can be used with procedures in the HSM. If local information is not available, nationwide crash cost data is available from the Federal Highway Administration (FHWA) and the U.S. DOT. This edition of the HSM develops crash costs from the FHWA report *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries* (3). The costs cited in this 2005 report are presented in 2001 dollars. Tables 4A-1 and 4A-2 summarize the relevant information for use in the HSM (rounded to the nearest hundred dollars) (3.)

The FHWA report presents human capital crash costs and comprehensive crash costs by crash type and severity. Human capital crash cost estimates include the monetary losses associated with medical care, emergency services, property damage, and lost productivity. Comprehensive crash costs include the human capital costs in addition to nonmonetary costs related to the reduction in the quality of life in order to capture a more accurate level of the burden of injury. Comprehensive costs are also generally used in analyses conducted by other federal and state agencies outside of transportation.

Table 4A-1. Crash Cost Estimates by Crash Severity

Crash Type	Human Capital Crash Costs	Comprehensive Crash Costs
Fatal (K)	$1,245,600	$4,008,900
Disabling Injury (A)	$111,400	$216,000
Evident Injury (B)	$41,900	$79,000
Possible Injury (C)	$28,400	$44,900
PDO (O)	$6,400	$7,400

Source: *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*, FHWA-HRT-05-051, October 2005

Table 4A-2. Crash Cost Estimates by Crash Type

Crash Type	Human Capital Crash Costs	Comprehensive Crash Costs
Rear-End, Signalized Intersection	$16,700	$26,700
Rear-End, Unsignalized Intersection	$10,900	$13,200
Sideswipe/Overtaking	$17,600	$34,000
Angle, Signalized Intersection	$24,300	$47,300
Angle, Unsignalized Intersection	$29,700	$61,100
Pedestrian/Bike at an Intersection	$72,800	$158,900
Pedestrian/Bike, Non-Intersection	$107,800	$287,900
Head-On, Signalized Intersection	$15,600	$24,100
Head-On, Unsignalized Intersection	$24,100	$47,500
Fixed Object	$39,600	$94,700
Other/Undefined	$24,400	$55,100

Source: *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*, FHWA-HRT-05-051, October 2005

Crash cost data presented in Tables 4A-1 and 4A-2 is applied in the HSM to calculate performance measures used in network screening (Chapter 4) and to convert safety benefits to a monetary value (Chapter 7). These values can be updated to current year values using the method presented in the following section.

Annual Adjustments

National crash cost studies are not typically updated annually; however, current crash cost dollar values are needed to effectively apply the methods in the HSM. A two-step process based on data from the U.S. Bureau of Labor Statistics (BLS) can be used to adjust annual crash costs to current dollar values. As noted in the FHWA report, this procedure is expected to provide adequate cost estimates until the next national update of unit crash cost data and methods (3).

In general, the annual adjustment of crash costs utilizes federal economic indexes to account for the economic changes between the documented past year and the year of interest. Adjustment of the 2001 crash costs (Tables 4A-1 and 4A-2) to current year values involves multiplying the known crash cost dollar value for a past year by an adjustment ratio. The adjustment ratio is developed from a Consumer Price Index (CPI), published monthly, and an Employment Cost Index (ECI), published quarterly, by the BLS. The recommended CPI can be found in the "all items" category of expenditures in the Average Annual Indexes tables of the BLS Consumer Price Index Detailed Report published online (1). The recommended ECI value for use includes total compensation for private industry workers and is not seasonally adjusted. The ECI values for use can be found in the ECI Current-Dollar Historical Listings published and regularly updated online (2).

Crash costs estimates can be developed and adjusted based on human capital costs only or comprehensive societal costs. When human capital costs only are used, a ratio based on the Consumer Price Index (CPI) is applied. When comprehensive crash costs are used, a ratio based on the Consumer Price Index (CPI) is applied to the human capital portion and a ratio based on the Employment Cost Index (ECI) is applied to the difference between the Comprehensive Societal costs and the Human Capital Costs. Adding the results together yields the adjusted crash cost. A short example of the recommended process for adjusting annual comprehensive crash costs to the year of interest follows.

Crash Cost Annual Adjustment

An agency wants to apply the EPDO Crash Frequency performance measure in order to prioritize high-crash locations within a city. Given human capital and comprehensive societal cost data from FHWA in 2001 dollars (1), what is the 2007 dollar value of crashes of various severity?

