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16. Abstract

SafetyAnalyst provides a set of software tools for use by state and local highway agencies for highway safety management. *SafetyAnalyst* can be used by highway agencies to improve their programming of site-specific highway safety improvements. *SafetyAnalyst* incorporates state-of-the-art safety management approaches into computerized analytical tools for supporting the decision-making process to identify safety improvement needs and develop a systemwide program of site-specific improvement projects. *SafetyAnalyst* includes six safety management tools: a network screening tool that identifies specific highway sites with potential for safety improvement; a diagnosis tool that is used to investigate the nature of accident patterns at individual sites; a countermeasure selection tool that assists users in the selection of countermeasures to reduce accident frequency and severity at specific sites; an economic appraisal tool that performs economic analyses of a countermeasure or several alternative countermeasures for an individual site or multiple sites; a priority ranking tool for ranking of sites and proposed improvement projects; and a countermeasure evaluation tool to conduct before/after evaluations of implemented safety improvements.

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SafetyAnalyst^{TM}: Software Tools for Safety Management of Specific Highway Sites

July 2010

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U.S. Department of Transportation
Federal Highway Administration

FOREWORD

This report provides a detailed description of the analytical methods used in *SafetyAnalyst*, a set of software tools to support highway safety management decision making by State and local highway agencies. The Federal Highway Administration (FHWA) managed development of *SafetyAnalyst* through a pooled-funded effort sponsored jointly by 27 State highway agencies and interested local organizations. Upon completion, FHWA transferred *SafetyAnalyst* to the American Association of State Highway and Transportation Officials (AASHTO), which is managing its long-term distribution, technical support, maintenance and enhancement as a licensed AASHTOWare product. *SafetyAnalyst* will support implementation of many of the analytical methods presented in Part B of the AASHTO Highway Safety Manual.

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Monique R. Evans
Director, Office of Safety
   Research and Development

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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1. INTRODUCTION

This report documents the development of the *SafetyAnalyst* software tools. *SafetyAnalyst* provides state-of-the-art analytical tools for use in the decision-making process to identify and manage a systemwide program of site-specific improvements to enhance highway safety by cost-effective means. *Safety Analyst* will provide updated automated analysis capabilities for use by highway agencies in safety management, such as network screening to identify potential improvement sites, and will automate capabilities that are currently performed manually, such as diagnosis of accident patterns and identification of potential countermeasures.

1.1 *SafetyAnalyst* Overview

SafetyAnalyst provides a set of software tools for use by state and local highway agencies for highway safety management. *SafetyAnalyst* can be used by highway agencies to improve their programming of site-specific highway safety improvements. *SafetyAnalyst* incorporates state-of-the-art safety management approaches into computerized analytical tools for supporting the decision-making process to identify safety improvement needs and develop a systemwide program of site-specific improvement projects. *SafetyAnalyst* has a strong basis in cost-effectiveness analysis; thus, *SafetyAnalyst* has an important role in ensuring that highway agencies get the greatest possible safety benefit from each dollar invested.

SafetyAnalyst is compatible with the Highway Safety Improvement Program (HSIP) (*1*). *SafetyAnalyst* can be used to identify locations for potential HSIP projects, to suggest the types of safety improvements that might be considered at those locations, and to evaluate the effectiveness of HSIP projects after they are implemented as the basis for highway agency reporting to FHWA on the HSIP program.

1.2 *SafetyAnalyst* Scope

SafetyAnalyst addresses site-specific safety improvements that involve physical modifications to the highway system. *SafetyAnalyst* is not intended for direct application to nonsite-specific highway safety programs that can improve safety for all highway travel such as vehicle design improvements, graduated licensing, occupant restraints, or alcohol/drug use programs. However, *SafetyAnalyst* has the capability not only to identify accident patterns at specific locations and determine whether those accident types are overrepresented, but also to determine the frequency and percentage of particular accident types systemwide or for specified portions of the system (particular highway segment or intersection types). This capability can be used to investigate the need for systemwide engineering improvements (e.g., shoulder rumble strips on freeways) and for enforcement and public education efforts that may be effective in situations where engineering countermeasures are not.

1.3 *SafetyAnalyst* Development Process and Timeline

SafetyAnalyst was developed in a pooled-fund effort managed by the Federal Highway Administration (FHWA) and sponsored jointly by 27 state highway agencies and interested local organizations; a Technical Working Group (TWG) made up of representatives from each sponsoring organization guided the development of *SafetyAnalyst* by setting overall objectives, reviewing interim products and providing recommendations for enhancements. Two contractor teams—an engineering team and a software development team—have worked closely with FHWA and the TWG to create *SafetyAnalyst*. This document constitutes the final report of the engineering team.

The development of *SafetyAnalyst* began in April 2001 with initial discussions among FHWA, the TWG, and the engineering team about the desirable scope and functionality for the software tools. White papers defining initial plans for the functionality of the software tools were completed in 2002 and 2003. Those plans were formulated in more detail in functional specifications for the software in 2003 and 2004. FHWA and the TWG reviewed the white papers and functional specifications at each stage and provided comments and recommendations to guide their development. The completed functional specifications were provided to the software development team who developed an interim version and then a final version of the *SafetyAnalyst* software tools. At each stage of development, the engineering team tested the software tools to assure that they met the functional specifications. The interim software tools were completed in 2006. The interim software tools were evaluated by FHWA and the TWG and functional specifications for modifications and enhancements to create the final software tools were then developed. The software development team completed the development of the final software tools in 2010.

The TWG identified the AASHTOWare program as the preferred mechanism for long-term distribution, technical support, maintenance, and enhancement of *SafetyAnalyst*. Upon completion of the *SafetyAnalyst* software tools,therefore, FHWA transferred the software to the AASHTOWare program, who will license it to highway agencies for their use in safety management. Under an AASHTOWare license, highway agencies can obtain the software for their use and will also receive technical support for implementation and future software enhancements.

1.4 *SafetyAnalyst* Components

The *SafetyAnalyst* software consists of four components:

- The **Analytical Tool** provides all of the safety management capabilities needed by users and is the primary focus of this report

- The *Administrative Tool* provides capabilities needed by a software administrator to set up *SafetyAnalyst* on a highway agency's computer network and to manage access to and use of the software

- The *Data Management Tool* provides capabilities for highway agencies to create and maintain the *SafetyAnalyst* database, including data on accidents and the characteristics of roadway segments, intersections, and ramps

- The *Implemented Countermeasures Tool* provides capabilities of highway agencies to create and maintain a special-purpose database that documents the date, location, and nature of post physical improvements to the highway network.

1.5 *SafetyAnalyst* Analytical Tool--Analysis Tools and Modules

SafetyAnalyst provides six tools to assist highway agencies in safety management of specific highway sites as part of the Analytical Tool described in Section 1.4. The following tools are included:

- The *Network Screening Tool* identifies sites with potential for safety improvement.

- The *Diagnosis Tool* is used to investigate the nature of accident patterns at specific sites.

- The *Countermeasure Selection Tool* assists users in the selection of countermeasures to reduce accident frequency and severity at specific sites.

- The *Economic Appraisal Tool* performs economic analyses of a countermeasure or several alternative countermeasures for an individual site or for multiple sites.

- The *Priority Ranking Tool* provides a priority ranking of sites and proposed improvement projects based on the benefit and cost estimates determined by the economic appraisal tool.

- The *Countermeasure Evaluation Tool* provides the capability to conduct before/after evaluations of implemented safety improvements.

Two pairs of *SafetyAnalyst* tools are so closely related that, in developing the software, each pair of tools was combined into a single software module. Thus, the *SafetyAnalyst* software includes four modules, rather than six. These modules are:

- Module 1—Network Screening Tool
- Module 2—Diagnosis Tool and the Countermeasure Selection Tool
- Module 3—Economic Appraisal Tool and the Priority Ranking Tool
- Module 4—Countermeasure Evaluation Tool

The following sections provide a brief summary of the capabilities of the six tools that comprise *SafetyAnalyst*. Later chapters provide an overview of each module and the detailed computational procedures for each module are presented in Appendices A through D.

Network Screening Tool

The network screening tool in Module 1 of *SafetyAnalyst* identifies sites with potential for safety improvement. Network-screening algorithms are used to identify locations of the following types of sites with potential for safety improvement:

- Sites with higher-than-expected accident frequencies which may indicate accident patterns that are potentially correctable in a cost-effective manner, and

- Sites whose accident frequencies are not higher than expected, given the traffic volumes and other characteristics present at the site, but which nevertheless experience sufficient numbers of accidents that may potentially be improved in a cost-effective manner.

In addition, the network screening tool can identify sites with high accident severities and with high proportions of specific accident types. The network screening algorithms focus on identifying spot locations and short roadway segments with potential for safety improvement, but also include the capability to identify extended route segments. Network screening and all other *SafetyAnalyst* algorithms can consider specific accident severity levels (fatalities and serious injuries, fatalities and all injuries, property-damage-only) or all severity levels combined. In screening specific highway sites, key network screening tools in *SafetyAnalyst* make extensive use of safety performance function (SPFs) to predict the accident frequency and severity for similar sites.

Diagnosis Tool

The diagnosis tool in Module 2 of *SafetyAnalyst* is used to diagnose the nature of accident patterns at specific sites. The diagnosis tool includes a capability to generate collision diagrams for particular sites, to identify the predominant accident patterns from those diagrams, and to determine whether those accident patterns represent higher-than-expected frequencies of particular accident types. The diagnosis tool includes a basic collision diagramming capability within *SafetyAnalyst*, but will also be able to interface with commercially available collision diagramming software packages. The diagnosis tool guides the user through appropriate office and field investigations to identify particular safety concerns at particular locations. Traditional engineering considerations, as well as a strong human factors component, are used in diagnosis of accident patterns. Output from this step is the identification of specific accident patterns and the development of a list of potential safety concerns that may need mitigation by countermeasures. The diagnosis tool also provides a capability to identify sites whose observed or expected accident experience

indicates that they are promising candidates for implementation of particular countermeasures.

Countermeasure Selection Tool

The countermeasure selection tool in Module 2 of *SafetyAnalyst* assists users in the selection of countermeasures to accident frequency and severity at specific sites. The user can select appropriate countermeasures for a particular site from lists of countermeasures incorporated in the software. The countermeasure selection tool suggests particular candidate countermeasures based on the type of site, the observed accident patterns, and the specific safety concerns identified in the diagnostic step. The user has the flexibility to select a single countermeasure, multiple countermeasures, or combinations of countermeasures for a specific site. Where two or more alternative countermeasures are selected by the user, a final choice among them can be made with the economic appraisal and priority ranking tools.

Economic Appraisal Tool

The economic appraisal tool in Module 3 of *SafetyAnalyst* performs an economic appraisal of a specific countermeasure or several alternative countermeasures for a specific site. Default construction cost estimates for candidate improvements are provided within this tool, but the user has the capability to modify the default estimates based on local experience. The user has the option to select the type of economic appraisal to be performed: cost effectiveness (countermeasure cost per accident reduced), benefit-cost ratio (ratio of monetary benefits to countermeasure costs), or net present value (excess of monetary benefits over countermeasure costs). Safety effectiveness measures (i.e., benefits) are estimated from data on the observed, expected, and predicted accident frequency and severity at the site; the accident patterns identified in the preceding tools; and accident modification factors (AMFs) for specific countermeasures. AMF is synonomous with the term crash modification factor in the Highway Safety Manual (*2*) The AMFs representing the safety effectiveness of particular countermeasures are based on the best available safety research. The analyses include appropriate consideration of the service life of the countermeasure and the time value of money. This tool can perform economic analyses consistent with the requirements of the FHWA Highway Safety Improvement Program (HSIP) so that analysis results will be readily acceptable to FHWA for implementation with Federal funds.

Priority Ranking Tool

The priority ranking tool in Module 3 of *SafetyAnalyst* provides a priority ranking of sites and proposed improvement projects based on the benefit and cost estimates determined by the economic appraisal tool. The priority ranking tool can compare the benefits and costs of projects across sites and rank those projects on the basis of cost effectiveness, benefit-

cost ratio, or net present value. The priority ranking tool also has the ability to determine an optimal set of projects to maximize safety benefits.

Countermeasure Evaluation Tool

The countermeasure evaluation tool in Module 4 of *SafetyAnalyst* provides users with the ability to conduct before/after evaluations of implemented safety improvements. Such evaluations are highly desirable to increase knowledge of project effectiveness and supplement or improve the safety effectiveness measures for improvements available for use in *SafetyAnalyst*. This tool is capable of performing before/after evaluations using the Empirical Bayes (EB) approach. The EB approach is a statistical technique that can compensate for regression to the mean, and it also allows for the proper accounting of changes in safety that may be due to changes in other factors, such as traffic volumes. This tool also provides users with a capability to evaluate shifts in proportions of accident types.

1.6 Expected Benefits of the *SafetyAnalyst* Software

SafetyAnalyst provides state-of-the-art tools for safety management that go beyond other tools currently available to highway agencies. *SafetyAnalyst* provides improved procedures for some functions that highway agencies already perform in automated fashion. In addition, *SafetyAnalyst* automates procedures that are now performed manually by highway agencies. The following discussion summarizes the potential benefits to highway agencies of using the *SafetyAnalyst* software tools.

Network Screening

State highway agencies generally have automated procedures for network screening to identify potential improvement sites, often known as high-accident locations. Typically, these procedures use threshold values of observed accident frequencies or accident rates, at times combined with an accident severity index. There are several potential drawbacks to these traditional procedures:

- Observed accident data are subject to regression to the mean, because high short-term accident frequencies are likely to decrease and low short-term accident frequencies are likely to increase as a matter of course, even if no improvements are made.

- The relationship between accident frequency and traffic volume is known to be nonlinear, but procedures based on accident rates treat that relationship as if it were linear.

- Most existing procedures focus on which sites have experienced the most accidents, not which sites could benefit most from a safety improvement.

- Some existing procedures do not explicitly distinguish between intersection and nonintersection accidents.
- Most existing procedures do not explicitly address the safety performance of individual interchange ramps.

Research during the last 20 years has developed new measures of effectiveness and new statistical methodologies for network screening to overcome the drawbacks of traditional procedures. The *SafetyAnalyst* software implements these new approaches. *SafetyAnalyst* uses an EB approach that combines observed and predicted accident frequencies to provide estimates of the safety performance of specific sites that are not biased by regression to the mean. The EB approach incorporates nonlinear regression relationships between traffic volume and expected accident frequency. The sites identified by the network screening methodology are referred to as *sites with potential for safety improvement* because they will be locations at which improvements projects can potentially result in substantial reductions in accident frequency or severity.

SafetyAnalyst asseses sites based on an estimate of their long-term expected accident frequency. A new measure that may also be chosen by the user for application in the *SafetyAnalyst* network screening application is the excess accident frequency. The excess accident frequency is the estimated accident frequency, above the expected value, that might be reduced if a safety improvement were implemented. Tables 1 and 2 present simple numerical examples with actual data for signalized intersections from a particular city to show that excess accident frequency provides site rankings that differ from those based on accident frequency and accident rate.

In Table 1, a group of signalized intersections has been ranked according to their accident frequencies during a 5-year period. The last column in the table shows the ranking based upon the excess accident frequency. It should be noted that, based on the accident frequency rankings, the city would improve the highest-volume location first. Based on excess accident frequency, the highest-ranking intersection would be a lower-volume intersection, ranked sixth in accident frequency, showing a greater potential for accident reduction.

In Table 2, the intersections in the same city have been ranked according to accident rate. The last column in the table shows the ranking based upon the excess accident frequency. It should be noted that, if the city improved the five highest-ranking intersections based on accident rate, it would not improve any of the three highest-ranking intersections based on the potential improvement benefits. It should also be noted that scarce financial resources will be allocated to sites ranked 33rd and 35th in excess accident frequency, while more than 30 intersections with greater potential for safety improvements might go untreated.

These comparisons show that state-of-the-art technology can help highway agencies make better decisions about where to invest the funds available for safety improvement.

Table 1. Comparison of Rankings by Accident Frequency and Excess Accident Frequency for Signalized Intersections in a Particular City

Intersection	Total accident frequency (1995 to 1999)	Average annual daily traffic (veh/day)	Accident frequency ranking	Excess accident frequency ranking
A	131	63502	1	2
B	104	35284	2	3
C	77	57988	3	11
D	75	46979	4	6
E	66	51933	5	10
F	51	48427	6	1
G	51	20423	7	15
H	46	34759	8	5
I	42	53396	9	61
J	38	25223	10	17

Table 2. Comparison of Rankings by Accident Rate and Excess Accident Frequency for Signalized Intersections in a Particular City

Intersection	Total accident frequency (1995 to 1999)	Average annual daily traffic (veh/day)	Accident frequency ranking	Excess accident frequency ranking
N	18	5063	1	33
M	22	7009	2	9
L	27	8152	3	8
R	14	4402	4	35
K	33	10458	5	4
B	104	35284	6	3
O	18	4242	7	14
A	131	63502	8	2
P	16	7815	9	19
J	38	25223	10	17

Diagnosis and Countermeasure Selection

Diagnosis of potential safety concerns at specific sites, whether those sites were identified by network screening or by other methods, is a process that is conducted manually by most highway agencies at present. An important step in diagnosis is the preparation of collision diagrams. Some agencies have automated the process of preparing collision diagrams for intersection locations; but in many agencies, the preparation of collision diagrams—as well as the rest of the diagnostic process—is conducted manually. A basic collision diagramming capability is included within *SafetyAnalyst*, but the Diagnosis Tool can also interface with commercially available collision diagramming software packages.

The *SafetyAnalyst* software automates the preparation of collision diagrams, the identification of accident types that are overrepresented at specific locations, and the investigation of the specific accident patterns that are present. The software serves as an expert system to guide the user through office and field investigations of particular sites. For example, *SafetyAnalyst* generates a site-specific list of questions to be answered in a field visit to the site. The questions asked are determined based on the available data about the accident experience, geometric design, and traffic control at the site; the answers provide more detailed information on site conditions and field assessments of whether particular conditions are present. The answers to the field investigation questions posed by *SafetyAnalyst* are entered into the software and are used in identifying potential countermeasures for implementation to improve safety.

The selection of countermeasures for implementation is made by the user, not by the software. However, *SafetyAnalyst* assists users by suggesting for consideration a list of alternative countermeasures that may address the site-specific safety concerns. The logic that identifies appropriate countermeasures considers the accident patterns and related site conditions investigated in the diagnostic process. The user can then select one or more of the suggested countermeasures for further consideration or can add other countermeasures that they consider appropriate.

The automation of these traditionally manual procedures using an expert system approach provides a benefit to highway agencies by assuring that diagnosis and countermeasure selection activities are comprehensive and thorough. Suggestion of field investigation checklists and lists of candidate countermeasures by the software may help assure that all potentially effective countermeasures are considered. These activities have traditionally been conducted in highway agencies by very experienced engineers; however, many of those experienced engineers are retiring, and *SafetyAnalyst* may help their less-experienced successors conduct such studies.

Economic Appraisal and Priority Ranking

SafetyAnalyst permits users to conduct economic appraisals of the costs and safety benefits of any countermeasures selected for implementation. The economic appraisal results can be used to compare alternative countermeasures for a particular site and to develop improvement priorities across sites. *SafetyAnalyst* includes an optimization program capable of selecting a set of safety improvements that maximizes the systemwide safety benefits of a program of improvements within a specific improvement budget.

Highway agencies currently use a variety of manual and automated methods for conducting economic appraisals of proposed countermeasures. Some current methods may be linked directly to an agency's accident records system, but others consist of spreadsheets into which data must be manually transferred. *SafetyAnalyst* provides an approach to economic appraisal that is consistent with the requirements of the FHWA HSIP, with data drawn from existing highway agency data files, while still providing flexibility for highway agencies to adapt the process to their own needs and policies. Highway agencies do not currently use formal optimization tools, but *SafetyAnalyst* allows an agency to determine that they are getting the most safety benefit possible for the dollars spent.

SafetyAnalyst incorporates the best AMFs available to represent the safety effectiveness of specific countermeasures. A wide variety of AMFs have been used by highway agencies across the nation. Many of these AMFs are based on older evaluations that were not well designed and well executed. For example, many of these evaluations may be substantially affected by regression to the mean. *SafetyAnalyst* incorporates the most reliable estimate of the safety benefits for each improvement type, and these estimates may be updated as new research results become available.

Evaluation of Implemented Countermeasures

SafetyAnalyst gives users the ability to conduct evaluations of improvements after they are implemented. The statistical approach to before/after evaluations is based on the EB approach and, thus, is able to compensate for regression to the mean. Evaluations use accident and traffic volume data from existing highway agency records together with the same regression relationships between accident frequency and traffic volume used in the network screening tool.

Most highway agencies do not routinely conduct evaluations of implemented countermeasures, and the few evaluations that are conducted are typically not well designed. *SafetyAnalyst* provides a tool to make well-designed before/after evaluations easy to conduct. This should help highway agencies to document the benefits of their safety improvement program and provide better estimates of the effectiveness of specific countermeasures to use in programming of future improvements.

1.7 Safety Performance Functinos used in *SafetyAnalyst*

SPFs are a key element of *SafetyAnalyst*. SPFs are regression models that are used to predict the accident frequency and severity for specific highway sites. SPFs are developed from statistical analysis of data for many similar sites.

SafetyAnalyst has the capability to conduct analyses for three basic site types: roadway segments, intersections, and ramps. *SafetyAnalyst* can analyze a number of specific categories for each of these site types; these categories that are considered by *SafetyAnalyst* are known as *site subtypes*. *SafetyAnalyst* includes SPFs for the following site subtypes:

Roadway Segments

- Rural two-lane highway segments
- Rural multilane undivided highway segments
- Rural multilane divided highway segments
- Rural freeway segments—4 lanes
- Rural freeway segments—6+ lanes
- Rural freeway segments within an interchange area—4 lanes
- Rural freeway segments within an interchange area—6+ lanes
- Urban two-lane arterial segments
- Urban multilane undivided arterial segments
- Urban multilane divided arterial segments
- Urban one-way arterial segments
- Urban freeway segments—4 lanes
- Urban freeway segments—6 lanes
- Urban freeway segments—8+ lanes
- Urban freeway segments within an interchange area—4 lanes
- Urban freeway segments within an interchange area—6 lanes
- Urban freeway segments within an interchange area—8+ lanes

Intersections

- Rural three-leg intersections with minor-road STOP control
- Rural three-leg intersections with signal control
- Rural four-leg intersections with minor-road STOP control
- Rural four-leg intersections with all-way STOP control
- Rural four-leg intersections with signal control
- Urban three-leg intersections with minor-road STOP control
- Urban three-leg intersections with signal control
- Urban four-leg intersections with minor-road STOP control
- Urban four-leg intersections with all-way STOP control
- Urban four-leg intersections with signal control

Ramps

- Rural diamond off-ramps
- Rural diamond on-ramps
- Rural parclo loop off-ramps
- Rural parclo loop on-ramps
- Rural free-flow loop off-ramps
- Rural free-flow loop on-ramps
- Rural direct or semidirect connection ramps
- Urban diamond off-ramps
- Urban diamond on-ramps
- Urban parclo loop off-ramps
- Urban parclo loop on-ramps
- Urban free-flow loop off-ramps
- Urban free-flow loop on-ramps
- Urban direct or semidirect connection ramps

Appendix E of this report presents the SPFs that are supplied with *SafetyAnalyst* and are used as default values by the software. Sections 2 through 5 of this report describe the specific uses that are made of SPFs in each *SafetyAnalyst* module.

The SPFs supplied with *SafetyAnalyst* are automatically calibrated by the software using each agency's data so that they are compatible with local conditions on each agency's highway network.

While the SPFs supplied with *SafetyAnalyst* are used by the software as defaults, highway agencies may develop SPFs from their own data and utlize them in *SafetyAnalyst*. The use of the default SPFs, with calibration, is expected to be satisfactory for most agencies, but the capability to incorporate an agency's own SPFs is provided for those agencies that wish to do so. Appendix F presents guidance for *SafetyAnalyst* users on developing SPFs from their agency's own data.

1.8 Data Needs for Using *SafetyAnalyst*

The *SafetyAnalyst* software tools need access to a database of site-specific data concerning an agency's road network, including data on roadway characteristics, traffic volumes, and accidents. Many of the data elements required for *SafetyAnalyst* are readily available to highway agencies, but some effort to assemble other data elements may be needed. *SafetyAnalyst* includes a data management tool to help users import and manage these data. While many additional data elements are desirable for *SafetyAnalyst* and may be evaluated, the minimum set of data elements required to use *SafetyAnalyst* includes:

Roadway Segment Characteristics Data

- Segment number
- Segment location (in a form that is linkable to accident locations)
- Segment length (mi)
- Area type (i.e., rural/urban)
- Number of through traffic lanes (by direction of travel)
- Median type (i.e., divided/undivided)
- Access control (i.e., freeway/nonfreeway)
- Two-way vs. one-way operation
- Traffic volume (AADT)

Intersection Characteristics Data

- Intersection number
- Intersection location (in a form that is linkable to accident locations)
- Area type (i.e., rural/urban)
- Number of intersection legs
- Type on intersection traffic control
- Major-road traffic volume (AADT)
- Minor-road traffic volume (AADT)

Ramp Characteristics Data

- Ramp number
- Ramp location (in a form that is linkable to accident locations)
- Area type (i.e., rural/urban)
- Ramp length (mi)
- Ramp type (i.e., on-ramp/off-ramp/freeway-to-freeway ramp)
- Ramp configuration (i.e., diamond/loop/directional/etc.)
- Ramp traffic volume (AADT)

Accident Data

- Accident location
- Date
- Collision type (accident type and manner of collision)
- Severity
- Relationship to junction
- Maneuvers by involved vehicles (i.e., straight ahead/left turn/right turn/etc.)

This minimum set of data elements are those needed to (a) assign accidents to specific sites and locate them within the site, (b) determine the site subtype for each site, (c) compute the expected crash frequency for each site using the SPF for the appropriate

site subtypes, and (d) characterize the accident experience of each site by accident type, manner of collision, severity, and location.

The *SafetyAnalyst* User Manual includes a data dictionary that defines the data requirements of agency data for using *SafetyAnalyst* in more detail.
SafetyAnalyst also utilizes other data that are not site-specific in nature in its calculations. These are referred to as default values. *SafetyAnalyst* provides the capability for the user to adjust all default values that are used in the calculations. Depending on the type of default value, they may be edited by the analyst at the time the analysis is conducted or edited globally by an Administrator with the Administration Tool. Some default values can be edited by either an analyst or an Administrator, but most are intended to be edited by one (but not both) types of users.

Administrators, who are individuals with administrative rights to the software, may access the Administration Tool to change system-level or global default values that are used for analyses across all four modules of the Analytical Tool. Some examples of global defaults are:

- SPF coefficients
- Accident cost estimates
- Types of countermeasures
- Implementation costs and service lives of countermeasures
- Safety effectiveness estimates (i.e., AMFs) of countermeasures

Any program user or analyst, even those who are not Administrators, may edit certain default values at the time an analysis is conducted. These values are referred to as analysis options and allow customization of individual analyses. Each analysis option has a default value, but the user may change these to specify or customize an analysis. Some examples of these options are:

- Accident severity
- Accident cost values
- Collision type
- Number of years of accident and AADT data to be used (history period)
- Statistical significance level

1.9 Relationship of *SafetyAnalyst* to Other Safety Analysis Tools

SafetyAnalyst has a close relationship to other safety analysis tools, including the AASHTO *Highway Safety Manual* (HSM) (*2*) and the FHWA Interactive Highway Safety Design Model (IHSDM) (*3*). These safety analysis tools have in common their extensive use of SPFs and AMFs to predict accident frequency and severity, as a supplement to observed accident frequencies and severities for individual sites, in estimating their expected accident frequency and severity.

The HSM is a source of both information and analysis tools for use by highway agencies in improving safety. HSM Part B presents a variety of analysis methodologies that can be used in the safety management process. HSM Part B includes six chapters that address the same aspects of safety management as the six *SafetyAnalyst* tools. HSM Part B was developed to include both traditional safety analysis approaches and state-of-the-art safety analysis approaches like those included in *SafetyAnalyst*. Thus, HSM Part B presents a broader range of analytical methods than *SafetyAnalyst*, but the best and most unbiased methods in HSM Part B are either identical to, or very similar to, those presented in *SafetyAnalyst*. In a few cases, a computational approach that is slightly simpler than the comparable *SafetyAnalyst* approach has been presented in HSM Part B to make the HSM method more readily applicable using manual computations. In these few cases, the *SafetyAnalyst* approach is preferable to the HSM approach, and is feasible because it is automated in *SafetyAnalyst*.

The IHSDM is a software tool developed by FHWA to assist highway agencies in incorporating highway design features in specific projects. IHSDM has six modules:

- Crash Prediction Module—estimates the expected frequency of accidents on a highway using geometric design and traffic characteristics.

- Design Consistency Module—estimates the magnitude of potential speed inconsistencies to help identify and diagnose safety concerns at horizontal curves.

- Intersection Review Module—performs a diagnostic review to systematically evaluate an intersection design for typical safety concerns.

- Policy Review Module—checks highway segment design elements relative to design policy.

- Traffic Analysis Module—estimates operational quality-of-service measures for a highway under current or projected future traffic flows.

- Driver/Vehicle Module—estimates a driver's speed and path along a highway and corresponding measures of vehicle dynamics.

Most of the IHSDM modules currently address the design of projects only on rural two-lane highways; however, the IHSDM Crash Prediction Module addresses rural two-lane highways, rural multilane undivided and divided highways (nonfreeways), and urban and suburban arterials. The IHSDM Crash Prediction Module provides safety prediction methods identical to those presented in HSM Part C.

IHSDM may be applied as part of the design of projects whose need has been established with the *SafetyAnalyst* network screening, diagnosis, and countermeasure selection tools (Modules 1 and 2) and whose justification has been established with the *SafetyAnalyst* economic appraisal and priority ranking tools (Module 3). Thus, a logical sequence for application of the available analytical tools in the safety management process is:

Before Project Implementation

- SafetyAnalyst Module 1 (network screening)
- SafetyAnalyst Module 2 (diagnosis and countermeasure selection)
- SafetyAnalyst Module 3 (economic appraisal and priority ranking)
- IHSDM (safety analyses as part of the design process)

After Project Implementation

- SafetyAnalyst Module 4 (countermeasure evaluation)

FHWA has created a web site that serves as a clearinghouse for AMFs. (*4*) *SafetyAnalyst* users are encouraged to consult this clearinghouse as a source of AMFs that may not yet be incorporated in *SafetyAnalyst*. The clearinghouse can also serve as a forum for highway agencies to share AMFs developed with *SafetyAnalyst* with other agencies *SafetyAnalyst* users are encouraged to submit any AMF that they develop for potential incorporation in the FHWA clearinghouse.

1.10 *SafetyAnalyst* Participants

SafetyAnalyst has been developed through a cooperative effort of FHWA and twenty-seven state highway agencies through the transportation pooled-fund program. The participating state highway agencies include:

- Arizona Department of Transportation
- California Department of Transportation
- Colorado Department of Transportation
- Florida Department of Transportation
- Georgia Department of Transportation
- Illinois Department of Transportation
- Indiana Department of Transportation
- Iowa Department of Transportation
- Kansas Department of Transportation
- Kentucky Transportation Cabinet
- Louisiana Department of Transportation and Development
- Maryland State Highway Administration
- Massachusetts Highway Department
- Michigan Department of Transportation
- Minnesota Department of Transportation
- Mississippi Department of Transportation
- Missouri Department of Transportation
- Montana Department of Transportation
- Nevada Department of Transportation
- New Hampshire Department of Transportation

- New York State Department of Transportation
- North Carolina Department of Transportation
- Ohio Department of Transportation
- Vermont Agency of Transportation
- Virginia Department of Transportation
- Washington State Department of Transportation
- Wisconsin Department of Transportation

In addition, three local agencies provided guidance during *SafetyAnalyst* development:

- Delaware Valley Regional Planning Commission
- North Jersey Transportation Planning Authority
- Traffic Improvement Association, Oakland County, Michigan

1.11 Organization of the Remainder of this Report

This section describes the organization of the remainder of this report. Sections 2 through 5 of the report present an overview of the capabilities of *SafetyAnalyst* Modules 1 through 4, respectively. Section 6 addresses conclusions and recommendations for future development of *SafetyAnalyst*.

Appendices A through D present a detailed description of the analytical procedures for *SafetyAnalyst* Modules 1 through 4, respectively. Appendix E presents the default SPFs used in *SafetyAnalyst* in more detail. Highway agencies that use *SafetyAnalyst* can also supply their own SPFs for use with the software; Appendix F presents procedures for use by highway agencies in developing such SPFs.

2. CAPABILITIES FOR MODULE 1—NETWORK SCREENING

This section of the report provides an overview of the capabilities of *SafteyAnalyst* Module 1 which performs network screening analyses. The purpose of Module 1 is to perform network screening reviews of an agency's entire roadway network, or any user-selected portion of the roadway network, to identify and prioritize sites that have potential for safety improvement. Sites with potential for safety improvement merit further investigation to determine what types of safety improvements, if any, may be appropriate. The identification of a site through a network screening analysis does not necessarily imply that a site has an existing safety concern. Rather, identification of a site through network screening indicates that the site experiences a sufficient number of accidents that there may be an opportunity for a cost-effective safety improvement project at the site. Thus, sites identified through network screening are candidates for detailed engineering studies to identify appropriate countermeasures, to assess whether those countermeasures are economically justified, and to establish implementation priorities. *SafetyAnalyst* Modules 2 and 3 can guide the user through these detailed engineering studies.

Network screening makes use of information on sites characteristics and safety performance to identify those sites that are the strongest candidates for further investigation. Three types of sites may be considered: roadway segments, intersections, and ramps. The data used in network screening fall under the following categories:

- Geometric design features
- Traffic control features
- Traffic volumes
- Observed accident frequencies
- Accident characteristics
- Safety performance functions (SPFs)

Conducting detailed engineering studies of candidate improvement sites to identify and prioritize appropriate countermeasures is an expensive process, even with the improvements in the efficiency of such investigations provided by *SafetyAnalyst* Modules 2 and 3. Therefore, only a limited set of sites can be investigated by a highway agency during any given year. The network screening procedures in *SafetyAnalyst* Module 1 can be adjusted to indentify a manageable number of sites for further detailed investigation.

The first step in network screening with *SafetyAnalyst* Module 1 is to choose the set of sites to be screened. This set of sites may include all roadway segments, intersections, and ramps under the jurisdiction of an agency or may include any subset of the network. An analyst has various ways of identifying sites to be included in the screening. For example, highway agencies that perform network screening at the district level can perform network screening separately for each district. Once an analyst has settled upon a site list for which screening is to be performed, the analyst specifies the type of screening to be conducted. The analyst can select from among the following types of screening:

- Basic network screening [with peak searching on roadway segments and Coefficient of Variation (CV) Test]
- Basic network screening (with sliding window on roadway segments)
- Screening for high proportion of specific accident type
- Sudden increase in mean accident frequency
- Steady increase in mean accident frequency
- Corridor screening

The first five types of screening listed above are conducted generally on a site-by-site basis, while corridor screening performs an analysis of multiple sites over an extended corridor. All sites in the corridor are treated as a single entity for analysis purposes. The six individual types of network screening approaches are described in Section 2.1 in summary form and in detail in Sections 2.4 through 2.9.

The primary output from Module 1 is a list of sites (or corridors) that are the strongest candidates for further investigation within *SafetyAnalyst*. The list will vary depending on the type of screening conducted. The number of sites will also vary depending upon the input parameters specified by the analyst. The analyst can modify the input parameters to obtain a list of sites of a desired length, or the analyst can specify the maximum percentage of sites to be included on the output report. Except when screening is based upon sudden or steady increases in mean accident frequencies, the list of sites included in the output reports is presented in priority order for further detailed investigation. Sites at the top of the output report have the greatest potential for safety improvement, while sites at the bottom of the output report have less potential for safety improvement.

The remainder of this section presents the following. First, a short summary of each network screening approach provided within *SafetyAnalyst* is presented. Second, common input parameters between the network screening approaches are discussed. Then, a short section is provided that addresses how an analyst begins a network screening analysis within *SafetyAnalyst*. This is followed by individual sections that describe the general concepts of each network screening approach provide within *SafetyAnalyst*. The different types of output reports are then discussed, and this section concludes with the benefits of the network screening capabilities provided within *SafetyAnalyst*. This section does not present the detailed algorithms of each network screening approach within *SafetyAnalyst*. Appendix A presents the detailed algorithms for each network screening approach.

2.1 Summary of Network Screening Approaches

SafetyAnalyst Module 1 provides six network screening approaches for identifying potential sites for safety improvement. Basic network screening using the peak searching approach utilizes Empirical Bayes (EB) principles to calculate an expected accident frequency or excess accident frequency for a site. This screening approach includes an iterative process of subdividing roadway segments into small subsegments for analysis purposes and also includes a statistical procedure to control the reliability of the results. Basic network screening using the peak searching approach is considered the most state-of-

the art and statistically sound network screening approach provided within *SafetyAnalyst* Module 1.

Similar to the peak searching approach, basic network screening using the sliding window approach applies EB principles to calculate expected or excess accident frequencies for sites. This network screening approach uses a more traditional method for screening roadway segments in which a window of specified length is incrementally moved along contiguous roadway segments for analysis purposes. The other primary difference between basic network screening using the peak searching approach verses the sliding window approach is that the sliding window approach does not directly incorporate statistical reliability as a screening criterion.

The screening methodology that tests for a high proportion of target accident types is intended to identify locations with an overrepresentation of particular accidents. This screening approach estimates the probability that the observed proportion of the specific target accident at a site is greater than what is expected for similar sites. When the probability that the observed proportion of a specific target accident at a site is greater than what is expected for similar sites meets a desired confidence level, sites are ranked in priority order for further investigation based upon on the difference between the observed proportions and the expected proportions of the specific target accident types.

A fourth screening approach identifies sites where the mean accident frequencies increased suddenly over time. Accident frequencies are analyzed in a time series. Sudden increases in mean accident frequencies are detected using a statistical test that looks for the difference between the means of two Poisson random variables.

Another screening method looks for steady increases in mean accident frequencies in a similar manner to the screening approach that looks for sudden increases in mean accident frequencies. The analyses are based on a time series of accident counts, and statistical tests that look for the difference between two Poisson random variables are used to detect steady increases in mean accident frequencies.

Finally, *SafetyAnalyst* provides the capability to perform corridor screening which may be used to compare the safety performance of extended corridors, rather than comparing the safety performance of individual sites. A corridor may be comprised of multiple roadway segments, intersections, and/or ramps which are aggregated together and analyzed as a single entity. Because this screening approach analyzes extended corridors rather than individual sites, the biases that occur in analyzing observed accidents at individual sites are less. Thus, simple procedures based on observed accident frequencies and rates are utilized.

2.2 Common Screening Capabilities

Several input parameters are common to the six network screening approaches. The common capabilities between each of the network screening approaches include:

- Selecting the accident severity level by which to screen
- Specifying the years of data for the analysis
- Specifying the accident and manner of collision types for the analysis

Details on each of the common network screening capabilities are provided next.

2.3 Accident Severity Levels

The analyst selects from four primary accident severity levels upon which to base an analysis. Analyses can be based upon:

- Total (TOT) accidents (i.e., all severity levels combined)
- Fatal and all injury (FI) accidents
- Fatal and severe injury (FS) accidents
- Property-damage-only (PDO) accidents

For basic network screening using the peak searching or sliding window approaches, the analyst can also screen based upon equivalent property-damage-only (EPDO) accidents, in which case, the analyst also inputs the relative severity weights for the different injury severity levels. Figure 1 presents a typical input screen where the analyst specifies the accident level for the analysis.

Figure 1. Module 1—Typical Input Screen With Several Common Input Parameters for Network Screening

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2.3.1 Analysis Period

The analyst specifies the years of data for the analysis. Figure 1 shows the analysis period options available to the analyst. By default, *SafetyAnalyst* incorporates up to the most recent 10 years of data available for a given site, unless otherwise specified. The analyst also has the option to specify certain calendar years for the analysis. All network screening analyses are based upon full calendar years of data. Analyses cannot be performed on a partial year of data.

The analyst has the option to limit the analysis period on any site in the site list to exclude years prior to major reconstruction. Major reconstruction is broadly defined to occur when reconstruction or implementation of a countermeasure brings about a change in the site subtype. For example, when a rural two-lane road is widened and becomes a four-lane divided highway or a stop-controlled intersection is signalized, these types of improvement would be classified as major reconstruction. Excluding years prior to major reconstruction is recommended for more accurate analyses of the safety performance of sites, given the most current site conditions.

2.3.2 Collision Types

The term collision type is used in *SafetyAnalyst* to represent the specific categories of accident type of single-vehicle accidents and manner of collision for multiple-vehicle accidents. The list of collision types considered in *SafetyAnalyst* for single- and multiple-vehicle collisions is presented below.

The analyst specifies the collision types to be considered in the analysis. First the analyst selects the broad category of accidents to be considered. Figure 2 shows a typical input screen on which the analyst selects the accident attribute for analysis. For example, typical accident attributes considered for analysis include:

- Collision type (Accident type and manner of collision)
- Vehicle turning movement
- Light condition
- Road surface condition

Then the analyst selects the specific collision types to include in the analysis. For example, if the analyst initially selects to screen based upon accident type and manner of collision, the analyst then selects from among the specific collision types that are listed under accident type and manner of collision such as (Figure 3):

Single-vehicle accident types include:

- Collision with parked motor vehicle
- Collision with railroad train
- Collision with bicyclist
- Collision with pedestrian

- Collision with animal
- Collision with fixed object
- Collision with other object
- Other single-vehicle collision
- Overturn
- Fire or explosion
- Other single-vehicle noncollision

Figure 2. Module 1—Typical Input Screen With Accident Screening Attributes
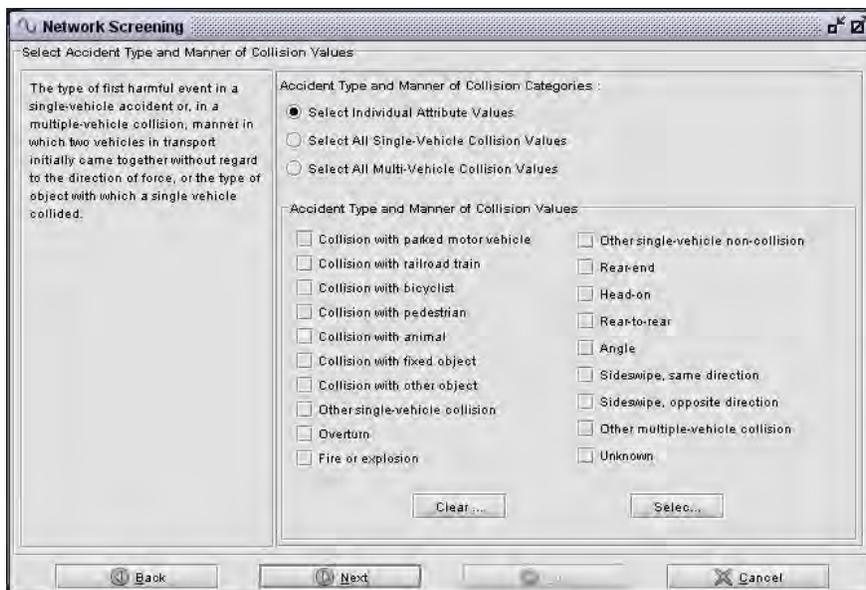
Figure 3. Module 1—Category Selection Screen for Accident Type and Manner of Collision Attribute

Multiple-vehicle accident types (based on manner of collision) include:

- Rear-end
- Head-on
- Rear-to-rear
- Angle
- Sideswipe, same direction
- Sideswipe, opposite direction
- Other multiple-vehicle collision
- Unknown

For all network screening approaches except the test of high proportions, the analyst may select one or more collision types to include in the analysis. Except for analyses based on all single-vehicle collisions and all multiple-vehicle collisions, for the test of high proportions the analyst may select one and only one collision type for the analysis. This limitation is due to the accident distributions calculated during the data import process.

The analyst does not have the capability to create nor modify the list of broad accident and manner of collision types; however, each agency has this ability. For example, agencies have the ability to modify the default list of accident types provided within *SafetyAnalyst* and/or define their own accident and manner of collision types for analysis. Defining the list of accident and manner of collision types to use in network screening and other *SafetyAnalyst* procedures is performed by an individual with administrative rights to the software in the Administration Tool and is not a capability provided to individual analysts.

2.4 Using Network Screening in *SafetyAnalyst*

SafetyAnalyst provides six network screening approaches to identify potential sites of interest for further investigation. Figure 4 shows the input screen where the analyst selects the screening method for a given analysis. On this same input screen, the analyst selects between conventional network screening and the generation of percentage reports. Each network screening approach is different in its methodology to identifying potential sites of interest. Thus, for a given site list being analyzed, each network screening approach will likely output a unique set of sites for further investigation. Figure 5 presents a typical site list for analysis within *SafetyAnalyst*.

The primary differences between conventional network screening and percentage reports are as follows. For conventional network screening, all screening approaches can be conducted, and all sites that meet the screening criteria are included in one output table. With percentage reports, the analyst specifies a maximum percentage of sites that will be included on the output reports, and only three (i.e., peak searching, sliding window, and corridor screening) of the six screening approaches can be conducted. Additionally, for the peak searching and sliding window approaches, separate output tables are provided for each site type included in the analysis (i.e., roadway segments, intersections, and ramps). Roadway segments are limited based upon percentages of cumulative lengths, and

intersections and ramps are limited based upon percentages of the number of sites. For corridor screening corridors are limited base upon percentages of cumulative lengths, similar to roadway segments.
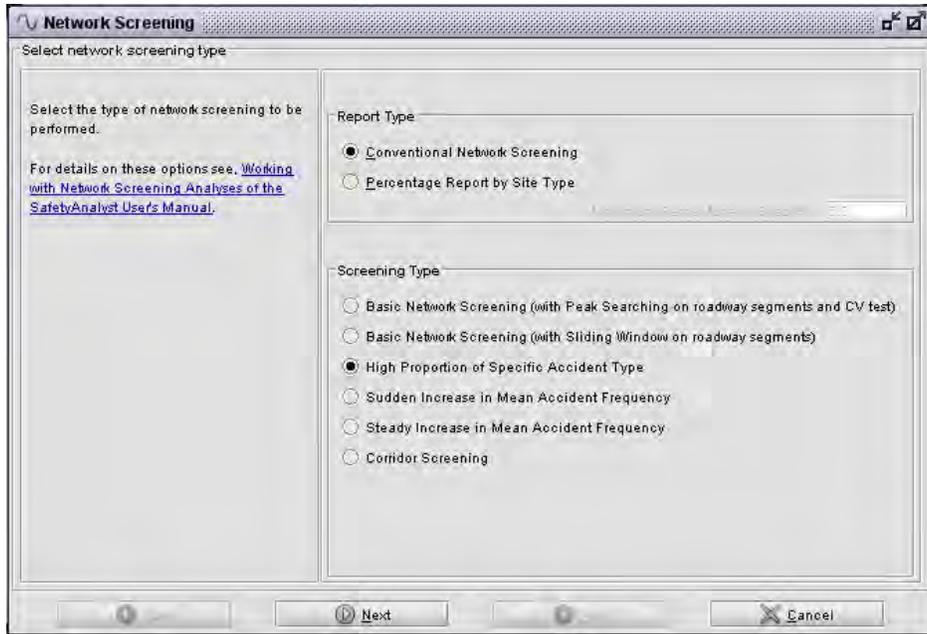
Figure 4. Module 1—Network Screening Type Selection Screen
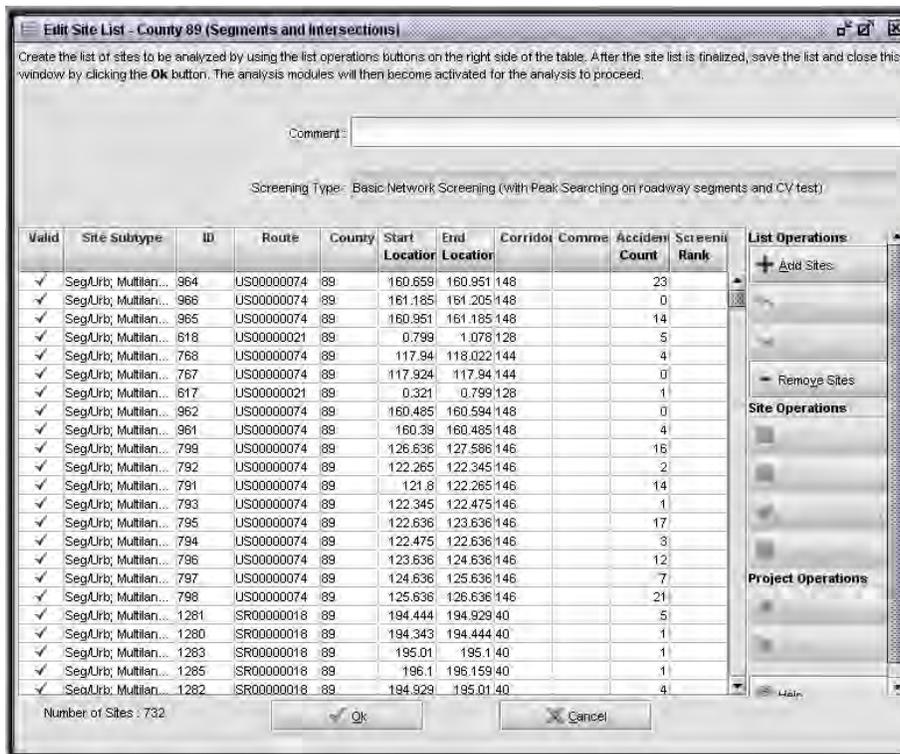
Figure 5. Sample Site List for Analysis Within *SafetyAnalyst*

No single network screening approach is the preferred methodology for all situations. An analyst is encouraged to analyze a given site list using more than one network screening approach to find common sites output from different the network screening methods. When sites are identified for further investigation through multiple screening methods, it reinforces that the sites deserve further investigation. The following sections explain the general concepts of each network screening approach provided by *SafetyAnalyst*.

2.5 Basic Network Screening (With Peak Searching on Roadway Segments and CV Test)

This basic network screening methodology utilizes Empirical Bayes (EB) principles to predict the potential for safety improvement of a site. In general, EB principles combine observed accident data with predicted accident values from regression relationships (i.e., safety performance functions) to calculate an expected accident value at a site. The analyst may select whether the expected accident value is expressed in terms of (a) an expected accident frequency, or (b) an excess accident frequency (i.e., the expected accident frequency that is in excess of what is considered normal for the site given its current site characteristics and traffic volume). The EB-weighted accident frequency is calculated for the last year in the analysis period and is used to rank the respective site, in comparison to the other sites being screened, for the potential for safety improvement. Sites with higher expected or excess accident frequencies are ranked higher in terms of their potential for safety improvement.

Employing EB concepts within this basic network screening approach is considered an improvement over identifying sites for their potential for safety improvement based strictly upon observed accident data because the number of accidents at a location is a random variable which fluctuates around some unknown mean. Because of this randomness, historical data (i.e., observed accidents counts) at a location are not considered an accurate reflection of a site's long-term accident characteristics. Employing an EB approach to network screening accounts for these random variations in accidents and provides for a better long-term estimate of the accident frequency at a site. The basic calculations for estimating the expected (or excess) accident frequency for a site using an EB approach are consistent with the procedures described by Hauer (*5, 6*).

This screening methodology also incorporates a statistical procedure to control the reliability of the results. The coefficient of variation (CV) of the expected or excess accident frequency is calculated for a site. The CV is defined as the ratio of the standard deviation to the mean. When the CV is low, it indicates there is low variation in the accident data, and hence greater reliability in the estimated accident frequency. When the CV is high, it indicates there is greater variation in the accident data, and thus less reliability in the estimated accident frequency. The analyst selects a CV threshold as a screening criterion for the reliability of the estimated accident frequencies.

For intersection and ramp sites analyzed using the peak searching approach, the expected or excess accident frequency is calculated for the entire site and the statistical reliability of

the estimate is assessed based upon the CV threshold value. For roadway segments, each individual site is initially subdivided into equal lengths of 0.1 mi. Figure 6 illustrates how a sample roadway segment site 0.67 mi in length would be initially subdivided for calculation purposes. Seven separate windows (i.e., subsegments) positioned across the site would be established for computational purposes. The expected or excess accident frequency for each subsegment is calculated along with the CV of the accident frequency for the subsegment. If the expected or excess accident frequency and CV value for at least one subsegment meet the threshold values input by the analyst for each of these parameters, then the entire roadway segment is included on the output report as a site for potential safety improvement. If the expected or excess accident frequency and CV value for none of the subsegments meet the threshold values input by the analyst, then the roadway segment site is subdivided into equal lengths of 0.2 mi (Figure 7), and the screening criteria are applied for a second iteration. This process is iterated until the expected or excess accident frequency and CV value for at least one subsegment meet the threshold values input by the analyst or the length of the divided subsegments is incrementally grown to equal the entire length of the site. For roadway segments, the entire site is rank ordered based upon the maximum (i.e., peak) expected or excess accident frequency of the subsegment that met both the accident frequency and CV criteria specified by the analyst. An important distinction with this screening approach for roadway segments is that all calculations are performed on subsegments (i.e., windows) within the boundaries of a given site. If a roadway segment site is less than 0.1 mi in length, then only one iteration is made, and the initial length of the subsegment equals the length of the site.

The basic inputs for this screening approach, in addition to those common to all screening approaches, include:

- **Safety Performance Measure:** The analyst specifies whether the site will be prioritized based upon the expected accident frequency or the excess accident frequency, for the last year of the analysis period. Accident data and traffic volume data for the entire analysis period are incorporated in these calculations of the expected or excess accident frequency for the last year of the analysis period. Excess accident frequency is the difference of the expected accident frequency (i.e., the EB-weighted accident frequency which is a weighted value of the observed and predicted accident frequencies) and the predicted accident frequency which is based purely on the estimates from the SPFs.

- **Area Weight:** The analyst specifies weights for urban and rural areas to calculate a weighted accident frequency. The analyst may wish to utilize these area weights due to the difficulties in combining lists of sites that include both urban and rural areas. Difficulties may arise because candidate improvement projects in urban areas often experience more accidents than improvement projects in rural areas; in addition, improvement projects in urban areas typically cost more than improvement projects in rural areas. Therefore, the utilization of area weights is viewed as a potential method of combining urban and rural sites within a site list for screening purposes. Conceptually, the
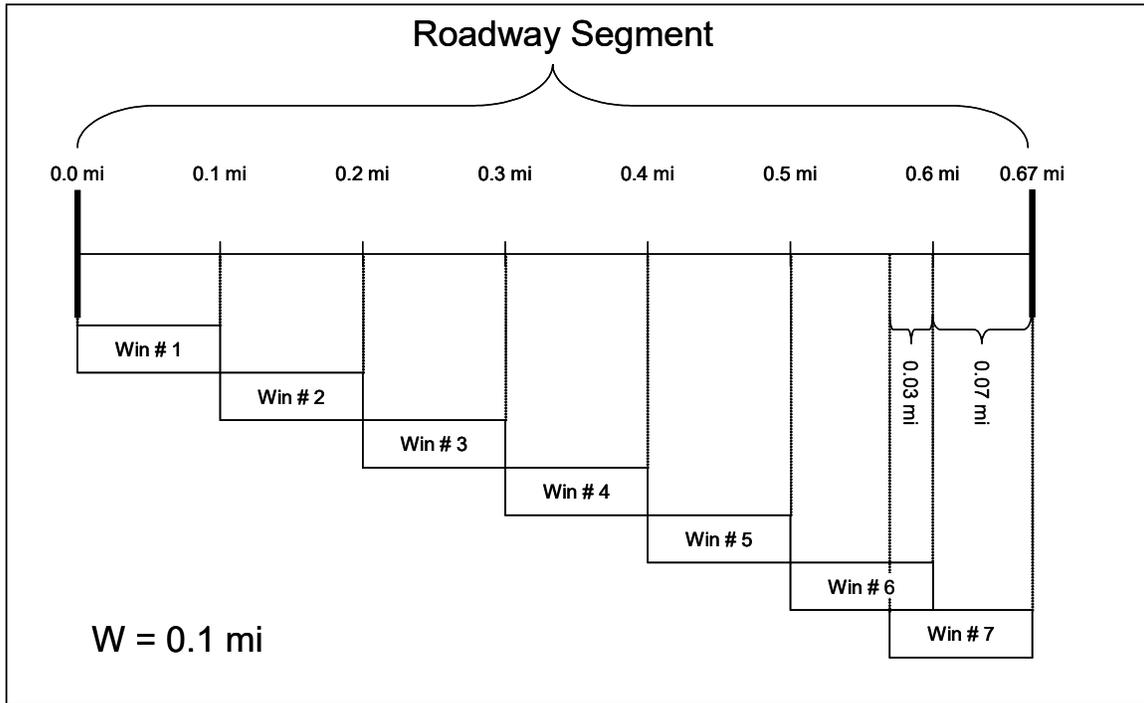
Figure 6. Module 1—Peak Searching Concepts: Initial Window Placement (W = 0.1 mi)
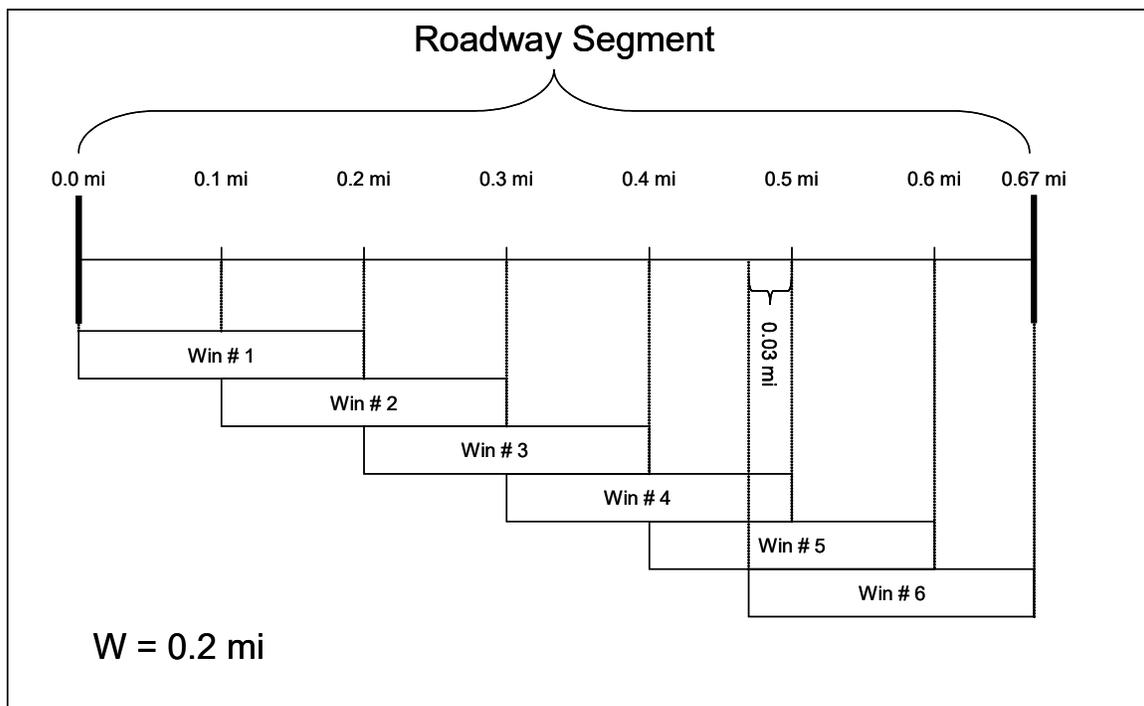
Figure 7. Module 1—Peak Searching Concepts: Window Placement When W = 0.2 mi

expected accident frequency (or excess accident frequency) at a site is multiplied by the area weight. This weighted accident frequency is then used to rank the site relative to others for potential safety improvements.

- **Accident Frequency Limiting Value:** These limiting values provide the capability to limit the number of sites on the output report based upon threshold values of either expected accident frequency or excess accident frequency. The expected accident frequency (or excess accident frequency) for a site must be greater than or equal to the specified limiting value to be included on the output report. Increasing the limiting value will likely reduce the number of sites included on the output report. Separate accident frequency limiting values must be specified for each site type included in the site list being analyzed.

- **EPDO Weights by Severity:** If the analyst chooses to screen based upon EPDO accidents, the analyst specifies the relative weight of fatal, serious injury, nonincapacitating, and possible injury accidents relative to PDO accidents.

- **Coefficient of Variation:** The coefficient of variation is a means to control the reliability of the results. The analyst specifies a CV limit for each site type included in the site list being analyzed. Only those sites where (a) the expected accident frequency or excess accident frequency is greater than or equal to the limiting value and (b) the CV of the accident frequency is less than or equal to the CV limit for the give site type will be included on the output report. Smaller CV limiting values improve the reliability in the estimated accident frequencies, while larger CV limiting values allow for less reliable results.

2.6 Basic Network Screening (With Sliding Window on Roadway Segments)

Similar to basic network screening using the peak searching approach, basic network screening using the sliding window approach applies EB principles to predict the potential for safety improvement of a site. Thus, the basic network screening peak searching approach and the basic network screening sliding window approach both use the same algorithms to calculate the expected accident frequency or excess accident frequency for a site. Again, the general calculations for basic network screening using the sliding window approach are consistent with the procedures described by Hauer (*2*). The EB-weighted accident frequency is calculated for the last year in the analysis period and is used to rank the respective site, in comparison to the other sites being screened, for the potential for safety improvement. Sites with higher expected or excess accident frequencies are ranked higher in terms of their potential for safety improvement.

There are several differences between the basic network screening peak searching approach and the basic network screening sliding window approach. The primary differences are as follows:

- The peak searching approach incorporates a statistical procedure to control the reliability of the results through the means of the coefficient of variation (CV) test; whereas no such test/procedure is incorporated into the sliding window methodology.

- For roadway segments, in the peak searching approach, individual roadway segment sites are subdivided into subsegments, and the calculations are performed for the subsegments within a given site. The sliding window approach incorporates a more traditional method for screening roadway segments in which a window of specified length is incrementally moved forward along contiguous sites, and the expected accident frequency is calculated for the window at the various locations. In this sliding window approach, windows are permitted to bridge contiguous sites. Thus, the calculations are not limited to a single site but may include multiple sites that are contiguous to one another.

In the sliding window approach, a window of specified length is moved forward in increments of specified length along each roadway segment in the site list. At each location of the window, calculations are performed to determine the expected accident frequency or excess accident frequency for the segment of roadway within the boundaries of the given window. A window may be comprised of a minimum of one subsegment but may consist of multiple subsegments, depending on the location or placement of the window relative to the roadway segment sites. The number and length of subsegments which comprise a given window is a function of the window length, the incremental length by which the window is moved forward along a set of contiguous sites, and the length of roadway segment sites. Windows do not have to be homogenous in nature.

For a given analysis, the beginning of the first window is placed at the beginning of the first roadway segment in the site list (i.e., the terminal of the first roadway segment with the smaller milepost value), and the expected or excess accident frequency is calculated for the length of this first window. The window is then moved forward by an incremental length. For example, a typical window length would be 0.3 mi (W = 0.3 mi), and a typical increment length would be 0.1 mi. This means that the beginning of the second window is 0.1 mi from the beginning of the first roadway segment. This also means that the second 0.3 mi window overlaps by 0.2 mi the first window and so on, as sliding windows are moved incrementally forward along a roadway segment (Figure 8).

As windows are moved incrementally forward across roadway segment sites in the site list, windows will bridge two or more contiguous roadway segments (e.g., the ending milepost value of one roadway segment along a given route equals the beginning milepost value of the next roadway segment). For example, assume a window of length 0.3 mi is positioned such that it spans two sample roadway segments, and the first roadway segment covers the first two-thirds of the window, and the second roadway segment comprises the final one-third of the window (Figure 9). In this case, the window will consist of two subsegments. The first subsegment length would equal 0.2 mi, and the second subsegment length would equal 0.1 mi. Figure 10 illustrates the placement of a window that bridges three sample

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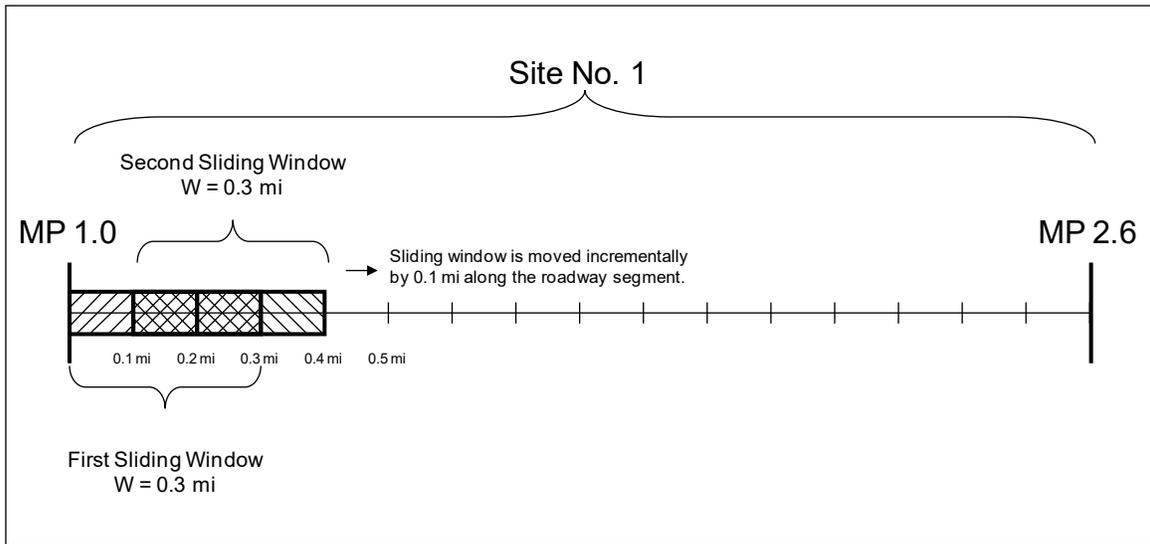
Figure 8. Module 1—Sliding Window Concepts: Incremental Moves
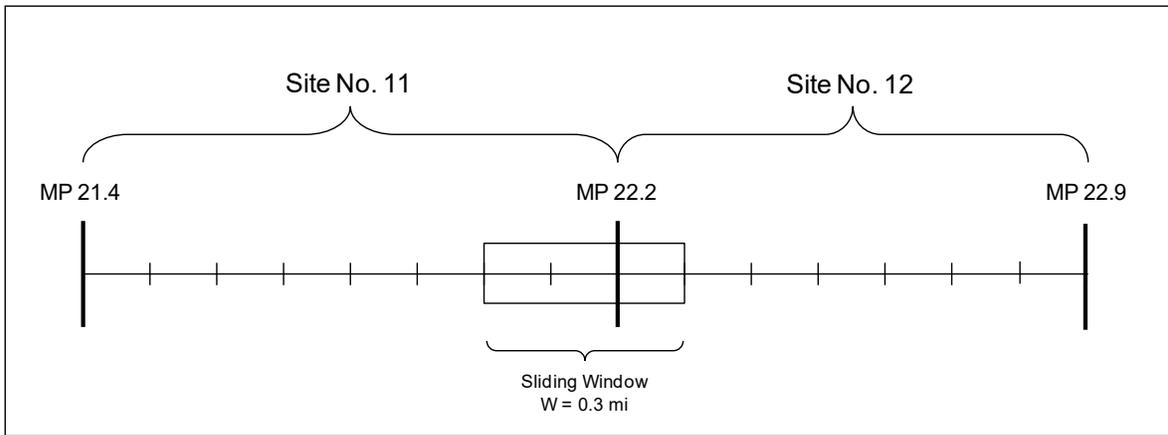
Figure 9. Module 1—Sliding Window Concepts: Bridging Two Contiguous Roadway Segments
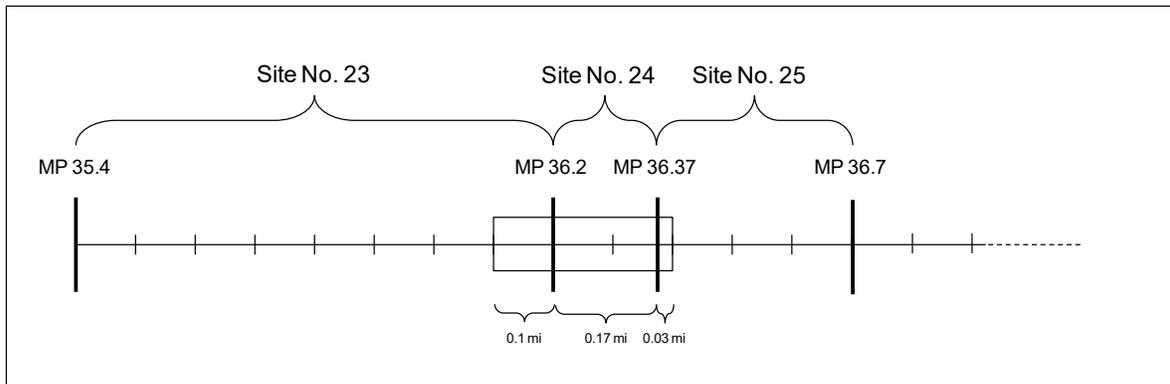
Figure 10. Module 1—Sliding Window Concepts: Bridging Three Contiguous Roadway Segments

roadway segments. In this case, the window is comprised of three subsegments. The first subsegment, pertaining to Site No. 23, is 0.1-mi in length; the second subsegment, pertaining to Site No. 24, is 0.17-mi in length; and the third subsegment, pertaining to Site No. 25, is 0.03-mi in length.

Sliding windows are moved forward incrementally until they reach the end of a contiguous set of roadway segment sites. For windows positioned near the end of a contiguous length of roadway segments, the calculations for determining the expected accident frequency or excess accident frequency for the portion of roadway within the boundaries of the given window are performed in the same manner as all previous windows. However, the length of the final window along a contiguous set of sites will vary as a function of the window length, the incremental length by which the window is moved forward, and the length of roadway segment that remains between the previous full length window and the end of the roadway segment. Two examples illustrate this concept. Figure 11 illustrates a situation where the last window of a contiguous set of sites is 0.28-mi in length. Assume there is a discontinuity between Sites No. 32 and 33 (i.e., Site No. 32 is the last site in a contiguous group of sites, and Site No. 33 is the first site in another group of contiguous sites). Figure 11A shows the position of the final window that is of full length (i.e., 0.3 mi). This 0.3-mi window spans Site 31 and 32. The beginning and ending mileposts of this window are 54.1 and 54.4, respectively. The distance from the end position of this window (i.e., MP 54.4) to the end of the site (i.e., MP 54.48) is 0.08-mi. This distance is less than the incremental length by which windows are moved forward (i.e., assume that the windows are moved forward by an incremental length of 0.1 mi). Figure 11B shows that the window is still moved forward by the same incremental length (i.e., 0.1 mi). However, the end position of the window is placed at the end of the contiguous site. Thus, the length of the final window is 0.28 mi which is less than the typical window length. This window consists of two subsegments which are 0.1 mi and 0.18 mi in length, respectively. Figure 11C shows the position of the next window, which is placed at the beginning of the next set of contiguous sites. It should be noted that there is no overlap between windows in Figure 11B and 11C.

Figure 12 illustrates the positions of windows at the end of contiguous sites when the window length is 0.3 mi, and windows are moved forward in increments of 0.2 mi. Again, assume there is a discontinuity between Sites No. 32 and 33. Figure 12A shows the position of the last full length window. Moving the window forward incrementally by 0.2 mi, Figure 12B shows the final window of the contiguous set of sites would be 0.18 mi in length. In this case, there is only 0.1 mi overlap between the last full length window (Figure 12A) and the final window (Figure 12B). Figure 12B consists of one subsegment 0.18 mi in length (i.e., the window length). Figure 12C shows the position of the next window, which is placed at the beginning of the next set of contiguous sites. This is the same position as illustrated in Figure 11C. As illustrated in Figures 11 and 12, at the end of a contiguous set of sites there is at most one window that is less than the full window length.
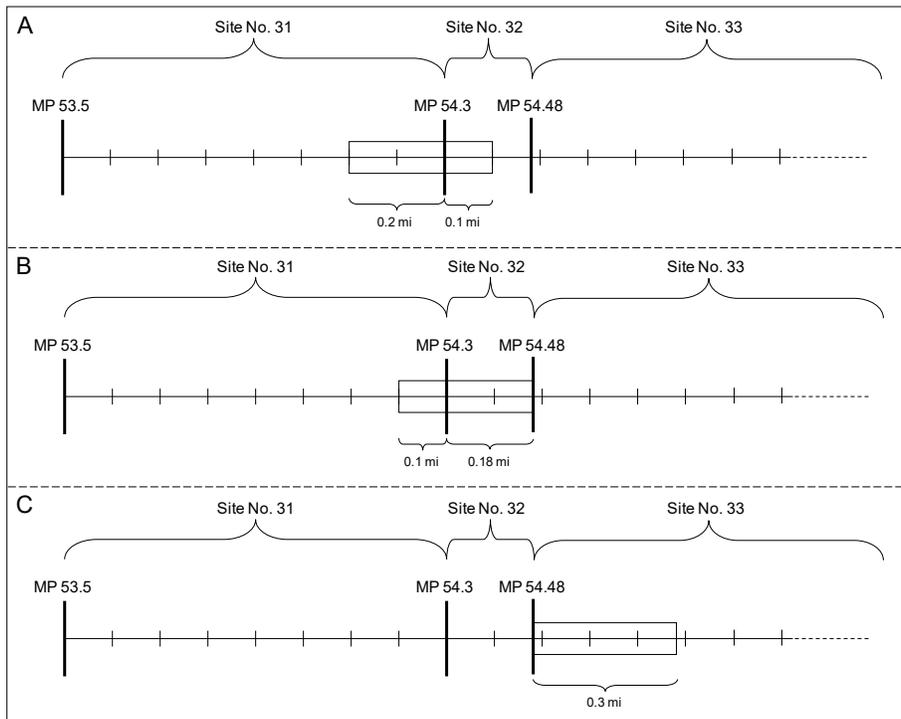
Figure 11. Module 1—Sliding Window Concepts: Window Positions at the End of Contiguous Roadway Segments When Window is Moved Incrementally by 0.1 mi
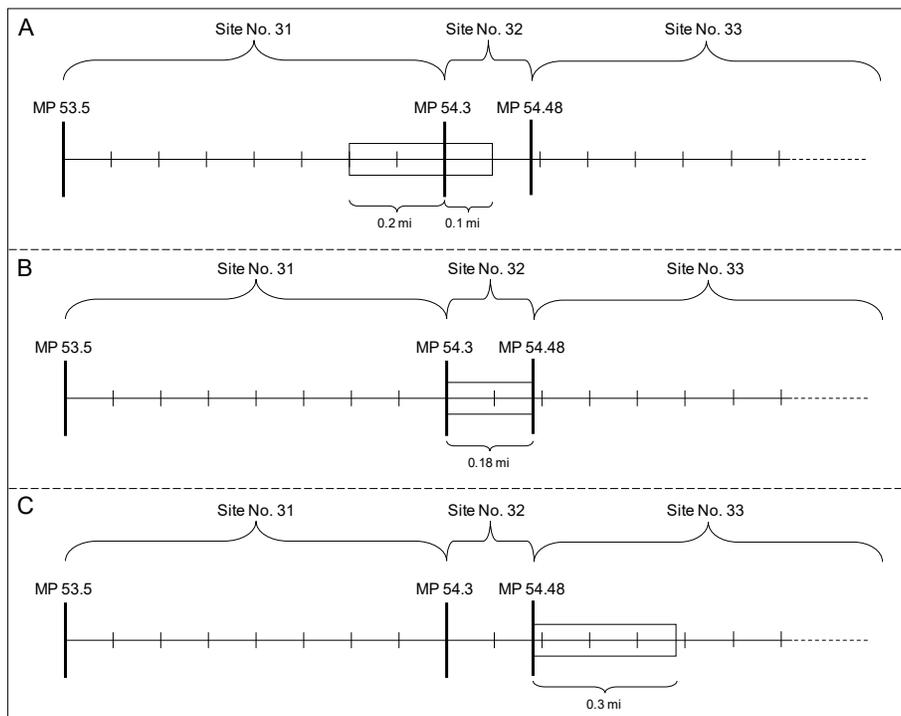
Figure 12. Module 1—Sliding Window Concepts: Window Positions at the End of Contiguous Roadway Segments When Window is Moved Incrementally by 0.2 mi

The basic inputs for the sliding window approach are similar to those for the peak searching approach. The inputs that are exactly the same between these two screening approaches are the safety performance measure, area weight, accident frequency limiting value, and EPDO weights by severity criteria. The inputs unique to the sliding window approach are:

- **Sliding Window Parameters:** When roadway segments sites are included in the site list being analyzed, the analyst specifies (a) the window length and (b) the increment length. The window length defines the length of the segment for which the expected or excess accident frequencies are calculated. The increment length defines the incremental length by which the window is iteratively moved forward along contiguous groups of sites. The increment length cannot be greater than the window length, and when the increment length is less than the window length, at minimum windows positioned one right after the other will overlap. Common window lengths and increment lengths for this screening method are 0.3 mi and 0.1 mi, respectively.

2.7 High Proportion of Specific Accident Type

The primary objective of this screening approach is to identify locations with an overrepresentation of particular accidents which may facilitate the selection of countermeasures and identify locations that are good candidates to be cost effectively treated. The general screening methodology identifies sites that have a higher proportion of a specific target accident than expected. A site is identified for further investigation when the probability that the observed proportion of the specific target accident at a site is greater than what is expected for similar sites. Sites that are identified for further investigation are ranked relative to the other sites based on the difference between the observed proportions and the expected proportions of the specific target accident.

The primary rationale for this screening method is that screening sites based strictly on expected or excess accident frequencies only tells a portion of the issue. Sites that are identified as having high expected or excess accident frequencies may not have well defined accident patterns for which countermeasures can be applied. Screening for high proportions of specific target accidents strives to identify locations with an overrepresentation of particular accidents which may facilitate the selection of countermeasures. The need for such a screening method arises from the fact that many locations may have relatively low accident frequencies but can be effectively treated with countermeasures because of well defined accident patterns.

Caution should be exhibited when using this screening technique. Screening for high proportion of specific accident types may identify sites with relatively low accident frequencies and overrepresented accidents as sites with high potential for safety improvements. However, an overrepresentation of one accident type may also be a reflection of the absence of other accident types.

With the exception of screening for all single-vehicle accidents or all multiple-vehicle accidents, this screening methodology cannot analyze multiple accident types being overrepresented in a given analysis. In other words, when screening for high proportions of specific target accident types, the analyst may select only one accident type of interest. To investigate the possibility of another accident type being overrepresented, a second analysis must be performed.

In this screening methodology, two proportions are compared for a given site. The first proportion is the proportion of accidents of the specific collision type of interest. This proportion is based upon the observed accidents at the specific site and is referred to as the observed proportion. The second proportion is the proportion of accidents of the specific collision type of interest, but it is based upon data from all sites of the same site subtype. This second proportion is referred to as the limiting proportion. In general, this methodology calculates the probability that the observed proportion is greater than the limiting proportion. When the observed proportion is greater than the limiting proportion the accident type may be overrepresented at the site and, therefore, further investigation of the site may be required.

This approach assumes target accidents for a site follow a binomial distribution and target accidents among similar sites follow a beta distribution, the natural conjugate prior of the binomial distribution (*7*). Using Bayes Theorem, the posterior distribution can then be determined and used to calculate the probability that the accident proportion for a site exceeds the accident proportion among similar sites. This probability is sometimes called a pattern score and represents the degree of belief that a given site experiences a greater proportion of accidents than sites. Consequently, a pattern score of one indicates with absolute certainty that the proportion is greater, while a score of zero indicates with certainty that it is not. To limit the list of ranked sites to only those with a relatively high pattern score, a limiting value of the pattern score, alpha (i.e., significance level), is used.

The basic inputs the analyst specifies for this screening approach, in addition to those common to all screening approaches, include:

- **Sliding Window Parameters:** When roadway segments sites are included in the site list being analyzed, the analyst specifies (a) the window length and (b) the increment length. This screening method analyzes roadways segments by subdividing the roadway segments into windows and incrementally moving the windows along a set of contiguous sites, in a manner that is analogous to (but not identical to) the sliding-window approach used for basic network screening. The primary difference is that when screening for high proportion of specific accident types, the window length should be greater due to calibration needs. The recommended window length when screening for high proportion of specific accident types is 1.0 mi.

- **Significance Level:** The analyst specifies the desired confidence level for the statistical validity of the test to assess the probability that the observed proportion of the specific accident type is greater than the limiting proportion.

2.8 Sudden Increase in Mean Accident Frequency

The objective of this screening approach is to identify sites where the mean accident frequency increased suddenly over time to more than what can be attributed to changes in traffic or general trends. When the mean accident frequency from year to year increases above a certain percentage, the site is identified for potential safety improvement. Sudden increases in mean accident frequency are detected utilizing a statistical test of significance which looks for the difference between the means of two Poisson random variables. Any time series of accident frequencies will display substantial fluctuations from year to year. A large part of this fluctuation is the result of the randomness inherent in the process of accident generation (i.e., accident frequencies vary from one period to another even if traffic, weather, road, and so forth, remain unchanged). Another part of the change in annual accident counts over time is attributable to casual factors such as changes in traffic flow, driver demography, weather, and so on. A third element of the change over time may be the result of certain factors whose precedence should be detected (e.g., decreased pavement friction and diminished sight distance). The goal of this screening methodology is to identify those fluctuations in accident patterns that are attributed to this third element. The basis of this screening methodology is that when the average accident frequency for a site in recent years appears significantly larger than in the preceding years, there is due reason to examine the site in more detail. This screening methodology is based upon procedures developed by Hauer (*8*).

All sites identified by this screening methodology are candidate sites for further investigation. The sites are not priority ranked relative to the others.

The basic inputs for this screening approach, in addition to those common to all screening approaches, include:

- **Limiting Value:** This is the percentage increase in the yearly mean accident frequencies above which there may be cause for concern.

- **Significance Level:** The analyst specifies the desired confidence level for the statistical validity of the test to assess whether the percentage increase in mean accident frequency for a given time period is greater than the limiting percentage.

2.9 Steady Increase in Mean Accident Frequency

The objective of this screening approach is to identify sites where the mean accident frequency increased steadily over time to more than can be attributed to changes in traffic or general trends. When the mean accident frequency from year to year increases at a rate greater than some specified limit, the site is identified for potential safety improvement. Similar to the methodology for detecting sudden increases in mean accident frequency,

steady increases in mean accident frequency are detected utilizing a statistical test of significance which looks for the difference between the means of two Poisson random variables.

The general process for detecting a steady increase in mean accident frequency is to fit a linear regression model to the data of accident frequency versus year and compare the value of the estimated slope of the regression equation to a limiting value. If the estimated slope of the regression equation is greater than the limiting value, there might be cause for concern so the site is identified for further examination. This screening methodology is based upon procedures developed by Hauer (*3*).

All sites identified by this screening methodology are candidate sites for further investigation. The sites are not priority ranked relative to the others.

The basic inputs for this screening approach, in addition to those common to all screening approaches, include:

- **Limiting Value:** This is the slope of the regression equation which might be indicative of a safety concern.
- **Significance Level:** The analyst specifies the desired confidence level for the statistical validity of the test to assess whether the slope of the observed accident frequencies is greater than the limiting slope.

2.10 Corridor Screening

Most *SafetyAnalyst* procedures are performed on a site-by-site basis, or in the case of roadway segments, the calculations are performed for a given window of interest which may span multiple roadway segments. In addition, several *SafetyAnalyst* procedures enable multiple sites to be aggregated together and be analyzed as a single unit or entity. In Module 1 the analyst can analyze an aggregated group of sites along a "corridor" and analyze the "corridor" as a single entity.

A corridor may be comprised of roadway segments, intersections, and/or ramps. Sites are assigned to a specific corridor at the Administrative level (i.e., sites are assigned to a specific corridor by the agency while importing their data into *SafetyAnalyst*). It is envisioned that agencies will divide selected portions of their highway system into corridors generally 10 mi in length or greater. The corridor screening approach can then be used to compare the safety performance of extended corridors, rather than comparing the safety performance of individual sites. It is not required, nor anticipated, that every site within the highway network will be assigned to a corridor. The analyst does not have the capability to assign more sites to a given corridor for analysis. When the analyst performs corridor screening, it is anticipated that most, if not all, sites for a given corridor will be included in the site list being analyzed.

Part of the rationale for corridor screening is that many agencies are taking a proactive approach towards implementing countermeasures with proven effectiveness over extended corridors to effectively eliminate or reduce accidents before they occur. This screening approach will help towards this effort. Because the analyses are based upon extended corridors and hence multiple sites, there is less variability or randomness in the accident data. Thus, the biases that occur in analyzing observed accidents at individual sites are less. Subsequently, simple procedures based on observed accident frequencies and rates are used and provide more reliable results than similar procedures when used to analyze individual sites.

As indicated above, several *SafetyAnalyst* procedures enable multiple sites to be analyzed as a single entity. For clarity, the distinctions between these procedures and capabilities are summarized here, as follows:

- Module 1 (i.e., network screening) is the only *SafetyAnalyst* module that analyzes corridors. Corridors are created at the Administrative level and may consist of roadway segments, intersections, and/or ramps.

- Projects are created by the analyst within a site list. Projects can be analyzed within Modules 2 and 3. Projects may only include roadway segments.

- Construction projects consist of sites where one or more countermeasures were implemented over a number of sites. The sites may include roadway segments, intersections and/or ramps. Analyses of construction projects are conducted in Module 4 to assess the safety effectiveness of the projects measured in terms of percent change in accident frequency or a change in the proportion of target accidents.

When specific corridors are identified for further analysis through network screening, subsequent analyses (i.e., diagnosis and countermeasure selection and economic analyses) of the corridor are performed on a site-by-site basis. An analyst may also analyze all of the roadway segments within a corridor together as a project.

The basic inputs for this screening approach, in addition to those common to all screening approaches, include:

- **Safety Performance Measure:** The analyst specifies whether corridors will be prioritized based upon (a) average accidents per mile per year (acc/mi/yr) or (b) average accidents per million vehicle miles of travel per year (acc/mvmt/yr). The first measure, average accidents per mile per year, is an accident frequency. This measure does not consider traffic exposure when analyzing the safety potential of a corridor. Comparing accident frequencies between two corridors may not be meaningful unless both corridors have the same level of exposure. The second measure, average accidents per million vehicle miles of travel per year, is an accident rate. Accident rates take into consideration the traffic volume exposure to evaluate the safety potential of a corridor. Inclusion of an exposure measure to estimate safety equalizes for

differences in the intensity of use between different corridors and makes comparisons more meaningful.

2.11 Primary Output Reports

Two types of output reports are available from Module 1: a primary or conventional output report and percentage report. The primary or conventional output report is explained in this section. The percentage report which consists of a listing limited to a user-specified maximum percentage of sites is described in Section 2.12.

The primary output from Module 1 is a list of sites (or corridors) that are the strongest candidates for further investigation within *SafetyAnalyst*. Samples of conventional output reports from the six network screening methods are presented below. The same site list, consisting of 732 roadway segment and intersection sites, is used for all of the examples, except for corridor screening.

Table 3 presents a prioritized list of sites generated using the basic network screening peak searching approach. Only the top 20 sites included in the output report are shown in Table 3. The basic inputs that generated this sample output table are as follows:

- Conventional Network Screening
- Basic Network Screening (with Peak Searching on roadway segments and CV Test)
- Accident Severity Level: Fatal and all injury accidents
- Safety Performance Measure: Expected accident frequency
- CV limit (roadway segments): 0.75
- CV limit (intersections): 0.75
- CV limit (ramps): 0.75
- Area Weights (Rural): 1.0
- Area Weights (Urban): 1.0
- Limiting Value (Roadway Segments): 1.0 acc/mi/yr
- Limiting Value (Intersections): 1.0 acc/yr
- Collision Type: Accident Type and Manner of Collision—All accident types
- Analysis Period: From 1995 to 2002

The first seven columns in the Table 3 (ID, Site Type, Site Subtype, County, Route, Site Start Location, and Site End Location) provide descriptive and location information for the entire site. The remaining columns present information related to the safety performance of the site as follows:

Table 3. Module 1—Conventional Network Screening Output Report: Basic Network Screening (With Peak Searching on Roadway Segments and CV Test)

ID	Site type	Site subtype	County	Route	Site start location	Site end location	Average observed accidents for entire site	Location with Highest Potential for Safety Improvement								Rank	Additional windows of interest
								Average observed accidents	Predicted accident frequency	Expected accident frequency	Variance	Start location	End location	No. of expected fatalities	No. of expected injuries		
2212	Segment	Seg/Rur; 2-lane	89	SR00000108	121.477	121.479	9.98	9.98	0.04	5.90	0.07	121.477	121.479	0.37	8.62	1	
434	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	10.463		5.03	5.03	3.14	4.83	0.48	-	-	0.05	7.32	2	
437	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	11.26		4.06	4.06	2.73	3.88	0.42	-	-	0.04	5.89	3	
445	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	16.721		3.94	3.94	3.21	3.86	0.43	-	-	0.04	5.85	4	
163	Intersection	Int/Rur; 3-leg signalized	89	US00000074	159.615		3.24	3.24	1.97	3.03	0.51	-	-	0.04	4.48	5	
449	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	203.146		3.05	3.05	2.43	2.98	0.26	-	-	0.03	4.52	6	
447	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	202.419		2.88	2.88	2.81	2.87	0.28	-	-	0.03	4.35	7	
81	Intersection	Int/Urb; 4-leg signalized	89	US00000074	130.013		2.91	2.91	2.52	2.86	0.29	-	-	0.03	4.34	8	
78	Intersection	Int/Urb; 4-leg signalized	89	US00000074	129.156		2.90	2.90	2.51	2.85	0.29	-	-	0.03	4.32	9	
1774	Segment	Seg/Urb; 2-lane arterial	89	SR00000049	205.254	205.354	2.66	2.66	0.34	2.62	0.07	205.254	205.354	0.03	3.86	10	

Table 3. Module 1—Conventional Network Screening Output Report: Basic Network Screening (With Peak Searching on Roadway Segments and CV Test) (Continued)

ID	Site type	Site subtype	County	Route	Site start location	Site end location	Average observed accidents for entire site	Location with Highest Potential for Safety Improvement								Rank	Additional windows of interest
								Average observed accidents	Predicted accident frequency	Expected accident frequency	Variance	Start location	End location	No. of expected fatalities	No. of expected injuries		
447	Segment	Seg/Rur; Fwy in intchng area (4 ln)	89	I00000312	258.141	258.207	2.92	2.92	0.64	2.38	0.09	258.141	258.207	0.07	3.66	11	
444	Intersection	Int/Urb; 4-leg minor-rd STOP	89	SR00000049	15.741		2.66	2.66	0.70	2.38	0.24	-	-	0.02	3.75	12	
439	Intersection	Int/Urb; 3-leg signalized	89	SR00000049	12.48		2.53	2.53	1.65	2.38	0.18	-	-	0.03	3.63	13	
79	Intersection	Int/Urb; 3-leg signalized	89	US00000074	129.609		2.58	2.58	1.29	2.32	0.16	-	-	0.03	3.54	14	
446	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	201.906		2.35	2.35	1.81	2.26	0.21	-	-	0.02	3.42	15	
705	Intersection	Int/Rur; 4-leg minor-rd STOP	89	SR00000110	6.938		0.21	0.21	2.14	2.14	0.00	-	-	0.05	3.89	16	
173	Intersection	Int/Urb; 4-leg signalized	89	US00000074	160.951		2.02	2.02	2.36	2.07	0.20	-	-	0.02	3.13	17	
2173	Segment	Seg/Urb; 2-lane arterial	89	SR00000108	104.035	104.141	2.03	2.15	0.12	2.02	0.07	104.041	104.141	0.02	2.98	18	104.035 - 104.135
2	Segment	Seg/Urb; Fwy (6 ln)	89	I00000253	130.937	131.273	0.86	2.17	0.63	2.02	0.07	130.937	131.037	0.04	2.84	19	
69	Intersection	Int/Rur; 3-leg signalized	89	US00000074	119.12		1.95	1.95	2.57	2.01	0.27	-	-	0.03	2.98	20	

- **Average Observed Accidents for Entire Site (Column 8):** This column on the output report the Average Observed Accidents for the Entire Site, take into consideration an ADT growth factor to scale the observed accident frequency to the final year of the analysis period. Several points need further explanation to understand this measure. First, the primary performance measure for the peak searching approach (and the sliding window approach) is the Expected Accident Frequency or Excess Accident Frequency for the Location with the Highest Potential for Safety Improvement. All sites are rank ordered based upon Column 11, headed Expected Accident Frequency or Excess Accident Frequency, depending upon the performance measure selected by the analyst. Second, the Expected Accident Frequency or Excess Accident Frequency is an estimate of the accident frequency for the final year of the analysis period. For example, if the analysis period is from 2003 to 2007. The Expected Accident Frequency or Excess Accident Frequency provided on the output report is an estimate of the accident frequency for the year 2007. So that all accident frequencies in this output report (i.e., observed, predicted, and expected) are comparable to one another, all accident frequencies are an estimate for the final year of the analysis period. *SafetyAnalyst* first calculates the simple average observed accident frequency for the entire site [i.e., considering all observed accidents reported to have occurred between the Site Start Location (Column 6) and the Site End Location (Column 7)] for the entire analysis period. This is essentially an average frequency for the middle of the analysis period, assuming the ADT grows yearly. For example, say the analysis period is from 2003 through 2007. The average observed accident frequency would essentially provide an estimate for the year 2005, because of the differences in ADT. If the ADT were the same for every year in the analysis period, then the simple average value would be applicable to every year. To make the Observed Accident Frequency directly comparable to the Expected Accident Frequency for the final year of the analysis period, the simple average observed accident frequency is calculated for the entire analysis period, and then it is multiplied by a growth factor (essentially accounting for growth in ADT) to scale it from the middle of the analysis period to the final year of the analysis period. If the ADT for a site remains constant throughout the analysis period, the growth factor would equal 1.0; if the ADT for the site grows annually, the growth factor would be greater than 1.0; and if the ADT for the site decreases, the growth factor would be less than 1.0. This calculation only considers observed accident frequencies and growth in ADT. For roadway segments and ramps, the units for this measure are acc/mi/yr. For intersections, the units are acc/yr.

- **Average Observed Accidents (Column 9):** This column on the output report presents the average observed accident frequency for that portion of the site identified as having the greatest potential for safety improvement. Only those observed accidents reported to have occurred between the limits as specified in Columns 13 and 14 are included in this calculation. The average observed accident frequency is scaled to the final year of the analysis period so that the observed, predicted, and expected accident frequencies are directly comparable. This calculation considers only observed accident frequencies and growth in ADT. For roadway segments and ramps, the units for this measure are acc/mi/yr. For intersections, the units are acc/yr.

- **Predicted Accident Frequency (Column 10):** This column on the output report presents the predicted accident frequency for that portion of the site identified as having the greatest potential for safety improvement. This predicted value is calculated directly from a safety performance function. This calculation does not consider the "observed" accidents at the site. This is essentially a preliminary calculation in the EB methodology. The predicted accident frequency is for the final year of the analysis period. For roadway segments and ramps, the units for this measure are acc/mi/yr. For intersections, the units are acc/yr.

- **Expected Accident Frequency (Column 11):** This column on the output report presents the expected accident frequency for that portion of the site identified as having the greatest potential for safety improvement. This expected value is calculated from a safety performance function and observed accident data. This is essentially the final output from the EB calculations. The expected accident frequency is for the final year of the analysis period. The value of the Expected Accident Frequency is always between the values for the Average Observed Accidents and the Predicted Accident Frequency for that portion of the site identified as having the greatest potential for safety improvement. The Expected Accident Frequency is the measure used to rank order sites for their potential for safety improvement. Sites with higher Expected Accident Frequencies have greater potential for safety improvement.
For roadway segments and ramps, the units for this measure are acc/mi/yr. For intersections, the units are acc/yr.

  If the analyst selects to screen based upon Excess Accident Frequency, the heading for Column 11 will be Excess Accident Frequency. The Excess Accident Frequency is calculated as the difference between the Expected Accident Frequency and the Predicted Accident Frequency. The units are the same for both expected and excess accident frequency.

- **Variance (Column 12):** This column on the output report presents the variance of the expected (or excess) accident frequency. For roadway segments and ramps, the units for this measure are $acc/mi^2/yr$. For intersections, the units are acc/yr.

- **Start Location (Column 13):** For roadway segments, this column on the output report presents the initial location (i.e., upstream boundary) of the window identified as having the highest potential for safety improvement. Thus, this is the initial location of the window that met the screening criteria and had the maximum (i.e., peak) expected or excess accident frequency. This column is left blank for intersections and ramps.

- **End Location (Column 14):** For roadway segments, this column on the output report presents the end location (i.e., downstream boundary) of the window identified as having the highest potential for safety improvement. Thus, this is the end location of the window that met the screening criteria and had the maximum (i.e., peak) expected or excess accident frequency. For intersections and ramps, this column is left blank. For peak searching the distance from the Start and End Location of the window with the highest potential for safety improvement will always be a multiple of 0.1 mi or will be the length of the entire site.

- **No. of Expected Fatalities (Column 15):** This column on the output report presents the expected number of fatalities for the final year of the analysis period for the location with the highest potential for safety improvement. This measure is provided only when the screening is based upon FI and FS accident severity levels. This measure is a prediction of the number of fatalities at the person level.

- **No. of Expected Injuries (Column 16):** This column on the output report presents the expected number of injuries for the final year of the analysis period for the location with the highest potential for safety improvement. This measure is provided only when the screening is based upon FI and FS accident severity levels. When screening is based upon the FI accident severity level, this measure is the expected number of all injuries. When screening is based upon the FS accident severity level, this measure is the expected number of severe injuries. This measure is a prediction of the number of injuries at the person level. Therefore, in most cases, the number of expected injuries will be greater than the expected injury accident frequency.

- **Rank:** The ranking of the site is based upon the expected or excess accident frequency. Sites with higher expected or excess accident frequencies are ranked higher in terms of their potential for safety improvement. Sites with lower expected or excess accident frequencies are ranked lower in terms of their potential for safety improvement.

- **Additional Windows of Interest:** For roadway segments, the entries in this column of the output report are the boundaries of other windows (i.e., subsegments) within the site that met the screening criteria but did not have the maximum (i.e. peak) expected or excess accident frequency. For intersections and ramps, this column is always blank.

Table 4 presents a prioritized list of sites generated using the basic network screening sliding window approach. Again, only the top 20 sites from the output report are shown in Table 4. The basic inputs that generated this sample output table are similar to those for the peak searching example above and are as follows:

- Conventional Network Screening
- Basic Network Screening (with Sliding Window on roadway segments)
- Accident Severity Level: Fatal and all injury accidents
- Safety Performance Measure: Expected accident frequency
- Window Length: 0.3 mi
- Window Increment: 0.1 mi
- Area Weights (Rural): 1.0
- Area Weights (Urban): 1.0
- Limiting Value (Roadway Segments): 1.0 acc/mi/yr
- Limiting Value (Intersections): 1.0 acc/yr
- Collision Type: Accident Type and Manner of Collision—All accident types
- Analysis Period: From 1995 To 2002

The column headings and information presented for Tables 3 and 4 are exactly the same. The only difference is the list of sites identified through the two screening methods. Of particular interest, note that both tables include many of the same sites (e.g., 15 of 20). For intersections (and ramps although not included on these output reports), output for the same sites are exactly the same, except for the ranking. In Table 4 for roadway segments, the length of the location with the highest potential for safety improvement is a window length of 0.3 mi or less if the window is positioned at the end of a contiguous set of sites. Also the expected accident frequencies for sites 1771, 1772, 1773, and 1774 are exactly the same. This is because the window with the highest potential for safety improvement for all four sites is the same, which means the window bridges the four contiguous adjacent sites.

Table 5 presents a prioritized list of sites generated using the test of high proportion of specific accident type. As the previous tables, only the top 20 sites from the output report are shown in Table 5. The basic inputs that generated this sample output table are as follows:

- Conventional Network Screening
- Screening for High Proportion of Specific Accident Type
- Accident Severity Level: Fatal and all injury accidents
- Window Length: 1.0 mi
- Window Increment: 0.1 mi
- Significance Level: 0.1
- Collision Type: Accident Type and Manner of Collision—Collision with fixed object
- Analysis Period: From 1995 to 2002

Table 4. Module 1—Conventional Network Screening Output Report: Basic Network Screening (With Sliding Window on Roadway Segments)

| ID | Site type | Site subtype | County | Route | Site start location | Site end location | Average observed accidents for entire site | Location with highest potential for safety improvement | | | | | | | | | Rank | Additional windows of interest |
								Average observed accidents	Predicted accident frequency	Expected accident frequency	Variance	Start location	End location	No. of expected fatalities	No. of expected injuries		
434	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	10.463		5.03	5.03	3.14	4.83	0.48	-	-	0.05	7.32	1	
437	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	11.26		4.06	4.06	2.73	3.88	0.42	-	-	0.04	5.89	2	
445	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	16.721		3.94	3.94	3.21	3.86	0.43	-	-	0.04	5.85	3	
163	Intersection	Int/Rur; 3-leg signalized	89	US00000074	159.615		3.24	3.24	1.97	3.03	0.51	-	-	0.04	4.48	4	
449	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	203.146		3.05	3.05	2.43	2.98	0.26	-	-	0.03	4.52	5	
447	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	202.419		2.88	2.88	2.81	2.87	0.28	-	-	0.03	4.35	6	
81	Intersection	Int/Urb; 4-leg signalized	89	US00000074	130.013		2.91	2.91	2.52	2.86	0.29	-	-	0.03	4.34	7	
78	Intersection	Int/Urb; 4-leg signalized	89	US00000074	129.156		2.90	2.90	2.51	2.85	0.29	-	-	0.03	4.32	8	
444	Intersection	Int/Urb; 4-leg minor-rd STOP	89	SR00000049	15.741		2.66	2.66	0.70	2.38	0.24	-	-	0.02	3.75	9	
439	Intersection	Int/Urb; 3-leg signalized	89	SR00000049	12.48		2.53	2.53	1.65	2.38	0.18	-	-	0.03	3.63	10	

Table 5. Module 1—Conventional Network Screening Output Report: High Proportion of Specific Accident Type (Continued)

ID	Site type	Site subtype	County	Route	Site start location	Site end location	Average observed accidents for entire site	Location with highest potential for safety improvement								Rank	Additional windows of interest
								Average observed accidents	Predicted accident frequency	Expected accident frequency	Variance	Start location	End location	No. of expected fatalities	No. of expected injuries		
79	Intersection	Int/Urb; 3-leg signalized	89	US00000074	129.609		2.58	2.58	1.29	2.32	0.16	-	-	0.03	3.54	11	
446	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	201.906		2.35	2.35	1.81	2.26	0.21	-	-	0.02	3.42	12	
705	Intersection	Int/Rur; 4-leg minor-rd STOP	89	SR00000110	6.938		0.21	0.21	2.14	2.14	0.00	-	-	0.05	3.86	13	
173	Intersection	Int/Urb; 4-leg signalized	89	US00000074	160.951		2.02	2.02	2.36	2.07	0.20	-	-	0.02	3.13	14	
69	Intersection	Int/Rur; 3-leg signalized	89	US00000074	119.12		1.95	1.95	2.57	2.01	0.27	-	-	0.03	2.98	15	
263	Intersection	Int/Urb; 4-leg minor-rd STOP	89	SR00000018	193.524		2.21	2.21	0.50	1.91	0.17	-	-	0.02	3.01	16	
1771	Segment	Seg/Urb; 2-lane arterial	89	SR00000049	204.69	205.168	0.33	1.75	0.26	1.72	0.04	205.148	205.354	0.02	2.53	17	
1772	Segment	Seg/Urb; 2-lane arterial	89	SR00000049	205.168	205.22	0.61	1.75	0.26	1.72	0.04	205.148	205.354	0.02	2.53	17	
1773	Segment	Seg/Urb; 2-lane arterial	89	SR00000049	205.22	205.254	1.82	1.75	0.26	1.72	0.04	205.148	205.354	0.02	2.53	17	
1774	Segment	Seg/Urb; 2-lane arterial	89	SR00000049	205.254	205.354	2.66	1.75	0.26	1.72	0.04	205.148	205.354	0.02	2.53	17	

Table 5. Module 1—Conventional Network Screening Output Report: High Proportion of Specific Accident Type

ID	Site type	Site subtype	County	Route	Site start location	Site end location	Location with highest potential for safety improvement			Limiting proportion	Probability that observed proportion exceeds limiting proportion	Difference between observed proportion and limiting proportion	Rank	Additional windows of interest
							Observed proportion	Start location	End location					
2227	Segment	Seg/Urb; 2-lane arterial	89	SR00000109	10.582	11.582	1.00	11.382	12.382	0.11	0.96	0.889	1	10.582-11.582, 10.682-11.682, 10.782-11.782, 10.882-11.882, 10.982-11.982, 11.082-12.082, 11.182-12.182, 11.282-12.282, 11.482-12.482
2228	Segment	Seg/Urb; 2-lane arterial	89	SR00000109	11.582	12.19	1.00	11.382	12.382	0.11	0.96	0.889	1	10.682-11.682, 10.782-11.782, 10.882-11.882, 10.982-11.982, 11.082-12.082, 11.182-12.182, 11.282-12.282, 11.482-12.482
2229	Segment	Seg/Urb; 2-lane arterial	89	SR00000109	12.19	12.579	1.00	11.382	12.382	0.11	0.96	0.889	1	11.282-12.282, 11.482-12.482
2136	Segment	Seg/Rur; 2-lane	89	SR00000108	89.056	89.759	1.00	89.346	90.346	0.19	0.97	0.811	4	89.446-90.446, 89.546-90.546, 89.646-90.646
2137	Segment	Seg/Rur; 2-lane	89	SR00000108	89.759	89.846	1.00	89.346	90.346	0.19	0.97	0.811	4	89.446-90.446, 89.546-90.546, 89.646-90.646
2138	Segment	Seg/Rur; 2-lane	89	SR00000108	89.846	90.018	1.00	89.346	90.346	0.19	0.97	0.811	4	89.446-90.446, 89.546-90.546, 89.646-90.646
2139	Segment	Seg/Rur; 2-lane	89	SR00000108	90.018	90.188	1.00	89.346	90.346	0.19	0.97	0.811	4	89.446-90.446, 89.546-90.546, 89.646-90.646
2140	Segment	Seg/Rur; 2-lane	89	SR00000108	90.188	90.208	1.00	89.346	90.346	0.19	0.97	0.811	4	89.446-90.446, 89.546-90.546, 89.646-90.646
2141	Segment	Seg/Rur; 2-lane	89	SR00000108	90.208	90.35	1.00	89.346	90.346	0.19	0.97	0.811	4	89.446-90.446, 89.546-90.546, 89.646-90.646
2142	Segment	Seg/Rur; 2-lane	89	SR00000108	90.35	90.77	1.00	89.446	90.446	0.19	0.97	0.811	4	89.546-90.546, 89.646-90.646
2204	Segment	Seg/Rur; 2-lane	89	SR00000108	116.511	116.977	1.00	116.545	117.545	0.19	0.97	0.811	4	116.645-117.645, 116.745-117.745, 116.845-117.845, 116.945-117.945
2205	Segment	Seg/Rur; 2-lane	89	SR00000108	116.977	117.501	1.00	116.545	117.545	0.19	0.97	0.811	4	116.645-117.645, 116.745-117.745, 116.845-117.845, 116.945-117.945, 117.045-118.045, 117.145-118.145, 117.245-118.245, 117.345-118.345

Table 5. Module 1—Conventional Network Screening Output Report: High Proportion of Specific Accident Type (Continued)

ID	Site type	Site subtype	County	Route	Site start location	Site end location	Location with highest potential for safety improvement			Limiting proportion	Probability that observed proportion exceeds limiting proportion	Difference between observed proportion and limiting proportion	Rank	Additional windows of interest
							Observed proportion	Start location	End location					
2206	Segment	Seg/Rur; 2-lane	89	SR00000108	117.501	117.727	1.00	116.545	117.545	0.19	0.97	0.811	4	116.645-117.645, 116.745-117.745, 116.845-117.845, 116.945-117.945, 117.045-118.045, 117.145-118.145, 117.245-118.245, 117.345-118.345, 117.645-118.645
2216	Segment	Seg/Rur; 2-lane	89	SR00000108	123.54	124.54	1.00	124.045	125.045	0.19	0.97	0.811	4	124.145-125.145, 124.245-125.245, 124.345-125.345, 124.445-125.445
2217	Segment	Seg/Rur; 2-lane	89	SR00000108	124.54	125.54	1.00	124.045	125.045	0.19	0.97	0.811	4	124.145-125.145, 124.245-125.245, 124.345-125.345, 124.445-125.445, 124.545-125.545, 124.645-125.645, 124.745-125.745, 124.845-125.845, 124.945-125.945, 125.045-126.045, 125.145-126.145, 125.245-126.245, 125.345-126.345
2218	Segment	Seg/Rur; 2-lane	89	SR00000108	125.54	126.54	1.00	125.245	126.245	0.19	0.97	0.811	4	124.545-125.545, 124.645-125.645, 124.745-125.745, 124.845-125.845, 124.945-125.945, 125.045-126.045, 125.145-126.145, 125.345-126.345
5217	Segment	Seg/Rur; 2-lane	89	SRT00000108	124.54	125.54	1.00	125.24	126.24	0.19	0.97	0.811	4	124.54-125.54, 124.64-125.64, 124.74-125.74, 124.84-125.84, 124.94-125.94, 125.04-126.04, 125.14-126.14, 125.34-126.34
5218	Segment	Seg/Rur; 2-lane	89	SRT00000108	125.54	126.54	1.00	125.24	126.24	0.19	0.97	0.811	4	124.64-125.64, 124.74-125.74, 124.84-125.84, 124.94-125.94, 125.04-126.04, 125.14-126.14, 125.34-126.34
1	Segment	Seg/Rur; Fwy (6+ ln)	89	I00000253	129.955	130.937	0.75	129.955	130.937	0.12	1.00	0.631	19	
2129	Segment	Seg/Rur; 2-lane	89	SR00000108	85.646	86.646	0.75	86.446	87.446	0.19	0.98	0.561	20	85.646-86.646, 86.046-87.046, 86.246-87.246, 86.346-87.346, 86.546-87.546

The majority of the columns in Table 5 are the same as those found in Tables 3 and 4. The only differences involve the columns that present information related to the safety performance of a site as follows:

- **Observed Proportion (Column 8):** This column on the output report presents the observed proportion of accidents of the specific collision type of interest, relative to all accidents for the given severity level. This proportion is based upon the observed accidents that occurred within the boundaries of the location with the highest potential for safety improvement.

- **Limiting Proportion (Column 11):** This column on the output report presents the limiting proportion is the proportion of accidents of the specific collision type of interest, relative to all accidents for the given severity level, and it is based upon data distributions for all sites of the same site subtype. For a site to be included on the output report, the probability that the observed proportion is greater than the limiting proportion must be greater than the user specified confidence level.

- **Probability that Observed Proportion Exceeds Limiting Proportion (Column 12):** This column on the output report presents the probability that the observed proportion is greater than the limiting proportion. Sites are included on the output report only if the probability is greater than the confidence level (i.e., 1-α, where α represents the significance level as shown in the basic inputs presented above) specified by the analyst.

- **Difference Between Observed Proportion and Limiting Proportion (Column 13):** Sites are ranked based on the difference between the observed proportion of accidents and the limiting proportion.