STEP 1—Adjust Human Capital Costs Using CPI ***Crash Cost Annual Adjustment***

1 2 3 4

Multiply human capital costs by a ratio of the CPI for the year of interest divided by the CPI for 2001. Based on U.S. Bureau of Labor Statistics data, the CPI for year 2001 was 177.1 and in 2007 was 207.3 (1).

$$\text{CPI Ratio}_{(2001-2007)} = \frac{207.3}{177.1} = 1.2$$

The 2007 CPI-adjusted human capital costs can be estimated by multiplying the CPI ratio by 2001 human capital costs. For fatal crashes the CPI-Adjusted Human Capital Costs are calculated as:

2007 Human Capital Cost of Fatal Crash = $1,245,600 × 1.2 = $1,494,700 [per fatal crash]

The 2007 human capital costs for all crash severity levels are summarized in the following table:

2007 CPI-Adjusted Human Capital Crash Costs

Crash Severity	2001 Human Capital Costs	2001 Comprehensive Societal Costs	2007 CPI-Adjusted Human Capital Costs
Fatal (K)	$1,245,600	$4,008,900	$1,494,700
Disabling Injury (A)	$111,400	$216,000	$133,700
Evident Injury (B)	$41,900	$79,000	$50,300
Possible Injury (C)	$28,400	$44,900	$34,100
PDO (O)	$6,400	$7,400	$7,700

STEP 2—Adjust Comprehensive Costs Using ECI ***Crash Cost Annual Adjustment***

1 2 3 4

Recall that comprehensive costs include the human capital costs. Therefore, in order to adjust the portion of the comprehensive costs that are not human capital costs, the difference between the comprehensive cost and the human capital cost is identified. For example, the unit crash cost difference in 2001 dollars for fatal (K) crashes is calculated as:

$4,008,900 – $1,245,600 = $2,763,300 [per fatal crash]

The differences for each crash severity level are shown in Step 3.

STEP 3—Adjust the Difference Calculated in Step 2 Using the ECI ***Crash Cost Annual Adjustment***

1 2 3 4

The comprehensive crash cost portion that does not include human capital costs is adjusted using a ratio of the ECI for the year of interest divided by the ECI for 2001. Based on U.S. Bureau of Labor Statistics data the Employment Cost Index for year 2001 was 85.8 and in 2007 was 104.9 (2). The ECI ratio can then be calculated as:

$$\text{ECI Ratio}(2001-2007)=\frac{104.9}{85.8}=1.2$$

This ratio is then multiplied by the calculated difference between the 2001 human capital and 2001 comprehensive cost for each severity level. For example, the 2007 ECI-adjusted difference for the fatal crash cost is:

1.2 × $2,763,300 = $3,316,000 [per fatal crash]

The following table summarizes the 2007 ECT-adjusted crash costs:

2007 ECI-Adjusted Crash Costs

Crash Severity	2001 Human Capital Costs	2001 Comprehensive Societal Costs	Cost Difference	2007 ECI-Adjusted Cost Difference
Fatal (K)	$1,245,600	$4,008,900	$2,763,300	$3,316,000
Disabling Injury (A)	$111,400	$216,000	$104,600	$125,500
Evident Injury (B)	$41,900	$79,000	$37,100	$44,500
Possible Injury (C)	$28,400	$44,900	$16,500	$19,800
PDO (O)	$6,400	$7,400	$1,000	$1,200

STEP 4—Calculate the 2007 Comprehensive Costs ***Crash Cost Annual Adjustment***

1 2 3 **4**

The 2007 CPI-adjusted costs (Step 2) and the 2007 ECI-adjusted cost differences (Step 3) are summed, as shown in the example below, to determine the 2007 Comprehensive Costs.

For example, the 2007 Comprehensive Cost for a fatal crash is calculated as:

2007 Comprehensive Fatal Crash Cost = $1,494,700 + $3,316,000 = $4,810,700 [per fatal crash]

Adjusted 2007 Comprehensive Crash Costs

Crash Severity	2007 CPI-Adjusted Human Capital Costs	2007 ECI-Adjusted Cost Difference	2007 Comprehensive Costs
Fatal (K)	$1,494,700	$3,316,000	$4,810,700
Disabling Injury (A)	$133,700	$125,500	$259,200
Evident Injury (B)	$50,300	$44,500	$94,800
Possible Injury (C)	$34,100	$19,800	$53,900
PDO (O)	$7,700	$1,200	$8,900

4A.1. APPENDIX REFERENCES

(1) BLS. 2001 Consumer Price Index Detailed Report Tables. U.S. Bureau of Labor Statistics, Washington, DC, 20212. Available from http://www.bls.gov/cpi/cpi_dr.htm.

(2) BLS. *Employment Cost Index Historical Listing Current-Dollar March 2001–June 2008 (December 2005=100)*. U.S. Bureau of Labor Statistics, Office of Compensation Levels and Trends, Washington, DC, 20212-0001. Available from http://www.bls.gov/web/eci/echistrynaics.pdf.

(3) Council, F. M., E. Zaloshnja, T. Miller, and B. Persaud. *Crash Cost Estimates by Maximum Police Reported Injury Severity within Selected Crash Geometries.* FHWA-HRT-05-051. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, October 2005.