Table 6 presents a list of sites generated by screening for sudden increases in mean accident frequency. Nine sites met the screening criteria as specified below. The sites are not ranked relative to the other sites. The basic inputs that generated this sample output table are as follows:

- Conventional Network Screening
- Sudden Increase in Mean Accident Frequency
- Accident Severity Level: Fatal and all injury accidents
- Limiting Value: 150.0
- Significance Level: 0.1
- Collision Type: Accident Type and Manner of Collision—All accident types
- Analysis Period: From 1995 to 2002

The first seven columns are again the same as those on all previous tables and provide descriptive and location information for the entire site. The only new column is Year which displays the year in which a sudden increase in the mean accident frequency for the site was observed.

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Table 6. Module 1—Conventional Network Screening Output Report: Sudden Increase in Mean Accident Frequency

ID	Site type	Site subtype	County	Route	Site start location	Site end location	Year
446	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	201.906		2001
447	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	202.419		2001
434	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	10.463		1998
282	Intersection	Int/Urb; 3-leg minor-rd STOP	89	SR00000018	200.097		2001
592	Intersection	Int/Urb; 3-leg minor-rd STOP	89	SR00000108	103.695		2001
22	Intersection	Int/Rur; 4-leg minor-rd STOP	89	US00000023	300.188		2001
141	Intersection	Int/Rur; 4-leg minor-rd STOP	89	US00000074	152.065		2001
678	Intersection	Int/Rur; 4-leg minor-rd STOP	89	SR00000110	1.954		2000
672	Intersection	Int/Rur; 4-leg minor-rd STOP	89	SR00000110	0.199		1998

Table 7 presents a list of sites identified by screening for steady increases in mean accident frequency. Three sites met the screening criteria as specified below. The sites are not ranked relative to the other sites. Table 7 consists of the same seven columns common with the previous output reports. The basic inputs that generated this sample output table are as follows:

- Conventional Network Screening
- Steady Increase in Mean Accident Frequency
- Accident Severity Level: Fatal and all injury accidents
- Limiting Value: 0.0
- Significance Level: 0.1
- Collision Type: Accident Type and Manner of Collision—All accident types
- Analysis Period: From 1995 to 2002

Table 7. Module 1—Conventional Network Screening Output Report: Steady Increase in Mean Accident Frequency

ID	Site type	Site subtype	County	Route	Site start location	Site end location
2258	Segment	Seg/Rur; 2-lane	89	SR00000110	2.887	3.887
78	Intersection	Int/Urb; 4-leg signalized	89	US00000074	129.156	78
434	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	10.463	434

Table 8 presents a list of corridors generated using the corridor screening approach. Twenty corridors were included in this analysis. The basic inputs that generated this sample output table are as follows:

- Conventional Network Screening
- Corridor Screening
- Accident Severity Level: Fatal and all injury accidents
- Safety Performance Measure: Accidents/mi/yr
- Collision Type: Accident Type and Manner of Collision—All accident types
- Analysis Period: From 1995 to 2002

Table 8. Module 1—Conventional Network Screening Output Report: Corridor Screening

Corridor	County	Route	Corridor start location	Corridor end location	Average acc/mi/yr	Rank
13	34	00000312	230.731	233.077	12.25	1
14	34	00000312	233.077	236.319	9.75	2
6	34	00000253W	8.741	15.702	6.24	3
15	69	00000312	236.319	241.935	5.76	4
7	34	00000253W	16.916	21.789	4.75	5
3	69	00000253E	107.524	114.104	3.23	6
1	89	00000253	129.955	132.939	2.76	7
16	69	00000312	242.052	247.664	2.63	8
12	34	00000312	223.444	230.731	2.62	9
11	34	00000312	216.903	223.444	2.45	10
5	34	00000253W	4.282	8.741	2.19	11
8	69	00000253W	21.789	26.737	1.77	12
19	89	00000312	247.664	249.139	1.60	13
20	89	00000312	248.915	258.727	1.41	14
10	34	T00000312	205.369	210.979	1.37	15
4	69	00000253E	114.104	120.382	1.15	16
2	69	00000253E	102.597	107.524	0.81	17
9	69	00000253W	26.737	30.697	0.79	18
18	80	T00000312	157.883	162.55	0.69	19
17	80	00000312	121.127	157.883	0.52	20

The first few columns of Table 8 (Corridor, County Route, Corridor Start Location, and Corridor End Location) provide descriptive and location information for the entire corridor. The other two columns present information on the safety performance of the corridors as follows:

- **Average acc/mi/yr (Column 6):** This value is based on observed accidents for a given corridor. The units of measurement are accidents per mile per year. If the analyst selects to screen based upon Accidents/mvmt/yr, then the heading for Column 6 will be Accident/mvmt/yr, and the units will be the number of accidents per million vehicle miles traveled per year.

  There is a slight difference in this safety performance measure compared to similar measures for basic network screening using the peak searching and sliding window approaches. For corridor screening, the average observed accident frequency (i.e., acc/mi/yr) and the average observed accident rate (i.e., acc/mvmt/yr) are the averages across the entire analysis period, whereas when screening using the peak searching and sliding window approaches, the average accident frequencies reflect estimates for the last year of the analysis period.

- **Rank (Column 7):** The corridors are ranked in descending order of accident/mi/yr or accident/mvmt/yr.

A unique feature of the corridor screening approach is that all corridors included in the analysis are included in the output report. No corridors are excluded from the output report based upon the screening criteria. Thus, the number of corridors included in the site list being analyzed will also be the number of corridors included on the output report.

2.12 Percentage Output Reports

Tables 3 through 8 are based on conventional network screening capabilities within *SafetyAnalyst*. An alternative capability for generating output reports allows the analyst to limit network screening output reports to a user-specified percentage of the site list. Percentage reports can be generated for basic network screening peak searching and sliding window approaches and corridor screening. The processes of identifying sites for a percentage report are very similar to the network screening processes for conventional network screening with some minor variations. When the analyst specifies the percentage report option, sites are rank ordered by the safety performance measure within each of the three site types (i.e., roadway segments, intersections, and ramps) for the peak searching and sliding window approaches. This differs from the process used in conventional network screening in which sites are rank ordered by the safety performance measure without regard to site type. Sites that exceed the specified Maximum Percentage of Sites for each site type are not included on the output report (i.e., for each site type, the sites with the lowest safety performance measure values identified by network screening are dropped from the site list until the number sites retained do not exceed the specified maximum percentage of sites). For example, when the analyst specifies the maximum percentage of sites to be X percent, the sites included on the output report for each site type are limited as follows:

- For roadway segments, sites that have the highest safety performance measure values (i.e., expected or excess accident frequencies) and whose cumulative segment lengths do not exceed X percent of the cumulative segment length of roadway segments on the site list being analyzed are included on the percentage report output. If at least one roadway segment on the site list being analyzed meets the screening criteria, then at least one roadway segment is included on the percentage report output.

- For intersections, sites that have the highest safety performance measure values (i.e., expected or excess accident frequencies) are included on the percentage report output such that the number of intersections does not exceed X percent of the total number of intersections on the site list being analyzed. If at least one intersection on the site list being analyzed meets the screening criteria, then at least one intersection is included on the percentage report output.

- For ramps, sites that have the highest safety performance measure values (i.e., expected or excess accident frequencies) are included on the percentage report

output such that the number of ramps does not exceed X percent of the total number of ramps on the site list being analyzed. If at least one ramp on the site list being analyzed meets the screening criteria, then at least one ramp is included on the percentage report output.

When the analyst specifies the percentage report option and selects corridor screening, corridors that have the highest safety performance measure values (i.e., average accidents per mile per year or average accidents per million vehicle miles of travel per year) and whose cumulative corridor lengths do not exceed X percent of the cumulative corridor lengths on the site list being analyzed are included on the percentage report output. At least one corridor is always included on the percentage report output for corridor screening.

Although the percentage report capability within *SafetyAnalyst* is intended to help agencies identify sites for inclusion on their 5 percent reports, the percentage report feature is broader in scope. The analyst specifies the maximum percentage of sites to include on the output report. *SafetyAnalyst* does not limit the analyst into specifying 5 percent of sites for the analysis. This flexibility makes the percentage report feature useful for applications other than the creation of a formal 5 percent report.

The tables that follow are based on network screening capabilities utilizing the percentage report feature. Tables 9 and 10 present a percentage report generated using the basic network screening peak searching approach. The same site list used to generate Table 3 is used in this analysis. The only differences in the inputs to the generation of Tables 9 and 10 compared to Table 3 are specifying (a) percentage reports rather than conventional network screening and (b) 5 percent for the maximum percentage of sites for inclusion in the percentage report outputs. At the bottom of each percentage report by site type, summary information is reported concerning the total number of sites ranked and the percentage of sites included in the report, either based on length or the number of sites in site list. Of particular interest, in Table 9 the percentages of roadway segment sites meeting the screening criteria (i.e., 1.1 percent) is much less than the maximum 5 percent of sites potentially included on the output report, whereas in Table 10 the percentage of intersections meeting the screening criteria (i.e., 4.7 percent) is around the maximum of 5 percent of sites potentially included on the output report.

Tables 11 and 12 present a percentage report generated using the basic network screening sliding window approach. The same site list used to generate Table 4 is used in this analysis. The only differences in the inputs specified in the generation of Tables 11 and 12 compared to Table 4 are specifying (a) percentage reports rather than conventional network screening and (b) 5 percent for the maximum percentage of sites for inclusion in the percentage report outputs. Comparing Tables 9 and 11, just a slightly higher percentage of sites in terms of length are included in Table 11 compared to Table 9. Tables 10 and 12 are exactly the same.

Table 9. Module 1—Percentage Report: Basic Network Screening (With Peak Searching on Roadway Segments and CV Test)— Roadway Segments

| ID | Site type | Site subtype | County | Route | Site start location | Site end location | Average observed accidents for entire site | Location with highest potential for safety improvement | | | | | | | | Rank | Additional windows of interest |
								Average observed accidents	Predicted accident frequency	Expected accident frequency	Variance	Start location	End location	No. of expected fatalities	No. of expected injuries		
2212	Segment	Seg/Rur; 2-lane	89	SR00000108	121.477	121.479	9.98	9.98	0.04	5.90	0.07	121.477	121.479	0.37	8.62	1	
1774	Segment	Seg/Urb; 2-lane arterial	89	SR00000049	205.254	205.354	2.66	2.66	0.34	2.62	0.07	205.254	205.354	0.03	3.86	2	
447	Segment	Seg/Rur; Fwy in intchng area (4 ln)	89	I00000312	258.141	258.207	2.92	2.92	0.64	2.38	0.09	258.141	258.207	0.07	3.66	3	
2173	Segment	Seg/Urb; 2-lane arterial	89	SR00000108	104.035	104.141	2.03	2.15	0.12	2.02	0.07	104.041	104.141	0.02	2.98	4	104.035-104.135
2	Segment	Seg/Urb; Fwy (6 ln)	89	I00000253	130.937	131.273	0.86	2.17	0.63	2.02	0.07	130.937	131.037	0.04	2.84	5	
1773	Segment	Seg/Urb; 2-lane arterial	89	SR00000049	205.22	205.254	1.82	1.82	0.19	1.79	0.03	205.22	205.254	0.02	2.64	6	
2460	Segment	Seg/Urb; 2-lane arterial	89	SR00000257	2.537	3.005	0.41	1.14	0.17	1.10	0.04	2.637	2.737	0.01	1.61	7	
438	Segment	Seg/Rur; Fwy in intchng area (6+ ln)	89	I00000312	253.675	254.2	0.24	1.26	0.31	1.02	0.02	253.675	253.775	0.03	1.79	8	

Total Roadway Segments Ranked = 8 out of 416 total segments in site list.
Total Roadway Segment Length Ranked = 1.637 out of 147.262 total segment length in site list.
Percentage of Roadway Segment Length Ranked = 1.1

Table 10. Module 1—Percentage Report: Basic Network Screening (With Peak Searching on Roadway Segments and CV Test)—Intersections

ID	Site type	Site subtype	County	Route	Site start location	Site end location	Average observed accidents for entire site	Location with highest potential for safety improvement								Rank	Additional windows of interest
								Average observed accidents	Predicted accident frequency	Expected accident frequency	Variance	Start location	End location	No. of expected fatalities	No. of expected injuries		
434	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	10.463		5.03	5.03	3.14	4.83	0.48	-	-	0.05	7.32	1	
437	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	11.26		4.06	4.06	2.73	3.88	0.42	-	-	0.04	5.89	2	
445	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	16.721		3.94	3.94	3.21	3.86	0.43	-	-	0.04	5.85	3	
163	Intersection	Int/Rur; 3-leg signalized	89	US00000074	159.615		3.24	3.24	1.97	3.03	0.51	-	-	0.04	4.48	4	
449	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	203.146		3.05	3.05	2.43	2.98	0.26	-	-	0.03	4.52	5	
447	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	202.419		2.88	2.88	2.81	2.87	0.28	-	-	0.03	4.35	6	
81	Intersection	Int/Urb; 4-leg signalized	89	US00000074	130.013		2.91	2.91	2.52	2.86	0.29	-	-	0.03	4.34	7	
78	Intersection	Int/Urb; 4-leg signalized	89	US00000074	129.156		2.90	2.90	2.51	2.85	0.29	-	-	0.03	4.32	8	
444	Intersection	Int/Urb; 4-leg minor-rd STOP	89	SR00000049	15.741		2.66	2.66	0.70	2.38	0.24	-	-	0.02	3.75	9	
439	Intersection	Int/Urb; 3-leg signalized	89	SR00000049	12.48		2.53	2.53	1.65	2.38	0.18	-	-	0.03	3.63	10	
79	Intersection	Int/Urb; 3-leg signalized	89	US00000074	129.609		2.58	2.58	1.29	2.32	0.16	-	-	0.03	3.54	11	
446	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	201.906		2.35	2.35	1.81	2.26	0.21	-	-	0.02	3.42	12	
705	Intersection	Int/Rur; 4-leg minor-rd STOP	89	SR00000110	6.938		0.21	0.21	2.14	2.14	0.00	-	-	0.05	3.89	13	
173	Intersection	Int/Urb; 4-leg signalized	89	US00000074	160.951		2.02	2.02	2.36	2.07	0.20	-	-	0.02	3.13	14	
69	Intersection	Int/Rur; 3-leg signalized	89	US00000074	119.12		1.95	1.95	2.57	2.01	0.27	-	-	0.03	2.98	15	

Number of Intersections Ranked = 15 out of 316 total intersections in site list.
Percentage of Intersections Ranked = 4.7

Table 11. Module 1—Percentage Report: Basic Network Screening (With Sliding Window on Roadway Segments)—Roadway Segments

| ID | Site type | Site subtype | County | Route | Site start location | Site end location | Average observed accidents for entire site | Location with highest potential for safety improvement | | | | | | | | Rank | Additional windows of interest |
								Average observed accidents	Predicted accident frequency	Expected accident frequency	Variance	Start location	End location	No. of expected fatalities	No. of expected injuries		
1771	Segment	Seg/Urb; 2-lane arterial	89	SR00000049	204.69	205.168	0.33	1.75	0.26	1.72	0.04	205.148	205.354	0.02	2.53	1	
1772	Segment	Seg/Urb; 2-lane arterial	89	SR00000049	205.168	205.22	0.61	1.75	0.26	1.72	0.04	205.148	205.354	0.02	2.53	1	
1773	Segment	Seg/Urb; 2-lane arterial	89	SR00000049	205.22	205.254	1.82	1.75	0.26	1.72	0.04	205.148	205.354	0.02	2.53	1	
1774	Segment	Seg/Urb; 2-lane arterial	89	SR00000049	205.254	205.354	2.66	1.75	0.26	1.72	0.04	205.148	205.354	0.02	2.53	1	
2172	Segment	Seg/Urb; 2-lane arterial	89	SR00000108	103.803	104.035	0.46	1.09	0.12	1.03	0.03	103.846	104.141	0.01	1.51	5	
2173	Segment	Seg/Urb; 2-lane arterial	89	SR00000108	104.035	104.141	2.03	1.09	0.12	1.03	0.03	103.846	104.141	0.01	1.51	5	
1	Segment	Seg/Rur; Fwy (6+ ln)	89	I00000253	129.955	130.937	0.30	1.22	0.44	1.01	0.03	130.755	131.055	0.00	1.39	7	
2	Segment	Seg/Urb; Fwy (6 ln)	89	I00000253	130.937	131.273	0.86	1.22	0.44	1.01	0.03	130.755	131.055	0.02	1.42	7	

Total Roadway Segments Ranked = 8 out of 416 total segments in site list.
Total Roadway Segment Length Ranked = 2.320 out of 147.262 total segment length in site list.
Percentage of Roadway Segment Length Ranked = 1.6

Table 12. Module 1—Percentage Report: Basic Network Screening (With Sliding Window on Roadway Segments)—Intersections

ID	Site type	Site subtype	County	Route	Site start location	Site end location	Average observed accidents for entire site	Location with highest potential for safety improvement								Rank	Additional windows of interest
								Average observed accidents	Predicted accident frequency	Expected accident frequency	Variance	Start location	End location	No. of expected fatalities	No. of expected injuries		
434	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	10.463		5.03	5.03	3.14	4.83	0.48	-	-	0.05	7.32	1	
437	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	11.26		4.06	4.06	2.73	3.88	0.42	-	-	0.04	5.89	2	
445	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	16.721		3.94	3.94	3.21	3.86	0.43	-	-	0.04	5.85	3	
163	Intersection	Int/Rur; 3-leg signalized	89	US00000074	159.615		3.24	3.24	1.97	3.03	0.51	-	-	0.04	4.48	4	
449	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	203.146		3.05	3.05	2.43	2.98	0.26	-	-	0.03	4.52	5	
447	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	202.419		2.88	2.88	2.81	2.87	0.28	-	-	0.03	4.35	6	
81	Intersection	Int/Urb; 4-leg signalized	89	US00000074	130.013		2.91	2.91	2.52	2.86	0.29	-	-	0.03	4.34	7	
78	Intersection	Int/Urb; 4-leg signalized	89	US00000074	129.156		2.90	2.90	2.51	2.85	0.29	-	-	0.03	4.32	8	
444	Intersection	Int/Urb; 4-leg minor-rd STOP	89	SR00000049	15.741		2.66	2.66	0.70	2.38	0.24	-	-	0.02	3.75	9	
439	Intersection	Int/Urb; 3-leg signalized	89	SR00000049	12.48		2.53	2.53	1.65	2.38	0.18	-	-	0.03	3.63	10	
79	Intersection	Int/Urb; 3-leg signalized	89	US00000074	129.609		2.58	2.58	1.29	2.32	0.16	-	-	0.03	3.54	11	
446	Intersection	Int/Urb; 4-leg signalized	89	SR00000049	201.906		2.35	2.35	1.81	2.26	0.21	-	-	0.02	3.42	12	
705	Intersection	Int/Rur; 4-leg minor-rd STOP	89	SR00000110	6.938		0.21	0.21	2.14	2.14	0.00	-	-	0.05	3.89	13	
173	Intersection	Int/Urb; 4-leg signalized	89	US00000074	160.951		2.02	2.02	2.36	2.07	0.20	-	-	0.02	3.13	14	
69	Intersection	Int/Rur; 3-leg signalized	89	US00000074	119.12		1.95	1.95	2.57	2.01	0.27	-	-	0.03	2.98	15	

Number of Intersections Ranked = 15 out of 316 total intersections in site list.
Percentage of Intersections Ranked = 4.7

Table 13 presents a percentage report generated based upon corridor screening. The same site list used in the previous corridor screening example that generated Table 8 is used in this analysis. All other inputs are the same, except that 10 percent is specified for the maximum percentage of sites (i.e., corridors) for inclusion in the percentage report outputs. In this example, the top three corridors are included in the percentage report, accounting for approximately 9 percent of the total corridor length analyzed.

Table 13. Module 1—Percentage Report: Corridor Screening

Corridor	County	Route	Corridor start location	Corridor end location	Average acc/mi/yr	Rank
13	34	00000312	230.731	233.077	12.25	1
14	34	00000312	233.077	236.319	9.75	2
6	34	00000253W	8.741	15.702	6.24	3

Total Corridors Ranked = 3 out of 20 total corridors in site list.
Total Corridor Length Ranked = 13.880 out of 159.566 total corridor length in site list.
Percentage of Corridor Length Ranked = 8.7.

2.13 Benefits of *SafetyAnalyst*'s Network Screening Capabilities

The primary benefits associated with utilizing *SafetyAnalyst*'s network screening capabilities include:

- Application of state-of-the-art procedures
- More reliable selection of sites for potential safety improvement
- Flexibility to cover a wide range of needs
- Capability to apply multiple network screening methods

Most current methods used by agencies for network screening to identify sites for potential safety improvement have been found to be biased. For any given site, these current methods rely on a relatively small numbers of accidents during relatively short time periods. Such small accident samples are potentially biased due to a statistical phenomenon known as *regression to the mean*. For any site with high short-term accident experience, the frequency of accidents is likely to decrease in the future (or "regress to the mean"), whether the site is improved or not. Traditional safety analysis procedures have often mistaken this natural decrease following a period with higher accident frequency for the effect of a safety improvement project. This bias leads to overoptimistic forecasts of the expected effectiveness of safety projects and disappointing results when projects are actually implemented.

The basic network screening methodologies within *SafetyAnalyst* (i.e., the peak searching and sliding window approaches) include procedures to compensate for regression to the mean and, thus, provide more reliable assessments of the safety performance of a site. This greater accuracy in estimating the safety performance of sites helps assure that highway agencies can make better safety improvement decisions.

The network screening capabilities within *SafetyAnalyst* also offer significant flexibility for analysts to conduct a wide range of network screening needs. In particular,

SafetyAnalyst provides the flexibility to easily modify inputs to create reports of desired length either through modifying the screening criteria or through the generation of percentage reports. Also, no single network screening approach is the preferred methodology for all situations. *SafetyAnalyst* incorporates six different network screening methodologies. By providing multiple screening methods, *SafetyAnalyst* provides a wide range of network screening needs, covering most situations or types of network screening analyses that analysts perform (or should perform) on a regular basis. In addition to incorporating multiple screening methods, *SafetyAnalyst* provides the capability to conduct analyses on wide range of collision types and accident severity levels, again adding to the range of situations or types of network screening analyses that can be performed.

Finally, because no single network screening approach is the preferred methodology for all situations, *SafetyAnalyst* provides the capability to analyze the entire roadway network, or portions of the roadway network, under the jurisdiction of a highway agency using multiple approaches. Analyzing the same set of sites through multiple approaches leads to better selection of sites for potential safety improvement. When sites are identified with more than one approach, there is greater confidence that the sites are good candidates for further investigation.

3. CAPABILITIES FOR MODULE 2—DIAGNOSIS AND COUNTERMEASURE SELECTION

This section of the report provides an overview of the capabilities of *SafetyAnalyst* Module 2 which performs diagnosis and countermeasure selection. The purpose of the diagnosis and countermeasure selection module is to guide the analyst in the diagnosis of potential safety concerns and the selection of a possible array of countermeasures for a specific site to mitigate the safety concern. This module combines the second and third steps of the safety management process into one module. A site evaluated with the diagnosis and countermeasure selection module may have been selected through the network screening process or may have been selected by the analyst on some other basis.

To diagnose potential of safety concerns at a specific site, this module provides the capability to:

- Generate accident summary statistics
- Generate collision diagrams
- Conduct statistical tests on accident frequencies and/or proportions

The primary intent of these three capabilities is to help the analyst identify certain accident patterns of interest for further diagnostic evaluation.

Although analysis of accident patterns is critical to diagnosis, it is not sufficient. Through the use of an "expert" system, this module also guides the analyst through appropriate office and field investigations to identify particular safety concerns at a site. This diagnostic process includes both traditional engineering considerations as well as a strong human factors component, to help diagnose safety concerns at a site. For example, some diagnostic questions are based on a highway design and traffic engineering approach; wherein design conditions associated with accidents at other sites are identified, and some diagnostic questions are based on a human factors approach; wherein the driver's interaction with the road environment is analyzed with respect to information requirements and task load.

The end result of the diagnostic process is a list of potential countermeasures that, if implemented at the site, could serve to mitigate particular accident patterns. The decision as to which countermeasure or countermeasures will be implemented needs expert judgment and is made by the analyst, and not by the software. The analyst may make this decision based on the output of the diagnosis and countermeasure selection tools, or the analyst may elect to proceed to the economic appraisal and priority ranking tools (i.e., Module 3) for additional input to make this decision. The analyst should also consider all other available information on site-specific conditions and highway agency policies and experience in deciding which countermeasure(s) to implement.

This module is intended for use by an analyst knowledgeable about safety. As part of the diagnostic process, answers to some of the diagnostic questions are not self-evident and

depend on expert judgment. Similarly, although through the expert system *SafetyAnalyst* suggests potential countermeasures based upon responses input by the analyst, the decision as to which countermeasure or countermeasures will actually be implemented or will be considered further through economic analyses is made by the analyst. The analyst should have some knowledge of the countermeasure before making this decision.

The remainder of this section presents the following. First, the three tools provided within *SafetyAnalyst* for diagnosing safety concerns through the identification of accident patterns of interest are discussed. Second, details concerning the expert system that guides the analyst through a series of diagnostic questions to aid in the identification of potential countermeasures for implementation are presented. Third, the primary outputs from the diagnostic and countermeasure selection process are presented. The section concludes with the benefits associated with the diagnostic and countermeasure selection capabilities provided within *SafetyAnalyst*.

3.1 Diagnosis—Identification of Accident Patterns of Interest

The diagnosis of potential safety concerns at a site begins by analyzing accident data. Three tools are provided within *SafetyAnalyst* for identifying accident patterns of interest (i.e., those accident patterns or collision types that may be over-represented at a site or simply that a high number of these collision types occur at the site and it is desirable to reduce this frequency) from the accident data. These tools include:

- Accident summary statistics
- Collision diagrams
- Statistical tests

Figure 13 shows the input screen where the analyst specifies which approach will be used to identify accident patterns of interest. The analyst is encouraged to use more than one approach.

Prior to selecting an approach for identifying accident patterns of interest, the analyst specifies the following parameters to filter the accident data that will be considered by these tools:

- **Analysis Direction**: The analyst has the option to include only those accidents that occurred in a given direction.

- **Accident Severity**: The analyst selects from four primary accident severity levels upon which to base the analysis: total (TOT) accidents, fatal and all injury (FI) accidents, fatal and severe injury (FS) accidents, and property-damage-only (PDO) accidents.

Figure 13. Module 2—Input Screen to Select Diagnostic Tools for Identifying Accident Patterns of Interest

- **Analysis Limits**: For roadway segments, the analyst may include those accidents that occurred along the entire portion of the site, or only a limited portion of the site, by specifying start and end locations. These limits are not applicable when the site is an intersection or a ramp.

- **Analysis Period**: The analyst specifies the years of data for the analysis. The analysis will include only those accidents for the specified years. The analyst has the option to limit the analysis period to exclude years prior to major reconstruction. If the *SafetyAnalyst* database indicates major reconstruction occurred at the site and the analyst selects this option, only those years following major reconstruction are included in the analysis. Major reconstruction is broadly defined to occur when reconstruction or an implemented countermeasure causes a change in the site subtype. Excluding years prior to major reconstruction is recommended for more accurate analysis of the safety performance, given the most current site conditions.

Figure 14 presents the input screen where the analyst specifies these four filtering parameters for the analysis.

Samples of accident summary statistics, a collision diagram, and a statistical test are presented below in the respective sections. The samples provided are based on the same urban four-leg signalized intersection. The basic inputs that generated the sample outputs are as follows:

- Analysis Direction: Northbound, Southbound, Eastbound, and Westbound
- Accident Severity Level: Total accidents
- Collision Type: Accident Type and Manner of Collision
- Analysis Period: From 1995 to 2002

Figure 14. Module 2—Input Screen With Filtering Parameters for Use in Identifying Accident Patterns of Interest

3.1.1 Accident Summary Statistics

The analyst has the ability to create an accident summary report for a site. The report is based strictly on observed accidents for the given site. The analyst can generate accident summary statistics for a broad range of common accident attributes, including:

- Accident month
- Accident severity level
- Accident time of day
- Alcohol/drug involvement
- Bicycle indicator
- Collision type (Accident type and manner of collision)
- Contributing circumstances, environment
- Contributing circumstances, road
- Day of week
- Driver age
- Driveway indicator

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- First harmful event
- Initial direction of travel
- Light condition
- Number of vehicles involved
- Pedestrian indicator
- Relationship to junction
- Roadway surface condition
- Run-off road indicator
- School bus indicator
- Tow-away indicator
- Vehicle configuration
- Vehicle maneuver/action
- Vehicle turning movement
- Weather condition
- Work zone related

The analyst can specify three separate ways to display the accident data: tables, bar charts, and pie charts. In tabular form, accident frequencies are provided by year and totals, observed proportions/percentages are provided for the site, and statewide proportions are provided when available. On bar charts, observed accident frequencies are shown by year. On pie charts, total accident frequencies are illustrated along with observed proportions. Table 14 and Figures 15 and 16 present sample accident summary statistics for accident type and manner of collision. In this sample data, rear-end accidents appear to be an accident pattern of interest for further investigation, based both on the frequency of occurrence and given that rear-end accidents account for approximately 68 percent of the accidents at the given site and at similar sites rear-end accidents account for approximately 56 percent of the accidents.

Table 14. Module 2—Sample Accident Summary Statistics for Accident Type Manner of Collision for an Urban 4-Leg Signalized Intersection (Tabular Form)

| Description	1995	1996	1997	1998	1999	2000	2001	2002	Total	Observed percent	Average percent
Collision with bicyclist	0	0	0	0	2	0	1	0	3	3	1
Collision with fixed object	0	1	0	0	0	0	0	0	1	1	2
Collision with other object	0	0	0	0	0	1	0	0	1	1	1
Overturn	0	0	1	0	0	0	0	0	1	1	0
Fire or explosion	0	0	0	0	0	0	0	1	1	1	0
Rear-end	9	11	6	8	6	7	11	7	65	68	56
Angle	1	1	3	2	4	1	4	0	16	17	25
Sideswipe, same direction	0	1	0	0	0	0	0	0	1	1	4
Other multiple-vehicle collision	2	0	2	0	1	1	1	0	7	7	5
Total Accidents	12	14	12	10	13	10	17	8	96	100	100
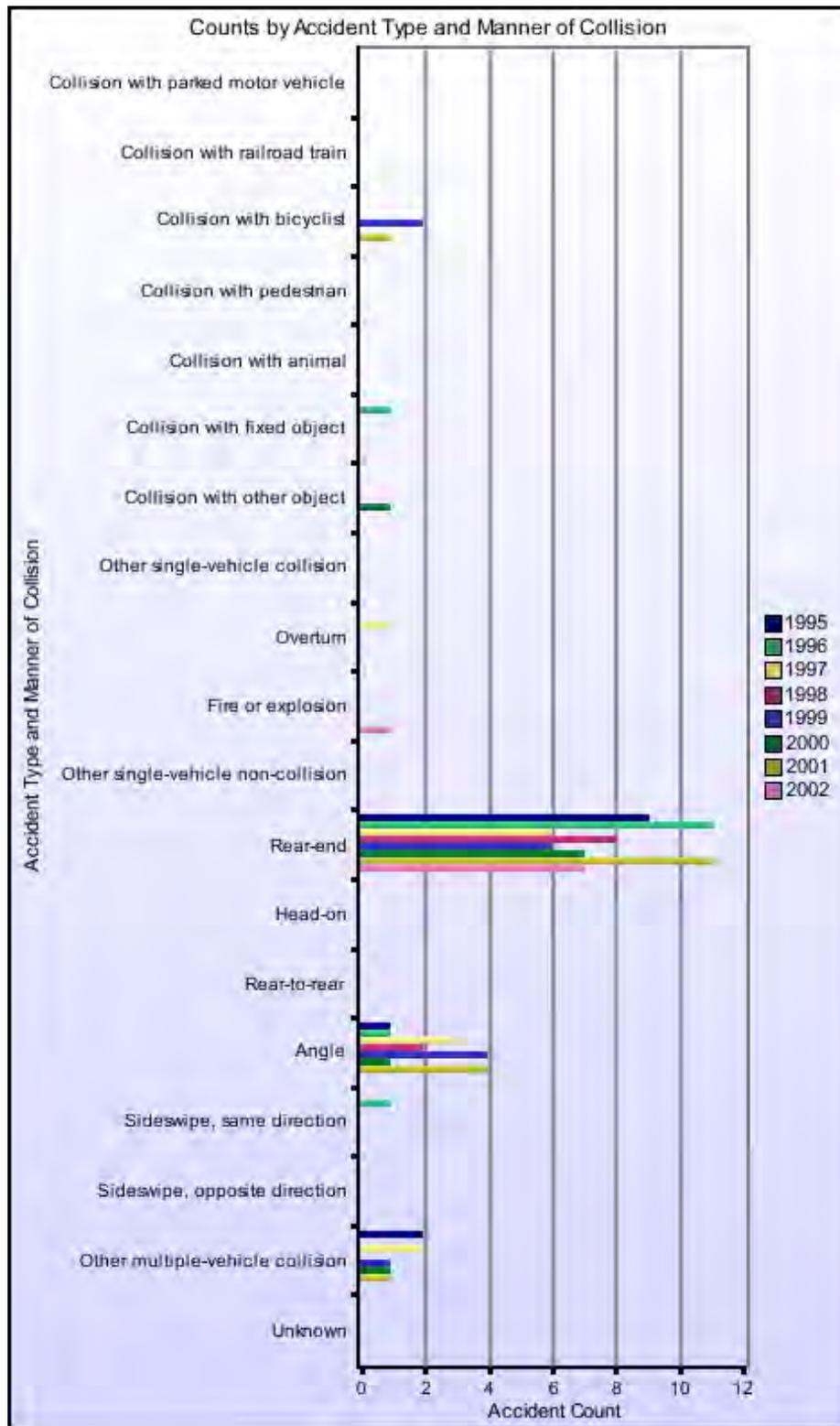
Figure 15. Module 2—Sample Accident Summary Statistics for Accident Type Manner of Collision for an Urban 4-Leg Signalized Intersection (Bar Chart)

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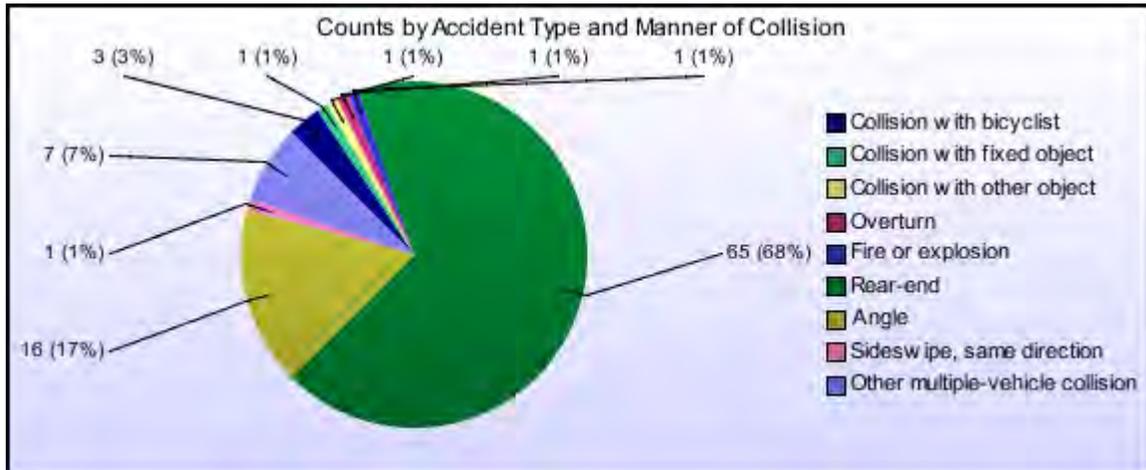
Figure 16. Module 2—Sample Accident Summary Statistics for Accident Type Manner of Collision for an Urban 4-Leg Signalized Intersection (Pie Chart)

3.1.2 Collision Diagrams

A collision diagram is a visual representation of the accident history at a given location. Each accident is represented on the diagram with schematic arrows and symbols. Abbreviated text may also be used to provide additional information about the accident that cannot be easily illustrated. Collision diagrams are useful to traffic and safety engineers because they provide a visual tool for quickly identifying patterns of accidents and high frequency accident types visually.

SafetyAnalyst provides the capability to create a basic collision diagram for three- and four-leg intersections, roadway segments, and ramps. The schematic type is always based upon collision type (i.e., accident type and manner of collision). The collision type schematic illustrates collisions classified as rear-end, angle, sideswipe, etc. The analyst can also generate collision diagrams that illustrate accident severity level, day of week, accident date, accident time, weather condition, light condition, surface condition, or driver age as an annotation to each collision schematic. A legend is provided for each collision diagram created and is customized for the schematic type and schematic text shown.

In some cases, certain accident characteristics necessary for plotting the collision on the diagram are not available (e.g. vehicle maneuver or direction of travel is unknown). When any of the collisions cannot be drawn due to missing information, the analyst is given the option to list all of the collisions not plotted in a supplemental table.

While *SafetyAnalyst*'s collision diagram capabilities are an appropriate tool to aid analysts in recognizing accident patterns and high frequency accident types, it is a basic tool. *SafetyAnalyst* is designed to be compatible with more thorough and complete commercial collision diagram software.

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Figure 17 illustrates a sample collision diagram. In this collision diagram, the schematics are annotated with accident severity levels. The legend depicts the meaning of each schematic. Given the frequency of rear-end accidents at this particular location, rear-end accidents appear to be an accident pattern of interest that the analyst may wish to investigate further as part of the diagnostic and countermeasure selection process.
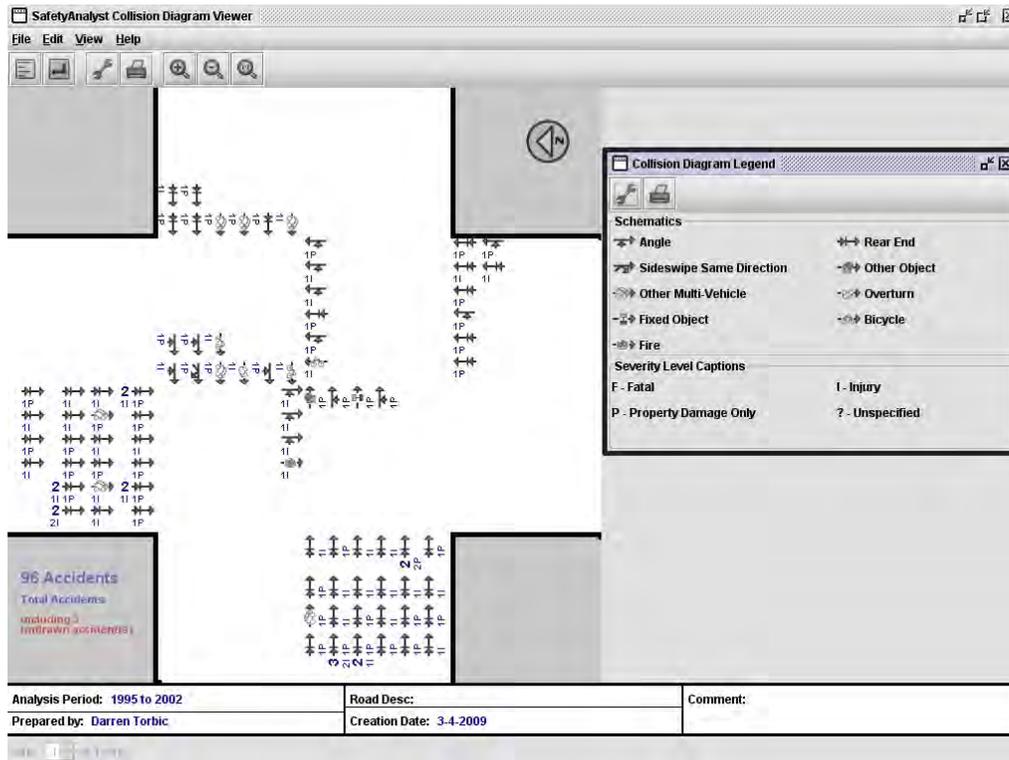
Figure 17. Module 2—Sample Collision Diagram for an Urban 4-Leg Signalized Intersection

3.1.3 Statistical Tests

SafetyAnalyst provides two basic statistical procedures for identifying accident patterns of interest for diagnosis and countermeasure selection. Statistical tests are performed based upon accident frequencies and accident proportions. Over representation of an accident pattern may be indicated by (1) a large count of accidents of a given collision type, (2) a large proportion of those accidents compared to proportions for similar sites, and/or (3) a combination of both. Statistical tests of both frequencies and proportions may be needed to determine whether a specific accident pattern deserves further attention. It is left to the analyst to weigh the outcome of one test compared to the other for a particular situation. For the detailed algorithms of both the test of frequencies and test of proportions, the reader is referred to Appendix B.

3.1.3.1 Test of Accident Frequencies

Two comparisons of accident frequencies are conducted at a site, or for a project, to assess whether the accident frequencies are larger than expected and deserve further investigation. The test of accident frequencies is based on comparing the average observed accident frequency and the average EB-adjusted accident frequency to a certain limiting value (i.e., minimum accident frequency). Average observed accident frequencies and average EB-adjusted accident frequencies are calculated for individual collision types and for all collision types combined. When either the average observed accident frequency or average EB-adjusted accident frequency for an individual collision type is greater than or equal to the limiting value, the collision type is highlighted for potential further investigation. The limiting value is specified by the analyst prior to running the test.

Table 15 presents the results of a test of frequencies. In this example, a limiting value of 1 accident/yr was specified.

Table 15. Module 2—Test of Frequencies and Proportions—Accident Pattern Identification

	Average observed accident frequency	Average EB-adjusted accident frequency	Observed proportion (%)	Limiting proportion (%)	Probability observed proportion exceeds limiting proportion
All Accident Attributes					
Accident Type and Manner of Collision					
Collision with pedestrian	0.25	0.24	1.8	0.7	0.77
Collision with animal	0.12	0.12	0.9	0.2	*1.00*
Collision with fixed object	0.12	0.12	0.9	1.9	0.37
Other single-vehicle collision	0.38	0.36	2.7	2.7	0.42
Overturn	0.12	0.12	0.9	0.3	*1.00*
Rear-end	*9.50*	*9.18*	69.1	56.0	*0.99*
Head-on	0.12	0.12	0.9	0.8	0.52
Angle	*1.62*	*1.63*	11.8	25.2	0.00
Sideswipe, same direction	0.75	0.72	5.5	4.0	0.61
Other multiple-vehicle collision	0.75	0.73	5.5	5.1	0.48
Accident Type and Manner of Collision TOTAL	*13.75*	*13.34*	100.0		

The first column in Table 15 displays the collision types. Columns 2 and 3 present the following:

- **Average Observed Accident Frequency (Column 2):** This column on the output report presents the average observed accident frequency for the analysis period as specified. This value is based strictly on observed accidents, the number of years in the analysis period, and for the case of roadway segments and ramps, the length of the segment/ramp being analyzed.

  The value for the Average Observed Accident Frequency presented in the output for the test of frequencies in Module 2 is slightly different than the Average Observed Accidents for Entire Site and the Average Observed Accidents for that portion of the site identified as having the greatest potential for safety improvement as presented in the Module 1 outputs for the "Peak Searching" and "Sliding Window" network screening methodologies. The primary difference is that the Average Observed Accident Frequency as calculated in Module 2 is based on the entire analysis period. This is an average frequency for the middle of the analysis period, assuming the ADT grows yearly. For example, say the analysis period is from 2003 through 2007. The average observed accident frequency would essentially provide an estimate for the year 2005, because of the differences in ADT. If the ADT was the same for every year in the analysis period, then the simple average value would be applicable to every year. The Average Observed Accidents for Entire Site and the Average Observed Accidents as calculated in Module 1 are scaled to the final year of the analysis period. In Module 1, this scaling is necessary so that all accident frequencies (i.e., observed, predicted, and expected) are comparable to one another.

  In summary, the average observed accident frequency calculated in Module 2 for tests for frequencies is the simple average observed accident frequency for the middle of the analysis period, and the average observed accident frequency calculated in Module 1 for "Peak Searching" and "Sliding Window" network screening methodologies are for the final year of the analysis period. For roadway segments and ramps, the units for this measure are acc/mi/yr. For intersections, the units are acc/yr.

- **Average EB-Adjusted Accident Frequency (Column 3):** This column on the output report presents the average EB-adjusted accident frequency for the analysis period as specified. This value is calculated from a safety performance function and observed accident data.

  The value for the Average EB-Adjusted Accident Frequency presented in the output for the test of frequencies in Module 2 is very similar to the Expected Accident Frequency for that portion of the site identified as having the greatest potential for safety improvement as presented in the Module 1 outputs for the "Peak Searching" and "Sliding Window" network screening methodologies. In both cases an Empirical Bayes approach is used for calculating the accident frequency. However, as discussed above for the Average Observed Accident Frequency, the Average EB-Adjusted Accident Frequency as calculated in Module 2 is based on the entire analysis period, where as Expected Accident

Frequency as calculated in Module 1 is scaled to the final year of the analysis period. In Module 1, this scaling is necessary so that all accident frequencies (i.e., observed, predicted, and expected) are comparable to one another.

For roadway segments and ramps, the units for this measure are acc/mi/yr. For intersections, the units are acc/yr.

In the sample output in Table 15, rear-end accidents and angle accidents are highlighted in Columns 2 and 3 because in both cases the Average Observed Accident Frequency and the Average EB-Adjusted Accident Frequency are greater than the limiting value of 1 acc/yr as specified for this example. Similarly, in the final row for total accidents, Columns 2 and 3 are highlighted because the average frequencies are greater than the limiting value.

Table 15 shows the combined results for test of frequencies and test of proportions. An explanation of the test of proportions is presented below.

3.1.3.2 Test of Accident Proportions

The objective of this test is to identify accident types that are over-represented at a location based upon the proportions of observed accidents at the given location compared to the proportion of accidents at similar locations. The primary rationale for this test is that diagnosing safety concerns by strictly focusing on accident frequencies (i.e., average observed and EB-Adjusted Accident Frequencies) only tells a portion of the issue. Some sites may experience high accident frequencies, but given the exposure levels (i.e., average daily traffic) and current site conditions, the safety experience may be what would be expected. However, it may also be the case that a particular type of accident is occurring more often at a given location than is typically expected. This may be assessed by comparing accident proportions rather than frequencies. By comparing observed proportions of particular accident types at a given location to proportions at similar locations, over representation of particular accident types can be determined and identified as accident patterns of interest for further investigation. The opposite may also be true. A site may experience relatively few accidents, but based upon the accident patterns at the site, the site can still be effectively treated with a countermeasure to reduce particular types of accidents that may be occurring.

The general approach for the test of proportions is similar to the methodology used in Module 1 to perform network screening based on a high proportion of specific accident type. Given the distribution of accident types at the given location, the observed proportions of accident types at the location are compared to accident proportions at similar locations. When the probability that the observed proportion of the particular accident type at the site is greater than what is expected for similar sites, the accident type is highlighted for potential further investigation. The analyst specifies the desired confidence level for the statistical validity of the test to assess the probability that the observed proportion of a particular accident type is greater than the proportion at similar sites.

Table 15 above presents the results of both the test of frequencies and test of proportions. In this example, a 90-percent confidence level was specified. Columns 4, 5, and 6 of Table 15 present the following information related to the test of proportions:

- **Observed Proportion (Column 4):** The observed proportion presented in this column on the output report is the proportion of accidents for each specific collision type, relative to all accidents for the given severity level that occurred at the site.

- **Limiting Proportion (Column 5):** The limiting proportion presented in this column on the output report is the proportion of accidents for each specific collision type, relative to all accidents for the given severity level, but it is based upon accident data distributions for sites of the same site subtype.

- **Probability Observed Proportion Exceeds Limiting Proportion (Column 6):** This column on the output report presents the probability that the observed proportion is greater than the limiting proportion. Collision types are highlighted in this column if the probability is greater than or equal to the confidence level (i.e., 1-α) specified by the analyst.

In the sample output in Table 15, rear-end and overturn accidents are highlighted in Column 6 because there is at least a 90-percent probability that the observed proportion for each specific collision type is greater than the limiting proportion. Given that the observed proportion of overturn accidents is relatively small (i.e., less than 1 percent of the total accidents at the site), overturn type accidents at this location are probably not of too much concern. This is also reflected by the frequency level for overturn type accidents. However, rear-end accidents account for approximately 69 percent of the total accidents at this location. At similar locations, rear-end accidents typically account for about 56 percent of the total accidents which suggests that rear-end accidents are slightly over represented at this particular location. Also, given the frequency of rear-end accidents at this particular location, rear-end accidents appear to be an accident pattern of interest that the analyst may wish to investigate further as part of the diagnostic and countermeasure selection process.

3.2 Diagnostic Investigation and Countermeasure Selection

Through the use of an expert system, this module guides the analyst through appropriate office and field investigations to identify potential safety concerns at a site. This process includes both traditional engineering considerations as well as a strong human factors component, to help diagnose potential safety concerns at a site. The end result of this diagnosis process is a list of potential countermeasures that, if implemented at the site, could mitigate particular accident patterns.

All diagnostic scenarios presented in *SafetyAnalyst* have a general format. Each scenario is characterized under a particular title, site type, site subtype, attributes, accident pattern, vehicle maneuvers, circumstance statement, scenario background rationale, and diagnostic

questions. The analyst selects which diagnostic scenario or scenarios related to the accident type of interest to review.

Upon selecting a diagnostic scenario, *SafetyAnalyst* leads the analyst through a series of diagnostic questions to help identify countermeasures that could potentially address the accident pattern of interest. The diagnostic questions are phrased to elicit a Yes, No, or Unknown response. Depending upon the response to a given question, the logic of the system will lead the analyst through a different series of questions.

A total of 393 diagnostic scenarios are incorporated in *SafeyAnalyst*. Diagnostic scenarios are available for roadway segments and intersections. Diagnostic scenarios have not been developed for ramps. For roadway segments, diagnostic scenarios are available for rural and urban two-lane roads and multilane divided and undivided highways (i.e., non freeways). Diagnostic scenarios have not been developed for urban one-way arterials, or freeways. For intersections, diagnostic scenarios are available for rural and urban three- and four-leg intersections with minor-road STOP control or signal control. Diagnostic scenarios have not been developed for intersections with all-way STOP control. Table 16 presents a summary of the *SafetyAnalyst* site subtypes for which diagnostic scenarios have been developed. The number presented in the Yes column under Diagnostic Scenarios Available indicates the number of diagnostic scenarios that have been developed for the respective site subtype. Table 17 presents the details/logic for a single scenario related to dilemma zone issues. The scenario is for an urban, four-leg signalized intersection and addresses rear-end accidents. All other scenarios have been developed with a similar format.

In the situation where an analyst does not know the answer to a diagnostic question, the analyst can provide an Unknown response to the question. Based upon the Unknown response, *SafetyAnalyst* suggests one or more procedures for the analyst to perform to gather sufficient information to provide a Yes or No response to complete the diagnostic review. The suggested diagnostic procedures could involve gathering information from the office and/or may require a field visit.

Upon completing the review of the diagnostic scenario or scenarios, the analyst is presented with a list of countermeasures for potential implementation and/or for further economic analysis within Module 3. Prior to completing the diagnostic investigation for a site, the analyst has the opportunity to revise the list of countermeasures by (a) removing countermeasures from the list and (b) including other countermeasures that may not have been identified during the review of diagnostic scenarios.

Module 2 provides a simplified economic procedure to aid with countermeasure selection. By inputting a desired reduction in accidents and specifying other economic criteria such as the service life of the countermeasure and the minimum attractive rate of return, *SafetyAnalyst* will perform a simple benefit-cost analysis. The output from this analysis is an estimate of the maximum cost for a countermeasure that can be justified economically.

Table 16. Module 2—SafetyAnalyst Site Subtypes for Which Diagnostic Scenarios Have Been Developed

SafetyAnalyst site subtypes	Diagnostic scenarios available	
	YES (number)	NO
Roadway Segments		
Rural two-lane roads	25	
Rural multilane undivided roads	42	
Rural multilane divided roads	9	
Rural freeways—4 lanes		X
Rural freeways—6+ lanes		X
Rural freeways within interchange area—4 lanes		X
Rural freeways within interchange area—6+ lanes		X
Urban two-lane arterial streets	14	
Urban multilane undivided arterial streets	21	
Urban multilane divided arterial streets	13	
Urban one-way arterial streets		X
Urban freeways—4 lanes		X
Urban freeways—6 lanes		X
Urban freeways—8+ lanes		X
Urban freeways within interchange area—4 lanes		X
Urban freeways within interchange area—6 lanes		X
Urban freeways within interchange area—8+ lanes		X
Intersections		
Rural three-leg intersection with minor-road STOP control	21	
Rural three-leg intersection with all-way STOP control		X
Rural three-leg intersection with signal control	37	
Rural four-leg intersection with minor-road STOP control	22	
Rural four-leg intersection with all-way STOP control		X
Rural four-leg intersection with signal control	37	
Urban three-leg intersection with minor-road STOP control	23	
Urban three-leg intersection with all-way STOP control		X
Urban three-leg intersection with signal control	45	
Urban four-leg intersection with minor-road STOP control	23	
Urban four-leg intersection with all-way STOP control		X
Urban four-leg intersection with signal control	45	
Ramps		
Rural diamond off-ramp		X
Rural diamond on-ramp		X
Rural parclo loop off-ramp		X
Rural parclo loop on-ramp		X
Rural free-flow loop off-ramp		X
Rural free-flow loop on-ramp		X
Rural free-flow outer connect ramp		X
Rural direct or semidirect connection		X
Urban diamond off-ramp		X
Urban diamond on-ramp		X
Urban parclo loop off-ramp		X
Urban parclo loop on-ramp		X
Urban free-flow loop off-ramp		X
Urban free-flow loop on-ramp		X
Urban free-flow outer connect ramp		X
Urban direct or semidirect connection		X

Table 17. Module 2—Example of a Diagnostic Scenario for an Urban 4-Leg Signalized Intersection Related to the Dilemma Zone

Title: Dilemma Zone
Site Type: Intersection
Site Subtype(s):
Int/Urb; 4-leg signalized
Attribute(s):
General
Accident Pattern(s):
Rear-end
Vehicle Maneuver(s):
2 changing lanes
2 thru
1 thru, 1 changing lanes

Statement: Rear-end accidents can occur due to contradictory decisions among drivers traveling along an approach as they enter the dilemma zone. The dilemma zone is the area where drivers must make the decision to stop or continue through the intersection when the signal turns yellow.

Rationale: The dilemma zone is the section of an approach to a signalized intersection in which drivers may make different decisions about whether to stop or go when the signal turns yellow. One definition of the dilemma zone is the section of an intersection approach from the point at which 90% of drivers will stop and only 10% will continue through the intersection, up to the point at which 90% of drivers will continue through the intersection and only 10% will stop. Generally, rear-end accidents in the dilemma zone occur when a leading vehicle encounters a yellow signal in the dilemma zone and the driver decides to stop, while the following driver decides to continue through the intersection and incorrectly assumes the leading vehicle will do the same. Approaches with higher operating speeds have a longer dilemma zone. Higher operating speeds or a wide range of operating speeds may result in more severe accidents.

Diagnostic Question(s):

Question: *(56) - Are rear-end accidents occurring at this intersection because drivers are having difficulty making the stop/go decision when the signal turns yellow?*
Yes:
Next Question: (112) - Is this signal warranted?
No:
Next Question: (EOS) - End of Scenario
Unknown:
Procedure: (28) - Review accident records.
Next Question: (EOS) - End of Scenario

Question: *(112) - Is this signal warranted?*
Yes:
Next Question: (42) - Are adjacent signalized intersections within 2600 ft (800 m) of this intersection?
No:
Countermeasure: (130) - Remove unwarranted signal
Next Question: (42) - Are adjacent signalized intersections within 2600 ft (800 m) of this intersection?
Unknown:
Procedure: (20) - Determine if signal is warranted (see Manual of Uniform Traffic Control Devices).
Procedure: (9) - Obtain information from relevant agencies or departments.
Next Question: (42) - Are adjacent signalized intersections within 2600 ft (800 m) of this intersection?

Question: *(42) - Are adjacent signalized intersections within 2600 ft (800 m) of this intersection?*
Yes:
Next Question: (111) - Is the signal at this intersection coordinated with preceding signalized intersections along the corridor?
No:
Next Question: (94) - Is the clearance interval appropriate for the cross section, the design vehicle (e.g., tractor-semitrailer, etc.), and the posted speed?
Unknown:
Procedure: (31) - Visit site.
Procedure: (9) - Obtain information from relevant agencies or departments.
Next Question: (111) - Is the signal at this intersection coordinated with preceding signalized intersections along the corridor?

Question: *(111) - Is the signal at this intersection coordinated with preceding signalized intersections along the corridor?*
Yes:
Next Question: (94) - Is the clearance interval appropriate for the cross section, the design vehicle (e.g., tractor-semitrailer, etc.), and the posted speed?
No:
Countermeasure: (49) - Add advanced detection
Countermeasure: (89) - Install dilemma detection system
Countermeasure: (125) - Provide signal coordination
Next Question: (94) - Is the clearance interval appropriate for the cross section, the design vehicle (e.g., tractor-semitrailer, etc.), and the posted speed?
Unknown:
Procedure: (9) - Obtain information from relevant agencies or departments.
Procedure: (57) - Review signal timing plan.
Next Question: (94) - Is the clearance interval appropriate for the cross section, the design vehicle (e.g., tractor-semitrailer, etc.), and the posted speed?

Table 17. Module 2—Example of a Diagnostic Scenario for an Urban 4-Leg Signalized Intersection Related to the Dilemma Zone (Continued)

Question: *(94) - Is the clearance interval appropriate for the cross section, the design vehicle (e.g., tractor-semitrailer, etc.), and the posted speed?* **Yes:** Next Question: (EOS) - End of Scenario **No:** Countermeasure: (57) - Improve change plus clearance interval Next Question: (EOS) - End of Scenario **Unknown:** Procedure: (9) - Obtain information from relevant agencies or departments. Procedure: (24) - Determine appropriate clearance intervals (see Highway Capacity Manual). Procedure: (57) - Review signal timing plan. Next Question: (EOS) - End of Scenario

3.3 Primary Output Report

The primary output report from Module 2 includes:

- A list of countermeasures for potential implementation and/or further economic analysis in Module 3;

- A summary of the detailed diagnostic scenarios reviewed during the investigation; and

- A list of office and/or field procedures to gather information which will help in responding to diagnostic questions for which the analyst did not readily know the answer.

Table 18 presents a sample output table from a Module 2 analysis that lists the potential countermeasures identified by diagnostic review of two scenarios. In addition to listing the countermeasure, this table includes:

- **Contraindication:** This column on the output report presents any potential negative impact that could be experienced due to the implementation of the countermeasure.

- **Recommended by:** This column on the output report indicates the scenario ID for all diagnostic scenarios that were reviewed and resulted in identification of the particular countermeasure. More than one scenario ID can be shown in this column. When the value in this column is User, this indicates that the countermeasure was selected by the analyst and was not identified through the review of diagnostic scenarios.

- **Accident Pattern:** This column on the output report indicates the accident pattern that the countermeasure was identified to mitigate.

- **Implemented:** This column indicates whether the respective countermeasure has been implemented at the respective site. SafetyAnalyst checks the Implemented Countermeasure database to see if a record exists that indicates the respective countermeasure has been implemented at the site. If a record exists which indicates that the countermeasure has been implemented at the site, the column will indicate Yes. Otherwise, the column will indicate No.

Table 18. Module 2—Example of Countermeasures Report

Countermeasure	Contraindication	Recommended by *	Accident pattern(s)	Implemented
Provide signal coordination	Only aids mainline	16	Rear-end	no
Add advanced detection	May increase delay	16	Rear-end	no
Install dilemma detection system		16	Rear-end	no
Improve change plus clearance interval	May increase delay	16	Rear-end	no
Narrow cross section by reducing number of approach lanes	Reduced capacity	18	Rear-end	no
Reduce speed limit on approaches		18	Rear-end	no
Increase enforcement to reduce speed on intersection approach		18	Rear-end	no
Narrow cross section by physically narrowing lanes		18	Rear-end	no
Change streetscape to increase stimulation of peripheral vision		18	Rear-end	no
Restrict movements to right-in and right-out at the access using channelizing island	Accidents may migrate with changes in volume patterns	18	Rear-end	no
Improve sight distance to intersection		User	user-selected CM	no
Improve sight distance to traffic signal		User	user-selected CM	no
* A scenario ID ending in 'u' indicates the countermeasure was user-selected and is not a result of the diagnosis.				

Table 19 presents the potential diagnostic scenarios that have been reviewed and could have been reviewed given the site subtype, accident pattern of interest, and vehicle maneuvers (for intersections). In this portion of the output report, those diagnostic scenarios that were reviewed in detail are presented first. The responses to the specific questions are provided, along with the identified countermeasures or procedures. The latter portion of this output lists those diagnostic scenarios that the analyst did not review. In Table 19, Diagnostic Scenario 16 related to the dilemma zone was reviewed in detail along with Diagnostic Scenario 18 related to speeds. Eight other diagnostic scenarios related to rear-end accidents involving two through movements were not reviewed in detail.

The final portion of the output report provides procedures for gathering information, either in the office or in the field, that will be useful for answering a diagnostic question for which the analyst did not initially know the answer. Some of the procedures are very basic, while others are more complicated and detailed. Table 20 lists two procedures that resulted from an unknown response for a question generated while reviewing Scenario 18 related to speed.

Table 19. Module 2—Example of Report Presenting Potential Diagnoses

3.3.1 Diagnosis 16: Dilemma Zone

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Evaluation Status: Complete

Statement:
Rear-end accidents can occur due to contradictory decisions among drivers traveling along an approach as they enter the dilemma zone. The dilemma zone is the area where drivers must make the decision to stop or continue through the intersection when the signal turns yellow.

Rationale:
The dilemma zone is the section of an approach to a signalized intersection in which drivers may make different decisions about whether to stop or go when the signal turns yellow. One definition of the dilemma zone is the section of an intersection approach from the point at which 90% of drivers will stop and only 10% will continue through the intersection, up to the point at which 90% of drivers will continue through the intersection and only 10% will stop. Generally, rear-end accidents in the dilemma zone occur when a leading vehicle encounters a yellow signal in the dilemma zone and the driver decides to stop, while the following driver decides to continue through the intersection and incorrectly assumes the leading vehicle will do the same. Approaches with higher operating speeds have a longer dilemma zone. Higher operating speeds or a wide range of operating speeds may result in more severe accidents.

Question:
   Are rear-end accidents occurring at this intersection because drivers are having difficulty making the stop/go decision when the signal turns yellow?
Answer:
   Yes
Recommended CM:
   None

Question:
   Is this signal warranted?
Answer:
   Yes
Recommended CM:
   None

Question:
   Are adjacent signalized intersections within 2600 ft (800 m) of this intersection?
Answer:
   Yes
Recommended CM:
   None

Question:
   Is the signal at this intersection coordinated with preceding signalized intersections along the corridor?
Answer:
   No
Recommended CM:
   Provide signal coordination
   Add advanced detection
   Install dilemma detection system

Question:
   Is the clearance interval appropriate for the cross section, the design vehicle (e.g., tractor-semitrailer, etc.), and the posted speed?
Answer:
   No
Recommended CM:
   Improve change plus clearance interval

3.3.2 Diagnosis 18: Speeds Too High

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Evaluation Status: Incomplete (at least one diagnostic question has not been answered)

Statement:
Rear-end accidents can occur due to high operating speeds or speed differentials among vehicles approaching an intersection. Drivers approaching the intersection at high speeds may be unable: to stop comfortably, to appropriately react to turning drivers who slow in a through lane or drivers slowing when the signal turns yellow, or to avoid other drivers changing lanes. As a result, following vehicles come into conflict with leading vehicles that are slowing, stopping, or changing lanes on the intersection approach.

Rationale:

Table 19. Module 2—Example of Report Presenting Potential Diagnoses (Continued)

A wide cross-section and wide lanes contribute to a road message that high speeds are acceptable. High operating speeds may occur at intersections near freeway exits or on freeway to highway transitions. Drivers from the freeway have adapted to traveling at higher speeds, and require several minutes to transition to lower speeds. Even when drivers are aware that this transition is required, it can take several minutes for drivers to adapt and reduce their speed. High operating speeds are a concern for vulnerable road users, such as pedestrians and bicyclists. Accesses near the intersection are a concern when operating speeds are high, for vehicles slowing, stopping, or turning into or out of the access.

Question:
   Is this the first signalized intersection following a freeway exit?
Answer:
   Yes
Recommended CM:
   None

Question:
   Is traffic on the intersection approach coming from the freeway traveling at higher speeds than traffic not originating from the direction of the freeway?
Answer:
   Unknown
Procedure(s):
   Measure 85th percentile speed (see ITE Traffic Engineering Handbook).
   Visit site.

Question:
   Are operating speeds higher than desirable given the presence of pedestrians, bicyclists, or accesses?
Answer:
   Yes
Recommended CM:
   Narrow cross section by reducing number of approach lanes
   Reduce speed limit on approaches
   Increase enforcement to reduce speed on intersection approach
   Narrow cross section by physically narrowing lanes
   Change streetscape to increase stimulation of peripheral vision
   Restrict movements to right-in and right-out at the access using channelizing island

3.3.3 Diagnosis 17: Traffic Congestion (Queuing)

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

3.3.4 Diagnosis 19: Inadequate Signal Visibility

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

3.3.5 Diagnosis 20: Inadequate Guidance for Drivers

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

3.3.6 Diagnosis 21: Accesses/Driveways

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

3.3.7 Diagnosis 22: Bus Stops Near Intersection

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

Table 19. Module 2—Example of Report Presenting Potential Diagnoses (Continued)

3.3.8 Diagnosis 23: Pedestrian Movements

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

3.3.9 Diagnosis 24: Downgrade

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

3.3.10 Diagnosis 25: Road Surface Condition/Drainage

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Attribute: Wet weather

Not Evaluated

Table 20. Module 2—Example of Report With Description of Recommended Procedures

3.4 Measure 85th percentile speed (see ITE Traffic Engineering Handbook)

85th percentile speed measurement.

Speed Measurement: Sources of information: ITE 1992 Traffic Engineering Handbook – pp. 64-67; ITE 1999 Traffic Engineering Handbook – pp. 245 -252. The ITE handbook refers to another more complete source: Manual of Transportation Engineering Studies, by Robertson, Hammer, and Nelson (undated).

3.5 Visit site

Visit the site to obtain information.

All of the responses to the diagnostic scenarios are saved within a workbook. In the event that an analyst provides an Unknown response during the initial review of the diagnostic scenario, the intent is that an analyst will print the associated output report and gather the necessary information either from the office or in the field, having the output report handy for a quick reference for how to gather the required information. Upon returning to *SafetyAnalyst*, the analyst can review the diagnostic scenario again to provide a Yes or No response to the question that generated the recommended procedures, thereby completing the review of the diagnostic scenario.

3.4 Benefits of *SafetyAnalyst's* Diagnosis and Countermeasure Selection Capabilities

The diagnostic and countermeasure selection procedures are tools to help analysts identify potential countermeasures for implementation at a site that would be expected to address an accident pattern. The primary benefits associated with this module are as follows:

- *SafetyAnalyst* provides three methods (i.e., accident summary statistics, collision diagrams, and statistical tests for accident frequencies and proportions) for identifying accident patterns of interest for further diagnosis. The analyst can utilize one or more of these methods in an easy fashion.

- The diagnostic scenarios guide analysts toward identifying countermeasures for potential implementation or further economic analysis.

- Highway agencies may add, delete, or modify the questions included in the diagnostic scenarios and the potential countermeasures suggested in response to specific answers to those questions.

- *SafetyAnalyst* does not make the final selection of countermeasures for potential implementation or further economic analysis; it is the analyst that makes the final selection. *SafetyAnalyst* is only a tool that the analyst can utilize during diagnostic investigations to help identify potential countermeasures. Once the analyst selects specific countermeasures, those selections can be entered into *SafetyAnalyst* for further consideration in Module 3.

4. CAPABILITIES FOR MODULE 3—ECONOMIC APPRAISAL AND PRIORITY RANKING

This section of the report provides an overview of the capabilities of *SafetyAnalyst* Module 3, the economic appraisal and priority ranking tools. The purpose of the economic appraisal and priority ranking tools is to conduct an economic analysis for implementing a countermeasure or combination of countermeasures so that monetary expenditures can be prioritized. The module is capable of assessing the economic benefits of countermeasures at a single site assisting a highway agency in setting priorities for safety countermeasures across a network. The types of problems that can be addressed with this module are summarized in Section 4.1.

SafetyAnalyst evaluates whether the proposed improvement(s) are economically efficient through a variety of economic criteria and calculations. All of the criteria address cost and benefits in terms of total accident severity, and some incorporate information from all severity levels when appropriate. Economic calculations for alternative improvements at a site are normalized through present values and equivalent analysis periods so they can be fairly compared.In Section 4.2, the economic criteria used by *SafetyAnalyst* are explained as well as their advantages and disadvantages.

Economic evaluations make use of site characteristics and countermeasure information to determine optimal countermeasure solutions for sites with potential for safety improvement. The data used in economic evaluations fall under the following categories:

- Location (e.g., route, county, and milepost for specific sites to improve)
- Select site characteristics for AMF and cost functions
- Name of countermeasure(s) [e.g., install left-turn lane]
- Safety effectiveness estimate for countermeasure(s) [e.g., AMFs]
- Service life of countermeasure(s)
- Construction implementation costs (e.g., cost of constructing the left-turn lane)

Some or all of these data are already included in the *SafetyAnalyst* databases and can be retrieved as part of the analysis. However, some data are not available and will need to be entered as part of the analysis. Section 4.4.1 details how the data needed for an analysis is assembled as well as sources of any system provided data.

SafetyAnalyst provides the capability to adjust all default values that are used in the calculations. Default values edited at the time of analysis or analysis options, allow customization of individual analyses. Some examples of these options are:

- Minimum attractive rate of return
- Number of years of accident and AADT data to be used (history period)
- Expected implementation year and number of analysis years
- Accident weights and costs by severity

Sections 4.4.2 through 4.4.5 discuss these features of Module 3.

The primary output from Module 3 is a list of sites with all alternative countermeasures proposed for them with the results of the economic analysis. Other output is available depending on the analysis specified. If priority ranking criteria were specified, another output section provides ranked site and countermeasures lists by these criteria. Similarly, an optimization report is produced if the optimal mix of sites and countermeasures within a limited budget is desired. These reports are discussed in Section 4.5.

4.1 Types of Problems Addressed With Economic Appraisal and Priority Ranking Tool

The economic appraisal and priority ranking tools provide a means to conduct an economic analysis for implementing a countermeasure, or combination of countermeasures, at a site and to assist highway agencies in setting priorities for safety countermeasures across a network. The extent of the economic appraisal performed by these tools is dependent upon the tasks at hand. For example, for a particular roadway segment, intersection, or interchange ramp, countermeasures might have already been selected, either based upon output from the countermeasure selection tool or through professional expertise; the economic appraisal tool can quantify the safety benefits in terms of the expected number of accidents to be reduced and in economic terms.

In this situation, the economic appraisal tool would perform an economic analysis for the particular countermeasure at the specific site, based upon the economic criterion selected. In another scenario, the economic appraisal tool can be used to determine which proposed countermeasure(s) (or combinations of countermeasures) at a specific site should receive top priority by evaluating the cost-effectiveness of each countermeasure and combination of countermeasures, based upon an economic criterion selected. In a final scenario, candidate countermeasures (or combinations of countermeasures) may have been selected at multiple sites throughout the highway network and the economic appraisal tool would be used to investigate which countermeasures should be implemented to maximize the net benefits given budgetary constraints.

Essentially, the economic appraisal and priority ranking tools provide a means for estimating the safety effectiveness in economic terms of countermeasures at a specific site within the highway network. This tool also provides the capability to rank countermeasures at a specific site using the safety effectiveness estimates and to identify a set of countermeasures that would provide maximum safety benefits within a given budget constraint.

4.2 Types of Economic Analyses and Choosing Among Them

SafetyAnalyst provides four different economic criteria to evaluate proposed countermeasures. The economic criteria include:

- Cost-effectiveness
- EPDO-based cost-effectiveness
- Benefit-cost ratio
- Net benefits

More than one criterion may be selected for evaluation, which allows for the comparison of results from the different approaches. The advantages and disadvantages of each criterion are presented next and may aid in the decision on which criterion or criteria are the most appropriate for the analysis. Appendix C presents the basic algorithms used in the processing of the economic analyses.

In evaluating a candidate improvement based upon the cost-effectiveness criterion, the cost-effectiveness is expressed in terms of the dollars spent per accident reduced. Projects with lower cost per accident reduced are more likely to maximize the benefits of an improvement program than projects with higher cost per accident reduced.

$$\text{Cost-effectiveness} = \text{Total Cost/Expected Number of Accidents Reduced} \qquad (1)$$

This approach has the advantage of simplicity and may be more accepted than alternative approaches because it does not incorporate any estimates of accident reduction benefits in monetary terms. The primary disadvantages of this approach are (1) it does not explicitly consider the severity of the accidents reduced, (2) it is not well suited for deciding among alternative candidate improvements for a given site, and (3) it does not explicitly provide an improvement program that maximizes safety benefits. The cost-effectiveness criterion may be selected if the notion that accidents have costs that can be expressed in economic terms is rejected.

With the EPDO-based cost-effectiveness approach, a severity weighting scheme is incorporated to overcome one of the disadvantages of the cost-effective criterion. However, the range of potential viewpoints on the appropriate values of these weights may introduce some of the same concerns as assigning monetary values to accidents of different severity levels.

Another approach to economic evaluation of candidate improvements is by the benefit-cost ratio. The benefit-cost ratio is the ratio of the present benefit of a project to its construction costs. For a countermeasure to be economically justified, its benefit-cost ratio should be greater than 1.0. The most desirable countermeasures are those with the highest benefit-cost ratios:

$$\text{Benefit-Cost Ratio} = \text{Benefit/Cost} \qquad\qquad (2)$$

Unlike the cost-effectiveness approach, benefit-cost ratios give explicit consideration to accident severity because accident cost estimates differ by severity level.

A disadvantage of the benefit-cost ratio approach is that if multiple benefit and cost terms exist, it is not always clear whether specific terms belong in the numerator or the denominator of the ratio. For example, it is not always clear whether some maintenance costs should be treated as a decrease in the annual safety benefit or should be converted to a present value and treated as an increase in the project cost.

The net benefit approach to economic appraisal assesses projects by benefits minus costs. Some consider this approach to be superior to the benefit-cost ratio approach because it eliminates the issue of whether particular cost items should appear in the numerator or denominator. For this approach, the most desirable improvements are those with the highest net benefit:

$$\text{Net Benefit} = \text{Benefit} - \text{Costs} \qquad\qquad (3)$$

When the net benefits approach is selected, the option to maximize the net benefits across all sites and countermeasures under evaluation is available, which takes into consideration budgetary constraints. An optimization algorithm is used to maximize the net benefits.

In summary, the cost-effectiveness approach shown in Equation (1) is intended for application when it is not desirable to attribute monetary costs to accidents. The last two approaches [benefit-cost ratio and net benefit as shown in Equations (2) and (3)] require a monetary estimate of the costs and benefits for each countermeasure. When the net benefit approach is selected, the choice to optimize the net benefits across all sites and countermeasures is available.

Typically, all costs and benefits are expressed in monetary terms, which require estimates of the dollar value of each accident reduced. All benefits and costs must be expressed consistently on either an annual or present-value basis. Conversion of costs or benefits between an annualized and present value basis requires an estimate of the service life of the improvement and a specified minimum attractive rate of return (also known as the discount rate). A challenge in the benefit-cost and net benefits approaches is deciding the monetary estimates of accident reduction benefits.

Both the benefit-cost ratio and net benefit approaches treat accident reduction as an economic benefit. Within *SafetyAnalyst* the specific procedures express benefits and costs on a present-value basis (i.e., the amount of future accident savings is converted to a present value and compared to the countermeasure construction cost which, by its nature is a present value). The use of a consistent basis for comparison, such as the present value, is necessary for:

- Comparing countermeasures with different service lives
- Comparing countermeasures when the accident reduction benefits are not uniform over time

4.3 Performing Economic Analyses in *SafetyAnalyst*

This section describes the specific program features that enable the specification of an economic analysis. The initial steps of selecting sites and countermeasures are followed by a description of the analysis options available for this module.

4.3.1 Specifying Sites and Countermeasures to be Evaluated

The first step in executing an economic analysis is selecting sites. In an economic analysis, the site list may contain a minimum of one site or the maximum number of sites contained in the inventory that an agency is interested in improving. Consequently, this list can contain a mix of site types, i.e., roadways, intersections, or ramps. If the list of sites to be improved contains roadways, then projects or subsegments may be created for evaluation.

Roadway projects are simply a grouping of segments, usually contiguous, that are treated as one analysis unit. Conversely, subsegments are smaller portions of an inventoried site. Together projects and subsegments allow for the economic analysis of a proposed improvement on an extended roadway section or only the portion of a roadway site intended for improvement.

Once the site list is complete, the countermeasure(s) to be considered for implementation at each site must be specified. Countermeasures identified by the diagnosis tool, user-specified countermeasures, and all other countermeasures that are appropriate for a site's facility type may be evaluated.

If the diagnosis and countermeasure selection process was previously performed on the same site list or a portion of the site list being used for an economic appraisal, the process may have yielded a number of countermeasures to be considered for further economic analysis for a given site. Those countermeasures identified during the diagnosis and countermeasure selection process are not automatically considered in an economic evaluation. The analyst must explicitly identify the countermeasures that will be included in the analysis. All, some, or none of the available countermeasures may be assigned to a given site.

For a given site that was included in a previous diagnostic and countermeasure selection process, other countermeasures may be selected for the economic evaluation that were not identified as part of the diagnostic and countermeasure selection process. Finally, if a site in the site list has not been included in a prior diagnostic and countermeasure selection process, proposed countermeasures may still be assigned to be included in the economic analyses based upon knowledge of the site and countermeasure.

Countermeasures are added to sites through two primary dialogs, the Proposed Countermeasure Dialog and the Enter/Edit Proposed Countermeasure Dialog. These are shown in Figures 18 and 19, respectively. However, the exact operation of the dialogs varies by the type of countermeasure being assigned. That is, there are some operational differences between adding a countermeasure to a site, adding a countermeasure to a project or subsegment, adding the same countermeasure to multiple sites at once, and creating a countermeasure combination. A countermeasure combination is the simultaneous implementation of more than one countermeasure, which will be analyzed as a single countermeasure.

Proposed Countermeasures Dialog

The proposed countermeasure dialog, shown in Figure 18, is divided into three sections: selected sites, available countermeasures for site subtypes and proposed site countermeasures. The selected sites section lists the sites to which countermeasures can be proposed for future implementation. *SafetyAnalyst* automatically provides a list of available countermeasures (default and user-specified) for potential implementation at a site in the middle section of the dialog. Once the countermeasures are assigned to the selected sites, they will be listed in the Proposed Countermeasure list at the bottom of the dialog.

The Available Countermeasures list contains several items of interest when selecting the countermeasure. The first column in the Available Countermeasure list, Recommended, is a flag to indicate if the associated countermeasure was identified by the Diagnostics and Countermeasure Selection module. The next column, Countermeasure ID, presents a unique countermeasure identifier. The Category column provides an aid in searching the list by grouping similar countermeasures by improvement type (e.g., *Access Management, Bicycle, Drainage, Education, Enforcement, Geometry, Lighting, Pavement, Pavement Markings, Pedestrian, Railroad, Roadside, Roadway, Rumble Strips, School, Sight Distance, Signals, Signing, Vegetation).* The next column presents the Title and description of the countermeasure. The next three columns present information on the safety effectiveness of the countermeasure (i.e., the applicable AMFs). The final two columns present information on the construction and the construction cost units.

AMFs provide estimates of the expected reduction (or increase) in accident frequency and/or severity after countermeasure implementation. They are used to estimate the number of accidents reduced from implementing the countermeasure or the safety benefits. AMFs are provided for total accident severity and fatal-and-all-injury accident severity and are express as decimal factors. An AMF value of one implies no change in the number of accidents. A value less than one implies a decrease in the anticipated number of accidents expected to occur after implementation (e.g., a value of 0.95 would imply a 5 percent reduction in accident frequency). Conversely, a value greater than one implies an increase in accidents is expected by implementing this countermeasure.

Figure 18. Proposed Countermeasures Dialog in Module 3

Figure 19. Enter/Edit Proposed Countermeasures Dialog in Module 3

AMFs used in *SafetyAnalyst* are usually represented as a single factor for all sites in a subtype. However, an AMF function is necessary when the incremental effect on safety for a countermeasure varies due to site characteristics at a given site. For example, the value of the AMF for widening lanes along a rural two-lane highway depends upon the lane widths before and after reconstruction and the traffic volume of the facility. Similarly, effectiveness estimates for improving horizontal curves are dependent on the change in curvature. For these types of countermeasures, several iterations of the analysis may be performed to find the best trade-off between safety and cost.

The construction cost for a countermeasure is determined in a manner similar to AMFs. Sometimes it will appear as a single value, and sometimes it will need to be calculated with a function based upon site characteristics. For example, if the cost of the countermeasure is determined by calculating the square footage of the site, then the site characteristics needed to calculate square feet (i.e., the number of lanes, lane width, shoulder width, length of site) will need to be reviewed.

Each countermeasure to be evaluated must be selected from the available countermeasure table and then assigned. Multiple countermeasures can be specified, by either assigning them individually or selecting multiple countermeasures prior to assigning them. If multiple countermeasures are selected at once, *SafetyAnalyst* will create a single treatment that combines the selected countermeasures. Currently, *SafetyAnalyst* does not have any logic to determine the appropriateness of combining countermeasures. The analyst must make the determination about whether the countermeasures are compatible and appropriate to combine. For example, "milling shoulder rumble strips" and "widening lanes to 8 feet" are compatible, whereas "widening shoulders to 8 feet" and "widening shoulders to 10 feet" are incompatible countermeasures.

An Enter/Edit Proposed Countermeasure dialog will request required economic information for each selected countermeasure.

Enter/Edit Proposed Countermeasure Dialog

The Enter/Edit Proposed Countermeasure dialog (Figure 19) provides an opportunity to review or edit the information required for a countermeasure's economic appraisal: an estimate of the countermeasure's safety effectiveness (AMF), the service life of the countermeasure (or the number of years that safety will be improved at a site resulting from the countermeasure), and the construction cost of implementing the countermeasure. Additionally through this dialog, changes may be made to the implementation location of the countermeasure and the ADT growth factor.

The dialog first requests any site characteristic information needed to calculate the AMF function or cost function for the selected countermeasure, then presents a final summary panel where estimates can be reviewed and edited. Each dialog that appears may be different depending on the type of countermeasure being assigned. For example, more

information may be needed to calculate cost by square feet than cost by linear mile. Also, the safety estimate for widening shoulders to different lengths may require input for the current site geometric configuration and proposed site geometric configuration.

The Enter/Edit Proposed Countermeasure dialog, shown in Figure 19, presents the final values that are used in the economic calculations. Most of the required data have default values that are presented in this dialog. The primary exceptions to this are AMFs. AMF functions and values do not exist for all countermeasures and/or all site subtypes to which they apply since they have only been provided when assessed by safety experts and found to have face validity. When these data (or any other required data) are missing, AMF values will need to be entered by the analyst or no economic analysis will be conducted on the countermeasure. Alternatively, AMF values may be edited globally in the Administration Tool by an individual with administrative rights to the software, as discussed in Section 1. However, for any required data, the default values may be edited here if there are site specific conditions that warrant it.

The default values presented on this screen represent the average values for all similar sites. Specific site information may be incorporated into the analysis by editing the values presented here. For example, if right-of-way acquisition, environmental impact, or utility relocation were necessary at this site, then construction costs may need to be adjusted. However, if the cost is manually edited the original cost can be returned by clicking the Recalculate Cost button. It should also be noted that safety and cost estimates may be adjusted globally at the Administrative level.

The ADT growth factor is set by an agency when importing inventory data or can be estimated using the last 2 years of available traffic data. Since this is the future growth rate assumed in the calculations, it may be optionally adjusted as part of the analysis. The subsegment location, CM Start Location and CM End Location, is the implementation location within a roadway segment site. When the implementation of a countermeasure is limited to just the area where a specific accident pattern is present, construction costs will be minimized while safety benefits will be maximized, increasing the economic feasibility. If the construction cost utilizes segment length in the calculation, then the cost is automatically adjusted when the subsegment is specified.

For a countermeasure combination, a summary review panel is presented for each countermeasure in the combination and an additional panel for the combined safety and cost estimates, where each panel is identical to Figure 19. Multiple countermeasures implemented together as a single treatment must have a final cost, service life, and AMF. The final AMF is simply the product of the individual AMFs. The service life of the combined treatment will be the maximum of each individual countermeasure service life.

The cost of a combined treatment is dependent on the service lives. If the service lives are different, an adjustment to the cost must be made. Since the expected benefits have been extended to the maximum service life, the costs should be extended to the same period. Therefore the cost of the countermeasure with the shorter service life is multiplied by a capital recovery factor and a uniform series present worth factor using the different service

lives and interest rate. Since this calculation involves a default minimum attractive rate of return, the default value of 4 percent is presented for possible adjustment before presenting the final calculations.

Site List Information Panel

After countermeasures have been proposed for some or all of the sites in the site list, the Site List Information panel should be updated to reflect the number of countermeasures proposed and assigned for each site. Figure 20 shows a typical site list panel ready for analysis in *SafetyAnalyst*. Each site must have at least one proposed countermeasure to be included in the economic analysis. Also, at least one site must have proposed countermeasures for the analysis to proceed.

4.3.2 Specifying Economic Criteria

The analyst selects from four primary economic criteria for an analysis. Analyses can be based upon:

- Cost-effectiveness
- EPDO-based cost-effectiveness
- Benefit-cost ratio
- Net benefits

Figure 21 presents a typical input screen on which the analyst specifies the economic criteria for the analysis.

All of the economic calculations require estimating the number of accidents reduced by a given countermeasure. To find this value, the EB-adjusted expected number of accidents for the history period is multiplied by an ADT growth factor for each year in the analysis period to estimate the EB-expected number of accidents without countermeasure implementation in the analysis period. The EB-expected number of accidents due to implementation is then calculated by multiplying an AMF to this value. Accidents reduced are then found by taking the difference of these two values.

Construction costs are computed from the annual construction cost, using the minimum attractive rate of return and service life of the countermeasure. Then the annualized construction cost is grown over the analysis period, using the same interest rate, and brought back to the present value. Basing the construction costs on the analysis period allows for the comparison of countermeasures with different service lives.
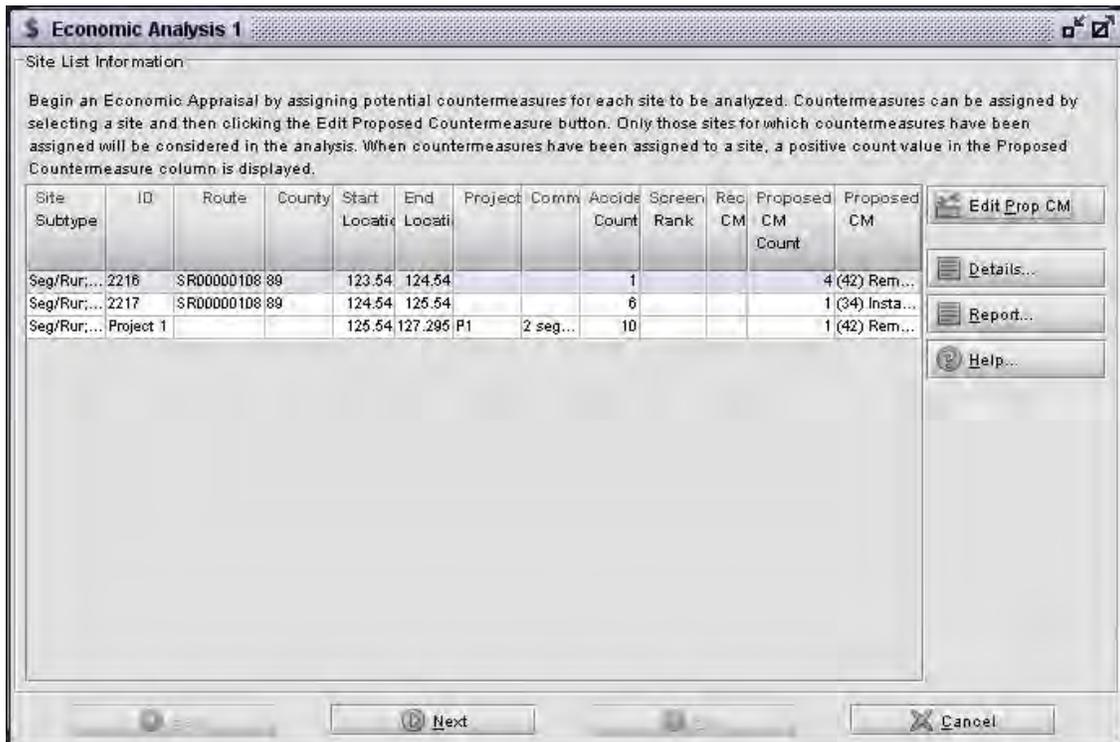
**Figure 20. Site List Information Panel in Module 3**

Figure 21. Typical Input Screen to Specify Economic Criteria in Module 3

Calculations for safety benefits vary by type of criterion. Since benefits are not expressed in monetary terms for the cost-effectiveness criteria, the project benefits are the accidents reduced as a result of a countermeasure. EPDO-based cost-effectiveness is the same as cost-effectiveness except a weighting scheme has been added. When this criterion is selected, the user will have an opportunity to adjust the default weights used in the calculations later in the analysis.

Safety benefits for the benefit-cost ratio and net benefits calculations are found by calculating a relative accident cost, based on a weighted accident cost using accident cost by severity and the proportion of accidents by severity for the site subtype. The relative accident cost is then multiplied by the accidents reduced and converted to a present value. Since these calculations utilize the minimum attractive rate of return, or the interest rate that reflects the time value of money, it is presented in this dialog for adjustment. However, the default value of 4 percent is recommended for all calculations. If the optimization of net benefits for a program of sites and countermeasures is desired, the net benefits criterion must be selected.

4.3.3 Specifying History and Accident Periods

The time periods of the analysis can be specified simultaneously for all sites in the Process Period panel, Figure 22. Selections may be made for the historical time period to use for estimating a site's average accident frequency as well as the future implementation period, or analysis period, on which safety benefits are based. In *SafetyAnalyst*, all evaluation periods are considered in entire calendar years, so that there is no seasonal bias in the evaluation data by using partial years. Therefore, all selections made here are based on whole calendar years or yearly units.

By default, the history period includes the 10 most recent available years of data for a site, since the analysis will benefit from using a long-term average for each site. However, selections may be made to specify specific historical data for the analysis. Additionally, the years prior to major reconstruction for any site are excluded by default.

Periods prior to major reconstruction should be excluded from the analysis, and their associated accidents because a site's estimated average accident frequency is based on its current characteristics and *SafetyAnalyst* may not account for the differences in the site characteristics between the current conditions and those prior to reconstruction.
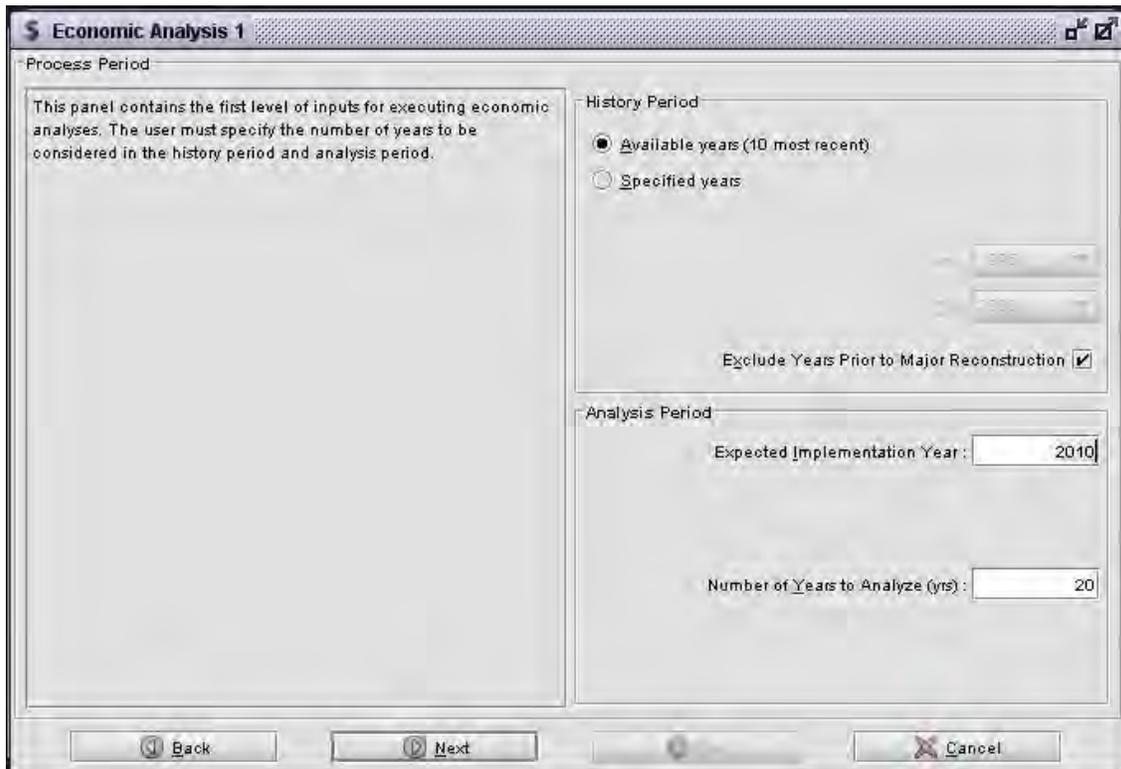
Figure 22. Specify Analysis Period Panel in Module 3

The Analysis Period has two selections, the expected implementation year and the number of years to analyze. The expected implementation year is the year to which present safety benefits and construction costs are set. By default, the expected year of countermeasure implementation for all proposed countermeasures is the next calendar year from today's date. However, this value should be adjusted if implementation is planned for a later year. The number of years to analyze is the number of years in the future period on which the economic analyses will be based. Since multiple countermeasures can be analyzed and compared with this module, each having different service lives or years of effectiveness, they can be made to be comparable by considering the same analysis period. The default value for this item is 20 years.

4.3.4 Specify Weight and Cost Values

If the benefit-cost ratio or net benefits criteria are being evaluated, the Accident Costs Panel (Figure 23) may be used to change the default cost estimates for accidents by severity used in the calculations. The default cost estimates are the Federal Highway Administration estimates for 2009.
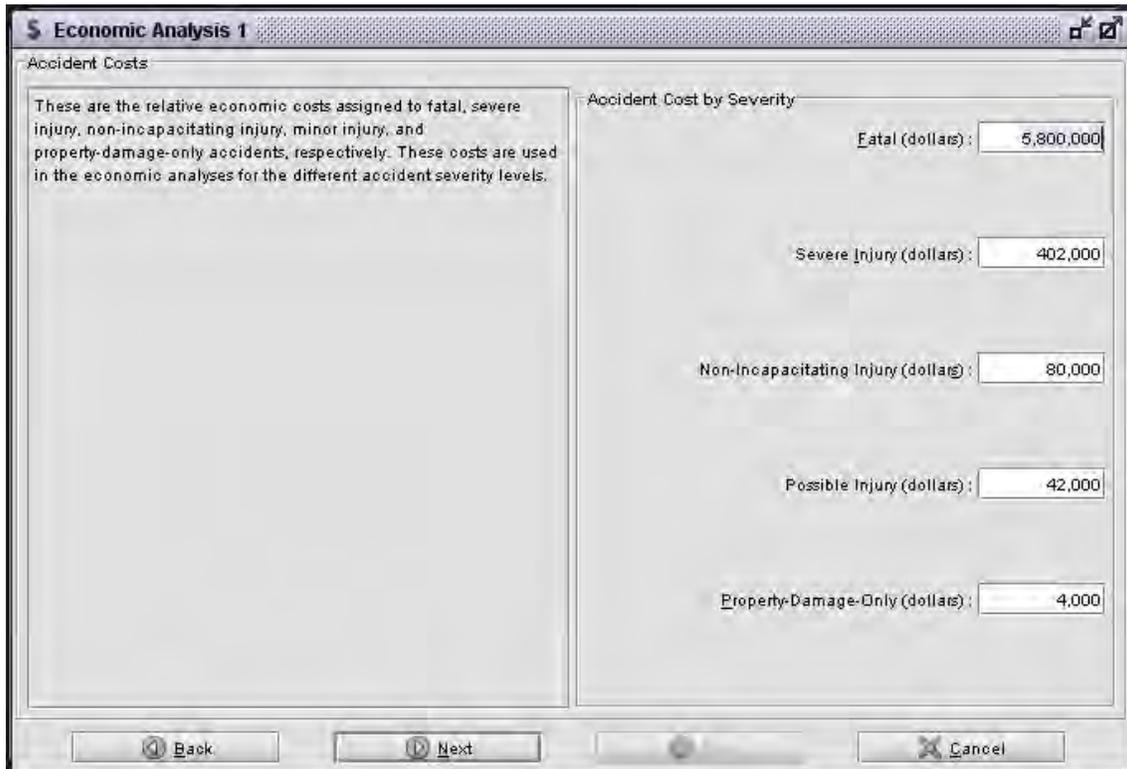
Figure 23. Specify Accident Costs in Module 3

If the EPDO-based cost-effectiveness criterion is being evaluated, the Accident Weights Panel (Figure 24) may be used to change the default weight estimates for accidents by severity used in the calculations.

4.3.5 Specify Priority Ranking Tables

Project priorities can be established in this module by ranking projects by one of the key safety-related measures available in *SafetyAnalyst*:

- **Cost-effectiveness:** dollars spent per accident reduced (i.e., the present value of constructing the countermeasure divided by the total number of accidents reduced)

- **EPDO-based cost-effectiveness:** dollars spent per weighted number of accidents reduced (i.e., the present value of constructing the countermeasure divided by a weighted estimate of accidents reduced by severity type)

Figure 24. Specify Accident Weights in Module 3

- **Benefit-cost ratio:** ratio of the monetary present value of the estimated annual accidents reduced to the present value of the construction cost of the countermeasure

- **Net benefits:** monetary present value of the estimated annual accidents reduced minus the present value of the construction cost of the countermeasure

- **Construction costs:** present value of the construction cost of the countermeasure

- **Safety benefits:** monetary present value of the estimated annual accidents reduced

- **Total accidents reduced:** number of total accidents reduced during the analysis period

- **FS accidents reduced:** number of fatal and severe injury accidents reduced during the analysis period

- **FI accidents reduced:** number of fatal and all injury accidents reduced during the analysis period

One or more of the above criteria, shown in Figure 25, may be selected for the analysis. For each criterion selected, a separate priority ranking table will be produced for the output

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report. Two options are available to control the format for each generated table: Countermeasures to Rank and Display Order.
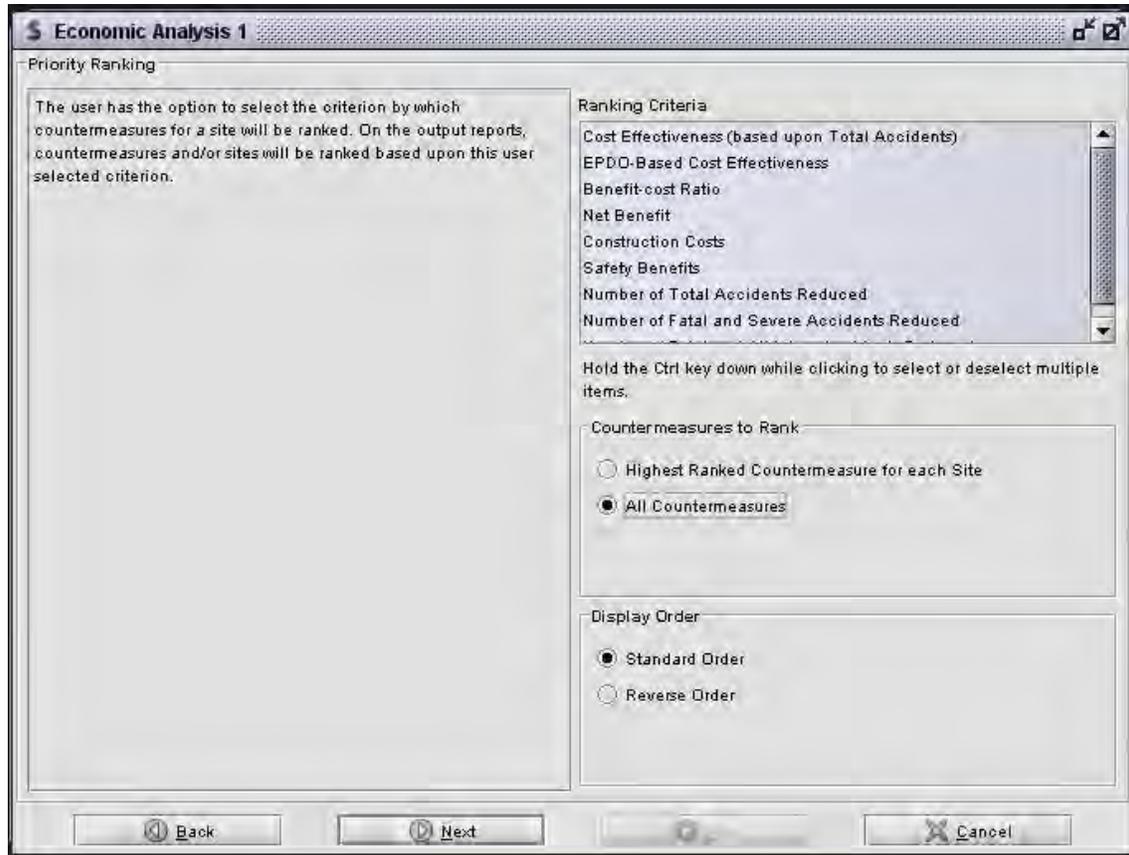
Figure 25. Priority Ranking Panel in Module 3

The Countermeasures to Rank option determines whether all countermeasures evaluated at a site will be ranked or just the highest ranked countermeasure for a site. For an analysis of a single site, the All Countermeasures option should be selected. The Display Order option determines the sort order of the criterion: Standard Order or Reverse Order. The Standard Order lists countermeasures from most economically attractive to least. For some criteria, larger values are more economically attractive, whereas, for others, smaller values are more economically attractive.

4.3.6 Specify Optimization Analysis

In addition to establishing the priority ranking of countermeasures for each site evaluated, the priority-ranking tool also ranks countermeasures across multiple sites when the net benefits economic criterion has been selected. This ranking is accomplished through a mathematical optimization technique called integer programming (IP).

IP is a linear programming technique that maximizes or minimizes an objective function, taking into account integer valued constraints. *SafetyAnalyst* uses an open-source product, lpsolve, to perform the IP analysis *(9)*.

In *SafetyAnalyst,* the optimization analysis identified the set of countermeasures for each site that maximizes the total net benefits for all sites considered, subject to the following constraints:

- Only one countermeasure can be selected for each site, including the No Build alternative.

- The total construction cost for the above selected countermeasures does not exceed the available budget.

Figure 26 shows the panel used to specify an optimization analysis.

To perform an optimization of net benefits, check the Optimize Net Benefits within Construction Budget option and enter the available construction budget in the Optimization Criteria section. When a nonlimiting budget value is entered, the countermeasures with the highest net benefits are determined for each site.

The computations involved for integer programming are quite laborious and repetitive and can require long run times. Therefore, the Optimization Program Data section of the panel provides algorithm options that may be adjusted. It is recommended that the default values be used initially and that they be adjusted only if the program doesn't return a solution in a reasonable amount of time.

The three algorithm options are:

- The Percent Tolerance of True Optimum Solution specifies a tolerance for the branch and bound algorithm. This tolerance is the difference between the best-found solution yet and the current solution and is currently set to a default value that appears satisfactory. If the difference is smaller than this tolerance then the solution (and all the sub-solutions) is rejected. A larger tolerance value can result in faster solving times, but results in a solution that is not the perfect solution.

- The Maximum Time to Run Optimization Program imposes limits on the run time of the optimization program. Zero seconds indicates no time limit is imposed. This parameter is currently set to a default value that appears satisfactory. When the run time limit is reached and an integer solution (albeit possibly not the best) has been found, then lpsolve will return SUBOPTIMAL. If no integer solution had been found yet by the run time limit, then solve will return TIMEOUT.

- The Maximum Iterations to Perform During the Optimization is currently set to a default value that appears satisfactory. If a TIMEOUT is reached or the algorithm takes an unreasonably long time to execute, this value may be decreased.

No concerns with encountering SUBOPTIMAL or TIMEOUT messages have yet been encountered with the default values for the parameters discussed above. So, as a practical matter, it is not expected that adjustment of the current default values will be needed.
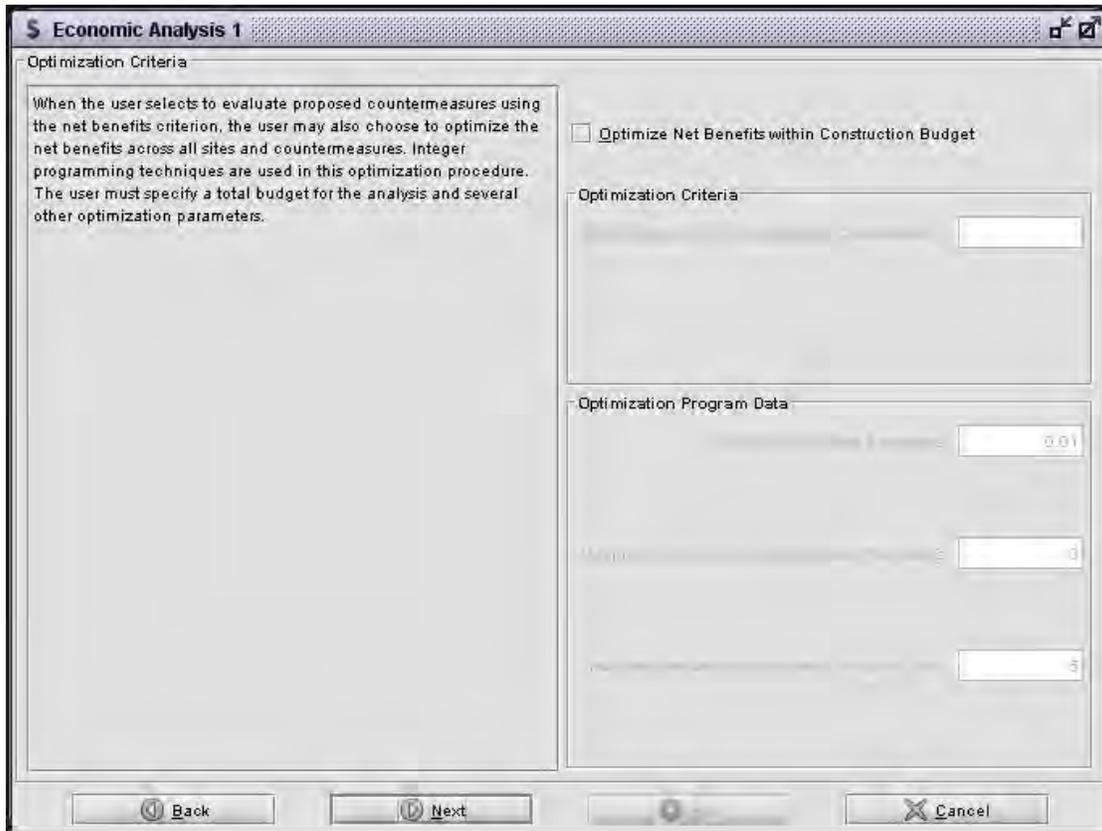
Figure 26. Optimization Selection Panel in Module 3

4.4 Primary Output Report

The primary output from Module 3 is a list of sites and the economic analyses for each proposed countermeasure selected. Secondary output may contain priority ranking tables and an optimization report when selected for an analysis. Samples of output reports from all economic criteria selections are presented below. These output reports are demonstrated assuming countermeasures "Remove shoulder edge drop-offs" and "Install continuous milled-in shoulder rumble strips" are being considered to eliminate fixed-object collisions at several sites with potential for safety improvement.

Table 21 presents the results of the economic evaluation for each site and alternative countermeasure. The analysis options that generated this sample output, presented in the upper left corner of the actual output report, are as follows:

- Types of Economic Analyses Performed: Cost-effectiveness, EPDO-based cost-effectiveness, Benefit-cost ratio, Net benefit

- Years of Data Considered: History Period (Available Years 1995 to 2002)

- No major reconstruction occurred at any sites during the history period

- Analysis Period: Implementation Year (2010), Years to Analyze (20)

- Minimum Attractive Rate of Return (Percent): 4

- Accident Costs by Severity: Fatal ($5,800,000), Severe Injury ($402,000), Non-incapacitating Injury ($80,000), Possible Injury ($42,000), Property Damage Only ($4,000)

- EPDO Weights: Fatal (1,450), Severe Injury (100), Non-incapacitating Injury (20), Possible Injury (10), Property Damage Only (1)

The economic appraisal results table contains many items of interest:

Cost-effectiveness—The cost-effectiveness of the countermeasure is expressed as dollars spent per accident reduced. Countermeasures with lower cost per accident reduced are more likely to maximize the benefits of an improvement program than countermeasures with higher cost per accident reduced. However, since safety benefits are not put in monetary terms, comparing it to the construction cost does not give an indication if the countermeasure is economically efficient.

EPDO-based Cost-effectiveness—Equivalent Property Damage Only (EPDO)-based cost-effectiveness is the cost-effectiveness estimate with a severity weighting scheme incorporated in it. Interpretation for this criterion is similar to the cost-effectiveness criterion, that is, lower is better.

Benefit-cost ratio—The benefit-cost ratio is the ratio of the present safety benefit of a countermeasure to its construction cost. When the benefit-cost ratio is greater than 1.0, the benefits of the proposed countermeasure are greater than its cost. The most desirable countermeasures are those with the highest benefit-cost ratios.

Net benefit—The net benefits criterion assesses countermeasures via the difference between safety benefits and construction costs. For a countermeasure to be economically justified by this criterion, the net benefits should be greater than zero. For this approach, the most desirable improvements are those with the highest net benefits.

Following the overall economic analysis table are the individual priority ranking tables, one for each criterion selected for analysis. Table 22 illustrates priority ranking of the Number of Total Accidents Reduced. This table could be modified to only show the highest ranked countermeasure for each site.

The final output report is the optimization result, shown in Table 23. This section of the report identifies the set of proposed countermeasure for each site that maximizes the overall safety benefit of any expenditure, taking into consideration budgetary constraints. The same analysis options to generate the economic results (Table 21) were used to generate this table with one additional criterion, the Construction Budget of $10,000,000. The safety benefits, construction cost, net benefits, and total accidents reduced are provided for each site and are totaled for all sites.

Table 21. Example of Economic Appraisal Results

Proposed site-CM	Site ID	Site type	County	Route	Beginning location	Ending location	Countermeasure	CM start location	CM end location	Construction cost	Cost effectiveness	Cost effectiveness EPDO	Benefit cost ratio	Net benefit
1	704	Segment	34	00000025	140.983	141.361	Install continuous milled-in shoulder (or edgeline) rumble strips	140.983	141.361	$567	$1,240	$44	43.78	$40,644
2	704	Segment	34	00000025	140.983	141.361	Remove shoulder-edge drop-offs	140.983	141.361	$7,560	$18,384	$1,457	1.33	$4,222
3	704	Segment	34	00000025	140.983	141.361	Combined, Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	140.983	141.361	$8,127	$9,610	$469	4.14	$42,786
6	705	Segment	34	00000025	141.361	141.482	Install continuous milled-in shoulder (or edgeline) rumble strips	141.361	141.482	$182	$1,673	$67	28.97	$8,505
7	705	Segment	34	00000025	141.361	141.482	Remove shoulder-edge drop-offs	141.361	141.482	$2,420	$24,803	$2,190	0.89	$–459
8	705	Segment	34	00000025	141.361	141.482	Combined, Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	141.361	141.482	$2,602	$12,966	$708	2.74	$7,605
11	706	Segment	34	00000025	141.482	142.482	Install continuous milled-in shoulder (or edgeline) rumble strips	141.482	142.482	$1,500	$4,915	$54	36.28	$88,683
12	706	Segment	34	00000025	141.482	142.482	Remove shoulder-edge drop-offs	141.482	142.482	$20,000	$72,871	$1,815	1.07	$2,361
13	706	Segment	34	00000025	141.482	142.482	Combined, Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	141.482	142.482	$21,500	$38,094	$571	3.40	$86,484
16	709	Segment	34	00000025	143.54	144.54	Install continuous milled-in shoulder (or edgeline) rumble strips	143.54	144.54	$1,500	$6,882	$109	19.12	$45,537
17	709	Segment	34	00000025	143.54	144.54	Remove shoulder-edge drop-offs	143.54	144.54	$20,000	$102,030	$3,676	0.57	$-14,489
18	709	Segment	34	00000025	143.54	144.54	Combined, Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	143.54	144.54	$21,500	$53,337	$1,162	1.80	$28,646
21	710	Segment	34	00000025	144.54	144.895	Install continuous milled-in shoulder (or dgeline) rumble strips	144.54	144.895	$533	$9,944	$122	17.06	$14,329
22	710	Segment	34	00000025	144.54	144.895	Remove shoulder-edge drop-offs	144.54	144.895	$7,100	$147,437	$4,139	0.50	$-5,898
23	710	Segment	34	00000025	144.54	144.895	Combined, Install continuous milled-in shoulder (or edgeline)rumble strips, Remove shoulder-edge drop-offs	144.54	144.895	$7,633	$77,074	$1,305	1.60	$7,670
26	711	Segment	34	00000025	144.895	144.968	Install continuous milled-in shoulder (or edgeline) rumble strips	144.895	144.968	$109	$1,438	$61	31.89	$5,668
27	711	Segment	34	00000025	144.895	144.968	Remove shoulder-edge drop-offs	144.895	144.968	$1,460	$21,315	$1,991	0.98	$-50
28	711	Segment	34	00000025	144.895	144.968	Combined, Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	144.895	144.968	$1,569	$11,142	$645	3.02	$5,325
31	712	Segment	34	00000025	144.968	145.522	Install continuous milled-in shoulder (or edgeline) rumble strips	144.968	145.522	$831	$3,862	$71	29.21	$39,280
32	712	Segment	34	00000025	144.968	145.522	Remove shoulder-edge drop-offs	144.968	145.522	$11,080	$57,266	$2,371	0.87	$-2,413
33	712	Segment	34	00000025	144.968	145.522	Combined, Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	144.968	145.522	$11,911	$29,936	$751	2.75	$34,833

Table 22. Priority Ranking: Total Accidents Reduced

Proposed site-CM	Site ID	Site type	County	Route	Beginning location	Ending location	CM title	CM start location	CM end location	Total accidents reduced*	Rank
3	704	Segment	34	US00000025	140.983	141.361	Combined, Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	140.983	141.361	1.42	1
13	706	Segment	34	US00000025	141.482	142.482	Combined, 23 Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	141.482	142.482	0.95	2
18	709	Segment	34	US00000025	143.54	144.54	Combined, Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	143.54	144.54	0.68	3
33	712	Segment	34	US00000025	144.968	145.522	Combined, Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	144.968	145.522	0.67	4
8	705	Segment	34	US00000025	141.361	141.482	Combined, Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	141.361	141.482	0.34	5
28	711	Segment	34	US00000025	144.895	144.968	Combined, Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	144.895	144.968	0.24	6
23	710	Segment	34	US00000025	144.54	144.895	Combined, Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	144.54	144.895	0.17	7

*These are estimates of the number of accidents reduced and not a guarantee.

Table 23. Optimization Results—Net Benefits

Proposed site-CM	Site ID	Site type	County	Route	Beginning location	Ending location	Countermeasure	CM start location	CM end location	Safety benefits	Construction costs	Net benefit	Total accidents reduced*
11	706	Segment	34	US00000025	141.482	142.482	Install continuous milled-in shoulder (or edgeline) rumble strips	141.482	142.482	$91,197	$1,500	$88,683	0.51
16	709	Segment	34	US00000025	143.54	144.54	Install continuous milled-in shoulder (or edgeline) rumble strips	143.54	144.54	$48,050	$1,500	$45,537	0.37
3	704	Segment	34	US00000025	140.983	141.361	Combined, Install continuous milled-in shoulder (or edgeline) rumble strips, Remove shoulder-edge drop-offs	140.983	141.361	$56,403	$8,127	$42,786	1.42
31	712	Segment	34	US00000025	144.968	145.522	Install continuous milled-in shoulder (or edgeline) rumble strips	144.968	145.522	$40,672	$831	$39,280	0.36
21	710	Segment	34	US00000025	144.54	144.895	Install continuous milled-in shoulder (or edgeline) rumble strips	144.54	144.895	$15,221	$533	$14,329	0.09
6	705	Segment	34	US00000025	141.361	141.482	Install continuous milled-in shoulder (or edgeline) rumble strips	141.361	141.482	$8,809	$182	$8,505	0.18
26	711	Segment	34	US00000025	144.895	144.968	Install continuous milled-in shoulder (or edgeline) rumble strips	144.895	144.968	$5,851	$109	$5,668	0.13
Total										266,203.19	$12,781	$244,787	3.05

*   These are estimates of the number of accidents reduced and not a guarantee.

Only countermeasures with positive net benefits are considered by the optimization algorithm. The "do-nothing" alternative is considered for each site and would dominate any countermeasure with negative benefits. A countermeasure dominates another countermeasure if it has greater benefits and costs less. In this case, a countermeasure with negative benefits is dominated by the do-nothing alternative, which optimizes net benefits within a budgetary constraint. However, this phenomenon can occur between any two countermeasures.

4.5 Benefits of *SafetyAnalyst*'s Economic Appraisal and Priority Ranking Capabiliities

The primary benefits of utilizing *Safety Analyst*'s economic analysis and priority ranking capabilities include:

- Application of state-of-the-art procedures
- Flexibility to cover a wide range of needs
- Increased confidence that projects being implemented are good investments and provide safety benefits that are as high as practical

Many highway agencies perform economic analyses for proposed projects, but these methods are not always automated. In addition, *SafetyAnalyst* uses the most recent and most reliable information on the potential safety benefits of specific improvement types.

5. CAPABILITIES FOR MODULE 4—COUNTERMEAUSRE EVALUATION

This section of the report provides an overview of the capabilities of *SafetyAnalyst* Module 4, the countermeasure evaluation tool. The purpose of the countermeasure evaluation module is to estimate the safety effect of countermeasures implemented at specific sites. The module is capable of assessing the safety effectiveness of a single countermeasure at specific sites or the collective effectiveness of a group of countermeasures in which the same countermeasures were implemented at a specified list of sites. In addition to safety effectiveness, the countermeasure evaluation tool also is capable of performing benefit-cost analyses for countermeasures, which are needed for evaluations of federally-funded HSIP projects. Finally, Module 4 includes a capability to evaluate the safety effectiveness of individual projects or groups of projects, which may have involved implementation of multiple countermeasures. Analysts must interpret the results of such analyses cautiously, because the safety effect of the multiple countermeasures are combined and cannot be determined separately. The types of evaluations that can be performed with this module are summarized in Section 5.1.

SafetyAnalyst estimates the effectiveness of implemented improvements(s) through a variety of observational before-after evaluations using appropriate statistical techniques. The primary statistical approach available within *SafetyAnalyst* is the Empirical Bayes (EB) technique. The EB technique is applied when the objective of the evaluation is to estimate the percent change in accident frequencies due to the implemented countermeasure. When the objective of the analysis is to test for shifts in the proportion of specific collision types, *SafetyAnalyst* utilizes the Wilcoxon signed rank test. The types of evaluations available in *SafetyAnalyst* are explained in Section 5.2.

Countermeasure evaluations make use of site characteristics and countermeasure information to determine effectiveness resulting from implementing countermeasure solutions at locations. The data used in countermeasure evaluations fall under the following categories:

- Location (e.g., route, county, and milepost for the specific sites to improve)

- Name of countermeasure (e.g., install left-turn lane)

- Construction implementation dates (e.g., start and end dates for the construction period)

- Construction implementation costs (e.g., cost of constructing the left-turn lane)

Some or all of these data are already included in the *SafetyAnalyst* databases and can be retrieved as part of the analysis. However, some data are not available and will need to be entered as part of the analysis. Section 5.3.1 explains how the data needed for an analysis are assembled.

SafetyAnalyst provides the capability to adjust all default values that are used in the calculations. Default values edited at the time of analysis, or analysis options, allow customization of individual analyses. Some examples of these options are:

- Desired confidence level of analysis
- Number of years of accident and AADT data to be used (before and after)
- Accident severity level to be evaluated
- Collision type to be evaluated

Sections 5.3.2 through 5.3.7 discuss these features of Module 4.

The primary output from Module 4 is an overall effectiveness table of the implemented countermeasure(s). There are two basic types of countermeasure evaluations, so there are two kinds of effectiveness tables. The first output report presents the effectiveness as a percent change in accident frequency, while the second type of output report presents the effectiveness as a change in proportion of target accident types. Several tables are presented which indicate whether the countermeasure impacted the safety performance of individual sites and provide some interim calculations. Other output is available depending on the analysis specified. If an economic analysis was specified, another output section provides results on the economic efficiency of the countermeasure(s). These reports are discussed in Section 5.4. Section 5.5 summerizes the benefits of using Module 4.

5.1 Types of Analyses Addressed with the Countermeasure Evaluation Tool

The countermeasure evaluation tool provides a means to assess the safety effect of an improvement, or combination of improvements, at a single location, set of locations, or across a network. This tool also provides a method to determine the economic efficiency of invested improvement funds. The extent of the analysis performed by these tools is dependent upon the tasks at hand. For example, for a particular roadway segment, intersection, or interchange ramp, countermeasures may have been implemented for which extimates if the safety benefits, in terms of the expected number of accidents reduced and in economic terms, are desired.

In this situation, the countermeasure evaluation tool would perform an analysis for the particular countermeasure at the specific site, based upon a percentage reduction in accidents or a shift in proportions of accidents by collision type. In another scenario, the countermeasure evaluation tool can be used to determine the effectiveness of countermeasure(s) implemented system-wide for the purposes of quantifying an AMF for a countermeasure. In a final scenario, the overall safety effectiveness of implemented countermeasure(s) may be assessed in comparison to their costs for the specific purpose of planning HSIP projects and programs.

Effectiveness measures used in these evaluations include: a percentage reduction in accidents, a shift in the proportions of accidents by collision type, and a benefit-cost ratio.

The next section provides an overview of the evaluation methods that produce these estimates.

5.2 Types of Countermeasure Evaluations

SafetyAnalyst provides two different types of countermeasure evaluations to assess their safety effectiveness. These methods are:

- Estimate Percent Change in Accident Frequency
- Estimate Change in Proportion of Target Accidents

The first method expresses the effectiveness measures as a percentage change (decrease or increase) in accident frequencies for all accidents, or in specific target accident types. The second procedure expresses effectiveness as a shift in proportion of specific collision types. Appendix D presents the basic algorithms used in the countermeasure evaluations. *SafetyAnalyst* also provides an economic evaluation to determine the cost-effectiveness of countermeasures. The calculations for this evaluation are also explained in Appendix D.

Both methods perform observational before-after evaluations to estimate the effectiveness of countermeasures using appropriate statistical techniques. However, the Percent Change in Accident Frequency evaluation is considered the primary statistical approach since it utilizes the Empirical Bayes (EB) technique. This technique uses SPFs developed from a set of reference sites similar to the improved site(s) to estimate the change in accident frequency that would have occurred at the improved site(s) had the improvement not been made. In stand-alone applications of the EB method, the SPFs are developed by regression modeling using a selected group of reference sites. An advantage in performing evaluations using *SafetyAnalyst* is that appropriate SPFs already incorporated within *SafetyAnalyst* are available to perform the evaluation. EB concepts are also used in the other *SafetyAnalyst* modules.

When a roadway segment, intersection, or ramp has a relatively high accident experience during a particular time period, its accident experience is likely to decrease even if it is not improved; this phenomenon is known as regression to the mean. When an improvement project is constructed at a location with relatively high accident experience, the natural decrease in accident frequency due to *regression to the mean* may be mistaken for an effect of the countermeasure. Thus, regression to the mean is a major threat to the validity of before-after evaluations. The EB approach is the only known approach to before-after evaluation that has the capability to compensate for regression to the mean and, for this reason, the EB approach is the primary evaluation technique.

The Change in Proportion of Target Accidents evaluation uses a nonparametric approach to assess whether the countermeasure affected the proportion of accidents of the specific type under consideration. In statistical terms, this is done by calculating the average difference in proportions across all sites and a confidence interval around that average difference at a prespecified confidence level (e.g., 90%). The statistical test performed is

the Wilcoxon signed rank test, a nonparametric test that does not require that the differences follow a normal distribution. This test is rather conservative; it is also relatively insensitive to outliers in the data.

The economic evaluation of implemented improvements is conducted by the calculation of the benefit-cost ratio. The benefit-cost ratio is the ratio of the present benefit of a project to the construction costs. When a countermeasure is cost-effective, its benefit-cost ratio is greater than 1.0. The best implemented countermeasures are those with the highest benefit-cost ratios.

Benefit-cost ratios give explicit consideration to accident severity because accident cost estimates differ by severity level.

5.3 Performing Countermeasure Evaluations in *SafetyAnalyst*

This section describes the specific program features for conducting a countermeasure evaluation. The initial steps of selecting sites and entering implemented countermeasure information are followed by a description of the analysis options available for this module.

5.3.1 Specifying Sites and Countermeasures to Evaluate

The first step in conducting a countermeasure evaluation is selecting sites. It is expected that an agency has a list of improved sites that they wish to evaluate. Consequently, specific sites may be added to the site list using a site selection query that explicitly identifies the sites by id or implemented countermeasure. Alternatively, all sites may be selected and then, as part of the analysis, *SafetyAnalyst* automatically will select only those sites that have implemented countermeasure records. For either method, there are a number of considerations for the site list.

To begin, the list of sites should include as many sites as possible, and should desirably contain at least the minimum number of sites. The ability to obtain statistically significant results is dependent on many factors: the number of years in the before and after analysis periods, the number of observed accidents at a site, the goodness of fit of the SPF, and the desired confidence limit. The likelihood of finding statistically significant safety effects due to a countermeasure increases as the number of evaluation sites increases (or any of the above improves). As a general rule, 10 to 20 sites with 3 to 5 years of before accident data and 3 to 5 years of after accident data are recommended. If less data are available or greater statistical reliability is needed, then more sites may be needed. However, the analysis will proceed with a minimum of one site, one year of before data, and one year of after data.

Although having the maximum number of sites is desirable, it may not be appropriate to combine all sites at which a particular countermeasure has been installed should not be evaluated together. Countermeasures may have different effects when applied in different

environments or for different categories of road users. Therefore, the list of sites should be of the same site type; i.e., all roadway segments, all intersections, or all ramps. In fact, this limitation is programmed in the software. Since the results from the analysis can potentially be used to update safety estimates of countermeasures, which are specific to site types and subtypes, it is desirable that all the sites selected for analysis are of the same subtype. However, no programming limitation exists to prevent a user from evaluating different subtypes together.

When selecting sites, consideration should be given to the time period in which countermeasure improvements occurred (i.e., the time period between the first installation date and the last installation date). The time period in which all the countermeasures were constructed, should not span several years and, therefore should also be considered in the selection of sites. Changes in construction practice used to implement the countermeasure, the materials used in the construction, and accident reporting standards over time create variability in the data that may not be captured fully by the evaluation process. Consequently, it is preferred that the projects evaluated are constructed within five years of each other.

The next consideration in site list creation pertains to roadway segments and the creation of "subsegments." If a given countermeasure was implemented on only a portion of a site (i.e., subsegment), then only the portion of the site that was improved will be used in the computations. Additionally, multiple subsegments of the same site can be analyzed.

5.3.2 Enter Countermeasure Construction Information

Before beginning a countermeasure evaluation, information regarding the countermeasure(s) must be provided. This is accomplished via the Implemented Countermeasure Tool. With this tool, the name(s) of the countermeasure(s) being evaluated, the year of implementation, and cost incurred can be imported or entered for each location included in the analysis.

To start the Implemented Countermeasure Tool, the dataset is selected to which the countermeasure information will be added (Figure 27). After a dataset is selected, the main interface for the Implemented Countermeasure tool is then shown.
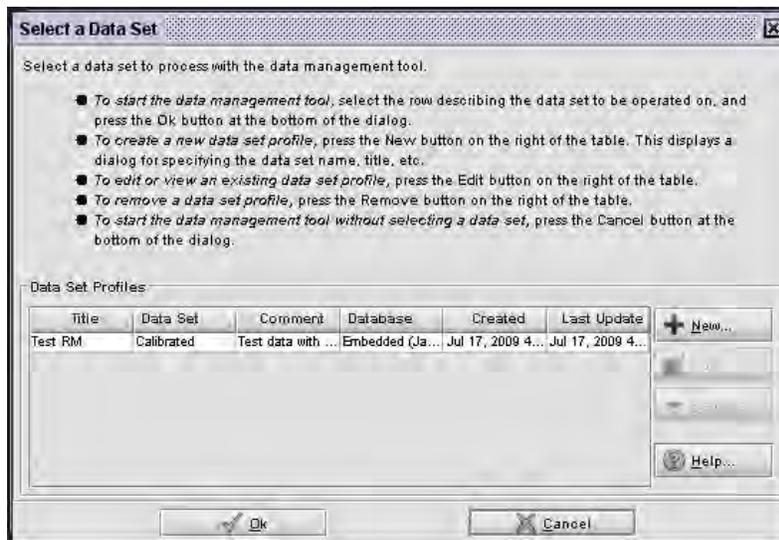
Figure 27. Select a Data Set Dialog in the Implemented Countermeasure Tool

There are two primary methods to add implemented countermeasure data in *SafetyAnalyst*, importing a comma delimited text file or manual data entry. Both methods are accessed through the Implemented CM tab of the dialog shown in Figure 28. The very top portion of this panel contains a button, labeled Edit Implemented CM, which can be used to invoke the manual entry editor while the remaining part of the panel is designated for importing this data.

Figure 28. Implemented CM Tab Within the Implemented Countermeasure Tool

Implemented Countermeasure information can be imported by specifying the file location of the data and then merging the new data to the dataset by clicking the Start button at the bottom of the panel. Multiple files may be designated for simultaneous importing by using the Add button to invoke a dialog to specify their location. Each imported file must be correctly formatted or contain the proper data elements. If the file format is unknown, the Export tab of this tool can be used to export existing implemented countermeasure records to an empty file with the proper data element headings so that the proper format may be determined.

Alternatively, implemented countermeasure data may be entered manually through the editor. After starting this editor, an Edit/View Construction Projects dialog, shown in Figure 29, can be used to add records to the database. Construction projects are the organizational structure of highway system improvements data and should not be confused with roadway projects, used in the Analytical tool, which represent groupings of roadway segment records.
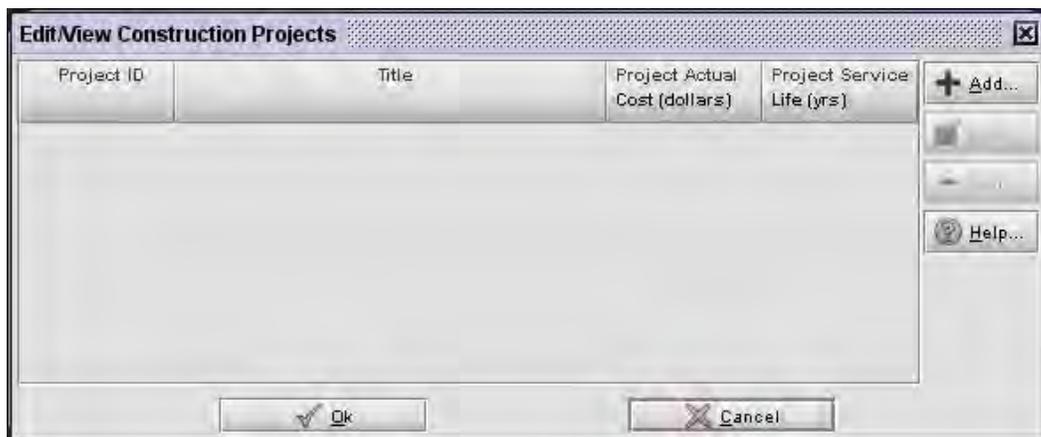
Figure 29. Edit/View Construction Projects Dialog Within the Implemented Countermeasure Tool

The Implemented Countermeasure Editor was designed to be flexible enough to handle a variety of agency construction project data. Consequently there are multiple ways of entering and organizing the information. For some agencies, construction projects are organized by contract awards. In this case, a project may consist of several improvements to a roadway section (or multiple sections), including all of the improvements to any ramps or intersections that occur within the roadway boundaries. For other agencies, a project may consist only of a single improvement made to a single site type and location. *SafetyAnalyst* supports both of these data organizations and will adapt the underlying data for proper use in countermeasure evaluation.

To begin adding a construction project, select the Add button to invoke the Specify the Construction Project dialog (Figure 30). This dialog is divided into two sections. The top portion of this dialog has data entry available for project-level information. The bottom portion of this dialog is used to enter the countermeasure information for a project.

Project-level information includes: Project ID, a description, title or, construction cost and service life. The Project ID is a unique identifier that ties all of the improvement information together. For some agencies, this ID is a contract number that identifies the improvement to the system. It is the only required data and must be entered before improvement data can be entered. The Title and Comment fields are optional data that provide an opportunity to enter a more complete description of the improvements.

Project Cost is the total construction cost of all improvements in the project. This is optional data and is included more for informational value than for actual use by the software. *SafetyAnalyst* can perform a benefit-cost analysis as part of a countermeasure evaluation. However, it needs the actual cost of each improvement. When a project consists of only one type of improvement (being applied to one site type—all roadways, intersections, or ramps) then the project cost can be divided among the individual location records—for example, among signals traffic added to each of a series of intersections. Conversely, when a project contains multiple types of improvements on multiple site types, then the project cost cannot be proportioned among the improvements and locations. Project Service Life, the time for which the improvements are expected to be effective at improving safety, works in a similar manner.
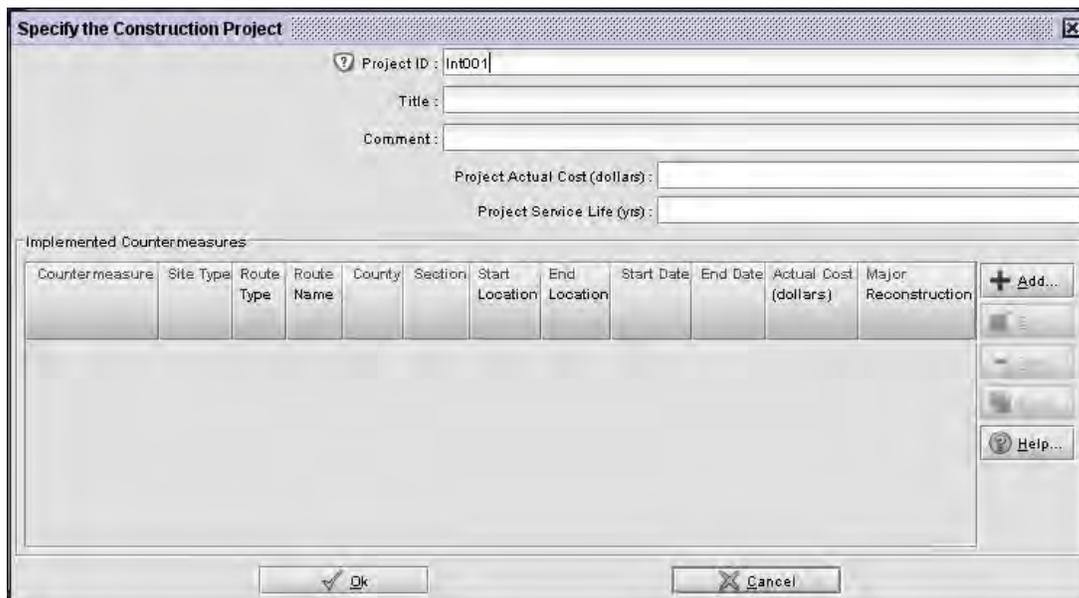
Figure 30. Specify the Construction Project Dialog Within the Implemented Countermeasure Tool

Once the Project ID is entered, individual countermeasures may be entered by clicking the Add button to start the Specify the Implemented Countermeasure dialog. With this dialog, shown in Figure 31, Site Type, Countermeasure, Start and End Date, and all location information (i.e., Location System, Route Type, Route Name, and Start and End Location) can be entered for an implemented countermeasure. Actual Cost and Service Life can also be provided, but are not required data.

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Figure 31. Specify the Implemented Countermeasure Dialog Within the Implemented Countermeasure Tool

The site type (i.e., roadways, intersections, or ramps) is entered so that the appropriate list of countermeasures can be selected. The countermeasure is entered by clicking the tool icon to invoke a dialog containing a list of all possible countermeasures appropriate for the site type. This list contains all of the countermeasures available in *SafetyAnalyst.* The list of available countermeasures can be updated by an Administrator to include agency specific countermeasures through the the Administration Tool. Only one countermeasure can be selected from this list. Consequently, if more than one improvement is being made, then separate countermeasure records must be created for each of them.

The Start Date and End Date specify the beginning and ending of construction. They can be entered directly in the cell or selected from the calendar tool next to them. The construction period is meant to include the time period that the facility was considered a work zone rather than the beginning and ending dates of a contract, which may be longer than construction. The location information specifies the location on the highway system that was improved.

Start Location and End Location data refer to the mileposts or offset distance. If a single intersection or ramp is being improved, only the start location must be provided. If an End location is also provided, then all intersections and ramps within the location selection are assigned the implemented countermeasure. Similarly, all roadway segments within a selection are considered improved. As a result if there are multiple non-contiguous locations within a project at which a countermeasure is installed then multiple records should be created. For example, if guardrail was installed at three different sections within a project, then three improvement records should be created. Otherwise, if project boundaries are entered, then the entire project would be considered improved. The location information must be entered for each implemented countermeasure record associated with a project. In other words, *SafetyAnalyst* does not automatically apply the location

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information in the first record to all other records. If an agency's inventory data were imported into *SafetyAnalyst* prior to adding implemented countermeasure information, then each field or drop-down box is pre-populated with the values available in an agency's data.

Actual Cost is the construction cost of the improvement and is optional. The actual cost of the implemented countermeasure is only necessary if the benefit-cost ratio is to be calculated during the countermeasure evaluation. Service Life is the time period during which the improvement will affect safety and is also optional. Actual Cost and Service Life can also be provided, but are not required data. A service life needs to be provided only if the service life for the implemented countermeasure is different from that provided in the countermeasure default file.

A major reconstruction check box is also provided. An improvement made to a location that significantly changes the operation or safety performance of a site is considered major reconstruction. *SafetyAnalyst* is able to limit accident history used at a location when accessing safety performance based on major reconstruction information. Consequently, this item should be selected if the improvement has a significant impact on safety. Examples include adding a signal to an intersection or additional lanes to a roadway, which may change the site subtype and require a different safety performance function. Straightening curves or flattening slopes are other examples.

5.3.3 Specifying Scope and Type of Evaluation

Specifying a countermeasure evaluation begins with selection of the analysis scope and evaluation type. Figure 32 illustrates this selection panel in Module 4. If *SafetyAnalyst* cannot find any construction project or countermeasure associated with any site or portion of a site on the applicable site list, a warning message will appear asking the user to supply the countermeasure information before the analysis can proceed.

The analysis scope determines if countermeasure evaluations are performed on entire construction projects or on individual countermeasures. Construction projects refer to the organizational structure of improvement data. A project may consist of many improvements made to a portion of the highway system, which may include roadways, intersections, and ramps (that are usually part of one contract award). A countermeasure is a single improvement made to a single facility type that occurred in a project. The Evaluate Countermeasure option is the typical analysis to determine safety effectiveness of an improvement for a type of site. The Evaluate Construction Project option provides a safety estimate for the multiple facility types and improvements that constitute a project. No statistical tests are conducted for this option.
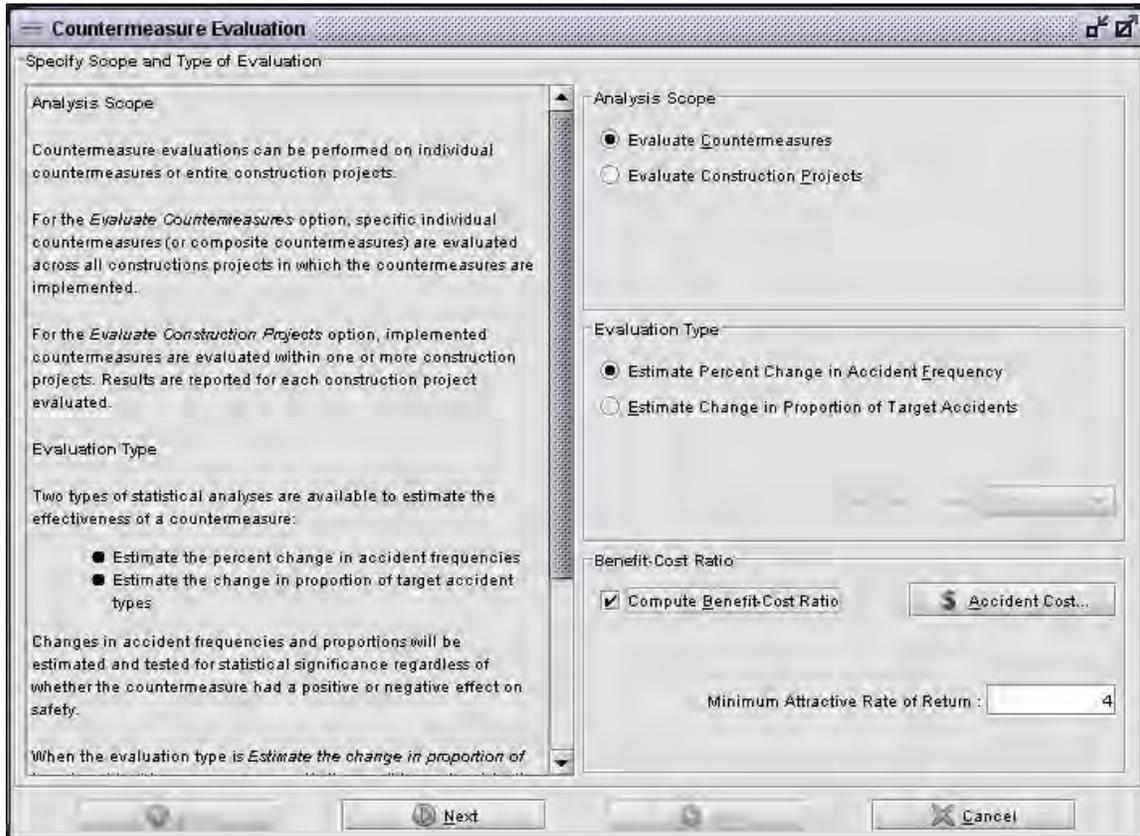
Figure 32. Specify Scope and Type of Evaluation Panel in Module 4

There are two Evaluation Type selections, Estimate Percent Change in Accident Frequency and Estimate Change in Proportion of Target Accidents, which were previously described in the Section 5.2. With each evaluation type, several other analyses may be specified.

The confidence level for statistical validity of the results may be specified when the analysis type Estimate Percent Change in Proportions of Target Accidents is selected. Although higher confidence levels are equated with greater reliability, offering several confidence levels (e.g., 80%, 85%, 90%, or 95%) allows the analyst to determine the tradeoff between significance and power. If the Percent Change in Accident Frequency evaluation is selected, the confidence levels of 90% and 95% are automatically evaluated by the software.

A benefit-cost analysis is available with the Percent Change evaluation. When this option is selected, a benefit-cost ratio will be calculated separately for each countermeasure as well as averaged over all countermeasures. The benefit-cost ratios are only calculated for the Total Accident severity level.

5.3.4 Select Implemented Countermeasures to Evaluate

SafetyAnalyst automatically provides a list of available countermeasures that have been implemented at sites included in the site list. The list of available countermeasures may include more countermeasures than the analyst intends to evaluate. The Select Implemented Countermeasures panel (Figure 33) is used to select the specific implemented countermeasure(s) to be evaluated.
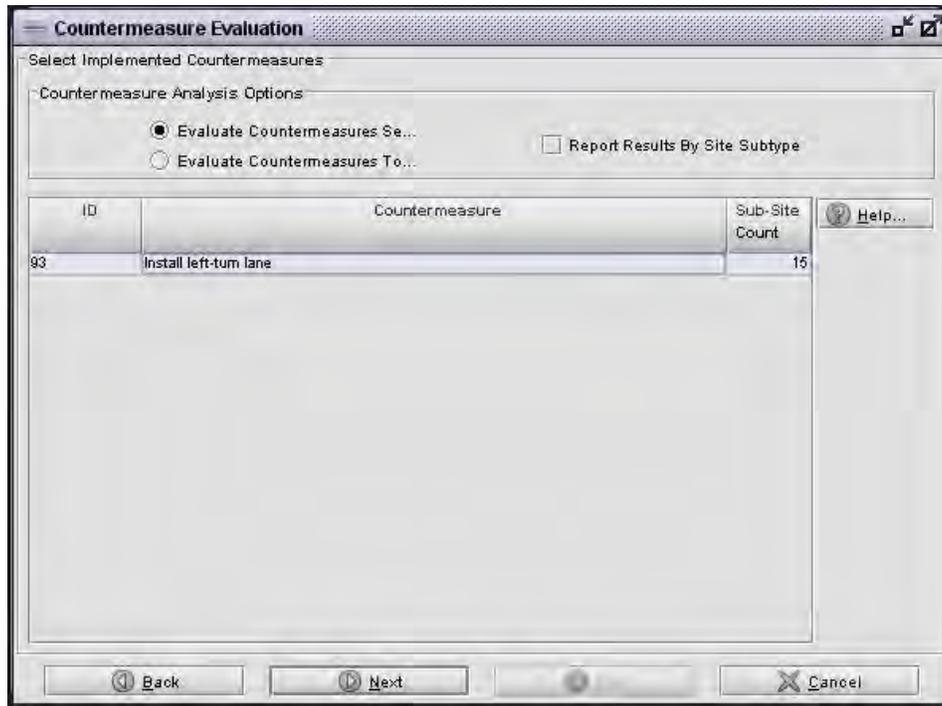
Figure 33. Select Implemented Countermeasures Panel in Module 4

Implemented countermeasures are presented in this list either as a single countermeasure or as a countermeasure combination, (i.e., multiple countermeasures that were implemented simultaneously at the same location). A sub-site count, representing the number of sub-sections of all sites in the site list at which the specific countermeasure was implemented, is given for each countermeasure or countermeasure combination. Only those sites included in this count will be included in the analysis. If a site intended for analysis is included on the site list panel, but does not have the correct countermeasure record, it will be excluded from the countermeasure evaluation.

One or more selections of implemented countermeasure types may be made from the automated list for evaluation. When multiple selections are made, two options are available to specify how the analysis is to be conducted: Evaluate Countermeasures Separately and Evaluate Countermeasures Together. The default option, Evaluate Countermeasures Separately, will evaluate each of the selected implemented countermeasures by itself and report the results for each implemented countermeasure individually. In contrast, a single combined analysis will be performed for the Evaluate Countermeasures Together option. That is, the multiple countermeasures are analyzed together as a single combined

countermeasure. For this latter selection, separate safety effectiveness measures for the individual countermeasures are not calculated. A construction project analysis works in a similar manner.

When multiple implemented countermeasures are combined for the evaluation, *SafetyAnalyst* performs no validation to confirm that it is appropriate to evaluate the selected countermeasures together. It is the analyst's responsibility to make sure the selected countermeasures can and should be evaluated together. Combining countermeasures is appropriate if the countermeasures are similar or if they are typically used together.

The final option available on this screen is the option to Report Results by Site Subtype. This option specifies whether the output report should include effectiveness results for each of the site subtypes individually or a single combined effectiveness result across all site subtypes in the analysis.

5.3.5 Specifying History and Accident Periods

With the panel for Specifying Analysis Period Constraints (Figure 34), the analysis period can be specified based on user-selected guidelines that will be applied to all evaluation sites. Selections may be made for the time period before countermeasure construction, after countermeasure construction, and a buffer period surrounding the time of countermeasure construction that will not be included in either the before or after evaluation periods.
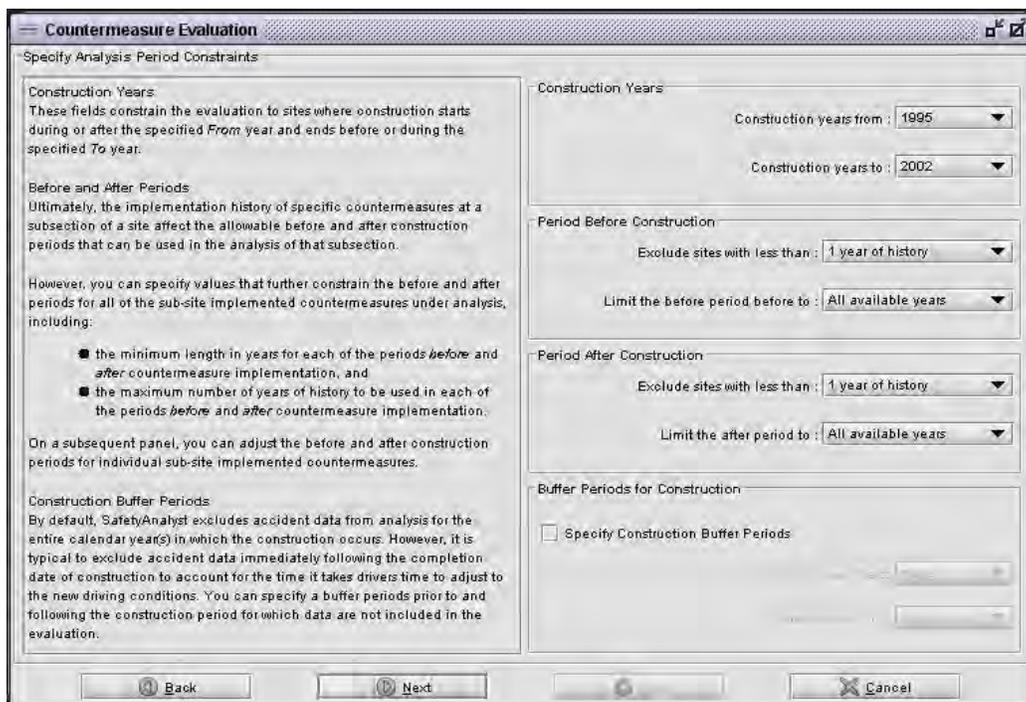

Figure 34. Specify Analysis Period Panel in Module 4

The before evaluation period begins with the earliest available data for a site and ends with the year prior to the beginning of the construction period. If any other countermeasures have been implemented at a particular site prior to the countermeasure being evaluated, then the before period should be adjusted so that the first year included is the year following any previous implemented countermeasure. Similarly, the after evaluation period begins at the start of the year following the construction period and ends with the most recent year of available data for a site. In a manner analogous to the before evaluation period, if any other countermeasures have been implemented on the site since the countermeasure being evaluated, then the after evaluation period should be adjusted so that the last year included in the analysis is the last year prior to construction of any later implemented countermeasure. Since the before and after evaluation periods may be adjusted by *SafetyAnalyst* when more than one countermeasure is implemented at a site, the years prior to major reconstruction are automatically excluded for the analysis. In addition to the adjustments made automatically by *SafetyAnalyst*, the before and after evaluation periods for individual sites can be adjusted on the next panel.

The buffer period is a period of time immediately before, during, and immediately after construction of a countermeasure. In before-after evaluations, it is typical to exclude accident data immediately following the completion date of construction. The rationale for a buffer period is that it takes drivers time to adjust to the new driving conditions, and this transition period during which drivers become adjusted to the conditions is not appropriate for inclusion in the after evaluation period and, therefore, is excluded from the evaluation.

In *SafetyAnalyst*, all evaluation periods are full calendar years, so that there is no seasonal bias in the evaluation results from using partial years. Therefore, if the construction dates for a project begin and end in the same calendar year, then that entire calendar year is considered the buffer period. If the construction spans multiple years, then each of those calendar years in their entirety are considered as the buffer period. However, if construction spans more than 3 years, the project will be excluded from the analysis.

The buffer period selections on the Specify Analysis Period Constraints panel can be used to extend the default buffer period by specifying the number of months of accident/ADT history to be excluded before or after countermeasure construction. The specified number of months is added to the beginning or ending date of the construction. If the specified buffer period extends into the next calendar year, all data from the calendar year during construction and the next calendar year during the buffer period will be excluded from the analysis. When the analyst wishes to accept the default assumption that the entire construction year(s) for each project, and nothing more, should be used as the buffer period, then the box labeled Specify Construction Buffer Periods should remain unchecked.

When multiple countermeasures are being evaluated, it is expected that they were constructed at the same time. However, *SafetyAnalyst* also allows them to be evaluated together if there is a short time period between them, as long as their combined construction period does not exceed 3 years.

SafetyAnalyst requires that at least one full calendar year of data must be available for each evaluation period (i.e., for both the before and after evaluation periods), to consider the site in the analysis calculations. If another countermeasure is implemented at the same site within a year of the countermeasure being evaluated, then the countermeasures must be combined. It is recommended that each evaluation period include 3 to 5 years of data to obtain statistically significant and reliable results. Therefore, the analysis will benefit from using the maximum amount of available data.

The default selections for the Specify Analysis Period Constraints panel are set to use the maximum amount of available data, since the analysis results will be most reliable with this selection.

5.3.6 Adjust Analysis Periods and Costs (Optional)

SafetyAnalyst provides the opportunity to adjust the analysis periods for each site individually (Figure 35). The Adjust Analysis Periods panel lists all sites that may be included in the countermeasure evaluation. This panel provides the opportunity to change both the sites included in the analysis and the dates of the evaluation period for each site. Thus, the sites to be included in the analysis can be reviewed for accuracy and completeness. Only those sites from the original site list that have the selected countermeasure record(s) associated with them are displayed. Therefore, if sites intended for evaluation do not appear on this screen, the analyst should cancel the evaluation and open the Implemented Countermeasure Tool to create the missing implemented countermeasure records for those sites.

Countermeasure Evaluation — Adjust Analysis Periods

Project	CM Titles	Site ID	Route	Start Locatic	End Locatic	Before Period Site Subtype	Before Period Start	Before Period End	Const. Period Start	Const. Period End	After Period Start	After Period End	Exclude
Int001	Install left,...	880	SR00000265	4.349	4.349	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	330	SR00000020	193.05	193.05	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	519	SR00000068	180.871	180.871	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	320	SR00000020	188.039	188.039	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	314	SR00000020	186.196	186.196	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	202	US00000182	139.552	139.552	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	874	SR00000265	0.607	0.607	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	252	SR00000018	50.053	50.053	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	518	SR00000068	180.286	180.286	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	251	SR00000018	49.21	49.21	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	328	SR00000020	192.257	192.257	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	544	SR00000068	197.205	197.205	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	722	SR00000113	12.566	12.566	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	879	SR00000265	3.236	3.236	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	
Int001	Install left...	246	SR00000018	47.044	47.044	Int/Urb; 4-leg ...	1995	1998	1999	1999	2000	2002	

Edit... — Site D... — Help...

Back — Next — Cancel

Figure 35. Adjust Analysis Periods Panel in Module 4

Site information (e.g., accident, ADT, and countermeasure data) may also be reviewed in this step of the analysis before proceeding. Selecting a site and clicking the Site Details button opens the site information dialog where yearly ADTs, individual accident records, and individual implemented countermeasure history for the site can be reviewed. The actual accidents used in the analysis may vary from the ones found for a site on this screen since analysis period selections, subsegment selections, and collision-type-specific analysis selections may affect what is included. It should be noted though that a site with zero accidents in both the before and after evaluation periods, will not contribute any meaningful information to the safety analysis calculations and could negatively affect benefit-cost analysis results. Such sites are automatically retained in the analysis at present, but could be eliminated from the analysis by the user, if desired. Also, it is especially important to confirm that all of the sites being evaluated have had the same or similar countermeasures installed.

Review of the site details may indicate that changes should be made to the before analysis period, construction period, after analysis period, the site analysis limits, or that the site should be excluded completely. To edit this information about a site, click the site to select it and then click the Edit button. An Edit the Sub-Site Implemented Countermeasure dialog (Figure 36) will appear. Alternatively, a cell may be edited directly by clicking in it and typing revised data. To exclude a site from further consideration, click the box in the Exclude column.


Figure 36. Edit the Sub-Site Implemented Countermeasure Dialog

In the Edit the Sub-Site Implemented Countermeasure Dialog, it is also possible to make changes to the cost and service life of the countermeasure. If the user selected to calculate

benefit-cost ratios, the construction cost information can also be reviewed or edited here. The construction cost must be provided for the benefit-cost ratio to be calculated for a site.

The final item of information that may be adjusted for a site is the Before Period Site Subtype. If the countermeasure(s) being evaluated caused the site subtype to change, e.g., adding lanes to a roadway or signalizing an intersection, then the Before Period Site Subtype should be changed to reflect the condition of the site in the before period as this value is originally populated with the site's current subtype designation. This will assure that the correct SPF, representing the before-period condition of the site, is used to predict the accident count that would have occurred in the after period if the countermeasure had not been implemented.

5.3.7 Select Accident Severity

There are four primary accident severity levels upon which to base a countermeasure evaluation. Effectiveness analyses can be determined for:

- Total (TOT) accidents
- Fatal and all injury (FI) accidents
- Fatal and severe injury (FS) accidents
- Property-damage-only (PDO) accidents

Calculations will be performed independently and presented in the output for each selection made. Also, if a benefit-cost analysis was previously selected, then Total accidents must be one of the selections. Figure 37 presents a typical input screen to specify the accident severity level for the analysis.
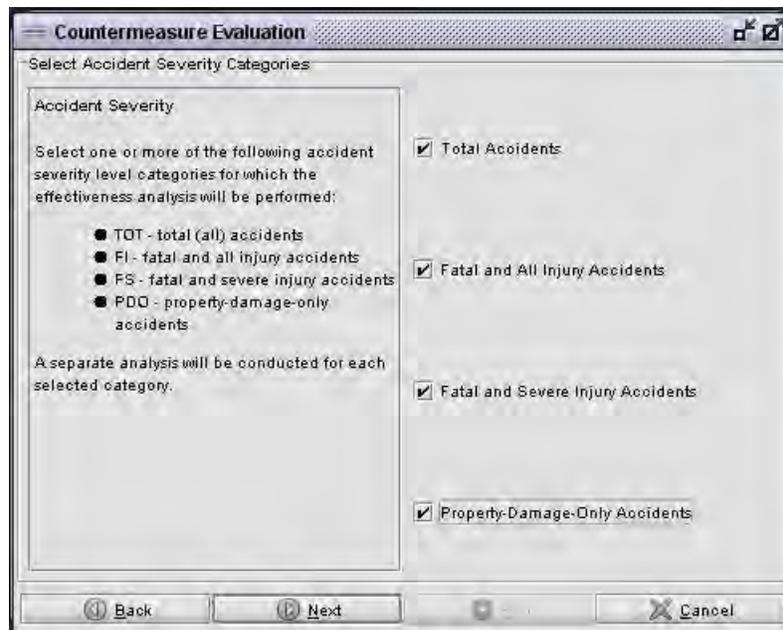
Figure 37. Select Accident Severity Panel in Module 4

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5.3.8 Specify Accident Category

The countermeasure evaluation can be performed for all accidents or for any of the individual accident attributes present in an agency's data. Selection of the accident attribute is made first, and then selection of the categories within the attribute is made. The list of available of accident attributes and categories is determined by an agency prior to the deployment of *SafetyAnalyst* and specified in the Administration Tool. Figures 38 and 39 show an example of what these screens may look like, but the actual appearance of these screens will depend on the specific selections made by the agency. If the analyst wishes to include all accidents in an evaluation the analyst should select any accident attribute and check all enumeration values for that attribute.
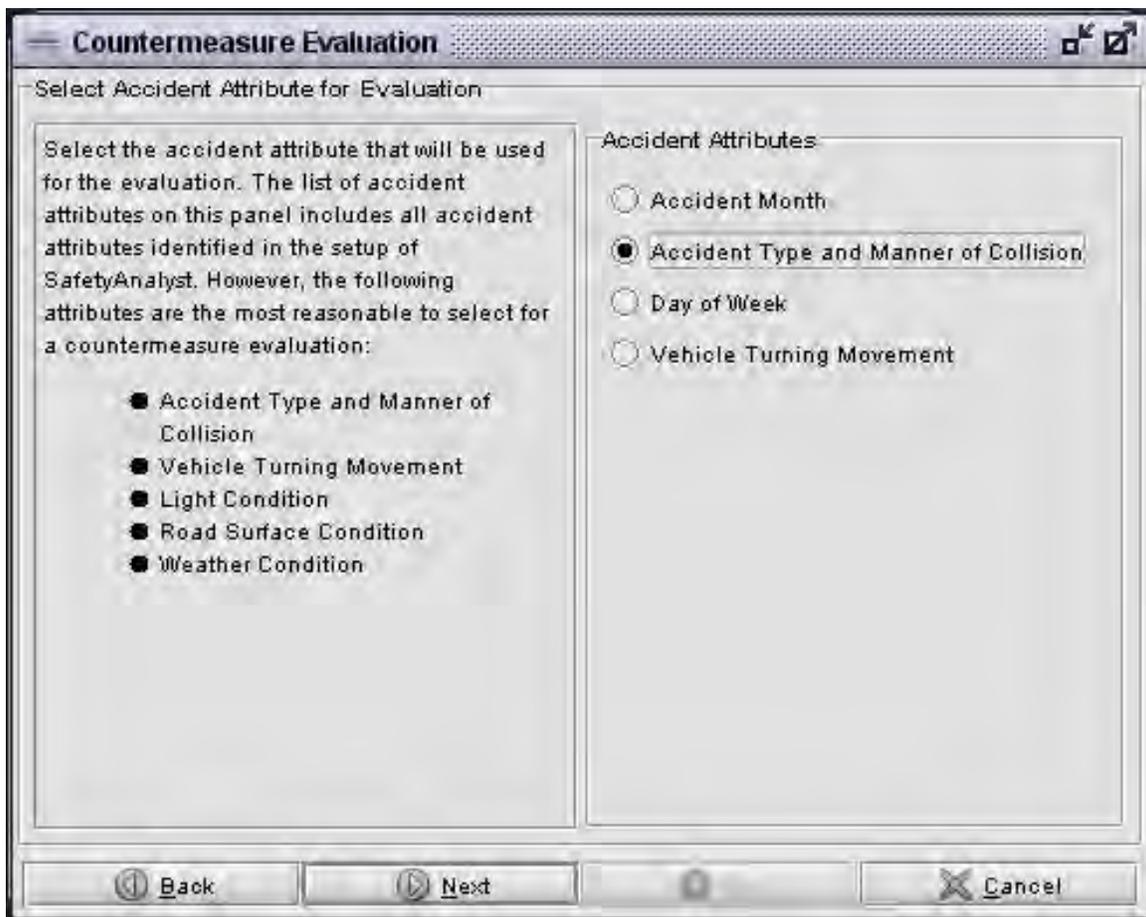
Figure 38. Select Accident Category Panel in Module 4
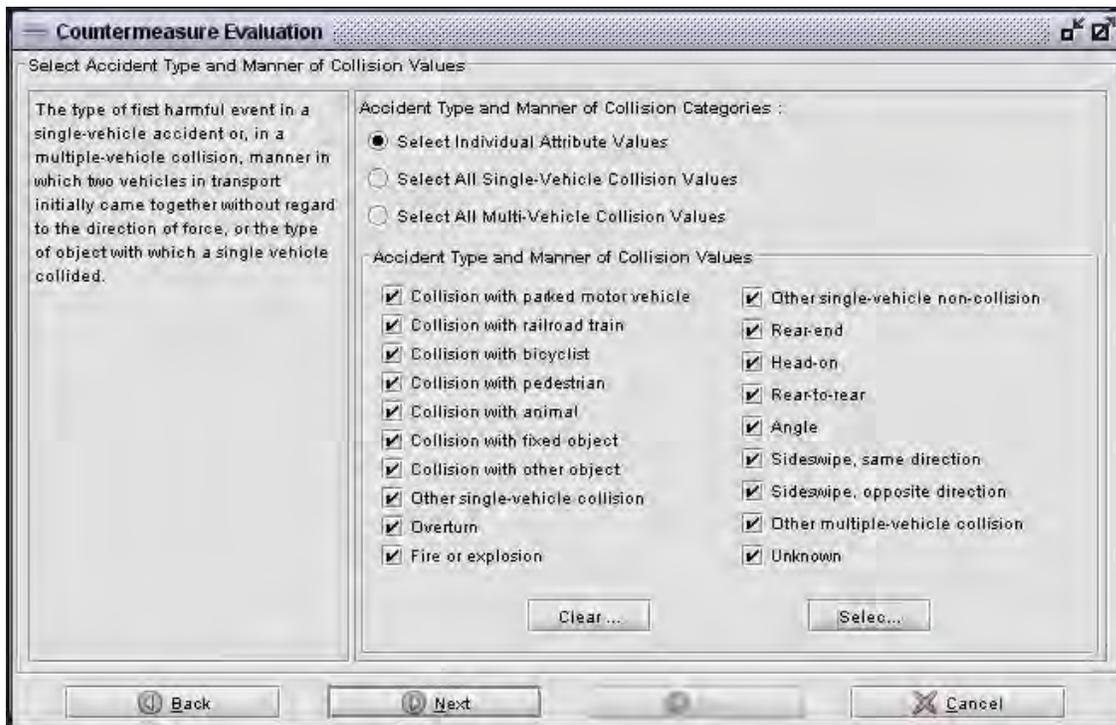
Figure 39. Select Accident Attribute Values Panel in Module 4

5.4 Primary Output Reports

Two types of output reports are generated during countermeasure evaluation, in accordance with the two basic types of before-after evaluations. One output report describes the countermeasure effectiveness as the percent change in accident frequency while the other output report describes the countermeasure effectiveness as the change in proportion of target accident types. The primary output table for each countermeasure presents the overall effectiveness estimates and statistical precision estimates and tests. Several secondary tables provide effectiveness estimates for each of the individual locations in the study. Samples of output reports from all evaluation types are presented below. These output reports are demonstrated assuming countermeasure Install left-turn lanes was installed at 15 locations in the test data set. The output reports presented in this Section are for a hypothetical case that serves only to illustrate the output reports, since the countermeasure in question—installing left-turn lanes—was not actually implemented at the 15 locations shown in the output report. The results shown in the example in Table 24 show no statistically significant change in accident frequency, but this is the expected result for sites where no countermeasure was actually implemented.

Table 24 presents the overall results of a Percent Change in Accident Frequency countermeasure evaluation. The analysis options that generated this sample output, presented in the upper left corner of the actual output report, are as follows:

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- Types of Countermeasure evaluations Performed: Percent Change in Accident Frequency
- Countermeasures: Install left-turn lane (93)
- Site subtype: Int/Urb; 4-leg signalized
- Number of Sites in the Site List: 15
- Number of Sites Evaluated: 15
- Average years in the Before Period: 4.0
- Average years in the After Period: 3.0

Table 24. Overall Effectiveness Result for Percent Change in Accident Frequency

Severity level	TOTAL	FI	FS	PDO
Evaluation	Percent Change in Accident Frequency			
Accident Type and Manner of Collision	Collision with parked motor vehicle; Collision with railroad train; Collision with bicyclist; Collision with pedestrian; Collision with animal; Collision with fixed object; Collision with other object; Other single-vehicle collision; Overturn; Fire or explosion; Other single-vehicle noncollision; Rear-end; Head-on; Rear-to-rear; Angle; Sideswipe, same direction; Sideswipe, opposite direction; Other multiple-vehicle collision; Unknown			
Effectiveness (Odds Ratio)	0.9692	0.9931	0.9559	0.9550
Effectiveness (% Change)	−3.082	−0.691	−4.409	−4.502
Direction of Change	Decrease	Decrease	Decrease	Decrease
Variance (Theta)	0.002	0.005	0.074	0.003
Standard Error (Theta)	0.042	0.071	0.273	0.056
Standard Error (E)	4.249	7.087	27.257	5.641
Test Statistic	0.725	0.097	0.162	0.798
Significance	Not significant at 90% confidence level	Not significant at 90% confidence level	Not significant at 90% confidence level	Not significant at 90% confidence level

The Overall Effectiveness table contains many items of interest:

Effectiveness (% Change)—This line of the output report presents the overall safety effectiveness estimate, expressed as a percentage change in accident frequency, for the given countermeasure (or group of countermeasures) being evaluated based upon the combined information from all sites (and/or projects) in the site list. In this example, total accidents decreased 3.082 percent while fatal and injury accidents decreased by 0.691 percent.

This overall safety effectiveness estimate may be converted to an accident modification factor (AMF). In particular, the overall safety effectiveness estimate expressed as a proportion (i.e., divided by 100) would be subtracted from the value of 1.00 when the implemented countermeasure resulted in a reduction in accidents. The proportion would be added to the value of 1.00 when the implemented countermeasure resulted in an increase in accidents. So, for total accidents, the reported 3.082 percent decrease in accident frequency corresponds to an AMF value of 0.96918 for the countermeasure. Similarly, the overall fatal and injury safety effectiveness estimate decrease of 0.691 percents results in an AMF value of 0.99309.

Such AMF values should generally be rounded to two decimal places and should only be used in planning other countermeasures if the evaluation results are statistically significant (see below). When the effectiveness of a countermeasure is evaluated with respect to a target collision type or types, the output report is similar to the report described above. The only key difference is that the effectiveness estimate of the countermeasure pertains strictly to the target collision types. The effect on other collision types is not estimated and is, therefore, unknown.

The change in target accidents can also be converted into an AMF, creating an accident-type-specific AMF.

Direction of Change—This line of the output report indicates the direction of the change in accident frequency. A decrease in the percentage indicates the implemented countermeasure resulted in a reduction in accident frequency; while an increase in the percentage indicates the implemented countermeasure resulted in an increase in accident frequency.

Standard Error (E)—This line of the output report presents the standard error of the treatment effectiveness [i.e., the standard error of the effectiveness (% change)]. The standard error is a customary measure of the uncertainty associate with a statistical estimate. Standard errors are valuable because they indicate the reliability of an estimate. A smaller standard error is preferred to a larger one, because a small standard error indicates that the estimate is close to its true value. When the standard error is large relative to the value of the estimate, less reliance should be placed on the analysis result.

Significance—This line of the output report provides an assessment of the statistical significance of the overall safety effectiveness estimate. One of three general messages is presented in a report:

- The countermeasure did not have a significant effect at the 90 percent confidence level.

- The countermeasure had a significant effect at the 90 percent confidence level.

- The countermeasure had a significant effect at the 95 percent confidence level.

Care should be used when interpreting the statistical significance of the result. Statistical significance simply means that the observed difference is not likely to have occurred by chance. It does not necessarily imply that the change in accidents is substantial, notable, or of practical significance. Spurious significant differences can be found with a small number of sites that have a large number of accidents or vice versa.

Several additional measures are also included in the overall effectiveness table and have been provided that may assist statisticians in understanding and interpreting the results:

Effectiveness (Odds Ratio)—This line of the output report presents a customary measure of the overall effectiveness. This measure is simply the ratio of the expected number of

accidents during the after period in the presence of the treatment to the expected number of accidents during the after period in the absence of the treatment. This estimate is adjusted to account for certain biases in the calculations.

Variance (Theta)—This line of the output report presents the variance of the odds ratio.

Standard Error (Theta)—This line of the output report presents the standard error of the odds ratio.

Test Statistic—The value in this line of the output report is used to assess the statistical significance of the treatment effect.

Following the overall summary table are the individual site effectiveness tables, one for each severity level selected for analysis. Table 25 shows the total accident table for this sample.

Table 25. Evaluation with Empirical Bayes Approach, CM(s): [Install Left-Turn Lane (93)], Total Accidents

Site	Countermeasure location	Observed no. of accidents		Before period no. of accidents		Expected no. of accidents w/o treatment	Accident reduction effectiveness		B/C ratio
		Before period	After period	Predicted w/SPF	Expected		Odds ratio	Percent change	
880	Route SR00000265, Milepost 4.349	79.0	7.0	42.0855	76.2202	59.0274	0.1186	–88.1411	124.9729
330	Route SR00000020, Milepost 193.05	60.0	49.0	32.9083	57.3574	44.7837	1.0941	9.4147	–7.6152
519	Route SR00000068, Milepost 180.871	41.0	47.0	32.2402	39.8574	28.9583	1.6230	62.3021	–26.8985
320	Route SR00000020, Milepost 188.039	43.0	31.0	34.2353	41.9757	31.8557	0.9731	–2.6862	1.6269
314	Route SR00000020, Milepost 186.196	46.0	30.0	39.0505	45.2469	34.8787	0.8601	–13.9876	10.9352
202	Route US00000182, Milepost 139.552	62.0	51.0	51.1335	61.1076	41.3487	1.2334	23.3414	–31.3695
874	Route SR00000265, Milepost 0.607	67.0	58.0	39.1417	64.6523	49.2916	1.1767	17.6672	–14.5909
252	Route SR00000018, Milepost 50.053	66.0	24.0	42.8281	64.1716	49.5444	0.4844	–51.5586	33.8730
518	Route SR00000068, Milepost 180.286	45.0	36.0	38.7693	44.3302	37.6295	0.9567	–4.3305	2.6259
251	Route SR00000018, Milepost 49.21	51.0	17.0	40.5557	50.0191	39.7710	0.4274	–57.2552	28.2325
328	Route SR00000020, Milepost 192.257	47.0	43.0	36.1425	45.7730	32.7329	1.3137	31.3665	–17.9728
544	Route SR00000068, Milepost 197.205	63.0	39.0	45.9855	61.6919	51.6380	0.7553	–24.4742	23.7761
722	Route SR00000113, Milepost 12.566	52.0	98.0	43.6729	51.1746	36.7232	2.6686	166.8612	–159.8444
879	Route SR00000265, Milepost 3.236	45.0	26.0	37.9878	44.0563	37.2595	0.6978	–30.2191	25.1358
246	Route SR00000018, Milepost 47.044	75.0	55.0	38.7744	71.9541	54.8087	1.0035	0.3490	–0.2459
Total									–0.1633

This table provides some of the intermediate statistics for individual sites which are used to calculate the overall effectiveness of a countermeasure. In this table, the number of observed accidents in the before and after period are provided. The number of predicted and expected accidents in the before period are also provided. The predicted number of accidents in the before period is estimated directly from the SPF for the site subtype. The expected number of accidents in the before period is the weighted sum of the observed

accident frequency and predicted accident frequency. The expected number of accidents without a treatment is an estimate of the accident count that would have occurred during the after period had the countermeasure not been installed at the analysis sites. Finally, the accident reduction effectiveness is expressed as the odds ratio and percent change.

A benefit-cost ratio for individual sites as well as the overall average is also provided. The benefit-cost ratio is determined by dividing the accident costs reduced by the actual construction costs. When the benefit-cost ratio is greater than 1.0, the benefits of adding a left-turn lane exceeded its costs. This ratio is only presented for those sites where cost information was provided and the summary ratio only contains similar information.

The evaluation output report also contains a Benefit Cost Summary where interim calculations of the benefit-cost analysis are stored. There are two tables of information: Benefit Cost of All Sites with Cost Specified (Table 26) and Benefit Cost by Site (Table 27). The first table is the total present value of safety benefits summed for all sites, the total present value of construction cost summary for all sites, and the ratio of those values or the overall benefit-cost ratio. The second table contains interim calculations of safety benefits and construction costs for each site.

Table 26. Benefit Cost of All Sites With Cost Specified

Title	All sites
Total Present Value Safety Benefit	−186,114.13
Total Present Value Construction Cost	$1,140,000
The Benefit Cost Ratio	−0.16

Table 27. Benefit Cost by Site

ID	Countermeasure location	Annual accidents reduced	Annual accident cost	Present value safety benefit	Construction cost	Annual construction cost	Present value construction cost	Benefit cost ratio
880	Route SR00000265, Milepost 4.349	346.85	$63,158	9,997,832.94	$80,000	$5,887	$80,000	124.97
330	Route SR00000020, Milepost 193.05	−28.11	$44,522	−571,141.17	$75,000	$5,519	$75,000	−7.62
519	Route SR00000068, Milepost 180.871	−120.28	$39,201	−2,151,879.28	$80,000	$5,887	$80,000	−26.90
320	Route SR00000020, Milepost 188.039	5.70	$46,865	122,015.88	$75,000	$5,519	$75,000	1.63
314	Route SR00000020, Milepost 186.196	32.52	$55,251	820,142.57	$75,000	$5,519	$75,000	10.94
202	Route US00000182, Milepost 139.552	−64.34	$80,120	−2,352,713.89	$75,000	$5,519	$75,000	−31.37
874	Route SR00000265, Milepost 0.607	−58.06	$44,055	−1,167,275.56	$80,000	$5,887	$80,000	−14.59
252	Route SR00000018, Milepost 50.053	170.30	$30,508	2,371,113.35	$70,000	$5,151	$70,000	33.87
518	Route SR00000068, Milepost 180.286	10.86	$42,370	210,068.90	$80,000	$5,887	$80,000	2.63
251	Route SR00000018, Milepost 49.21	151.81	$28,525	1,976,271.52	$70,000	$5,151	$70,000	28.23
328	Route SR00000020, Milepost 192.257	−68.45	$43,150	−1,347,958.03	$75,000	$5,519	$75,000	−17.97
544	Route SR00000068, Milepost 197.205	84.25	$49,467	1,902,088.92	$80,000	$5,887	$80,000	23.78
722	Route SR00000113, Milepost 12.566	−408.51	$64,301	−11,988,326.73	$75,000	$5,519	$75,000	−159.84
879	Route SR00000265, Milepost 3.236	75.06	$58,698	2,010,861.76	$80,000	$5,887	$80,000	25.14
246	Route SR00000018, Milepost 47.044	−1.28	$29,578	−17,215.29	$70,000	$5,151	$70,000	−0.25

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The information in the Benefit Cost by Site table includes:

Annual accidents reduced—This column of the output report presents the expected accidents reduced over the service life of the countermeasure. It is calculated by using the Expected Number of Accidents Without Treatment in the after period multiplied by the Percentage Reduction value (both found in Table 25 of the report in *SafetyAnalyst*). This value is then adjusted to the entire service life period.

Annual accident cost—This column of the output report presents average cost per accident, which is a weighted average based on FHWA accident costs and the average severity distribution of accidents for the site subtype as well as the Expected Number of Accidents Without Treatment by severity.

Present value safety benefit—To estimate the safety benefits for a site, the Accidents Reduced over the service life of the countermeasure is multiplied by the average Accident Cost then converted to a present value, based on the minimum attractive rate of return and service life of the countermeasure.

Construction cost, annual construction cost, and present value construction cost—The construction cost of the countermeasure at the time of implementation is annualized over the service life of the countermeasure then converted to a present value for comparison with the safety benefits.

Benefit-cost ratio—The benefit-cost ratio is calculated by taking the ratio of the Present Value of Safety Benefits to the Present Value of Construction Cost.

5.4.1 Output Report for an Evaluation of Change in Proportion of Target Accident Types

Table 28 presents the overall results of a Change in Proportion of Target Accident Types countermeasure evaluation. The analysis options that generated this sample output, presented in the upper left corner of the actual output report, are as follows:

- Types of Countermeasure Evaluations Performed: Percent Change in Proportion of Target Accident Types
- Countermeasures: Install left-turn lane (93)
- Site subtype: Int/Urb; 4-leg signalized
- Number of Sites in the Site List: 15
- Number of Sites Evaluated: 15
- Average years in the Before Period: 4.0
- Average years in the After Period: 3.0

Table 28. Change in Proportion of Target Accidents

Severity Level	TOTAL	FI	FS	PDO
Evaluation	Change in Proportion of Target Accidents			
Accident Type and Manner of Collision	Rear-end			
Simple average proportion BEFORE	0.65	0.71	0.17	0.62
Simple average proportion AFTER	0.61	0.62	0.13	0.62
Simple average difference (After-Before)	–0.04	–0.09	–0.04	–0.00
Number of sites included in the statistical analysis	15	15	7	15
Estimated median treatment effect	0.00	–0.08	–0.12	0.03
Selected (nominal) significance level	0.10	0.10	0.10	0.10
Lower confidence limit of median treatment effect	–0.13	–0.17	–0.50	–0.07
Upper confidence limit of median treatment effect	0.05	–0.01	0.40	0.10
Summary of statistical significance	Not Significant	Significant	Not Significant	Not Significant

The Change in Proportion of Target Accident Table contains many items of interest:

Number of sites included in the statistical analysis—This number is not necessarily the same as the number of sites included in the site list. Only those sites where the difference in the after and before proportions of the target accident type is nonzero are included in the statistical analysis.

Estimated median treatment effect—This line of the output report presents the average difference between the after and before proportions (i.e., treatment effect), based only on those sites where the difference in the after and before proportions of the target accident type is nonzero. Because the Wilcoxon signed rank test uses only those sites with an observed nonzero change in proportion, this methodology produces an estimate of the median rather than mean difference in proportions. Thus, the test results are less influenced by extreme changes in proportions.

The estimated median treatment effect can also be converted to an accident modification factor (AMF). However, these AMFs would be collision-type-specific and not applicable to all collision types like the AMFs used in Module 3.

Selected (nominal) significance level—This line of the ouput report presents the significance level used for testing the statistical validity of the results. That is, when converted to a confidence level, it represents how likely the confidence interval will contain the true parameter. Decreasing the significance level will widen the confidence interval. The value shown here is the value selected while setting up the analysis.

Lower and upper confidence limit of median treatment effect—Like the standard error for the Percent Change in Accident Frequency, the confidence interval provides an estimate of the reliability of the treatment effect and is used to assess the statistical significance of the treatment effect. If all things are equal between two countermeasure evaluations, then results with the smaller confidence interval are more reliable than one with a larger confidence interval.

Summary of statistical significance—This line of the output report indicates the statistical validity of the treatment effect given the desired confidence level. Care should be used when interpreting the statistical significance of the result. Statistical significance simply means that the observed difference is not likely to have occurred by chance. Statistical significance does not necessarily imply that the change in accidents is substantial, notable, or of practical significance.

Several additional measures are also included in this table and have been provided more for informational purposes than interpretive purposes:

Simple average proportion BEFORE—This line of the output report is the average proportion of the target accident type before the countermeasure was installed at the study sites.

Simple average proportion AFTER—This line of the output report is the average proportion of the target accident type after the countermeasure was installed at the study sites.

Simple average difference (AFTER-BEFORE)—This line of the output report the average difference between after and before proportions.

A table on the proportions of the target accident type by site by year is also included in the output report (see Table 29). This table illustrates sites for which the largest differences in proportions occurred.

Table 29. Proportions by Site by Year; Severity: Total Accidents

ID	Countermeasure location	1995	1996	1997	1998	1999	2000	2001	2002	Ave prop before	Ave prop after	Difference
880	Route SR00000265, Milepost 4.349	0.78	0.73	0.86	0.88		0.43	0.0	0.0	0.81	0.43	−0.38
330	Route SR00000020, Milepost 193.05	0.58	0.57	0.5	0.65		0.53	0.54	0.84	0.58	0.65	0.07
519	Route SR00000068, Milepost 180.871	0.58	0.38	0.2	0.17		0.43	0.54	0.46	0.37	0.47	0.1
320	Route SR00000020, Milepost 188.039	0.73	0.58	0.46	0.57		0.5	0.69	0.5	0.58	0.58	0.0
314	Route SR00000020, Milepost 186.196	0.64	0.73	0.44	0.67		0.8	0.67	0.55	0.63	0.67	0.04
202	Route US00000182, Milepost 139.552	0.6	0.5	0.64	0.8		0.52	0.67	0.85	0.63	0.65	0.02
874	Route SR00000265, Milepost 0.607	0.57	0.61	0.67	0.67		0.63	0.71	0.72	0.63	0.69	0.06
252	Route SR00000018, Milepost 50.053	0.74	0.5	0.77	0.88		0.22	0.5	0.2	0.73	0.33	−0.39
518	Route SR00000068, Milepost 180.286	0.38	0.43	0.75	0.5		0.67	0.81	0.38	0.49	0.67	0.18
251	Route SR00000018, Milepost 49.21	1.0	0.67	0.81	0.82		0.89	0.0	0.29	0.84	0.59	−0.25
328	Route SR00000020, Milepost 192.257	0.55	0.5	0.54	0.73		0.53	0.82	0.65	0.57	0.65	0.08
544	Route SR00000068, Milepost 197.205	0.63	0.56	0.6	0.86		0.75	0.71	0.67	0.65	0.72	0.07
722	Route SR00000113, Milepost 12.566	0.79	0.8	0.71	0.78		0.8	0.82	0.41	0.77	0.67	−0.1
879	Route SR00000265, Milepost 3.236	0.77	0.79	0.55	0.57		0.57	0.82	0.63	0.69	0.69	0.0
246	Route SR00000018, Milepost 47.044	0.74	0.79	0.84	0.78		0.68	0.87	0.72	0.79	0.75	−0.04

5.5 Benefits of *SafetyAnalyst*'s Countermeasure Evaluation Tool

Module 4 provides the capability to conduct before-after evaluations using state-of-the-art statistical techniques (i.e., Empirical Bayes technique) to assess the overall safety effectiveness of a given countermeasure. As countermeasure evaluations are conducted, Module 4 results can and should be used to update the accident modification factors (AMFs) within the *SafetyAnalyst* database. These AMFs are used primarily within Module 3 for economic appraisal and priority ranking of sites. Module 4 results can be used either to update AMFs already provided within the *SafetyAnalyst* database or to provide new AMFs for countermeasures for which no previous estimate existed. By utilizing the capabilities of Module 4 to improve and update safety effectiveness information within *SafetyAnalyst* (i.e., primarily Module 3), agencies can incorporate results for future use in their safety planning.

6. CONCLUSIONS

SafetyAnalyst provides a set of software tools for use by state and local highway agencies for highway safety management. *SafetyAnalyst* integrates six safety management tools into a single software package: a network screening tool that identifies specific highway sites with potential for safety improvement; a diagnosis tool that is used to investigate the nature of accident patterns at individual sites; a countermeasure selection tool that assists users in the selection of countermeasures to reduce accident frequency and severity at specific sites; an economic appraisal tool that performs economic analyses of a countermeasure or several alternative countermeasures for an individual site or multiple sites; a priority ranking tool for ranking of sites and proposed improvement projects; and a countermeasure evaluation tool to conduct before/after evaluations of implemented safety improvements.

Agencies should realize several benefits as a result of implementing the *SafetyAnalyst* software. First, use of *SafetyAnalyst* should improve effectiveness in decision making, as *SafetyAnalyst* automates state-of-the-art statistical approaches described in Part B of the HSM to improve the identification and programming of site-specific highway safety improvements. Second, use of *SafetyAnalyst* should improve efficiency in decision support as *SafetyAnalyst* integrates all parts of the safety management process into a single, modular software package that is easy to use. In addition, incorporation of the EB methodology into traditional safety analysis procedures, like network screening and countermeasure evaluations, will increase the reliability of safety estimates by reducing regression to the mean bias. Multiple statistical methods available for network screening, accident pattern identification, economic appraisal, and safety effectiveness studies allow straightforward management of a wide range of needs, and provisions to customize the software, either globally or for an individual analysis, provide essential flexibility to meet the needs of varied users.

For the long term viability of *SafetyAnalyst*, it is essential that the software be continually enhanced to meet the changing needs of the users. The current capabilities and functionalities of the software were decided under the guidance of FHWA and the TWG. In the future, as an AASHTOWare product, a committee of AASHTO representatives will guide future enhancements to the software. A list of potential future enhancements that have already been identified is presented below. As enhancements are made to the software and priorities are re-assessed, this list of potential future enhancements should be revisited periodically under the guidance of AASHTO.

Potential future enhancements to the *SafetyAnalyst* Software that have been identified to date include:

- Provide capability for a user to specify a countermeasure and have the software identify locations where that countermeasure would be appropriate

- Incorporate roundabouts as a site subtype that can be analyzed

- Revise Module 3 output to include a single table with all ranking criteria

- Provide capability to screen for more than one accident type

- Conduct analyses of intersections on a per-approach basis

- Conduct analyses for an entire interchange

- Incorporate the coefficient of variation test (i.e., CV test) into the basic network screening sliding window approach

- Provide capability to test for shifts in accident severity during countermeasure evaluation

- Develop and incorporate new diagnostic scenarios for Module 2

- Incorporate new countermeasures into the countermeasure database and provide new or revised AMFs as evaluations are completed either from ongoing research or from application of Module 4 by *SafetyAnalyst* users

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Appendix A

Detailed Procedures for *SafetyAnalyst* Module 1— Network Screening

APPENDIX A. DETAILED PROCEDURES FOR *SAFETYANALYST* MODULE 1—NETWORK SCREENING

A.1 Basic Network Screening for High Accident Frequency

The basic network screening methodology utilizes Empirical Bayes (EB) principles to predict the potential for safety improvement (PSI) of a site. This is the only network screening methodology that uses EB concepts. In general terms, this network screening approach combines observed accident data with predicted accident values from regression relationships (i.e., safety performance functions) to calculate an expected accident value at a site. The basic network screening methodology may be applied to all site types (i.e., roadway segments, intersections, and ramps). The EB calculations are similar for all site types, with slight variations. The user must choose to perform basic network screening from among two approaches: "peak searching" or "sliding window." The procedures or steps to perform the basic network screening calculations for roadway segments are presented first, followed by the procedures for intersections and ramps.

A.1.1 Screening of Roadway Segments

The procedures for calculating accident frequencies for roadway segments using the peak searching approach is presented first, followed by the procedures for calculating accident frequencies for roadway segments using the sliding window approach.

A.1.1.1 Peak Searching Approach for Roadway Segments

The peak searching approach for roadway segments can be based on either expected accident frequencies or excess accident frequencies, and these measures may be weighted relative to accident severity level and/or area type. When using the peak searching approach, roadway segments in the site list may be of various lengths. The following paragraphs explain how "peak" values of expected accident frequencies or excess accident frequencies are calculated and used to rank roadway segments for potential safety improvement.

The peak searching approach for roadway segments is a slightly more rigorous screening methodology compared to that of the sliding window approach. One area that distinguishes the peak searching approach from the sliding window approach concerns the manner in which windows are located within or moved along roadway segments. The placement and process for locating windows is different between the two approaches. Although the placement and process for locating windows is different between the two approaches, this difference is not what truly differentiates the soundness of the peak searching approach over the sliding window approach. The primary difference is that the peak searching approach applies a statistical test to the calculations of the expected accident frequencies

(or excess accident frequencies) to judge the statistical validity of the results. The only test that is applied in the sliding window approach is determining whether the expected accident frequency (or excess accident frequency) is greater than or less than a limiting value. Only sites with expected accident frequencies (or excess accident frequencies) greater than or equal to the specified limiting value are included in the output reports as sites with potential for safety improvement. The peak searching approach has a similar requirement, but this type of test is related to the magnitude of the expected value and not the statistical validity of the value. Only the peak searching approach tests for both, that is (a) the magnitude of the expected value (i.e., expected accident frequency or excess accident frequency) and (b) the statistical reliability of the estimate.

The peak searching approach tests the statistical validity (i.e., reliability) of expected accident frequencies (or excess accident frequencies) by calculating coefficients of variation (CV) and comparing them to a specified limit (i.e., CV_{Limit}). The coefficient of variation of a variable X is simply the ratio of the standard deviation to the mean of the expected value (i.e., $STD(X)/E(X)$). 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. By increasing or decreasing the CV_{Limit}, the user controls the desired precision level output.

The remainder of this section describes in detail the procedures for calculating the potential for safety improvement based upon the peak searching approach for roadway segments. Appendix A.1.1.1.1 describes the procedures for calculating the potential for safety improvement based upon expected accident frequency according to the peak searching approach. Appendix A.1.1.1.2 describes the procedures for calculating the potential for safety improvement based upon excess accident frequency according to the peak searching approach, and Appendix A.1.1.1.3 describes the procedures for calculating the potential for safety improvement according to the peak searching approach for roadway segments if area weights are applied to give a certain area (i.e., rural or urban) higher priority.

A.1.1.1 Calculations of PSI Based on Expected Accident Frequency

To implement the peak searching procedure for a given roadway segment, the procedure starts by dividing the site into 0.1 mi windows. The windows do not overlap, with the possible exception of the last window overlapping with the previous. Expected accident frequencies are then calculated for each window, and the results are subjected to statistical testing. If no statistically significant peak accident frequencies are found in any of the initial windows, the ending window location for each window is incrementally moved forward growing the windows to a window length of 0.2 mi., and the calculations are performed again to identify statistically significant peak accident frequencies. The algorithm continues in this fashion until a peak is found or the window length equals the site length.

For the first iteration, the beginning of the first window is placed at the beginning of the roadway segment, and the average expected accident frequency is calculated for this window. Expected accident frequency and its variance for the window are calculated in

accordance with Step 0 through Step 8. The notation used for this peak searching approach and for all other network screening procedures described in Appendix A is defined in Table 7.

NOTE: Generally, the Roman alphabet is used to refer to observed data, while the Greek alphabet refers to statistically estimated quantities.

Step 0: Determine the length (W) and position of the window within the given roadway segment.

NOTE 1: Step 1 through Step 8 are repeated for each window.

NOTE 2: If the site is shorter than the window length, then the window length equals the site length (i.e., W = SL).

Step 1: Using the appropriate SPF model parameters, compute for each year (y = 1, 2,...,Y) the predicted number of accidents, κ_y, per mile, for TOT and FI accidents for the window as follows:

$$\kappa_{y(TOT)} = SPF_{TOT}\{ADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times ADT_y^{\beta_1} \qquad (A\text{-}1)$$

$$\kappa_{y(FI)} = SPF_{FI}\{ADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_y^{\beta_1} \qquad (A\text{-}2)$$

NOTE 1: *SafetyAnalyst* currently only supports the functional forms of Equation (A-1) and Equation (A-2) for safety performance functions

NOTE 2: Although not explicitly shown in Equation (A-1) and Equation (A-2), SPF_{TOT} and SPF_{FI} each have their own set of parameters, α, $\beta 1$, and overdispersion parameter d.

NOTE 3: When the user specifies that the screening is to only consider a certain collision type, the respective proportion or proportions of $P_{CT(TOT)}$ and $P_{CT(FI)}$ are obtained from the *SafetyAnalyst* database. When the collision type of interest is "all" TOT accidents, then $P_{CT(TOT)} = 1$; similarly, when the accident type of interest is "all" FI accidents, then $P_{CT(FI)} = 1$.

NOTE 4: If multiple collision types are selected for analysis, then $P_{CT(TOT)}$ and $P_{CT(FI)}$ are the sum of the individual proportions pertaining to the selected collision types.

NOTE 5: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, (D) replace $P_{(CT/FI)}$ in Equation (A-2) with $P_{(CT/FS/FI)}$, and (E) proceed as normal for FI calculations.

NOTE 6: If the screening is based upon PDO or EPDO, calculations must be performed for TOT and FI accidents to obtain values for PDO or EPDO accidents. Calculations for PDO or EPDO accidents cannot be based upon calculations from TOT and FS accidents.

NOTE 7: When a site is flagged for inclusion on the output report, the value, κ_Y, is included on the output report under the column heading Predicted Accident Frequency.

NOTE 8: If $\kappa_{(FI)} > \kappa_{y(TOTI)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly, If $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

Step 2: Using the model predictions computed in *Step 1*, compute the yearly correction factors, C_y, for TOT and FI accidents for years $y = 1, 2,...,Y$:

$$C_{y(TOT)} = \frac{\kappa_{y(TOT)}}{\kappa_{1(TOT)}} \tag{A-3}$$

$$C_{y(FI)} = \frac{\kappa_{y(FI)}}{\kappa_{1(FI)}} \tag{A-4}$$

Table A-1. Summary of Nomenclature Used in Network Screening

Term	Explanation
i	Subscript to represent site i
y	Subscript to represent the year y - The first year for which data are available or the first year after major reconstruction is Year 1, i.e., y=1 - The last year, the year for which the ranking is produced, is year Y, i.e., y=Y
SUB	Subscript to denote subsegment (of a window)
TOT	Subscript to denote total accidents
FI	Subscript to denote fatal and all injury accidents
FS	Subscript to denote fatal and severe injury accidents
PDO	Subscript to denote property damage only accidents
PSI	Potential for Safety Improvement
ALPHA	The significance level when performing a statistical test. Typical values for ALPHA are 0.05, 0.10, 0.15, 0.20, or 0.25. The confidence level equals (1-ALPHA). These values are sometimes expressed in percent
E(X)	Expected value (mean) of a random variable X
Var(X)	Variance of a random variable X
STD(X)	Standard deviation of a random variable X; Var(X) = $[STD(X)]^2$
SE(X)	Standard error of a random variable X; SE(X) = STD(mean of X) = [STD(X)]/vn where n is the sample size
CV(X)	Coefficient of variation of variable X; CV(X)=STD(X)/E(X)
ADT_y	ADT at a site during year y (nonintersection sites)
$MajADT_y$	Major road ADT at an intersection during year y
$MinADT_y$	Minor road ADT at an intersection during year y
SL	Segment length of a site (nonintersection sites), expressed in mi
SPF_{TOT}, SPF_{FI} $\square$, $\square1$, $\square2$, d	Safety Performance Function, applicable to a given type of sites. It includes the following regression coefficients (on the log scale) and parameters: - $\square$: intercept - $\square1$: coefficient of ADT (nonintersection sites) or of MajADT (major road ofintersection) - $\square2$: coefficient of MinADT (minor road of intersection) - d: overdispersion parameter associated with the negative binomial regression (expressed on a per mile basis for nonintersection sites) **NOTE 1:** Two SPFs are available for a given type of site: SPF_{TOT} and SPF_{FI}. Each has its own set of parameters.
$P_{CT(TOT)}$, $P_{CT(FI)}$, $P_{CT(FS/FI)}$ $c_{y(TOT)}$, $c_{y(FI)}$	- $P_{CT(TOT)}$: proportion of TOTAL accidents of a specified collision type to all TOTAL accidents - $P_{CT(FI)}$: proportion of FI accidents of a specified collision type to all FI accidents - $P_{CT(FS/FI)}$: proportion of FS accidents of a specified collision type to all FI accidents - $c_{y(TOT)}$: calibration factor for TOTAL accidents in year y - $c_{y(FI)}$: calibration factor for FI accidents in year y **NOTE 2:** All coefficients and parameters related to SPFs are provided in the master *SafetyAnalyst* database.

Table A-1. Summary of Nomenclature Used in Network Screening (Continued)

AccRate$_{(F/CT/FS)}$, AccRate$_{(I/CT/FS)}$, AccRate$_{(F/CT/FI)}$, AccRate$_{(I/CT/FI)}$	-AccRate$_{(F/CT/FS)}$: number of fatalities per the number of FS accidents of a specified collision type -AccRate$_{(I/CT/FS)}$: number of injuries per the number of FS accidents of a specified collision type -AccRate$_{(F/CT/FI)}$: number of fatalities per the number of FI accidents of a specified collision type -AccRate$_{(I/CT/FI)}$: number of injuries per the number of FI accidents of a specified collision type
K_y	Observed number of accidents at a site during year y
$\square_y$	Predicted number of accidents using the SPF at a site during year y (expressed on a per mile basis for nonintersection sites)
C_y	Yearly correction factor for year y relative to year 1
W	A weighting factor to combine observed and predicted accident frequencies at a site
X_y	EB-adjusted expected number of accidents at a site during year y (expressed on a per mile basis for nonintersection sites)
$P_F, P_{SI}, P_{NI}, P_{MI}$	Proportions of fatal, incapacitating injury, nonincapacitating injury, and possible injury accidents of all FI accidents - F: Subscript to denote fatal accidents - SI: Subscript to denote severe injury accidents - NI: Subscript to denote nonincapacitating injury accidents - MI: Subscript to denote possible injury accidents **NOTE:** These proportions are stored in the *SafetyAnalyst* database.
$SW_F, SW_{SI}, SW_{NI}, SW_{MI}$	Relative severity weights applied to fatal, severe injury, nonincapacitating injury, and possible injury accidents, respectively **NOTE:** These weights are stored in the *SafetyAnalyst* database.
RC_{FI}	Relative weight of FI accidents as compared to PDO accidents
EPDO	Equivalent Property Damage Only
W	Window length (used in peak searching and sliding window algorithms)
AW	Area weight, applied to a rural area relative to an urban area
f, g	Shape parameters of the beta function B(f,g) with 0 and 1 as the lower and upper bounds for specific target accident types **NOTE:** These parameters are stored in the *SafetyAnalyst* database.

NOTE: When screening for FS accidents, $C_{y(FS)}$ should not be calculated or used. Instead $C_{y(FI)}$ should be used. In fact $C_{y(FS)} = C_{y(FI)}$ except when predicted accidents is set to $\kappa_{y(TOT)}$ in Note 8 of *Step 1*.

Step 3: Using $\kappa_1,..., \kappa_Y$ and the overdispersion parameter, d, compute the weights, w, for TOT and FI accidents:

$$w_{TOT} = \frac{1}{1 + d_{TOT}\sum_{y=1}^{Y} \kappa_{y(TOT)} \times L} \tag{A-5}$$

$$w_{FI} = \frac{1}{1 + d_{FI}\sum_{y=1}^{Y} \kappa_{y(FI)} \times L} \tag{A-6}$$

NOTE 1: The weights, $w_{(TOT)}$ and $w_{(FI)}$, are always calculated based upon the "all" accidents for TOT and FI severity levels. In other words, for those instances when basic network screening is based upon a certain collision type or types, the predicted value calculated in *Step 1* is scaled, based upon a proportion or a sum of proportions. Rather than using the scaled value of predicted accidents in equations Equation (A-5) and Equation (A-6), the predicted value before multiplying by the respective proportion will be used to calculate the weights $w_{(TOT)}$ and $w_{(FI)}$. The same principle applies when the calculations are based upon FS injuries. The weight $w_{(FS)}$ will actually be based upon "all" FI accidents. The rationale for this is because weights, $w_{(TOT)}$ and $w_{(FI)}$, are used in subsequent steps to combine observed accidents and predicted accidents. The weights, $w_{(TOT)}$ and $w_{(FI)}$, are calculated based upon the accuracy/reliability of the SPFs. In concept the accuracy/reliability of the SPF does not change when the screening is based upon certain collision types or FS injury accidents. The same SPFs for TOT and FI accidents are still being used for all calculations, and the accuracy/reliability of the TOT and FI SPFs does not change. If the "scaled" predicted values were used in equations Equation (A-5) and Equation (A-6), then the weights would be adjusted for the wrong reason, not because

A-5

the accuracy/reliability of the SPFs changed but because the predicted values were scaled as a necessity due to unrelated circumstances.

NOTE 2: In Equation (A-5) and Equation (A-6), L is equal to the segment length, SL.

Step 4: Calculate the base EB-adjusted expected number of accidents, X_1, for TOT and FI accidents during Year 1 on a per mile basis:

$$X_{1(TOT)} = w_{TOT}\kappa_{1(TOT)} + \frac{(1-w_{TOT})}{w}\frac{\sum_{y=1}^{Y}K_{y(TOT)}}{\sum_{y=1}^{Y}C_{y(TOT)}} \tag{A-7}$$

$$X_{1(FI)} = w_{FI}\kappa_{1(FI)} + \frac{(1-w_{FI})}{w}\frac{\sum_{y=1}^{Y}K_{y(FI)}}{\sum_{y=1}^{Y}C_{y(FI)}} \tag{A-8}$$

NOTE 1: The observed accidents in Equation (A-7) and Equation (A-8) should be those of the respective collision types and severity levels as specified by the user.

Step 5: Calculate X_Y on a per mile basis. X_Y is the EB-adjusted expected number of accidents for y = Y, the last year for which data exist for the site, for TOT, FI, and PDO accidents:

$$X_{Y(TOT)} = X_{1(TOT)}C_{Y(TOT)} \tag{A-9}$$

$$X_{Y(FI)} = X_{1(FI)}C_{Y(FI)} \tag{A-10}$$

$$X_{Y(PDO)} = X_{Y(TOT)} - X_{Y(FI)} \tag{A-11}$$

NOTE 1: If $X_{Y(FI)} > X_{Y(TOT)}$, then set $X_{Y(FI)} = X_{Y(TOT)}$

NOTE 2: When the analysis is based on TOT, FI, or PDO accident types, if X_Y is less than the user specified limiting value, the respective window will not be flagged.

Step 6: To obtain a measure of the precision of these expected accident frequencies, calculate the variance of X_Y for TOT, FI, and PDO accidents:

$$Var(X_{Y(TOT)}) = X_{Y(TOT)}(1 - w_{TOT})\frac{C_{Y(TOT)}}{\sum_{y=1}^{Y}C_{y(TOT)}} \tag{A-12}$$

$$Var(X_{Y(FI)}) = X_{Y(FI)}(1 - w_{FI})\frac{C_{Y(FI)}}{\sum_{y=1}^{Y}C_{y(FI)}} \tag{A-13}$$

$$Var(X_{Y(PDO)}) = Var(X_{Y(TOT)}) + Var(X_{Y(FI)}) \tag{A-14}$$

NOTE 1: If in *Step 5* $X_{Y(FI)}$ is greater than $X_{Y(TOT)}$ and then $X_{Y(FI)}$ is set equal to $X_{Y(TOT)}$, then set $Var(X_{Y(FI)}) = Var(X_{Y(TOT)})$.

NOTE 2: Because FI accidents are a subset of TOT accidents, the calculation in Equation (A-14), which assumes statistical independence of TOT and FI accidents, is only an approximation. In fact, Equation (A-14) overestimates $Var(X_{Y(PDO)})$.

When the user specifies that the expected value of the accident frequency is to be unweighted relative to accident severity level, then X_Y and $Var(X_Y)$ are the final calculations for a given window. When the user specifies that the expected value of the accident frequency is to be a cost-weighted estimate (EPDO), proceed to *Step 7*.

Step 7: Calculate the EPDO expected number of accidents using the relative severity weights, SW, for fatal (F), severe injury (SI), nonincapacitating injury (NI), and possible injury (MI) severity levels. To calculate the EPDO expected number of accidents, let RC_{FI} be the relative weight of FI accidents as compared to PDO accidents. RC_{FI} is calculated as follows:

$$RC_{FI} = P_F SW_F + P_{SI} SW_{SI} + P_{NI} SW_{NI} + P_{MI} SW_{MI} \tag{A-15}$$

Then, calculate the EPDO expected number of accidents as:

$$X_{Y(EPDO)} = X_{Y(PDO)} + RC_{FI} \times X_{Y(FI)} \tag{A-16}$$

NOTE: When the analysis is based on EPDO accident types, if $X_{Y(EPDO)}$ is less than the user specified limiting value, the respective window will not be flagged.

Step 8: Calculate the variance of the EPDO estimate:

$$Var\left(X_{Y(EPDO)}\right) = Var\left(X_{Y(TOT)}\right) + (RC_{FI} - 1)^2 Var(X_{Y(FI)}) \tag{A-17}$$

When the user specifies that the expected value of the accident frequency is to be an EPDO weighted estimate, then $X_{Y(EPDO)}$ and $Var(X_{Y(EPDO)})$ are the final calculations for a given window.

The window is then moved to the right by 0.1 mi, and the expected accident frequency is computed again for the window in this new location. This process is repeated until the end of a window reaches the end of the roadway segment. In the case of a roadway segment where the length is not in 0.1 mi increments, the last window starts at a distance of 0.1 mi from the end of the segment. Figure A-1 illustrates how these 0.1 mi windows would be located given a 0.67 mi roadway segment.
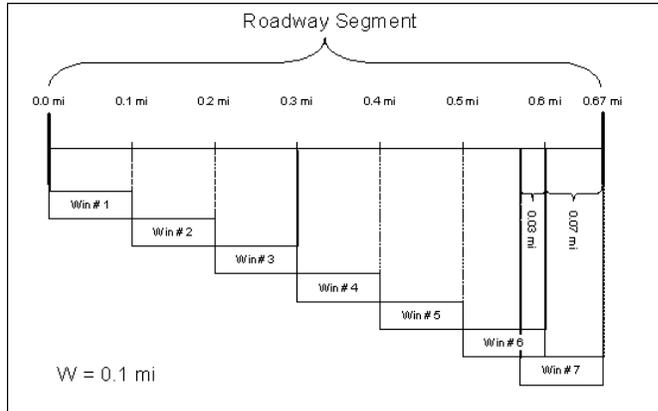
Figure A-1. Peak Searching Concepts: Initial Window Placement (W = 0.1 mi)

The peak searching approach is presented in this appendix for the five severity levels: TOT, FI, FS, PDO, and EPDO. However, it should be noted that the calculations of the variances pertaining to PDO and EPDO accidents are approximations, so results of analyses for TOT and FI accidents may be viewed as having a somewhat higher degree of reliability (i.e., statistical validity) than results of analyses for PDO and EPDO accidents.

Step 9: The expected accident frequency for each 0.1 mi window is then subjected to a statistical precision test by calculating the coefficient of variation of the expected accident frequency. The coefficient of variation of the expected accident frequency is calculated as follows for the respective accident severity levels:

Expected Accident Frequency

$$CV_{(TOT)} = \frac{\sqrt{Var(X_{Y(TOT)})}}{X_{Y(TOT)}} \tag{A-18}$$

$$CV_{(FI)} = \frac{\sqrt{Var(X_{Y(FI)})}}{X_{Y(FI)}} \tag{A-19}$$

$$CV_{(PDO)} = \frac{\sqrt{Var(X_{Y(PDO)})}}{X_{Y(PDO)}} \tag{A-20}$$

$$CV_{(EPDO)} = \frac{\sqrt{Var(X_{Y(EPDO)})}}{X_{Y(EPDO)}} \tag{A-21}$$

Step 10: As part of the input process, the user specifies a CV_{Limit} for expected accident frequency. The CV_{Limit} is set by default within *SafetyAnalyst*. The user has the option to override the default value. From all of the 0.1 mi windows with X_Y greater than or equal to the user specified limit, the CVs are compared to the respective CV_{Limit}. When at least one CV is less than CV_{Limit}, the entire roadway segment (i.e., site) is flagged. From all windows that have a CV less than CV_{Limit} and the respective X_Y is greater than or equal to the user specified limit, the 0.1 mi window with the largest (peak) expected accident

A-8

frequency is selected. The entire flagged roadway segment is placed on the list of roadway segments to be ranked and the location of the window "passing the test" and the value of its expected accident frequency is included in the output. Thus, the PSI = Peak(X_Y).

NOTE 1: The boundaries of the window pertaining to Peak(X_Y) and the magnitude of Peak(X_Y) are included on the main section of the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual). If more than one window pertaining to a site has the same Peak(X_Y) value, the boundaries of the first window moving incrementally along the site from the beginning of the site to the end of the site (i.e., the window with the smallest milepost values or the furthest upstream window) are included on the main section of the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual). The boundaries of the other windows with values of Peak(X_Y) pertaining to the site are listed under the Additional Windows of Interest column in the output report.

NOTE 2: The boundaries of all flagged windows (i.e., windows that pass the two tests of CV less than CV_{Limit} and X_Y is greater than or equal to the user specified limit) pertaining to a site, not included on the main section of the output report, are listed under the Additional Windows of Interest column in the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual).

NOTE 3: When the user screens by FS or FI accidents, the number of expected fatalities and number of expected injuries will also be included on the output report. To obtain these values, the PSI of a site is multiplied by the corresponding accident rates for the given site subtype. These accident rates are found in the *SafetyAnalyst* database. When the user specifies that the screening is to only consider a certain collision type, the respective accident rate $AccRate_{(F/CT/FS)}$ and $AccRate_{(I/CT/FS)}$ or $AccRate_{(F/CT/FI)}$ and $AccRate_{(I/CT/FI)}$ are obtained from the *SafetyAnalyst* database. When more than one collision type is of interest, the respective accident rates used in Equations (A-22) through (A-25) are calculated by an alternative formula. The number of expected fatalities and injuries is calculated as follows (Note: No. of Expected Fatalities$_{(F/FS)}$ = No. of Expected Fatalities$_{(F/FI)}$):

$$\text{No. of Expected Fatalities}_{(F/FS)} = \text{Peak}(X_Y)_{FI} \times \text{AccRate}_{(F/CT/FI)} \qquad \text{(A-22)}$$

$$\text{No. of Expected Injuries}_{(I/FS)} = \text{Peak}(X_Y)_{FS} \times \text{AccRate}_{(I/CT/FS)} \qquad \text{(A-23)}$$

$$\text{No. of Expected Fatalities}_{(F/FI)} = \text{Peak}(X_Y)_{FI} \times \text{AccRate}_{(F/CT/FI)} \qquad \text{(A-24)}$$

$$\text{No. of Expected Injuries}_{(I/FI)} = \text{Peak}(X_Y)_{FI} \times \text{AccRate}_{(I/CT/FI)} \qquad \text{(A-25)}$$

NOTE 4: For each site included on the output report, the average observed accident frequency per mile per year for the entire site and for the location with the highest potential for safety improvement will be included on the output report. The values are calculated as follows:

Entire Site: Average observed accident frequency/mi/yr

$$K_{iRoadways(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} \qquad (A\text{-}26)$$

$$K_{iRoadways(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FS)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \qquad (A\text{-}27)$$

$$K_{iRoadways(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FI)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \qquad (A\text{-}28)$$

$$K_{iRoadways(PDO)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{i,y(FI)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} (A\text{-}29)$$

$$K_{iRoadways(EPDO)} = K_{iRoadways(PDO)} + RC_{FI} K_{iRoadways(FI)} \qquad (A\text{-}30)$$

NOTE: If $K_{iRoadways(FI)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FI)} = K_{iRoadways(TOT)}$. Similarly if $K_{iRoadways(FS)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FS)} = K_{iRoadways(TOT)}$.

Location with Highest Potential for Safety Improvement: Average observed accident frequency/mi/yr

$$K_{iRoadways(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} \qquad (A\text{-}31)$$

$$K_{iRoadways(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FS)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \qquad (A\text{-}32)$$

$$K_{iRoadways(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FI)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \qquad (A\text{-}33)$$

$$K_{iRoadways(PDO)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{i,y(FI)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} (A\text{-}34)$$

$$K_{iRoadways(EPDO)} = K_{iRoadways(PDO)} + RC_{FI} K_{iRoadways(FI)} \qquad (A\text{-}35)$$

NOTE: If $K_{iRoadways(FI)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FI)} = K_{iRoadways(TOT)}$. Similarly if $K_{iRoadways(FS)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FS)} = K_{iRoadways(TOT)}$.

If a roadway segment is not flagged, then the window size is increased by 0.1 mi (W = 0.2 mi). The beginning of the first 0.2 mi window is placed at the beginning of the roadway segment and subsequent windows are moved to the right 0.1 mi at a time (see Figure A-6). The expected accident frequency and its variance for each window are determined in accordance with *Step 1* through *Step 8* defined above. As before, from all of the 0.2 mi windows with X_Y greater than or equal to the user specified limit, the expected accident frequency is then subjected to the same statistical precision test by calculating the coefficient of variation of the expected accident frequency. From among all of the windows that pass the two tests (i.e., CV less than CV_{Limit} and X_Y is greater than or equal to the user specified limit), the window with the largest (peak) expected accident frequency is selected, and its peak value of X_Y is used to rank the entire roadway segment (i.e., site). The boundaries of the respective window are also included on the main section of the

output report. From all windows that pass the two tests (i.e., CV less than CV_{Limit} and X_Y is greater than or equal to the user specified limit), if more than one window within a site has the same $Peak(X_Y)$ value, the boundaries of the first window moving incrementally along the site from the beginning of the site to the end of the site are included on the main section of the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual). The boundaries of all other flagged windows are listed under the Additional Windows of Interest column in the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual).
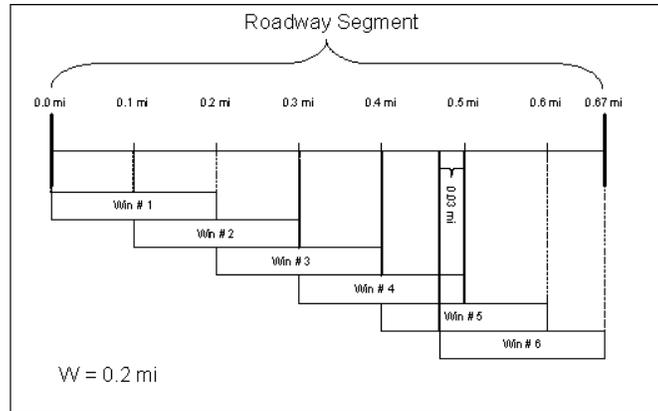

Figure A-2. Peak Searching Concepts: Window Placement When W = 0.2 mi

If statistical significance is not achieved for any window of length W = 0.2 mi, a window of length W = 0.3 mi is tried, and so on in 0.1 mi increments, until the window length is equal to the entire length of the roadway segment. Figure A-3 to Figure A-7 illustrate the window positions for window lengths all the way up to a length equal to that of the roadway segment. If statistical significance is not achieved for any length of window for a given roadway segment (i.e., no windows are flagged), then the roadway segment (i.e., site) is not included in the output.

In summary, when a window is flagged (i.e., it passes the two tests of (a) CV being less than CV_{Limit} and (b) X_Y being greater than or equal to the user specified limit), $PSI = Peak(X_Y)$. This $Peak(X_Y)$ is the measure used to rank the individual roadway segment within the output. The boundaries of the respective peak window are included in the output along with the boundaries of all other flagged windows.
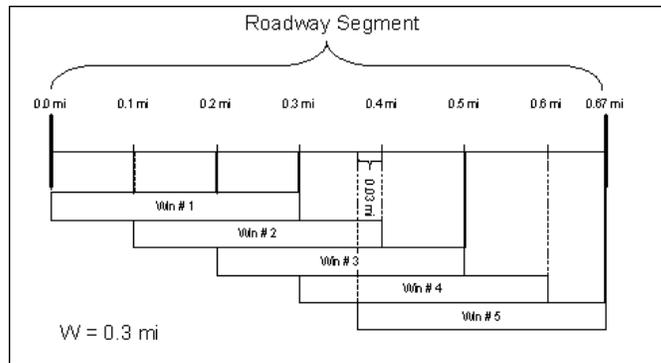
Figure A-3. Peak Searching Concepts: Window Placement When W = 0.3 mi
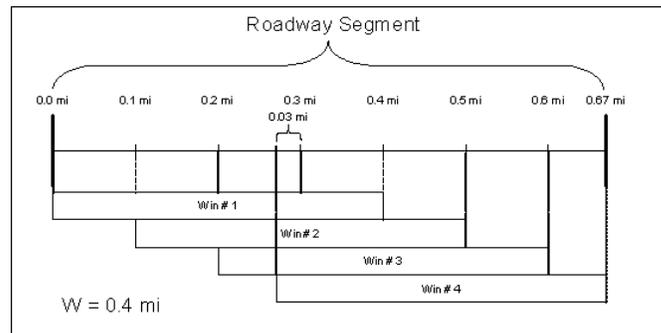

**Figure A-4. Peak Searching Concepts: Window Placement When W = 0.4 mi**
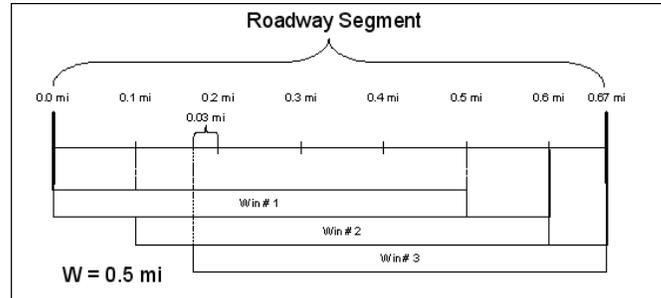
**Figure A-5. Peak Searching Concepts: Window Placement When W = 0.5 mi**
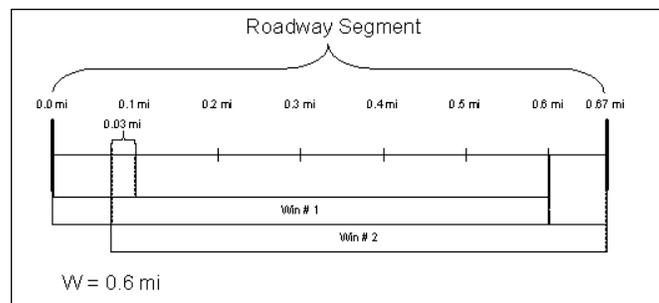
**Figure A-6. Peak Searching Concepts: Window Placement When W = 0.6 mi**
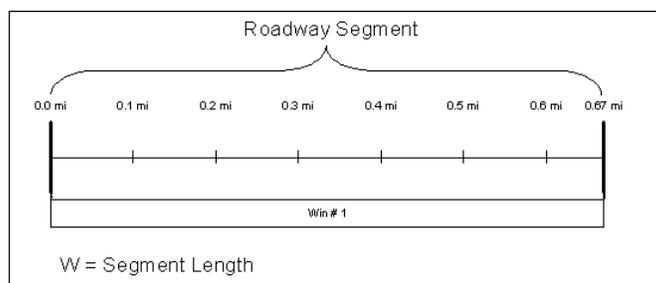
Figure A-7. Peak Searching Concepts: Window Placement When W = Segment Length

A.1.1.1.2 Calculations of PSI Based on Excess Accident Frequency

When the peak searching approach is based on excess accident frequency, excess accident frequency is calculated along with its variance for each window, and similar statistical procedures are performed (i.e., CV test) for the various windows. For a given roadway segment, the procedure starts with a window length of 0.1 mi (W = 0.1 mi). The beginning of the first window is placed at the beginning of the roadway segment, and the average expected accident frequency is calculated for this window. Excess accident frequency and its variance are calculated for each window in accordance with *Step 1* through *Step 10*. As with the peak searching approach based on expected accident frequency, the window sizes increase in the same manner described in Appendix A.1.1.1.1.

Step 0: Determine the length (W) and position of the window within the given roadway segment.

NOTE 1: *Step 1* through *Step 10* are repeated for each window.

NOTE 2: If the site is shorter than the window length, then the window length equals the site length (i.e., W = SL).

Step 1: Using the appropriate SPF model parameters, compute for each year (y = 1, 2,...,Y) the predicted number of accidents per mile, κ_Y, for TOT and FI accidents for the window as follows:

$$\kappa_{y(TOT)} = SPF_{TOT}\{ADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times ADT_y^{\beta_1} \tag{A-1}$$

$$\kappa_{y(FI)} = SPF_{FI}\{ADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_y^{\beta_1} \tag{A-2}$$

NOTE 1: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, (D) replace $P_{(CT/FI)}$ in Equation (A-2) with $P_{(CT/FS/FI)}$, and (E) proceed as normal for FI calculations.

A-13

NOTE 2: If the screening is based upon PDO or EPDO, calculations must be performed for TOT and FI accidents to obtain values for PDO or EPDO accidents. Calculations for PDO or EPDO accidents cannot be based upon calculations from TOT and FS accidents.

NOTE 3: When a site is flagged for inclusion on the output report, the value, κ_Y, is included on the output report under the column heading Predicted Accident Frequency.

NOTE 4: If $\kappa_{y(FI)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly, if $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

Step 2: Using the model predictions computed in *Step 1*, compute the yearly correction factors, C_y, for TOT and FI accidents for years y = 1, 2,...,Y:

$$C_{y(TOT)} = \frac{\kappa_{y(TOT)}}{\kappa_{1(TOT)}}$$ (A-3)

$$C_{y(FI)} = \frac{\kappa_{y(FI)}}{\kappa_{1(FI)}}$$ (A-4)

NOTE: When screening for FS accidents, $C_{y(FS)}$ should not be calculated or used. Instead $C_{y(FI)}$ should be used. In fact $C_{y(FS)}=C_{y(FI)}$ except when predicted accidents is set to $\kappa_{y(TOT)}$ in Note 4 of *Step 1*.

Step 3: Using κ_1,..., κ_Y and the overdispersion parameter, d, compute the weights, w, for TOT and FI accidents:

$$w_{TOT} = \frac{1}{1+d_{TOT}\sum_{y=1}^{Y}\kappa_{y(TOT)}\times L}$$ (A-5)

$$w_{FI} = \frac{1}{1+d_{FI}\sum_{y=1}^{Y}\kappa_{y(FI)}\times L}$$ (A-6)

NOTE 1: The weights, $w_{(TOT)}$ and $w_{(FI)}$, are always calculated based upon the "all" accidents for TOT and FI severity levels. In other words, for those instances when basic network screening is based upon a certain collision type or types, the predicted value calculated in *Step 1* is scaled, based upon a proportion or a sum of proportions. Rather than using the scaled value of predicted accidents in equations Equation (A-5) and Equation (A-6), the predicted value before multiplying by the respective proportion will be used to calculate the weights $w_{(TOT)}$ and $w_{(FI)}$. The same principle applies when the calculations are based upon FS injuries. The weight $w_{(FS)}$ will actually be based upon "all" FI accidents. The rationale for this is because weights, $w_{(TOT)}$ and $w_{(FI)}$, are used in subsequent steps to combine observed accidents and predicted accidents. The weights, $w_{(TOT)}$ and $w_{(FI)}$, are calculated based upon the accuracy/reliability of the SPFs. In concept the accuracy/reliability of the SPF does not change when the screening is based upon certain collision types or FS injury accidents. The same SPFs for TOT and FI accidents are still being used for all calculations, and the accuracy/reliability of the TOT and FI SPFs does not change. If the "scaled" predicted values were used in equations Equation (A-5)

and Equation (A-6), then the weights would be adjusted for the wrong reason, not because the accuracy/reliability of the SPFs changed but because the predicted values were scaled as a necessity due to unrelated circumstances.

NOTE 2: In Equation (A-5) and Equation (A-6), L is equal to the segment length SL.

Step 4: Calculate the base EB-adjusted expected number of accidents, X_1, for TOT and FI accidents during Year 1 on a per mile basis:

$$X_{1(TOT)} = w_{TOT}\kappa_{1(TOT)} + \frac{(1-w_{TOT})}{w}\frac{\sum_{y=1}^{Y}K_{y(TOT)}}{\sum_{y=1}^{Y}C_{y(TOT)}} \tag{A-7}$$

$$X_{1(FI)} = w_{FI}\kappa_{1(FI)} + \frac{(1-w_{FI})}{w}\frac{\sum_{y=1}^{Y}K_{y(FI)}}{\sum_{y=1}^{Y}C_{y(FI)}} \tag{A-8}$$

NOTE 1: The observed accidents in Equation (A-7) and Equation (A-8) should be those of the respective collision types and severity levels as specified by the user.

Step 5: Calculate X_Y on a per mile basis. X_Y is the EB-adjusted expected number of accidents for y = Y, the last year for which data exist for the site, for TOT, FI, and PDO accidents:

$$X_{Y(TOT)} = X_{1(TOT)}C_{Y(TOT)} \tag{A-9}$$

$$X_{Y(FI)} = X_{1(FI)}C_{Y(FI)} \tag{A-10}$$

$$X_{Y(PDO)} = X_{Y(TOT)} - X_{Y(FI)} \tag{A-11}$$

NOTE 1: If $X_{Y(FI)} > X_{Y(TOT)}$, then set $X_{Y(FI)} = X_{Y(TOT)}$

NOTE 2: When the analysis is based on TOT, FI, or PDO accident types, if X_Y is less than the user specified limiting value, the respective window will not be flagged.

Step 6: To obtain a measure of the precision of these expected accident frequencies, calculate the variance of X_Y for TOT, FI, and PDO accidents:

$$Var(X_{Y(TOT)}) = X_{Y(TOT)}(1 - w_{TOT})\frac{C_{Y(TOT)}}{\sum_{y=1}^{Y}C_{y(TOT)}} \tag{A-12}$$

$$Var(X_{Y(FI)}) = X_{Y(FI)}(1 - w_{FI})\frac{C_{Y(FI)}}{\sum_{y=1}^{Y}C_{y(FI)}} \tag{A-13}$$

$$Var(X_{Y(PDO)}) = Var(X_{Y(TOT)}) + Var(X_{Y(FI)}) \tag{A-14}$$

NOTE 1: If in *Step 5*, $X_{Y(FI)}$ is greater than $X_{Y(TOT)}$ and then $X_{Y(FI)}$ is set equal to $X_{Y(TOT)}$, then set $Var(X_{Y(FI)}) = Var(X_{Y(TOT)})$.

NOTE 2: Because FI accidents are a subset of TOT accidents, the calculations in Equation (A-14), which assumes statistical independence of TOT and FI accidents, is only an approximation. In fact, Equation (A-14) overestimates $Var(X_{Y(PDO)})$.

Step 7: Calculate the excess accident frequency for all severity levels:

$$Excess_{Y(TOT)} = X_{Y(TOT)} - \kappa_{Y(TOT)} \tag{A-36}$$

$$Excess_{Y(FI)} = X_{Y(FI)} - \kappa_{Y(FI)} \tag{A-37}$$

$$Excess_{Y(PDO)} = Excess_{Y(TOT)} - Excess_{Y(FI)} \tag{A-38}$$

NOTE 1: If $X_{Y(FI)}$ is greater than $X_{Y(TOT)}$, then set $X_{Y(FI)} = X_{Y(TOT)}$.

NOTE 2: When the analysis is based on TOT, FI, or PDO accident types, if $Excess_Y$ is less than the user specified limiting value, the respective window will not be flagged.

Step 8: Calculate the variance of the excess accident frequency for all severity levels.

Knowing that the variance of an SPF-predicted accident frequency is, in general form:

$$Var(\kappa_Y) = d(\kappa_Y)^2 \tag{A-39}$$

Then,

$$Var(Excess_{Y(TOT)}) = Var(X_{Y(TOT)}) + d_{TOT}(\kappa_{Y(TOT)})^2 \tag{A-40}$$

$$Var(Excess_{Y(FI)}) = Var(X_{Y(FI)}) + d_{TOT}(\kappa_{Y(FI)})^2 \tag{A-41}$$

$$Var(Excess_{Y(PDO)}) = Var(Excess_{Y(TOT)}) + Var(Excess_{Y(FI)}) \tag{A-42}$$

NOTE: If $\kappa_{Y(FI)}$ is greater than $\kappa_{Y(TOT)}$, then set $\kappa_{Y(FI)} = \kappa_{Y(TOT)}$ and $d_{FI} = d_{TOT}$.

When the user specifies that the excess accident frequency is to be unweighted relative to accident severity level, then $Excess_Y$ and $Var(Excess_T)$ are the final calculations for a given window. When the user specifies that the excess accident frequency is to be a cost-weighted estimate (EPDO), proceed to *Step 9*.

Step 9: Calculate the EPDO excess accidents using the relative severity weights, SW, for fatal (F), severe injury (SI), nonincapacitating injury (NI), and possibly injury (MI) severity levels. To calculate the EPDO excess accidents, let RC_{FI} be the relative severity weight of FI accidents as compared to PDO accidents. RC_{FI} is calculated as follows:

$$RC_{FI} = P_F SW_F + P_{SI} SW_{SI} + P_{NI} SW_{NI} + P_{MI} SW_{MI} \tag{A-15}$$

Then, calculate the EPDO excess accidents as:

$$\text{Excess}_{Y(EPDO)} = \text{Excess}_{Y(PDO)} + RC_{FI}\text{Excess}_{Y(FI)} \qquad (A\text{-}43)$$

NOTE: When the analysis is based on EPDO accidents, if Excess$_Y$ is less than the user specified limiting value, the respective window will not be flagged.

Step 10: Calculate the variance of the EPDO excess accident estimate:

$$\text{Var}\left(\text{Excess}_{Y(EPDO)}\right) = \text{Var}\left(\text{Excess}_{Y(TOT)} + (RC_{FI} - 1)^2\text{Var}\left(\text{Excess}_{Y(FI)}\right)\right) \qquad (A\text{-}44)$$

When the user specifies that the excess accident frequency is to be an EPDO weighted estimate, then Excess$_{Y(EPDO)}$ and Var(Excess$_{Y(EPDO)}$) are the final calculations for a given window.

The window is then moved to the right by 0.1 mi, and the excess accident frequency is computed again for the window in this new location. This process is repeated until the end of a window reaches the end of the roadway segment.

Step 11: To perform the statistical precision test for each window, the coefficient of variation of the excess accident frequency is calculated as follows:

$$CV_{\text{Excess}(TOT)} = \frac{\sqrt{\text{Var}(\text{Excess}_{Y(TOT)})}}{\text{Excess}_{Y(TOT)}} \qquad (A\text{-}45)$$

$$CV_{\text{Excess}(FI)} = \frac{\sqrt{\text{Var}(\text{Excess}_{Y(FI)})}}{\text{Excess}_{Y(FI)}} \qquad (A\text{-}46)$$

$$CV_{\text{Excess}(PDO)} = \frac{\sqrt{\text{Var}(\text{Excess}_{Y(PDO)})}}{\text{Excess}_{Y(PDO)}} \qquad (A\text{-}47)$$

$$CV_{\text{Excess}(EPDO)} = \frac{\sqrt{\text{Var}(\text{Excess}_{Y(EPDO)})}}{\text{Excess}_{Y(EPDO)}} \qquad (A\text{-}48)$$

Step 12: As part of the input process, the user specifies a CV$_{Limit}$ for excess accident frequency. The respective CV$_{Limit}$ is set by default within *SafetyAnalyst*. The user has the option to override the default value. From all of the 0.1 mi windows with Excess$_Y$ greater than or equal to the user specified limit, the CVs are compared to the respective CV$_{Limit}$. When at least one CV is less than CV$_{Limit}$ and the respective Excess$_Y$ is greater than or equal to the user specified limit, the entire roadway segment (i.e., site) is flagged. From all windows that have a CV less than CV$_{Limit}$ and Excess$_Y$ greater than or equal to the user specified limit, the window with the largest (peak) excess accident frequency is selected. The entire flagged roadway segment is placed on the list of roadway segments to be ranked and the location of the window "passing the test" and the value of its excess accident frequency is included in the output. Thus, the PSI = Peak(Excess$_Y$).

NOTE 1: The boundaries of the window pertaining to Peak (Excess$_Y$) are included on the main section of the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual). If more than one window pertaining to a site has the same Peak(Excess$_Y$) value, the boundaries of the first window moving incrementally along the site from the beginning of the site to the end of the site (i.e., the window with the smallest milepost values or the farthest upstream window) are included on the main section of the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual). The boundaries of the other windows with values of Peak(Excess$_Y$) pertaining to the site are listed under the Additional Windows of Interest column in the output report.

NOTE 2: The boundaries of all flagged windows (i.e., windows that pass the two tests of CV less than CV$_{Limit}$ and Excess$_Y$ is greater than or equal to the user specified limit) pertaining to a site, not included on the main section of the output report, are listed under the Additional Windows of Interest column in the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual).

NOTE 3: When the user screens by FS or FI accidents, the number of excess fatalities and number of excess injuries will also be included on the output report. To obtain these values, the PSI of a site is multiplied by the corresponding accident rates for the given site subtype. These accident rates are found in the *SafetyAnalyst* database. When the user specifies that the screening is to only consider a certain collision type, the respective accident rate AccRate$_{(F/CT/FS)}$ and AccRate$_{(I/CT/FS)}$ or AccRate$_{(F/CT/FI)}$ and AccRate$_{(I/CT/FI)}$ are obtained from the *SafetyAnalyst* database. When more than one collision type is of interest, the respective accident rates used in Equations (A-49) through (A-52) are calculated by an alternative formula. The number of excess fatalities and injuries is calculated as follows (Note: No. of Excess Fatalities$_{(F/FS)}$ = No. of Excess Fatalities$_{(F/FI)}$):

$$\text{No. of Excess Fatalities}_{(F/FS)} = \text{Peak(Excess}_Y)_{FI} \times \text{AccRate}_{(F/CT/FI)} \qquad \text{(A-49)}$$

$$\text{No. of Excess Injuries}_{(I/FS)} = \text{Peak(Excess}_Y)_{FS} \times \text{AccRate}_{(I/CT/FS)} \qquad \text{(A-50)}$$

$$\text{No. of Excess Fatalities}_{(F/FI)} = \text{Peak(Excess}_Y)_{FI} \times \text{AccRate}_{(F/CT/FI)} \qquad \text{(A-51)}$$

$$\text{No. of Excess Injuries}_{(I/FI)} = \text{Peak(Excess}_Y)_{FI} \times \text{AccRate}_{(I/CT/FI)} \qquad \text{(A-52)}$$

NOTE: If No. Excess Fatalities$_{(F/FS)}$ < 0, then set No. Excess Fatalities$_{(F/FS)}$ = 0.

NOTE 4: For each site included on the output report, the average observed accident frequency per mile per year for the entire site and for the location with the highest potential for safety improvement will be included on the output report. These values are calculated as follows:

Entire Site: Average observed accident frequency/mi/yr

$$K_{iRoadways(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} \tag{A-26}$$

$$K_{iRoadways(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FS)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-27}$$

$$K_{iRoadways(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-28}$$

$$K_{iRoadways(PDO)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{iy(FI)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-29}$$

$$K_{iRoadways(EPDO)} = K_{iRoadways(PDO)} + RC_{FI}K_{iRoadways(FI)} \tag{A-30}$$

NOTE: If $K_{iRoadway(FI)} > K_{iRoadway(TOT)}$, then $K_{iRoadway(FI)} = K_{iRoadway(TOT)}$. Similarly, if $K_{iRoadway(FS)} > K_{iRoadway(TOT)}$, then $K_{iRoadway(FS)} = K_{iRoadway(TOT)}$.

Location with Highest Potential for Safety Improvement: Average observed accident frequency/mi/yr

$$K_{iRoadways(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} \tag{A-31}$$

$$K_{iRoadways(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FS)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-32}$$

$$K_{iRoadways(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-33}$$

$$K_{iRoadways(PDO)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{iy(FI)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-34}$$

$$K_{iRoadways(EPDO)} = K_{iRoadways(PDO)} + RC_{FI}K_{iRoadways(FI)} \tag{A-35}$$

NOTE: If $K_{iRoadway(FI)} > K_{iRoadway(TOT)}$, then $K_{iRoadway(FI)} = K_{iRoadway(TOT)}$. Similarly, if $K_{iRoadway(FS)} > K_{iRoadway(TOT)}$, then $K_{iRoadway(FS)} = K_{iRoadway(TOT)}$.

If statistical significance is not achieved for any window of length W = 0.1 mi, then a window of length W = 0.2 mi is tried, and so on in 0.1 mi increments, until the window length is equal to the entire length of the roadway segment. If statistical significance is not achieved for any length of window for a given roadway segment, then the roadway segment (i.e., site) is not included in the output.

A.1.1.1.3 Calculations of PSI Rating Weighted by Area Type of Roadway Segment

If within the peak searching approach sites are to be weighted based on their area type to account for differences in costs between urban and rural safety improvement projects, Peak(X_Y) or Peak(Excess$_Y$) are calculated in accordance to the procedures described in Appendix A.1.1.1.1 and Appendix A.1.1.1.2 with slight modifications to certain steps. The

values of the AWs are input by the user for urban and rural areas. By default, AW = 1 for urban sites. Thus, all rural sites are weighted relative to urban sites.

When the weighted PSI Rating is calculated for **expected accident frequencies**, *Step 0* through *Step 10* in Appendix A.1.1.1.1 are still applicable, but the selected area weight, AW, is applied as follows to Equation (A-7) and Equation (A-8) when calculating X_1 in *Step 4*:

$$X_{1(TOT)} = \left[w_{TOT} \kappa_{1(TOT)} + \frac{(1 - w_{TOT})}{w} \frac{\sum_{y=1}^{Y} \kappa_{y(TOT)}}{\sum_{y=1}^{Y} c_{y(TOT)}} \right] \times AW \tag{A-53}$$

$$X_{1(FI)} = \left[w_{FI} \kappa_{1(FI)} + \frac{(1 - w_{FI})}{w} \frac{\sum_{y=1}^{Y} \kappa_{y(FI)}}{\sum_{y=1}^{Y} c_{y(FI)}} \right] \times AW \tag{A-54}$$

Similarly, the variance Equation (A-12) and Equation (A-13) in *Step 6* are adjusted to account for the area weight, AW.

$$Var\left(X_{Y(TOT)}\right) = \left[X_{Y(TOT)}(1 - w_{TOT}) \frac{c_{Y(TOT)}}{\sum_{y=1}^{Y} c_{y(TOT)}} \right] \times AW \tag{A-55}$$

$$Var\left(X_{Y(FI)}\right) = \left[X_{Y(FI)}(1 - w_{FI}) \frac{c_{Y(FI)}}{\sum_{y=1}^{Y} c_{y(FI)}} \right] \times AW \tag{A-56}$$

When the weighted PSI Rating is calculated for **excess accident frequencies**, *Step 0* through *Step 12* in Appendix A.1.1.1.2 are still applicable, but the selected area weight, AW, is applied as follows to Equation (A-36) and Equation (A-37) when calculating $Excess_Y$ in *Step 7*:

$$Excess_{Y(TOT)} = \left[X_{Y(TOT)} - \kappa_{Y(TOT)} \right] \times AW \tag{A-57}$$

$$Excess_{Y(FI)} = \left[X_{Y(FI)} - \kappa_{Y(FI)} \right] \times AW \tag{A-58}$$

NOTE: In Equation (A-57) and Equation (A-58), the area weight (AW) has not been applied to $X_{Y(TOT)}$ nor $X_{Y(FI)}$ in previous steps. Therefore, the AW is applied to both terms in the equations.

The variance Equation (A-40) and Equation (A-41) in *Step 8* also adjusted to account for the area weight.

$$Var\left(Excess_{Y(TOT)}\right) = Var\left(X_{Y(TOT)}\right) + \left[d_{TOT}(\kappa_{Y(TOT)})^2 \right] \times AW \tag{A-59}$$

$$Var\left(Excess_{Y(FI)}\right) = Var\left(X_{Y(FI)}\right) + \left[d_{FI}(\kappa_{Y(FI)})^2 \right] \times AW \tag{A-60}$$

Whether the PSI is calculated for expected accident frequency or excess accident frequency, for each site included on the output report, the weighted average observed

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accident frequency per mile per year for the entire site and for the location with the highest potential for safety improvement will be included on the output report. These values are calculated as follows:

Entire Site: Weighted average observed accident frequency/mi/yr

$$K_{iRoadways(TOT)} = \left(\left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times SL_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}} \right) \times C_{Y(TOT)} \right) \times AW \tag{A-61}$$

$$K_{iRoadways(FS)} = \left(\left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FS)}}{Y_i \times SL_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}} \right) \times C_{Y(FI)} \right) \times AW \tag{A-62}$$

$$K_{iRoadways(FI)} = \left(\left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i \times SL_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}} \right) \times C_{Y(FI)} \right) \times AW \tag{A-63}$$

$$K_{iRoadways(PDO)} = \left(\left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times SL_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}} \right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i \times SL_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}} \right) \times C_{Y(FI)} \right) \times AW \tag{A-64}$$

$$K_{iRoadways(EPDO)} = K_{iRoadways(PDO)} + RC_{FI} K_{iRoadyways(FI)} \tag{A-65}$$

NOTE: If $K_{iRoadways(FI)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FI)} = K_{iRoadways(TOT)}$. Similarly if $K_{iRoadways(FS)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FS)} = K_{iRoadways(TOT)}$.

Location with Highest Potential for Safety Improvement: Weighted average observed accident frequency/mi/yr

$$K_{iRoadways(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times W_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}} \right) \times C_{Y(TOT)} \times AW \tag{A-66}$$

$$K_{iRoadways(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FS)}}{Y_i \times W_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}} \right) \times C_{Y(FI)} \times AW \tag{A-67}$$

$$K_{iRoadways(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i \times W_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}} \right) \times C_{Y(FI)} \times AW \tag{A-68}$$

$$K_{iRoadways(PDO)} = \left(\left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times W_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}} \right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i \times W_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}} \right) \times C_{Y(FI)} \right) \times AW \tag{A-69}$$

$$K_{iRoadways(EPDO)} = K_{iRoadways(PDO)} + RC_{FI} K_{iRoadyways(FI)} \tag{A-70}$$

NOTE: If $K_{iRoadway(FI)} > K_{iRoadway(TOT)}$, then set $K_{iRoadway(FI)} = K_{iRoadway(TOT)}$. Similarly if $K_{iRoadway(FS)} > K_{iRoadway(TOT)}$, then set $K_{iRoadway(FS)} = K_{iRoadway(TOT)}$.

Similarly, whether the PSI is calculated for expected accident frequency or excess accident frequency, for each site included on the output report, the weighted predicted accident frequency per mile per year for year Y for the location with the highest potential for safety improvement will be included on the output report. These values are calculated as follows:

$$K_{Y,AW(TOT)} = C_{Y(TOT)} \times e^{\alpha} \times ADT_Y^{\beta_1} \times AW \tag{A-71}$$

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$$\kappa_{Y,AW(FI)} = c_{Y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_Y^{\beta_1} \times AW \tag{A-72}$$

$$\kappa_{Y,AW(PDO)} = \kappa_{Y,AW(TOT)} - \kappa_{Y,AW(FI)} \tag{A-73}$$

$$\kappa_{Y,AW(EPDO)} = \kappa_{Y,AW(PDO)} + RC_{FI}\kappa_{Y,AW(FI)} \tag{A-74}$$

NOTE 1: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents $[P_{(CT/FS/FI)}]$ for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, and (D) include $P_{(CT/FS/FI)}$, in Equation (A-72) as a multiplier.

NOTE 2: If $\kappa_{Y,AW(FI)} > \kappa_{Y,AW(TOT)}$, then set $\kappa_{Y,AW(FI)} = \kappa_{Y,AW(TOT)}$. Similarly, if $\kappa_{Y,AW(FS)} > \kappa_{Y,AW(TOT)}$, then set $\kappa_{Y,AW(FS)} = \kappa_{Y,AW(TOT)}$.

A.1.1.2 Sliding Window Approach for Roadway Segments

In this approach, a sliding window of user-specified length moves forward in increments of user-specified size along each roadway segment in the site list. At each location of the window, calculations are performed to determine the expected accident frequency or excess accident frequency for the segment of roadway within the boundaries of the given sliding window. A sliding window will be comprised of a minimum of one subsegment but may consist of multiple subsegments, depending on the location or placement of the window relative to the roadway segment sites. The number and length of subsegments which comprise a given sliding window is a function of the window length, the incremental length by which the sliding window is moved forward along a set of contiguous sites, and the length of roadway segment sites in the roadway segment inventory database.

For a given analysis, the beginning of the first sliding window is placed at the beginning of the first roadway segment in the site list (i.e., the terminal of the first roadway segment with the smaller milepost value), and calculations as described below are conducted over the length of this first sliding window. The user specifies an incremental length by which the sliding window is moved forward. For example, the user might choose to specify a window length of 0.3 mi (W = 0.3 mi) that moves forward in increments of 0.1 mi. This means that the beginning of the second sliding window is 0.1 mi from the beginning of the first roadway segment. This also means that the second 0.3 mi sliding window overlaps by 0.2 mi with the first sliding window and so on, as sliding windows are moved incrementally forward along a roadway segment (see Figure A-8). By default, sliding window lengths are set to 0.3 mi, and windows are moved forward in 0.1 mi increments. Figure A-8 assumes that the first sliding window is located or positioned on a roadway segment site having a length greater than the window length. In this case, the window consists of one subsegment equal to the length of the sliding window.
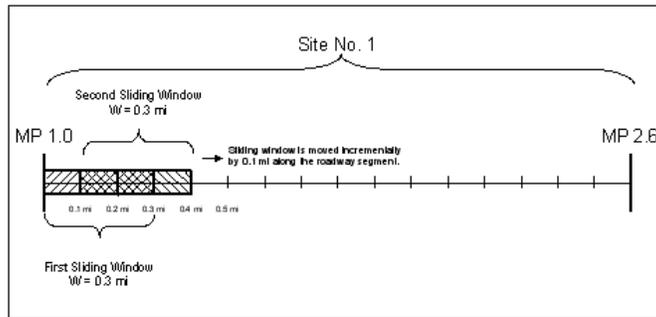
Figure A-8. Sliding Window Concepts: Incremental Moves

As the windows move incrementally forward across sites in the site list, the sliding window will bridge two or more contiguous roadway segments (e.g., the ending milepost value of one roadway segment along a given route equals the beginning milepost value of the next roadway segment). For example, assume a sliding window of length 0.3 mi is positioned such that it spans two roadway segments, and the first roadway segment covers the first two-thirds of the window, and the second roadway segment comprises the final one-third of the window (see Figure A-9). In this case, the window will consist of two subsegments. The first subsegment length would equal 0.2 mi, and the second subsegment length would equal 0.1 mi. Figure A-10 illustrates the placement of a sliding window that bridges three roadway segments. In this case, the window is comprised of three subsegments. The first subsegment, pertaining to Site No. 23, is 0.1-mi in length; the second subsegment, pertaining to Site No. 24, is 0.17-mi in length; and the third subsegment, pertaining to Site No. 25, is 0.03-mi in length.
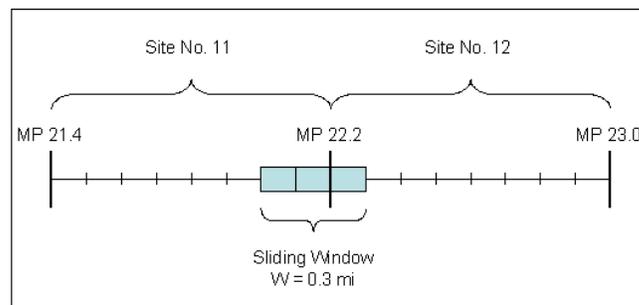

**Figure A-9. Sliding Window Concepts: Bridging Two Contiguous Roadway Segments**
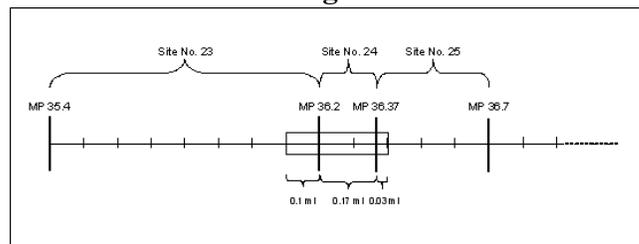
Figure A-10. Sliding Window Concepts: Bridging Three Contiguous Roadway Segments

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Sliding windows are moved forward incrementally until they reach the end of a contiguous set of sites. At the positions of the sliding windows near the end of a contiguous length of roadway segments, the calculations for determining the expected accident frequency or excess accident frequency for the segment of roadway within the boundaries of the given sliding window are performed in the same manner as all previous windows. However, the length of the final sliding window along a contiguous set of sites will vary as a function of the window length, the incremental length by which the sliding window is moved forward, and the length of roadway segment that remains between the previous full length sliding window and the end of the roadway segment. Several examples illustrate this concept. Figure A-11 illustrates a situation where the last sliding window of a contiguous set of sites is 0.28-mi in length. Assume there is a discontinuity between Sites No. 32 and 33 (i.e., Site No. 32 is the last site in a contiguous group of sites, and Site No. 33 is the first site in another group of contiguous sites). Figure A-11 A shows the position of the final window that is of full length (i.e., 0.3 mi). This 0.3-mi window spans Site 31 and 32. The beginning and ending mileposts of this window are 54.1 and 54.4, respectively. The distance from the end position of this window (i.e., MP 54.4) to the end of the site (i.e., MP 54.48) is 0.08-mi. This distance is less than the incremental length by which sliding windows are moved forward (i.e., assuming that the sliding windows are moved forward in an incremental length of 0.1 mi). Figure A-11 B shows that the window is still moved forward by the same incremental length (i.e., 0.1 mi). However, the end position of the window is placed at the end of the contiguous site. Thus, the length of the final window is 0.28 mi which is less than the typical window length. This window consists of two subsegments which are 0.1 mi and 0.18 mi in length, respectively. Figure A-11C shows the position of the next window, which is placed at the beginning of the next set of contiguous sites. Note, that there is no overlap between windows in Figure A-11B and Figure A-11C.
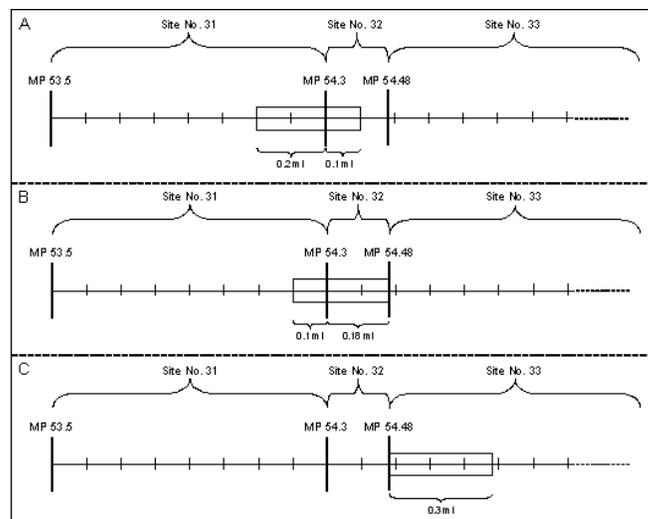

Figure A-11. Sliding Window Concepts: Window Positions at the End of Contiguous Roadway Segments When Window is Moved Incrementally by 0.1 mi

Figure A-12 illustrates the positions of the sliding windows at the end of contiguous sites when the window length is 0.3 mi, and windows are moved forward in increments of 0.2 mi. Again, assume there is a discontinuity between Sites No. 32 and 33. Figure A-12A assumes that the position of the last full length window is as shown in Figure A-12A. Moving the window forward incrementally by 0.2 mi Figure A-12B shows the final window of the contiguous set of sites would be 0.18-mi in length. In this case, there is only 0.1 mi overlap between the last full length window (Figure A-12A) and the final window (Figure A-12B). Figure A-12B consists of one subsegment 0.18-mi in length (i.e., the window length). Figure A-12C shows the position of the next window, which is placed at the beginning of the next set of contiguous sites. This is the same position as illustrated in Figure A-11C. As illustrated in Figure A-11 and Figure A-12, at the end of a contiguous set of sites there is at most one window that is less than the full window length.

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 sites. The sliding windows pertaining to these sites would be the lengths of the sites, and each window would consist of only one subsegment equal to the length of the site and window. Discontinuities between roadway segment sites may occur as a result of discontinuities in:

- Route type
- Mileposts or route
- Section identifier
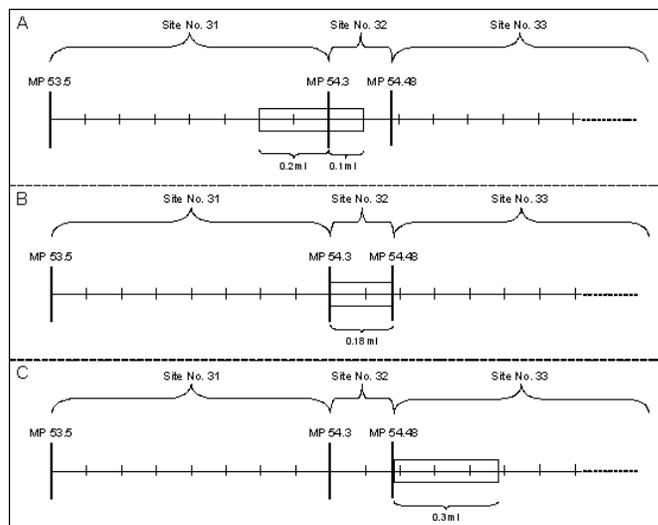
Figure A-12. Sliding Window Concepts: Window Positions at the End of Contiguous Roadway Segments When Window is Moved Incrementally by 0.2 mi

For any given position and length of sliding window, the calculations as described below are performed for basic network screening of roadway segments using the sliding window approach. The subsegments within the sliding window may be nonhomogeneous, requiring in some cases the application of different SPFs or at least a different application of the same SPF with different ADTs.

A roadway segment is ranked based on the maximum value of either the expected accident frequencies or the excess accident frequencies, from all sliding windows that pertain to the particular roadway segment. When a sliding window bridges two or more roadway segments, the value of the expected accident frequency or excess accident frequency from that window pertains to all respective roadway segments. The procedures for calculating expected accident frequencies and excess accident frequencies are presented next. In all subsequent calculations, the value of expected accident frequency or excess accident frequency for a given window is expressed on a per mile basis.

The remainder of this section describes in detail the procedures for calculating the potential for safety improvement based upon the sliding window approach for roadway segments. Appendix A.1.1.2.1 describes the procedures for calculating the potential for safety improvement based upon expected accident frequency according to the sliding window approach. Appendix A.1.1.2.2 describes the procedures for calculating the potential for safety improvement based upon excess accident frequency according to the sliding window approach, and Appendix A.1.1.2.3 describes the procedures for calculating the potential for safety improvement according to the sliding window approach for roadway segments if area weights are applied to give a certain area (i.e., rural or urban) higher priority.

A.1.1.2.1 Calculations of PSI Based on Expected Accident Frequency on Roadway Segments

The objective for this procedure is to compute the expected number of accidents for a sliding window. The expected number of accidents for a sliding window is simply the sum of the expected accident frequencies for each of the subsegments that comprise the sliding window divided by the window length. For simplicity, the discussion below pertains to a sliding window with homogenous subsegments. If the subsegments which comprise the sliding window are not homogenous, the same computations are made for each subsegment in the sliding window, but different SPFs or a different application of the same SPF with different ADTs are applied.

For each subsegment within a sliding window, the accident history is identified from the *SafetyAnalyst* database. Similarly, the appropriate SPFs are identified for TOT and FI accidents from the *SafetyAnalyst* system database. The accident history, since the first year of available data or the year after the most recent date of major reconstruction, is combined with the appropriate SPF estimate to initially produce two expected accident profiles for TOT and FI accidents. At most 10 years of data are used for this calculation. The expected number of PDO accidents is the expected TOT accidents minus the expected FI accidents.

Step 0 through *Step 14* describe the calculations for a contiguous group of roadway segments. *Step 0* through *Step 8* pertain to individual subsegments within a given sliding window. *Step 0* through *Step 12* pertain to calculating expected accident frequencies and variances for every sliding window in a group of contiguous roadway segments. *Step 0* through *Step 14* pertain to finding the PSI of each roadway segment in a contiguous group

of roadway segments and flagging other windows of interest. The procedures for calculating expected accident frequency according to the sliding window approach are very similar to the procedures for calculating expected accident frequency according to the peak search approach described in Appendix A.1.1.1.1, with slight variations to *Step 0* and the equations in *Step 4* and *Step 6*. All of the steps are presented below to illustrate the methodology of the sliding window approach based on expected accident frequency.

Step 0: Determine the length (W) and position of the first sliding window for a contiguous group of roadway segments, and then determine the boundaries and lengths of each subsegment (SL$_{SUB}$) within the window, so that *Step 1* through *Step 8* can be repeated for each subsegment.

NOTE 1: The summation of all subsegment lengths within a sliding window is equal to the window length (i.e., $\sum SL_{SUB} = W$).

NOTE 2: If the first site within the contiguous group is longer than the window length, then the window is of full length, and the window consists of only one subsegment.

NOTE 3: If the contiguous group of sites is greater than the window length, but the first site is less than the window length, then the window will consist of multiple subsegments.

NOTE 4: If the contiguous group of sites is actually one roadway segment that is discontinuous from sites upstream and downstream and the site is shorter than the user-specified window length, then the window length is equal to the site length, and the window consists of only one subsegment.

Step 1: Using the appropriate SPF model parameters, compute for each year (y = 1, 2,...,Y) the predicted number of accidents, κ_y, per mile, for TOT and FI accidents for the first subsegment as follows:

$$\kappa_{y(TOT)} = SPF_{TOT}\{ADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times ADT_y^{\beta_1} \qquad (A\text{-}1)$$

$$\kappa_{y(FI)} = SPF_{FI}\{ADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_y^{\beta_1} \qquad (A\text{-}2)$$

NOTE 1: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, (D) replace $P_{(CT/FI)}$ in Equation (A-2) with $P_{(CT/FS/FI)}$, and (E) proceed as normal for FI calculations.

NOTE 2: If the screening is based upon PDO or EPDO, calculations must be performed for TOT and FI accidents to obtain values for PDO or EPDO accidents. Calculations for PDO or EPDO accidents cannot be based upon calculations from TOT and FS accidents.

NOTE 3: If $\kappa_{y(FI)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly, if $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

Step 2: Using the model predictions computed in *Step 1*, compute the yearly correction factors, C_y, for TOT and FI accidents for years y = 1, 2,...,Y:

$$C_{y(TOT)} = \frac{\kappa_{y(TOT)}}{\kappa_{1(TOT)}} \tag{A-3}$$

$$C_{y(FI)} = \frac{\kappa_{y(FI)}}{\kappa_{1(FI)}} \tag{A-4}$$

NOTE: When screening for FS accidents, $C_{y(FS)}$ should not be calculated or used. Instead $C_{y(FI)}$ should be used. In fact $C_{y(FS)} = C_{y(FI)}$ except when predicted accidents is set to $\kappa_{y(TOT)}$ in Note 3 of *Step 1*.

Step 3: Using $\kappa_1,..., \kappa_Y$ and the overdispersion parameter, d, compute the weights, w, for TOT and FI accidents:

$$w_{TOT} = \frac{1}{1 + d_{TOT}\sum_{y=1}^{Y}\kappa_{y(TOT)} \times L} \tag{A-5}$$

$$w_{FI} = \frac{1}{1 + d_{FI}\sum_{y=1}^{Y}\kappa_{y(FI)} \times L} \tag{A-6}$$

NOTE 1: The weights, $w_{(TOT)}$ and $w_{(FI)}$, are always calculated based upon the "all" accidents for TOT and FI severity levels. In other words, for those instances when basic network screening is based upon a certain collision type or types, the predicted value calculated in *Step 1* is scaled, based upon a proportion or a sum of proportions. Rather than using the scaled value of predicted accidents in equations Equation (A-5) and Equation (A-6), the predicted value before multiplying by the respective proportion will be used to calculate the weights $w_{(TOT)}$ and $w_{(FI)}$. The same principle applies when the calculations are based upon FS injuries. The weight $w_{(FS)}$ will actually be based upon "all" FI accidents. The rationale for this is because weights, $w_{(TOT)}$ and $w_{(FI)}$, are used in subsequent steps to combine observed accidents and predicted accidents. The weights, $w_{(TOT)}$ and $w_{(FI)}$, are calculated based upon the accuracy/reliability of the SPFs. In concept the accuracy/reliability of the SPF does not change when the screening is based upon certain collision types or FS injury accidents. The same SPFs for TOT and FI accidents are still being used for all calculations, and the accuracy/reliability of the TOT and FI SPFs does not change. If the "scaled" predicted values were used in equations Equation (A-5) and Equation (A-6), then the weights would be adjusted for the wrong reason, not because the accuracy/reliability of the SPFs changed but because the predicted values were scaled as a necessity due to unrelated circumstances.

NOTE 2: In Equation (A-5) and Equation (A-6), L is equal to the subsegment length, SL_{SUB}.

Step 4: Calculate the base EB-adjusted expected number of accidents, X_1, for TOT and FI accidents during Year 1:

$$X_{1(TOT)} = w_{TOT}\kappa_{1(TOT)}SL_{SUB} + (1 - w_{TOT})\frac{\sum_{y=1}^{Y}K_{y(TOT)}}{\sum_{y=1}^{Y}C_{y(TOT)}} \tag{A-75}$$

$$X_{1(FI)} = w_{FI}\kappa_{1(FI)}SL_{SUB} + (1 - w_{FI})\frac{\sum_{y=1}^{Y}K_{y(FI)}}{\sum_{y=1}^{Y}C_{y(FI)}} \tag{A-76}$$

NOTE 1: The observed accidents in Equation (A-75) and Equation (A-76) should be those of the respective collision types and severity levels as specified by the user.

Step 5: Calculate X_Y, the EB-adjusted expected number of accidents for y = Y, the last year for which data exist for the site, for TOT, FI, and PDO accidents:

$$X_{Y(TOT)} = X_{1(TOT)}C_{Y(TOT)} \tag{A-9}$$

$$X_{Y(FI)} = X_{1(FI)}C_{Y(FI)} \tag{A-10}$$

$$X_{Y(PDO)} = X_{Y(TOT)} - X_{Y(FI)} \tag{A-11}$$

NOTE: If $X_{Y(FI)} > X_{Y(TOT)}$, then set $X_{Y(FI)} = X_{Y(TOT)}$.

Step 6: To obtain a measure of the precision of these expected accident frequencies, calculate the variance of X_Y for TOT, FI, and PDO accidents:

$$Var(X_{Y(TOT)}) = X_{Y(TOT)}(1 - w_{TOT})\frac{C_{Y(TOT)}}{\sum_{y=1}^{Y}C_{y(TOT)}} \tag{A-77}$$

$$Var(X_{Y(FI)}) = X_{Y(FI)}(1 - w_{FI})\frac{C_{Y(FI)}}{\sum_{y=1}^{Y}C_{y(FI)}} \tag{A-78}$$

$$Var(X_{Y(PDO)}) = Var(X_{Y(TOT)}) + Var(X_{Y(FI)}) \tag{A-14}$$

NOTE 1: If in *Step 5* $X_{Y(FI)}$ is greater than $X_{Y(TOT)}$ and then $X_{Y(FI)}$ is set equal to $X_{Y(TOT)}$, then set $Var(X_{Y(FI)}) = Var(X_{Y(TOT)})$.

NOTE 2: Because FI accidents are a subset of TOT accidents, the calculation in Equation (A-14), which assumes statistical independence of TOT and FI accidents, is only an approximation. In fact, Equation (A-14) overestimates $Var(X_{Y(PDO)})$.

When the user specifies that the expected value of the accident frequency is to be unweighted relative to accident severity level, then X_Y and $Var(X_Y)$ are the final calculations for a given subsegment. Proceed to *Step 9*. When the user specifies that the expected value of the accident frequency is to be a cost-weighted estimate (EPDO), proceed to *Step 7*.

Step 7: Calculate the EPDO expected number of accidents using the relative severity weights, SW, for fatal (F), severe injury (SI), nonincapacitating injury (NI), and possible injury (MI) severity levels. To calculate the EPDO expected number of accidents, let RC_{FI} be the relative weight of FI accidents as compared to PDO accidents. RC_{FI} is calculated as follows:

$$RC_{FI} = P_F SW_F + P_{SI} SW_{SI} + P_{NI} SW_{NI} + P_{MI} SW_{MI} \tag{A-15}$$

Then, calculate the EPDO expected number of accidents as:

$$X_{Y(EPDO)} = X_{Y(PDO)} + RC_{FI} X_{Y(FI)} \tag{A-16}$$

Step 8: Calculate the variance of the EPDO estimate:

$$Var(X_{Y(EPDO)}) = Var(X_{Y(TOT)}) + (RC_{FI} - 1)^2 Var(X_{Y(FI)}) \tag{A-17}$$

When the user specifies that the expected value of the accident frequency is to be an EPDO weighted estimate, then $X_{Y(EPDO)}$ and $Var(X_{Y(EPDO)})$ are the final calculations for a given subsegment.

Step 9: Repeat *Step 1* through *Step 8* for all subsegments in a given sliding window.

NOTE: Depending on whether the analysis is to include TOT, FI, PDO, or EPDO estimates, all of the calculations in *Step 1* through *Step 8* may not be necessary. Only those pertaining to the selected severity level actually need to be performed.

Step 10: Calculate the expected accident frequency across all subsegments within a given sliding window expressed on a per mile basis.

$$Sum(X_{Y(TOT)}) = \frac{1}{W} \Sigma_{SUB} X_{Y(TOT)} \tag{A-79}$$

$$Sum(X_{Y(FI)}) = \frac{1}{W} \Sigma_{SUB} X_{Y(FI)} \tag{A-80}$$

$$Sum(X_{Y(PDO)}) = \frac{1}{W} \Sigma_{SUB} X_{Y(PDO)} \tag{A-81}$$

$$Sum(X_{Y(EPDO)}) = \frac{1}{W} \Sigma_{SUB} X_{Y(EPDO)} \tag{A-82}$$

The summations in Equation (A-79) through Equation (A-82) are multiplied by 1/W, where W is the sliding window length, so that the value of $Sum(X_Y)$ is on a per mile basis. Again, depending on whether the analysis is to include TOT, FI, PDO, or EPDO estimates, all of these calculations may not be necessary.

Step 11: Calculate the variance of the expected accident frequency for the sliding window.

A-30

$$\text{Var}\left[\text{Sum}(X_{Y(TOT)})\right] = \frac{1}{w}\Sigma_{SUB}\text{Var}(X_{Y(TOT)}) \tag{A-83}$$

$$\text{Var}\left[\text{Sum}(X_{Y(FI)})\right] = \frac{1}{w}\Sigma_{SUB}\text{Var}(X_{Y(FI)}) \tag{A-84}$$

$$\text{Var}\left[\text{Sum}(X_{Y(PDO)})\right] = \frac{1}{w}\Sigma_{SUB}\text{Var}(X_{Y(PDO)}) \tag{A-85}$$

$$\text{Var}\left[\text{Sum}(X_{Y(EPDO)})\right] = \frac{1}{w}\Sigma_{SUB}\text{Var}(X_{Y(EPDO)}) \tag{A-86}$$

Depending on whether the analysis is to include TOT, FI, PDO, or EPDO estimates, all of these calculations may not be necessary.

Step 12: By the user-specified increment length, move the sliding window forward towards the end of a contiguous group of roadway segments, and repeat *Step 0* through *Step 12* calculating Sum(X_Y) and Var[Sum(X_Y)] for all windows that pertain to the group of contiguous roadway segments.

Step 13: For each roadway segment in the group of contiguous roadway segments, flag all windows for which Sum(X_Y) for the respective measure of interest (i.e., TOT, FI, PDO, or EPDO) is greater than or equal to the limiting value for expected accident frequency for roadway segments. The boundaries of all flagged windows pertaining to a given roadway segment are included in the output for the given site. This includes the windows that are entirely located within the boundaries of the roadway segment and any window with at least a portion of a subsegment located within the roadway segment.

NOTE 1: If no windows are flagged for a given roadway segment, that roadway segment is not included on the output report.

Step 14: From the flagged windows for each roadway segment in the group of contiguous roadway segments, find Max[Sum(X_Y)], the maximum of Sum(X_Y) values across all windows, for the respective measure of interest (i.e., TOT, FI, PDO, or EPDO). The value of Max[Sum(X_Y)] is the measure used to rank the individual roadway segments within the site list. Thus, PSI = Max[Sum(X_Y)]. The PSI and the boundaries of the respective sliding window are included in the output for a given site.

NOTE 1: The boundaries of the window pertaining to Max[Sum(X_Y)] are included in the main section of the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual). If more than one window pertaining to a site has the same Max[Sum(X_Y)] value, the boundaries of the first window moving incrementally along the site from the beginning of the site to the end of the site (i.e., the window with the smallest milepost values or the furthest upstream window) are included in the main section of the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual). The boundaries of the other windows with values of Max[Sum(X_Y)] pertaining to the site are listed under the Additional Windows of Interest column in the output report.

NOTE 2: The boundaries of all flagged windows pertaining to a site, not included in the main section of the output report, are listed under the Additional Windows of Interest column in the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual).

NOTE 3: When the user screens by FS or FI accidents, the number of expected fatalities and number of expected injuries will also be included on the output report. To obtain these values, the PSI of a site is multiplied by the corresponding accident rates for the given site subtype. These accident rates are found in the *SafetyAnalyst* database. When the user specifies that the screening is to only consider a certain collision type, the respective accident rate $AccRate_{(F/CT/FS)}$ and $AccRate_{(I/CT/FS)}$ or $AccRate_{(F/CT/FI)}$ and $AccRate_{(I/CT/FI)}$ are obtained from the *SafetyAnalyst* database. When more than one collision type is of interest, the respective accident rates used in Equations (A-87) through (A-90) are calculated by an alternative formula. The number of expected fatalities and injuries is calculated as follows (Note: No. of Expected Fatalities$_{(F/FS)}$ = No. of Expected Fatalities$_{(F/FI)}$):

$$\text{No. of Expected Fatalities}_{(F/FS)} = Max[Sum(X_Y)]_{FI} \times AccRate_{(F/CT/FI)} \tag{A-87}$$

$$\text{No. of Expected Injuries}_{(I/FS)} = Max[Sum(X_Y)]_{FS} \times AccRate_{(I/CT/FS)} \tag{A-88}$$

$$\text{No. of Expected Fatalities}_{(F/FI)} = Max[Sum(X_Y)]_{FI} \times AccRate_{(F/CT/FI)} \tag{A-89}$$

$$\text{No. of Expected Injuries}_{(I/FI)} = Max[Sum(X_Y)]_{FI} \times AccRate_{(I/CT/FI)} \tag{A-90}$$

NOTE 4: For each site included on the output report, the average observed accident frequency per mile per year for the entire site and for the location with the highest potential for safety improvement will be included on the output report. These values are calculated as follows:

Entire Site: Average observed accident frequency/mi/yr.

$$K_{iRoadways(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} \tag{A-26}$$

$$K_{iRoadways(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FS)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-27}$$

$$K_{iRoadways(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-28}$$

$$K_{iRoadways(PDO)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{iy(FI)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-29}$$

$$K_{iRoadways(EPDO)} = K_{iRoadways(PDO)} + RC_{FI} K_{iRoadways(FI)} \tag{A-30}$$

NOTE: If $K_{iRoadways(FI)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FI)} = K_{iRoadways(TOT)}$. Similarly if $K_{iRoadways(FS)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FS)} = K_{iRoadways(TOT)}$.

Location with Highest Potential for Safety Improvement: Average observed accident frequency/mi/yr.

$$K_{iRoadways(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} \qquad (A\text{-}31)$$

$$K_{iRoadways(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FS)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \qquad (A\text{-}32)$$

$$K_{iRoadways(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FI)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \qquad (A\text{-}33)$$

$$K_{iRoadways(PDO)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{i,y(FI)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \qquad (A\text{-}34)$$

$$K_{iRoadways(EPDO)} = K_{iRoadways(PDO)} + RC_{FI} K_{iRoadways(FI)} \qquad (A\text{-}35)$$

NOTE: If $K_{iRoadways(FI)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FI)} = K_{iRoadways(TOT)}$. Similarly if $K_{iRoadways(FS)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FS)} = K_{iRoadways(TOT)}$.

NOTE 5: For each sliding window where PSI = Max[Sum(X_Y)] (i.e., Location with the Highest Potential for Safety Improvement), the predicted accident frequency per mile for year Y will be included on the output report. These values are calculated as follows. If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, and (D) replace $P_{(CT/FI)}$ in Equation (A-93) with $P_{(CT/FS/FI)}$ as a multiplier.

$$\kappa_{Y,W(TOT)} = \frac{1}{W} \sum_{SUB} C_{Y(TOT)} \times e^{\alpha} \times ADT_Y^{\beta_1} \times SL_{SUB} \qquad (A\text{-}92)$$

$$\kappa_{Y,W(FI)} = \frac{1}{W} \sum_{SUB} C_{Y(FI)} \times e^{\alpha} \times ADT_Y^{\beta_1} \times SL_{SUB} \qquad (A\text{-}93)$$

$$\kappa_{Y,W(PDO)} = \kappa_{Y,W(TOT)} - \kappa_{Y,W(FI)} \qquad (A\text{-}94)$$

$$\kappa_{Y,W(EPDO)} = \kappa_{Y,W(PDO)} + RC_{FI} \kappa_{Y,W(FI)} \qquad (A\text{-}95)$$

NOTE: If $\kappa_{Y,W(FI)} > \kappa_{Y,W(TOT)}$, then set $\kappa_{Y,W(FI)} = \kappa_{Y,W(TOT)}$. Similarly, if $\kappa_{Y,W(FS)} > \kappa_{Y,W(TOT)}$, then set $\kappa_{Y,W(FS)} = \kappa_{Y,W(TOT)}$.

Although variances are calculated for all estimates in this screening approach, they are not used in ranking sites. Variance, a measure of precision, is an important output parameter, however, since a high variance may be considered in diagnosis as one possible explanation for the high ranking of a site.

A.1.1.2.2 Calculations of PSI Based on Excess Accident Frequency on Roadway Segments

The procedures for calculating the PSI based on excess accident frequency are very similar to those for calculating the PSI based on expected accident frequency. Excess accident frequency is determined by comparing the SPF predicted accident frequency to the EB adjusted expected accident frequency. The steps for these calculations are presented below. *Step 0* through *Step 16* describe the calculations for a contiguous group of roadway segments. *Step 0* through *Step 10* pertain to individual subsegments within a given sliding window. *Step 0* through *Step 14* pertain to calculating excess accident frequencies and variances for every sliding window in a group of contiguous roadway segments. *Step 0* through *Step 16* pertain to finding the PSI of each roadway segment in a contiguous group of roadway segments and flagging other windows of interest.

The procedures for calculating excess accident frequency according to the sliding window approach are very similar to the procedures for calculating excess accident frequency according to the peak searching approach described in Appendix A.1.1.1.2, with slight modifications to *Step 0*, *Step 4*, *Step 6*, *Step 7*, and *Step 8*. All of the steps are presented below to illustrate the methodology of the sliding window approach based on excess accident frequency.

Step 0: Determine the length (W) and position of the first sliding window for a contiguous group of roadway segments, and then determine the boundaries and lengths of each subsegment (SL_{SUB}) within the window.

NOTE 1: The summation of all subsegment lengths within a Sliding window is equal the window length (i.e., $\sum SL_{SUB} = W$).

NOTE 2: If the first site within the contiguous group is longer than the window length, then the window is of full length, and the window consists of only one subsegment.

NOTE 3: If the contiguous group of sites is greater than the window length, but the first site is less than the window length, then the window will consist of multiple subsegments.

NOTE 4: If the contiguous group of sites is actually one roadway segment that is discontinuous from sites upstream and downstream and the site is shorter than the user-specified window length, then the window length is equal to the site length, and the window consists of only one subsegment.

Step 1: Using the appropriate SPF model parameters, compute for each year (y = 1, 2,...,Y) the predicted number of accidents per mile, κ_y, for TOT and FI accidents for the first subsegment as follows:

$$\kappa_{y(TOT)} = SPF_{TOT}\{ADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times ADT_y^{\beta_1} \tag{A-1}$$

$$\kappa_{y(FI)} = SPF_{FI}\{ADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_y^{\beta_1} \tag{A-2}$$

NOTE 1: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, (D) replace $P_{(CT/FI)}$ in Equation (A-2) with $P_{(CT/FS/FI)}$, and (E) proceed as normal for FI calculations.

NOTE 2: If $\kappa_{y(FI)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly, if $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

Step 2: Using the model predictions computed in *Step 1*, compute the yearly correction factors, C_y, for TOT and FI accidents for years y = 1, 2,...,Y:

$$C_{y(TOT)} = \frac{\kappa_{y(TOT)}}{\kappa_{1(TOT)}} \tag{A-3}$$

$$C_{y(FI)} = \frac{\kappa_{y(FI)}}{\kappa_{1(FI)}} \tag{A-4}$$

NOTE: When screening for FS accidents, $C_{y(FS)}$ should not be calculated or used. Instead, $C_{y(FI)}$ should be used. In fact $C_{y(FS)} = C_{y(FI)}$ except when predicted accidents is set to $\kappa_{y(TOT)}$ in Note 2 of *Step 1*.

Step 3: Using $\kappa_1,...,\kappa_Y$ and the overdispersion parameter, d, compute the weights, w, for TOT and FI accidents:

$$w_{TOT} = \frac{1}{1 + d_{TOT}\sum_{y=1}^{Y}\kappa_{y(TOT)} \times L} \tag{A-5}$$

$$w_{FI} = \frac{1}{1 + d_{FI}\sum_{y=1}^{Y}\kappa_{y(FI)} \times L} \tag{A-6}$$

NOTE 1: The weights, $w_{(TOT)}$ and $w_{(FI)}$, are always calculated based upon the "all" accidents for TOT and FI severity levels. In other words, for those instances when basic network screening is based upon a certain collision type or types, the predicted value calculated in *Step 1* is scaled, based upon a proportion or a sum of proportions. Rather than using the scaled value of predicted accidents in equations Equation (A-5) and Equation (A-6), the predicted value before multiplying by the respective proportion will be used to calculate the weights $w_{(TOT)}$ and $w_{(FI)}$. The same principle applies when the calculations are based upon FS injuries. The weight $w_{(FS)}$ will actually be based upon "all" FI accidents. The rationale for this is because weights, $w_{(TOT)}$ and $w_{(FI)}$, are used in subsequent steps to combine observed accidents and predicted accidents. The weights, $w_{(TOT)}$ and $w_{(FI)}$, are calculated based upon the accuracy/reliability of the SPFs. In concept the accuracy/reliability of the SPF does not change when the screening is based upon

certain collision types or FS injury accidents. The same SPFs for TOT and FI accidents are still being used for all calculations, and the accuracy/reliability of the TOT and FI SPFs does not change. If the "scaled" predicted values were used in equations Equation (A-5) and Equation (A-6), then the weights would be adjusted for the wrong reason, not because the accuracy/reliability of the SPFs changed but because the predicted values were scaled as a necessity due to unrelated circumstances.

NOTE 2: In Equation (A-5) and Equation (A-6), L is equal to the subsegment length, SL_{SUB}.

Step 4: Calculate the base EB-adjusted expected number of accidents, X_1, for TOT and FI accidents during Year 1:

$$X_{1(TOT)} = w_{TOT} \kappa_{1(TOT)} SL_{SUB} + (1 - w_{TOT}) \frac{\sum_{y=1}^{Y} K_{y(TOT)}}{\sum_{y=1}^{Y} C_{y(TOT)}} \tag{A-75}$$

$$X_{1(FI)} = w_{FI} \kappa_{1(FI)} SL_{SUB} + (1 - w_{FI}) \frac{\sum_{y=1}^{Y} K_{y(FI)}}{\sum_{y=1}^{Y} C_{y(FI)}} \tag{A-76}$$

NOTE 1: The observed accidents in Equation (A-75) and Equation (A-76) should be those of the respective collision types and severity levels as specified by the user.

Step 5: Calculate X_Y, the EB-adjusted expected number of accidents for y = Y, the last year for which data exist for the site, for TOT, FI, and PDO accidents:

$$X_{Y(TOT)} = X_{1(TOT)} C_{Y(TOT)} \tag{A-9}$$

$$X_{Y(FI)} = X_{1(FI)} C_{Y(FI)} \tag{A-10}$$

$$X_{Y(PDO)} = X_{Y(TOT)} - X_{Y(FI)} \tag{A-11}$$

NOTE: If $X_{Y(FI)} > X_{Y(TOT)}$, then set $X_{Y(FI)} = X_{Y(TOT)}$

Step 6: To obtain a measure of the precision of these expected accident frequencies, calculate the variance of X_Y for TOT, FI, and PDO accidents:

$$Var(X_{Y(TOT)}) = X_{Y(TOT)}(1 - w_{TOT}) \frac{C_{Y(TOT)}}{\sum_{y=1}^{Y} C_{y(TOT)}} \tag{A-77}$$

$$Var(X_{Y(FI)}) = X_{Y(FI)}(1 - w_{FI}) \frac{C_{Y(FI)}}{\sum_{y=1}^{Y} C_{y(FI)}} \tag{A-78}$$

$$Var(X_{Y(PDO)}) = Var(X_{Y(TOT)}) + Var(X_{Y(FI)}) \tag{A-14}$$

NOTE: If in *Step 5*, $X_{Y(FI)}$ is greater than $X_{Y(TOT)}$ and then $X_{Y(FI)}$ is set equal to $X_{Y(TOT)}$, then set $Var(X_{Y(FI)}) = Var(X_{Y(TOT)})$.

Step 7: Calculate the excess accident frequency for all severity levels:

$$\text{Excess}_{Y(TOT)} = X_{Y(TOT)} - \kappa_{Y(TOT)}SL_{SUB} \tag{A-96}$$

$$\text{Excess}_{Y(FI)} = X_{Y(FI)} - \kappa_{Y(FI)}SL_{SUB} \tag{A-97}$$

$$\text{Excess}_{Y(PDO)} = \text{Excess}_{Y(TOT)} - \text{Excess}_{Y(FI)} \tag{A-38}$$

NOTE: If $\kappa_{Y(FI)}$ is greater than $\kappa_{Y(TOT)}$, then set $\kappa_{Y(FI)} = \kappa_{Y(TOT)}$.

Step 8: Calculate the variance of the excess accident frequency for all severity levels.

Knowing that the variance of an SPF-predicted accident frequency is, in general form:

$$\text{Var}(\kappa_Y) = d(\kappa_Y)^2 \tag{A-39}$$

Then,

$$\text{Var}\left(\text{Excess}_{Y(TOT)}\right) = \text{Var}\left(X_{Y(TOT)}\right) + d_{TOT}\left(\kappa_{Y(TOT)}SL_{SUB}\right)^2 \tag{A-98}$$

$$\text{Var}\left(\text{Excess}_{Y(FI)}\right) = \text{Var}\left(X_{Y(FI)}\right) + d_{FI}\left(\kappa_{Y(FI)}SL_{SUB}\right)^2 \tag{A-99}$$

$$\text{Var}\left(\text{Excess}_{Y(PDO)}\right) = \text{Var}\left(\text{Excess}_{Y(TOT)}\right) + \text{Var}\left(\text{Excess}_{Y(FI)}\right) \tag{A-42}$$

NOTE: If $\kappa_{Y(FI)}$ is greater than $\kappa_{Y(TOT)}$, then set $\kappa_{Y(FI)} = \kappa_{Y(TOT)}$ and $d_{FI} = d_{TOT}$.

When the user specifies that the excess accident frequency is to be unweighted relative to accident severity level, then Excess_Y and $\text{Var}(\text{Excess}_Y)$ are the final calculations for a given subsegment. Proceed to *Step 11*. When the user specifies that the excess accident frequency is to be a cost-weighted estimate (EPDO), proceed to *Step 9*.

Step 9: Calculate the EPDO excess accidents using the relative severity weights, SW, for fatal (F), severe injury (SI), nonincapacitating injury (NI), and possible injury (MI) severity levels. To calculate the EPDO excess accidents, let RC_{FI} be the relative severity weight of FI accidents as compared to PDO accidents. RC_{FI} is calculated as follows:

$$RC_{FI} = P_F SW_F + P_{SI} SW_{SI} + P_{NI} SW_{NI} + P_{MI} SW_{MI} \tag{A-15}$$

Then, calculate the EPDO excess accidents as:

$$\text{Excess}_{Y(EPDO)} = \text{Excess}_{Y(PDO)} + RC_{FI} \text{Excess}_{Y(FI)} \tag{A-43}$$

Step 10: Calculate the variance of the EPDO excess accident estimate:

A-37

$$\text{Var}\left(\text{Excess}_{Y(EPDO)}\right) = \text{Var}\left(\text{Excess}_{Y(TOT)} + (RC_{FI} - 1)^2 \text{Var}(\text{Excess}_{Y(FI)})\right) \tag{A-44}$$

When the user specifies that the excess accident frequency is to be an EPDO weighted estimate, then $\text{Excess}_{Y(EPDO)}$ and $\text{Var}(\text{Excess}_{Y(EPDO)})$ are the final calculations for a given subsegment.

Step 11: Repeat *Step 1* through *Step 10* for all subsegments in a given sliding window. *Step 9* and *Step 10* are only needed when the user specifies an EPDO weighted estimate.

NOTE: Depending on whether the analysis is to include TOT, FI, PDO, or EPDO estimate, all of the calculations in *Step 1* through *Step 10* may not be necessary. Only those pertaining to the selected accident type actually need to be performed.

Step 12: Calculate the excess accident frequency across all subsegments within a given sliding window, expressed on a per mile basis.

$$\text{Sum}\left(\text{Excess}_{Y(TOT)}\right) = \frac{1}{W} \Sigma_{SUB} \text{Excess}_{Y(TOT)} \tag{A-100}$$

$$\text{Sum}\left(\text{Excess}_{Y(FI)}\right) = \frac{1}{W} \Sigma_{SUB} \text{Excess}_{Y(FI)} \tag{A-101}$$

$$\text{Sum}\left(\text{Excess}_{Y(PDO)}\right) = \frac{1}{W} \Sigma_{SUB} \text{Excess}_{Y(PDO)} \tag{A-102}$$

$$\text{Sum}\left(\text{Excess}_{Y(EPDO)}\right) = \frac{1}{W} \Sigma_{SUB} \text{Excess}_{Y(EPDO)} \tag{A-103}$$

The summations in Equation (A-100) through Equation (A-103) are multiplied by 1/W so that the value of $\text{Sum}(\text{Excess}_Y)$ is expressed on a per mile basis. Again, depending on whether the analysis is to include TOT, FI, PDO, or EPDO estimates, all of these calculations may not be necessary.

Step 13: Calculate the variance of the excess accident frequency for the given sliding window.

$$\text{Var}\left[\text{Sum}(\text{Excess}_{Y(TOT)})\right] = \frac{1}{W} \Sigma_{SUB} \text{Var}(\text{Excess}_{Y(TOT)}) \tag{A-104}$$

$$\text{Var}\left[\text{Sum}(\text{Excess}_{Y(FI)})\right] = \frac{1}{W} \Sigma_{SUB} \text{Var}(\text{Excess}_{Y(FI)}) \tag{A-105}$$

$$\text{Var}\left[\text{Sum}(\text{Excess}_{Y(PDO)})\right] = \frac{1}{W} \Sigma_{SUB} \text{Var}(\text{Excess}_{Y(PDO)}) \tag{A-106}$$

$$\text{Var}\left[\text{Sum}(\text{Excess}_{Y(EPDO)})\right] = \frac{1}{W} \Sigma_{SUB} \text{Var}(\text{Excess}_{Y(EPDO)}) \tag{A-107}$$

Depending on whether the analysis is to include TOT, FI, PDO, or EPDO estimates, all of these calculations may not be necessary.

Step 14: By the user-specified increment length, move the sliding window forward towards the end of the contiguous group of roadway segments, and repeat *Step 0* through *Step 14* calculating Sum(Excess$_Y$) and Var[Sum(Excess$_Y$)] for all windows that pertain to the group of contiguous roadway segments.

Step 15: For each roadway segment in the group of contiguous roadway segments, flag all windows for which Sum(Excess$_Y$) for the respective measure of interest (i.e., TOT, FI, PDO, or EPDO) is greater than or equal to the limiting value for excess accident frequency for roadway segments. The boundaries of all flagged windows pertaining to a given roadway segment are included in the output for the given site. This includes the windows that are entirely located within the boundaries of the roadway segment and any window with at least a portion of a subsegment located within the roadway segment.

NOTE: If no windows are flagged for a given roadway segment, the roadway segment is not included in the output report.

Step 16: From the flagged windows for each roadway segment in the group of contiguous roadway segments, find Max[Sum(Excess$_Y$)], the maximum of Sum(Excess$_Y$), for the respective measure of interest (i.e., TOT, FI, PDO, or EPDO). The value of Max[Sum(Excess$_Y$)] is the measure used to rank the individual roadway segments within the site list. Thus, PSI = Max[Sum(Excess$_Y$)]. The PSI and the boundaries of the respective sliding window are included in the output for a given site.

NOTE 1: The boundaries of the window pertaining to Max[Sum(Excess$_Y$)] are included in the main section of the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual). If more than one window pertaining to a site has the same Max[Sum(Excess$_Y$)] value, the boundaries of the first window moving incrementally along the site from the beginning of the site to the end of the site (i.e., the window with the smallest milepost values or the furthest upstream window) are included in the main section of the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual). The boundaries of the other windows with values of Max[Sum(Excess$_Y$)] pertaining to the site are listed under the Additional Windows of Interest column in the output report.

NOTE 2: The boundaries of all flagged windows pertaining to a site, not included in the main section of the output report, are listed under the Additional Windows of Interest column in the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual).

NOTE 3: When the user screens by FS or FI accidents, the number of excess fatalities and number of excess injuries will also be included on the output report. To obtain these values, the PSI of a site is multiplied by the corresponding accident rates for the given site subtype. These accident rates are found in the *SafetyAnalyst* database. When the user specifies that the screening is to only consider a certain collision type, the respective accident rate AccRate$_{(F/CT/FS)}$ and AccRate$_{(I/CT/FS)}$ or AccRate$_{(F/CT/FI)}$ and AccRate$_{(I/CT/FI)}$ are obtained from the *SafetyAnalyst* database. When more than one collision type is of interest,

the respective accident rates used in Equations (A-108) through (A-111) are calculated by an alternative formula. The number of excess fatalities and injuries is calculated as follows (Note: No. of Excess Fatalities $_{(F/FS)}$ = No. of Excess Fatalities$_{(F/FI)}$).

$$\text{No. of Excess Fatalities}_{(F/FS)} = \text{Max}[\text{Sum}(\text{Excess}_Y)]_{FI} \times \text{AccRate}_{(F/CT/FI)} \qquad \text{(A-108)}$$

$$\text{No. of Excess Injuries}_{(I/FS)} = \text{Max}[\text{Sum}(\text{Excess}_Y)]_{FS} \times \text{AccRate}_{(I/CT/FS)} \qquad \text{(A-109)}$$

$$\text{No. of Excess Fatalities}_{(F/FI)} = \text{Max}[\text{Sum}(\text{Excess}_Y)]_{FI} \times \text{AccRate}_{(F/CT/FI)} \qquad \text{(A-110)}$$

$$\text{No. of Excess Injuries}_{(I/FI)} = \text{Max}[\text{Sum}(\text{Excess}_Y)]_{FI} \times \text{AccRate}_{(I/CT/FI)} \qquad \text{(A-111)}$$

NOTE: If No. of Excess Fatalities$_{(F/FS)}$ < 0, then set No. of Excess Fatalities$_{(F/FS)}$ = 0.

NOTE 4: For each site included on the output report, the average observed accident frequency per mile per year for the entire site and for the location with the highest potential for safety improvement will be included on the output report. These values are calculated as follows:

Entire Site: Average observed accident frequency/mi/yr.

$$K_{iRoadways(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} \qquad \text{(A-26)}$$

$$K_{iRoadways(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FS)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \qquad \text{(A-27)}$$

$$K_{iRoadways(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FI)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \qquad \text{(A-28)}$$

$$K_{iRoadways(PDO)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{i,y(FI)}}{Y_i \times SL_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \text{(A-29)}$$

$$K_{iRoadways(EPDO)} = K_{iRoadways(PDO)} + RC_{FI} K_{iRoadways(FI)} \qquad \text{(A-30)}$$

NOTE: If $K_{iRoadways(FI)}$ > $K_{iRoadways(TOT)}$, then set $K_{iRoadways(FI)}$ = $K_{iRoadways(TOT)}$. Similarly, if $K_{iRoadways(FS)}$ > $K_{iRoadways(TOT)}$, then set $K_{iRoadways(FS)}$=$K_{iRoadways(TOT)}$.

Location with Highest Potential for Safety Improvement: Average observed accident frequency/mi/yr.

$$K_{iRoadways(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} \qquad \text{(A-31)}$$

$$K_{iRoadways(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FS)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \qquad \text{(A-32)}$$

$$K_{iRoadways(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FI)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \qquad \text{(A-33)}$$

$$K_{iRoadways(PDO)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{i,y(FI)}}{Y_i \times W_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \quad \text{(A-34)}$$

$$K_{iRoadways(EPDO)} = K_{iRoadways(PDO)} + RC_{FI} K_{iRoadways(FI)} \tag{A-35}$$

NOTE: If $K_{iRoadway(FI)} > K_{iRoadway(TOT)}$, then set $K_{iRoadway(FI)} = K_{iRoadway(TOT)}$. Similarly, if $K_{iRoadway(FS)} > K_{iRoadway(TOT)}$, then set $K_{iRoadway(FS)} = K_{iRoadway(TOT)}$.

NOTE 5: For each sliding window where PSI = Max[Sum(Excess$_Y$)] (i.e., Location with the Highest Potential for Safety Improvement), the predicted accident frequency per year for year Y will be included on the output report. These values are calculated as follows. If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, and (D) replace $P_{(CT/FI)}$ in Equation (A-93) with $P_{(CT/FS/FI)}$ as a multiplier.

$$\kappa_{Y,W(TOT)} = \frac{1}{W}\Sigma_{SUB}\, C_{Y(TOT)} \times e^{\alpha} \times ADT_Y^{\beta_1} \times SL_{SUB} \tag{A-92}$$

$$\kappa_{Y,W(FI)} = \frac{1}{W}\Sigma_{SUB}\, C_{Y(FI)} \times e^{\alpha} \times ADT_Y^{\beta_1} \times SL_{SUB} \tag{A-93}$$

$$\kappa_{Y,W(PDO)} = \kappa_{Y,W(TOT)} - \kappa_{Y,W(FI)} \tag{A-94}$$

$$\kappa_{Y,W(EPDO)} = \kappa_{Y,W(PDO)} + RC_{FI}\kappa_{Y,W(FI)} \tag{A-95}$$

NOTE: If $\kappa_{Y,W(FI)} > \kappa_{Y,W(TOT)}$, then set $\kappa_{Y,W(FI)} = \kappa_{Y,W(TOT)}$. Similarly, if $\kappa_{Y,W(FS)} > \kappa_{Y,W(TOT)}$, then set $\kappa_{Y,W(FS)} = \kappa_{Y,W(TOT)}$.

Note that although several variances are calculated for all estimates in this screening methodology, they are not used in ranking sites. Variance, a measure of precision, is an important output parameter, however, since a high variance may be considered in diagnosis as one possible explanation for the high ranking of a site.

A.1.1.2.3 Calculations of PSI Rating Weighted by Area Type of Roadway Segment

The site list selected by the user may contain urban or rural sites, or both. Thus the user can rank urban sites or rural sites separately or combined. However, should the user wish to weight rural sites relative to urban sites (e.g., by relative cost of improvement projects) prior to ranking them in a combined set, then the following procedure may be used to account for differences in costs between urban and rural safety improvement projects. Area weights (AW) are applied to the expected accident frequencies or excess accident frequencies to calculate a weighted PSI rating. Values of the area weights (AW) are input by the user for urban and rural areas. By default, AW = 1 for urban sites. Thus, all rural sites are weighted relative to urban sites.

When the weighted PSI Rating is calculated for **expected accident frequencies**, *Step 0* through *Step 13* in Appendix A.1.1.2.1 are still applicable, but the selected area weight, AW, would be applied as follows to Equation (A-75) and Equation (A-76) when calculating X_1 in *Step 4*:

$$X_{1(TOT)} = \left[w_{TOT}\kappa_{1(TOT)}SL_{SUB} + (1 - w_{TOT})\frac{\sum_{y=1}^{Y}K_{y(TOT)}}{\sum_{y=1}^{Y}C_{y(TOT)}} \right] \times AW \qquad \text{(A-112)}$$

$$X_{1(FI)} = \left[w_{FI}\kappa_{1(FI)}SL_{SUB} + (1 - w_{FI})\frac{\sum_{y=1}^{Y}K_{y(FI)}}{\sum_{y=1}^{Y}C_{y(FI)}} \right] \times AW \qquad \text{(A-113)}$$

Similarly, the variance Equation (A-77) and Equation (A-78) in *Step 6* will have to be adjusted to account for the area weight, AW.

$$Var\left(X_{Y(TOT)}\right) = \left[X_{Y(TOT)}(1 - w_{TOT})\frac{C_{Y(TOT)}}{\sum_{y=1}^{Y}C_{y(TOT)}} \right] \times AW \qquad \text{(A-114)}$$

$$Var\left(X_{Y(FI)}\right) = \left[X_{Y(FI)}(1 - w_{FI})\frac{C_{Y(FI)}}{\sum_{y=1}^{Y}C_{y(FI)}} \right] \times AW \qquad \text{(A-115)}$$

When the weighted PSI Rating is calculated for **excess accident frequencies**, *Step 0* through *Step 16* in Appendix A.1.1.2.2 are still applicable, but the selected area weight, AW, would be applied as follows to Equation (A-96) and Equation (A-97) when calculating $Excess_y$ in *Step 7*:

$$Excess_{Y(TOT)} = \left[X_{Y(TOT)} - \kappa_{Y(TOT)}SL_{SUB} \right] \times AW \qquad \text{(A-116)}$$

$$Excess_{Y(FI)} = \left[X_{Y(FI)} - \kappa_{Y(FI)}SL_{SUB} \right] \times AW \qquad \text{(A-117)}$$

NOTE: In Equation (A-116) and Equation (A-117), the area weight (AW) has not **been** applied to $X_{Y(TOT)}$ nor $X_{Y(FI)}$ in previous steps. Therefore, the AW is applied to both terms in the equations.

The variance Equation (A-98) and Equation (A-99) in *Step 8* also have to be adjusted to account for the area weight.

$$Var\left(Excess_{Y(TOT)}\right) = Var\left(X_{Y(TOT)}\right) + \left[d_{TOT}(\kappa_{Y(TOT)}SL_{SUB})^2 \right] \times AW \qquad \text{(A-118)}$$

$$Var\left(Excess_{Y(FI)}\right) = Var\left(X_{Y(FI)}\right) + \left[d_{FI}(\kappa_{Y(FI)}SL_{SUB})^2 \right] \times AW \qquad \text{(A-119)}$$

Thus, the final estimate of the PSI rating is expressed as PSI Rating = $Max[Sum(X_Y)]$ or $Max[Sum(Excess_Y)]$, where $Sum(X_Y)$ and $Sum(Excess_Y)$ incorporate the user selected area weight value, AW. It is this PSI Rating for the last year of data that is used to rank an individual roadway segment within the site list.

Whether the PSI is calculated for expected accident frequency or excess accident frequency, for each site included on the output report, the weighted average observed accident frequency per mile per year for the entire site and for the location with the highest potential for safety improvement will be included on the output report. These values are calculated as follows:

Entire Site: Weighted average observed accident frequency/mi/yr.

$$K_{iRoadways(TOT)} = \left(\left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times SL_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}} \right) \times C_{Y(TOT)} \right) \times AW \tag{A-61}$$

$$K_{iRoadways(FS)} = \left(\left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FS)}}{Y_i \times SL_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}} \right) \times C_{Y(FI)} \right) \times AW \tag{A-62}$$

$$K_{iRoadways(FI)} = \left(\left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FI)}}{Y_i \times SL_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}} \right) \times C_{Y(FI)} \right) \times AW \tag{A-63}$$

$$K_{iRoadways(PDO)} = \left(\left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times SL_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}} \right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FI)}}{Y_i \times SL_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}} \right) \times C_{Y(FI)} \right) \times AW \tag{A-64}$$

$$K_{iRoadways(EPDO)} = K_{iRoadways(PDO)} + RC_{FI} K_{iRoadyways(FI)} \tag{A-65}$$

NOTE: If $K_{iRoadways(FI)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FI)} = K_{iRoadways(TOT)}$. Similarly if $K_{iRoadways(FS)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FS)} = K_{iRoadways(TOT)}$.

Location with Highest Potential for Safety Improvement: Weighted average observed accident frequency/mi/yr.

$$K_{iRoadways(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times W_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}} \right) \times C_{Y(TOT)} \times AW \tag{A-66}$$

$$K_{iRoadways(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FS)}}{Y_i \times W_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}} \right) \times C_{Y(FI)} \times AW \tag{A-67}$$

$$K_{iRoadways(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FI)}}{Y_i \times W_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}} \right) \times C_{Y(FI)} \times AW \tag{A-68}$$

$$K_{iRoadways(PDO)} = \left(\left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times W_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}} \right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FI)}}{Y_i \times W_i} \right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}} \right) \times C_{Y(FI)} \right) \times AW \tag{A-69}$$

$$K_{iRoadways(EPDO)} = K_{iRoadways(PDO)} + RC_{FI} K_{iRoadyways(FI)} \tag{A-70}$$

NOTE: If $K_{iRoadways(FI)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FI)} = K_{iRoadways(TOT)}$. Similarly if $K_{iRoadways(FS)} > K_{iRoadways(TOT)}$, then set $K_{iRoadways(FS)} = K_{iRoadways(TOT)}$.

Similarly, whether the PSI is calculated for expected accident frequency or excess accident frequency, for each site included on the output report, the weighted predicted accident frequency per mile for year Y for the location with the highest potential for safety improvement will be included on the output report. These values are calculated as follows:

A-43

$$\kappa_{Y,AW(TOT)} = \frac{1}{W} \Sigma_{SUB}\, c_{Y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times ADT_Y^{\beta_1} \times SL_{SUB} \times AW \qquad \text{(A-120)}$$

$$\kappa_{Y,AW(FI)} = \frac{1}{W} \Sigma_{SUB}\, c_{Y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_Y^{\beta_1} \times SL_{SUB} \times AW \qquad \text{(A-121)}$$

$$\kappa_{Y,AW(PDO)} = \kappa_{Y,AW(TOT)} - \kappa_{Y,AW(FI)} \qquad \text{(A-73)}$$

$$\kappa_{Y,AW(EPDO)} = \kappa_{Y,AW(PDO)} + RC_{FI}\kappa_{Y,AW(FI)} \qquad \text{(A-74)}$$

NOTE 1: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, and (D) replace $P_{(CT/FI)}$ in Equation (A-121) with $P_{(CT/FS/FI)}$, as a multiplier.

NOTE 2: If $\kappa_{Y,AW(FI)} > \kappa_{Y,AW(TOT)}$, then set $\kappa_{Y,AW(FI)} = \kappa_{Y,AW(TOT)}$. Similarly, if $\kappa_{Y,AW(FS)} > \kappa_{Y,AW(TOT)}$, then set $\kappa_{Y,AW(FS)} = \kappa_{Y,AW(TOT)}$.

A.1.2 Screening of Intersections

When the user selects basic network screening and the current site list includes intersections, the following calculations are used to rank intersections for future safety improvements. These calculations are similar in principle to those for basic network screening of roadway segments.

A.1.2.1 Calculations of PSI Based on Expected Accident Frequency at Intersections

The objective of this procedure is to compute the expected number of accidents for an intersection. The steps of the procedures for intersections are very similar to those presented in Appendix A.1.1.1.1 and Appendix A.1.1.2.1. The main differences between the procedures for intersections as compared to the procedures for roadway segments are as follows:

1. The form of the SPFs for intersections is different from that of the SPFs for roadway segments.

2. For roadway segments, the procedures account for subsegment lengths. For intersections, there is no length variable.

3. For roadway segments, calculations are typically combined for multiple subsegments. For intersections, there are no such components.

Step 1 through *Step 9* describe the procedures and calculations for a given intersection.

Step 1: Using the appropriate SPF model parameters, compute for each year ($y = 1, 2,...,Y$) the predicted number of accidents, κ_y, for TOT and FI accidents as follows:

$$\kappa_{Y(TOT)} = SPF_{TOT}\{MajADT, MinADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^\alpha \times MajADT_y^{\beta_1} \times MinADT_y^{\beta_2} \quad \text{(A-122)}$$

$$\kappa_{Y(FI)} = SPF_{FI}\{MajADT, MinADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^\alpha \times MajADT_y^{\beta_1} \times MinADT_y^{\beta_2} \quad \text{(A-123)}$$

NOTE 1: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, (D) replace $P_{(CT/FI)}$ in Equation (A-123) with $P_{(CT/FS/FI)}$ as a multiplier, and (E) proceed as normal for FI calculations.

NOTE 2: If the screening is based upon PDO or EPDO, calculations must be performed for TOT and FI accidents to obtain values for PDO or EPDO accidents. Calculations for PDO or EPDO accidents cannot be based upon calculations from TOT and FS accidents.

NOTE 3: When a site is flagged for inclusion on the output report, the value, κ_Y is included on the output report under the column heading Predicted Accident Frequency.

NOTE 4: If $\kappa_{y(FI)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly, if $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

Step 2: Using the model predictions computed in *Step 1*, compute the yearly correction factors, C_y, for TOT and FI accidents for years $y = 1, 2,...,Y$ (note that $C_{1(TOT)} = 1$ and $C_{1(FI)} = 1$):

$$C_{y(TOT)} = \frac{\kappa_{y(TOT)}}{\kappa_{1(TOT)}} \quad \text{(A-3)}$$

$$C_{y(FI)} = \frac{\kappa_{y(FI)}}{\kappa_{1(FI)}} \quad \text{(A-4)}$$

NOTE 1: When screening for FS accidents, $C_{y(FS)}$ should not be calculated or used. Instead $C_{y(FI)}$ should be used. In fact $C_{y(FS)} = C_{y(FI)}$ except when predicted accidents is set to $\kappa_{y(TOT)}$ in Note 4 of *Step 1*.

Step 3: Using $\kappa_1,..., \kappa_Y$ and the overdispersion parameter, d, compute the weights, w, for TOT and FI accidents:

$$w_{TOT} = \frac{1}{1 + d_{TOT} \sum_{y=1}^{Y} \kappa_{y(TOT)} \times L} \quad \text{(A-5)}$$

$$w_{FI} = \frac{1}{1 + d_{FI} \sum_{y=1}^{Y} \kappa_{y(FI)} \times L} \quad \text{(A-6)}$$

NOTE 1: The weights, $w_{(TOT)}$ and $w_{(FI)}$, are always calculated based upon the "all" accidents for TOT and FI severity levels. In other words, for those instances when basic network screening is based upon a certain collision type or types, the predicted value calculated in *Step 1* is scaled, based upon a proportion or a sum of proportions. Rather than using the scaled value of predicted accidents in equations Equation (A-5) and Equation (A-6), the predicted value before multiplying by the respective proportion will be used to calculate the weights $w_{(TOT)}$ and $w_{(FI)}$. The same principle applies when the calculations are based upon FS injuries. The weight $w_{(FS)}$ will actually be based upon "all" FI accidents. The rationale for this is because weights, $w_{(TOT)}$ and $w_{(FI)}$, are used in subsequent steps to combine observed accidents and predicted accidents. The weights, $w_{(TOT)}$ and $w_{(FI)}$, are calculated based upon the accuracy/reliability of the SPFs. In concept the accuracy/reliability of the SPF does not change when the screening is based upon certain collision types or FS injury accidents. The same SPFs for TOT and FI accidents are still being used for all calculations, and the accuracy/reliability of the TOT and FI SPFs does not change. If the "scaled" predicted values were used in equations Equation (A-5) and Equation (A-6), then the weights would be adjusted for the wrong reason, not because the accuracy/reliability of the SPFs changed but because the predicted values were scaled as a necessity due to unrelated circumstances.

NOTE 2: In Equation (A-5) and Equation (A-6), L is equal to the segment length, which is always equal to one for intersections.

Step 4: Calculate the base EB-adjusted expected number of accidents, X_1, for TOT and FI accidents during Year 1:

$$X_{1(TOT)} = w_{TOT}\kappa_{1(TOT)} + (1 - w_{TOT})\frac{\sum_{y=1}^{Y}K_{y(TOT)}}{\sum_{y=1}^{Y}C_{y(TOT)}} \tag{A-124}$$

$$X_{1(FI)} = w_{FI}\kappa_{1(FI)} + (1 - w_{FI})\frac{\sum_{y=1}^{Y}K_{y(FI)}}{\sum_{y=1}^{Y}C_{y(FI)}} \tag{A-125}$$

NOTE 1: The observed accidents are Equation (A-124) and Equation (A-125) should be those of the respective collision types and severity levels as specified by the user.

Step 5: Calculate X_Y, the EB-adjusted expected number of accidents for y = Y, the last year for which data exist for the site, for TOT, FI, and PDO accidents: NOTE: If $X_{Y(FI)} > X_{Y(TOT)}$, then set $X_{Y(FI)} = X_{Y(TOT)}$.

$$X_{Y(TOT)} = X_{1(TOT)}C_{Y(TOT)} \tag{A-9}$$

$$X_{Y(FI)} = X_{1(FI)}C_{Y(FI)} \tag{A-10}$$

$$X_{Y(PDO)} = X_{Y(TOT)} - X_{Y(FI)} \tag{A-11}$$

Step 6: To obtain a measure of the precision of the expected accident frequencies, calculate the variance of X_Y for TOT, FI, and PDO accidents:

$$Var\left(X_{Y(TOT)}\right) = X_{Y(TOT)}(1 - w_{TOT})\frac{c_{Y(TOT)}}{\sum_{y=1}^{Y} c_{y(TOT)}} \tag{A-77}$$

$$Var\left(X_{Y(FI)}\right) = X_{Y(FI)}(1 - w_{FI})\frac{c_{Y(FI)}}{\sum_{y=1}^{Y} c_{y(FI)}} \tag{A-78}$$

$$Var\left(X_{Y(PDO)}\right) = Var\left(X_{Y(TOT)}\right) + Var\left(X_{Y(FI)}\right) \tag{A-14}$$

NOTE 1: If in *Step 5*, $X_{Y(FI)}$ is greater than $X_{Y(TOT)}$ and then $X_{Y(FI)}$ is set equal to $X_{Y(TOT)}$, then set $Var(X_{Y(FI)}) = Var(X_{Y(TOT)})$.

NOTE 2: Because FI accidents are a subset of TOT accidents, the calculation in Equation (A-14), which assumes statistical independence of TOT and FI accidents, is only an approximation. In fact, Equation (A-14) overestimates $Var(X_Y[PDO])$.

When the user has specified that the expected value of the accident frequency is to be unweighted relative to accident severity level, then X_Y and $Var(X_Y)$ are the final calculations for a given intersection. Proceed to *Step 9*. When the user has specified that the expected value of the accident frequency is to be a cost-weighted estimate (EPDO), proceed to *Step 7*.

Step 7: Calculate the EPDO expected number of accidents using the relative severity weights, SW, for fatal (F), severe injury (SI), nonincapacitating injury (NI), and possible injury (MI) severity levels. To calculate the EPDO expected number of accidents, let RC_{FI} be the relative weight of FI accidents as compared to PDO accidents. RC_{FI} is calculated as follows:

$$RC_{FI} = P_F SW_F + P_{SI} SW_{SI} + P_{NI} SW_{NI} + P_{MI} SW_{MI} \tag{A-15}$$

Then, calculate the EPDO expected number of accidents as:

$$X_{Y(EPDO)} = X_{Y(PDO)} + RC_{FI} X_{Y(FI)} \tag{A-16}$$

Step 8: Calculate the variance of the EPDO estimate:

$$Var\left(X_{Y(EPDO)}\right) = Var\left(X_{Y(TOT)}\right) + (RC_{FI} - 1)^2 Var\left(X_{Y(FI)}\right) \tag{A-17}$$

When the user has specified that the expected value of the accident frequency is to be an EPDO weighted estimate, then $X_{Y(EPDO)}$ and $Var(X_{Y(EPDO)})$ are the final calculations for a given intersection and proceed to *Step 9*.

NOTE: Depending on whether the analysis is to include TOT, FI, PDO, or EPDO estimates, all of these calculations may not be necessary in *Step 1* through *Step 8*. Only those pertaining to the selected accident type(s) actually need to be performed.

Step 9: When screening based upon basic network screening using the sliding window approach, if the value of X_Y is greater than or equal to the limiting value for expected accident frequency for intersections, then the intersection is flagged and included in the output. The value of X_Y will be the measure used to rank the individual intersection within the output. Thus, for intersections, the PSI = X_Y. The intersections for which X_Y is less than the limiting value for expected accident frequency for intersections are not included in the output. When screening based upon basic network screening using the peak searching approach, an intersection is flagged when X_Y is greater than or equal to the limiting value for expected accident frequency for intersections and the CV is less than CV_{Limit}.

NOTE 1: When the user screens by FS or FI accidents, the number of expected fatalities and number of expected injuries will also be included on the output report. To obtain these values, the PSI of a site is multiplied by the corresponding accident rates for the given site subtype. These accident rates are found in the *SafetyAnalyst* database. When the user specifies that the screening is to only consider a certain collision type, the respective accident rate $AccRate_{(F/CT/FS)}$ and $AccRate_{(I/CT/FS)}$ or $AccRate_{(F/CT/FI)}$ and $AccRate_{(I/CT/FI)}$ are obtained from the *SafetyAnalyst* database. When more than one collision type is of interest, the respective accident rates used in Equations (A-126) through (A-129) are calculated by an alternative formula. The number of expected fatalities and injuries is calculated as follows [Note: No. of Expected Fatalities$_{(F/FS)}$ = No. of Expected Fatalities$_{(F/FI)}$].

$$\text{No. of Expected Fatalities}_{(F/FS)} = X_{Y(FI)} \times AccRate_{(F/CT/FI)} \tag{A-126}$$

$$\text{No. of Expected Injuries}_{(I/FS)} = X_{Y(FS)} \times AccRate_{(I/CT/FS)} \tag{A-127}$$

$$\text{No. of Expected Fatalities}_{(F/FI)} = X_{Y(FI)} \times AccRate_{(F/CT/FI)} \tag{A-128}$$

$$\text{No. of Expected Injuries}_{(I/FI)} = X_{Y(FI)} \times AccRate_{(I/CT/FI)} \tag{A-129}$$

NOTE 2: For each site included on the output report, the average observed accident frequency per year for the site will be included on the output report. These values are calculated as follows:

$$K_{iIntersections(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{y(TOT)} \tag{A-130}$$

$$K_{iIntersections(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FS)}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{y(FI)} \tag{A-131}$$

$$K_{iIntersections(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{y(FI)} \tag{A-132}$$

$$K_{iIntersections(PDO)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{y(FI)} \tag{A-133}$$

$$K_{iIntersections(EPDO)} = K_{iIntersections(PDO)} + RC_{FI} K_{iIntersections(FI)} \tag{A-134}$$

NOTE: If $K_{iIntersections(FI)} > K_{iIntersections(TOT)}$, then set $K_{iIntersections(FI)} = K_{iIntersections(TOT)}$. Similarly, if $K_{iIntersections(FS)} > K_{iIntersections(TOT)}$, then set $K_{iIntersections(FS)} = K_{iIntersections(TOT)}$.

This value will be repeated in both columns for average observed accident frequency for the entire site and for the location with highest potential for safety improvement.

A.1.2.2 Calculations of PSI Based on Excess Accident Frequency at Intersections

The procedures for calculating the PSI based on excess accident frequency are very similar to those for calculating the PSI based on expected accident frequency. Excess accident frequency is determined by comparing the SPF predicted accident frequency to the EB-adjusted expected accident frequency. The steps for these calculations are presented below.

Step 1: Using the appropriate SPF model parameters, compute for each year ($y = 1, 2,...,Y$) the predicted number of accidents, κ_Y, for TOT and FI accidents.

$$\kappa_{Y(TOT)} = SPF_{TOT}\{MajADT, MinADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^\alpha \times MajADT_y^{\beta_1} \times MinADT_y^{\beta_2} \quad \text{(A-122)}$$

$$\kappa_{Y(FI)} = SPF_{FI}\{MajADT, MinADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^\alpha \times MajADT_y^{\beta_1} \times MinADT_y^{\beta_2} \quad \text{(A-123)}$$

NOTE 1: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, (D) replace $P_{(CT/FI)}$ in Equation (A-123) with $P_{(CT/FS/FI)}$ as a multiplier, and (E) proceed as normal for FI calculations.

NOTE 2: If the screening is based upon PDO or EPDO, calculations must be performed for TOT and FI accidents to obtain values for PDO or EPDO accidents. Calculations for PDO or EPDO accidents cannot be based upon calculations from TOT and FS accidents.

NOTE 3: When a site is flagged for inclusion on the output report, the value, κ_Y, is included on the output report under the column heading Predicted Accident Frequency.

NOTE 4: If $\kappa_{y(FI)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly, if $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

Step 2: Using the model predictions computed in *Step 1*, compute the yearly correction factors, C_y, for TOT and FI accidents for years $y = 1, 2,...,Y$:

$$C_{y(TOT)} = \frac{\kappa_{y(TOT)}}{\kappa_{1(TOT)}} \quad \text{(A-3)}$$

$$C_{y(FI)} = \frac{\kappa_{y(FI)}}{\kappa_{1(FI)}} \quad \text{(A-4)}$$

NOTE 1: When screening for FS accidents, $C_{y(FS)}$ should not be calculated or used. Instead $C_{y(FI)}$ should be used. In fact $C_{y(FS)} = C_{y(FI)}$ except when predicted accidents is set to $\kappa_{y(TOT)}$ in Note 4 of *Step 1*.

Step 3: Using $\kappa_1,..., \kappa_Y$ and the overdispersion parameter, d, compute the weights, w, for TOT and FI accidents:

$$w_{TOT} = \frac{1}{1 + d_{TOT} \sum_{y=1}^{Y} \kappa_{y(TOT)} \times L} \tag{A-5}$$

$$w_{FI} = \frac{1}{1 + d_{FI} \sum_{y=1}^{Y} \kappa_{y(FI)} \times L} \tag{A-6}$$

NOTE 1: The weights, $w_{(TOT)}$ and $w_{(FI)}$, are always calculated based upon the "all" accidents for TOT and FI severity levels. In other words, for those instances when basic network screening is based upon a certain collision type or types, the predicted value calculated in *Step 1* is scaled, based upon a proportion or a sum of proportions. Rather than using the scaled value of predicted accidents in equations Equation (A-5) and Equation (A-6), the predicted value before multiplying by the respective proportion will be used to calculate the weights $w_{(TOT)}$ and $w_{(FI)}$. The same principle applies when the calculations are based upon FS injuries. The weight $w_{(FS)}$ will actually be based upon "all" FI accidents. The rationale for this is because weights, $w_{(TOT)}$ and $w_{(FI)}$, are used in subsequent steps to combine observed accidents and predicted accidents. The weights, $w_{(TOT)}$ and $w_{(FI)}$, are calculated based upon the accuracy/reliability of the SPFs. In concept the accuracy/reliability of the SPF does not change when the screening is based upon certain collision types or FS injury accidents. The same SPFs for TOT and FI accidents are still being used for all calculations, and the accuracy/reliability of the TOT and FI SPFs does not change. If the "scaled" predicted values were used in equations Equation (A-5) and Equation (A-6), then the weights would be adjusted for the wrong reason, not because the accuracy/reliability of the SPFs changed but because the predicted values were scaled as a necessity due to unrelated circumstances.

NOTE 2: In Equation (A-5) and Equation (A-6), L is equal to the segment length, which is always equal to one for intersections.

Step 4: Calculate the base EB-adjusted expected number of accidents, X_1, for TOT and FI accidents during Year 1:

$$X_{1(TOT)} = w_{TOT}\kappa_{1(TOT)} + (1 - w_{TOT})\frac{\sum_{y=1}^{Y} \kappa_{y(TOT)}}{\sum_{y=1}^{Y} C_{y(TOT)}} \tag{A-124}$$

$$X_{1(FI)} = w_{FI}\kappa_{1(FI)} + (1 - w_{FI})\frac{\sum_{y=1}^{Y} \kappa_{y(FI)}}{\sum_{y=1}^{Y} C_{y(FI)}} \tag{A-125}$$

NOTE 1: The observed accidents in equations Equation (A-124) and Equation (A-125) should be those of the respective collision types and severity levels as specified by the user.

Step 5: Calculate X_Y for y = Y, the last year for which data exist for the site, for TOT, FI, and PDO accidents:

$$X_{Y(TOT)} = X_{1(TOT)} C_{Y(TOT)} \tag{A-9}$$

$$X_{Y(FI)} = X_{1(FI)} C_{Y(FI)} \tag{A-10}$$

$$X_{Y(PDO)} = X_{Y(TOT)} - X_{Y(FI)} \tag{A-11}$$

NOTE: If $X_{Y(FI)} > X_{Y(TOT)}$, then set $X_{Y(FI)} = X_{Y(TOT)}$.

Step 6: To obtain a measure of the precision of the expected accident frequencies, calculate the variance of X_Y for TOT, FI, and PDO accidents:

$$\text{Var}\left(X_{Y(TOT)}\right) = X_{Y(TOT)}(1 - w_{TOT})\frac{C_{Y(TOT)}}{\sum_{y=1}^{Y} C_{y(TOT)}} \tag{A-77}$$

$$\text{Var}\left(X_{Y(FI)}\right) = X_{Y(FI)}(1 - w_{FI})\frac{C_{Y(FI)}}{\sum_{y=1}^{Y} C_{y(FI)}} \tag{A-78}$$

$$\text{Var}\left(X_{Y(PDO)}\right) = \text{Var}\left(X_{Y(TOT)}\right) + \text{Var}\left(X_{Y(FI)}\right) \tag{A-14}$$

NOTE: If in *Step 5*, $X_{Y(FI)}$ is greater than $X_{Y(TOT)}$ and then $X_{Y(FI)}$ is set equal to $X_{Y(TOT)}$, then set $\text{Var}(X_{Y(FI)}) = \text{Var}(X_{Y(TOT)})$.

Step 7: Calculate the excess accident frequency for all severity levels:

$$\text{Excess}_{Y(TOT)} = X_{Y(TOT)} - \kappa_{Y(TOT)} \tag{A-36}$$

$$\text{Excess}_{Y(FI)} = X_{Y(FI)} - \kappa_{Y(FI)} \tag{A-37}$$

$$\text{Excess}_{Y(PDO)} = \text{Excess}_{Y(TOT)} - \text{Excess}_{Y(FI)} \tag{A-38}$$

NOTE: If $\kappa_Y(FI)$ is greater than $\kappa_Y(TOT)$, then set $\kappa_Y(FI) = \kappa_Y(TOT)$.

Step 8: Calculate the variance of the excess accident frequency for all severity levels.

Knowing that the variance of an SPF-predicted accident frequency is, in general form:

$$\text{Var}(\kappa_Y) = d(\kappa_Y)^2 \tag{A-39}$$

Then,

$$\text{Var}\left(\text{Excess}_{Y(TOT)}\right) = \text{Var}\left(X_{Y(TOT)}\right) + d_{TOT}(\kappa_{Y(TOT)})^2 \tag{A-40}$$

$$\text{Var}\left(\text{Excess}_{Y(FI)}\right) = \text{Var}\left(X_{Y(FI)}\right) + d_{TOT}(\kappa_{Y(FI)})^2 \tag{A-41}$$

A-51

$$Var\left(Excess_{Y(PDO)}\right) = Var\left(Excess_{Y(TOT)}\right) + Var\left(Excess_{Y(FI)}\right) \qquad \text{(A-42)}$$

NOTE: If $\kappa_{Y(FI)}$ is greater than $\kappa_{Y(TOT)}$, then set $\kappa_{Y(FI)} = \kappa_{Y(TOT)}$ and $d_{FI} = d_{TOT}$.

When the user specifies that the excess accident frequency is to be unweighted relative to accident severity level, then $Excess_Y$ and $Var(Excess_Y)$ are the final calculations for a given intersection. Proceed to *Step 11*. When the user specifies that the excess accident frequency is to be a cost-weighted estimate (EPDO), proceed to *Step 9*.

Step 9: Calculate the EPDO excess accidents using the relative severity weights, SW, for fatal (F), severe injury (SI), nonincapacitating injury (NI), and possible injury (MI) severity levels. To calculate the EPDO expected excess accidents, let RC_{FI} be the relative severity weight of FI accidents as compared to PDO accidents. RC_{FI} is calculated as follows:

$$RC_{FI} = P_F SW_F + P_{SI} SW_{SI} + P_{NI} SW_{NI} + P_{MI} SW_{MI} \qquad \text{(A-15)}$$

Then, calculate the EPDO excess accidents as:

$$Excess_{Y(EPDO)} = Excess_{Y(PDO)} + RC_{FI} Excess_{Y(FI)} \qquad \text{(A-43)}$$

Step 10: Calculate the variance of the EPDO excess accident estimate:

$$Var\left(Excess_{Y(EPDO)}\right) = Var\left(Excess_{Y(TOT)} + (RC_{FI} - 1)^2 Var\left(Excess_{Y(FI)}\right)\right) \qquad \text{(A-44)}$$

When the user specifies that the excess accident frequency is to be an EPDO weighted estimate, then $Excess_{Y(EPDO)}$ and $Var(Excess_{Y(EPDO)})$ are the final calculations for a given intersection. Proceed to *Step 11*.

NOTE: Depending on whether the analysis is to include TOT, FI, PDO, or EPDO estimates, all of these calculations may not be necessary in *Step 1* through *Step 10*. Only those steps pertaining to the selected accident type(s) actually need to be performed.

Step 11: When screening based upon basic network screening using the sliding window approach, if the value of $Excess_Y$ is greater than or equal to the limiting value for excess accident frequency for intersections, then the intersection is flagged and included in the output. The value of $Excess_Y$ is the measure used to rank the individual intersection within the output. Thus, for intersections, the PSI = $Excess_Y$. The intersections for which $Excess_Y$ is less than the limiting value for excess accident frequency for intersections are not included in the output. When screening based upon basic network screening using the peak searching approach, an intersection is flagged when $Excess_Y$ is greater than or equal to the limiting value for excess accident frequency for intersections and the CV is less than

CV_{Limit}. Calculate the CV of the excess accident frequency for the intersection using Equations (A-45) through (A-48).

NOTE 1: When the user screens by FS or FI accidents, the number of excess fatalities and number of excess injuries will also be included on the output report. To obtain these values, the PSI of a site is multiplied by the corresponding accident rates for the given site subtype. These accident rates are found in the *SafetyAnalyst* database. When the user specifies that the screening is to only consider a certain collision type, the respective accident rate $AccRate_{(F/CT/FS)}$ and $AccRate_{(I/CT/FS)}$ or $AccRate_{(F/CT/FI)}$ and $AccRate_{(I/CT/FI)}$ are obtained from the *SafetyAnalyst* database. When more than one collision type is of interest, the respective accident rates used in Equations (A-135) through (A-138) are calculated by an alternative formula. The number of excess fatalities and injuries is calculated as follows (Note: No. of Excess Fatalities$_{(F/FS)}$ = No. of Excess Fatalities$_{(F/FI)}$):

$$\text{No. of Excess Fatalities}_{(F/FS)} = \text{Excess}_{Y(FI)} \times AccRate_{(F/CT/FI)} \tag{A-135}$$

$$\text{No. of Excess Injuries}_{(I/FS)} = \text{Excess}_{Y(FS)} \times AccRate_{(I/CT/FS)} \tag{A-136}$$

$$\text{No. of Excess Fatalities}_{(F/FI)} = \text{Excess}_{Y(FI)} \times AccRate_{(F/CT/FI)} \tag{A-137}$$

$$\text{No. of Excess Injuries}_{(I/FI)} = \text{Excess}_{Y(FI)} \times AccRate_{(I/CT/FI)} \tag{A-138}$$

NOTE: If No. of Excess Fatalities$_{(F/FS)}$ < 0, then No. of Excess Fatalities$_{(F/FS)}$ = 0.

NOTE 2: For each site included on the output report, the average observed accident frequency per year for the site will be included on the output report. These values are calculated as follows:

$$K_{iIntersections(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{y(TOT)} \tag{A-130}$$

$$K_{iIntersections(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FS)}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{y(FI)} \tag{A-131}$$

$$K_{iIntersections(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{y(FI)} \tag{A-132}$$

$$K_{iIntersections(PDO)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{y(FI)} \tag{A-133}$$

$$K_{iIntersections(EPDO)} = K_{iIntersections(PDO)} + RC_{FI} K_{iIntersections(FI)} \tag{A-134}$$

NOTE: If $K_{iIntersections(FI)}$ > $K_{iIntersections(TOT)}$, then set $K_{iIntersections(FI)}$ = $K_{iIntersections(TOT)}$. Similarly, if $K_{iIntersections(FS)}$ > $K_{iIntersections(TOT)}$, then set $K_{iIntersections(FS)}$ = $K_{iIntersections(TOT)}$.

This value will be repeated in both columns for average observed accident frequency for the entire site and for the location with the highest potential for safety improvement.

A.1.2.3 Calculation of PSI Rating Weighted by Area Type of Intersection

The site list selected by the user may contain urban or rural intersections, or both. Thus the user can rank urban intersections or rural intersections separately or combined. However, should the user wish to weight rural sites relative to urban sites (e.g., by relative cost of improvement projects) prior to ranking them in a combined set, then the following procedure is used to account for differences in costs between urban and rural safety improvement projects. Area weights (AW) are applied to the expected accident frequencies or excess accident frequencies to calculate a weighted PSI rating. Values of AW are input by the user for urban and rural areas. By default, AW = 1 for urban intersections. Thus, all rural sites are weighted relative to urban sites.

When the weighted PSI Rating is applied to **expected accident frequencies**, *Step 1* through *Step 9* in Appendix A.1.2.1 are repeated as needed for a given intersection. The area weight, AW, is applied as follows to Equation (A-124) and Equation (A-125) when calculating X_1 in *Step 4*:

$$X_{1(TOT)} = \left[w_{TOT} \kappa_{1(TOT)} + (1 - w_{TOT}) \frac{\sum_{y=1}^{Y} K_{y(TOT)}}{\sum_{y=1}^{Y} C_{y(TOT)}} \right] \times AW \tag{A-139}$$

$$X_{1(FI)} = \left[w_{FI} \kappa_{1(FI)} + (1 - w_{FI}) \frac{\sum_{y=1}^{Y} K_{y(FI)}}{\sum_{y=1}^{Y} C_{y(FI)}} \right] \times AW \tag{A-140}$$

Similarly, the variance Equation (A-12) and Equation (A-13) in *Step 6* are adjusted to account for the area weight, AW.

$$Var\left(X_{Y(TOT)}\right) = \left[X_{Y(TOT)} (1 - w_{TOT}) \frac{C_{Y(TOT)}}{\sum_{y=1}^{Y} C_{y(TOT)}} \right] \times AW \tag{A-114}$$

$$Var\left(X_{Y(FI)}\right) = \left[X_{Y(FI)} (1 - w_{FI}) \frac{C_{Y(FI)}}{\sum_{y=1}^{Y} C_{y(FI)}} \right] \times AW \tag{A-115}$$

When the weighted PSI Rating is applied to **excess accident frequencies**, *Step 1* through *Step 11* in Appendix A.1.2.2 are repeated as needed for a given intersection. The area weight, AW, is applied as follows to Equation (A-36) and Equation (A-37) when calculating Excess$_Y$ in *Step 7*:

$$Excess_{Y(TOT)} = \left[X_{Y(TOT)} - \kappa_{Y(TOT)} \right] \times AW \tag{A-57}$$

$$Excess_{Y(FI)} = \left[X_{Y(FI)} - \kappa_{Y(FI)} \right] \times AW \tag{A-58}$$

NOTE: In Equation (A-57) and Equation (A-58), the area weight (AW) has not been applied to $X_{Y(TOT)}$ nor $X_{Y(FI)}$ in previous steps. Therefore, the AW is applied to both terms in the equations.

The variance Equation (A-77) and Equation (A-78) in *Step 8* also have to be adjusted to account for the area weight.

$$\text{Var}\left(\text{Excess}_{Y(\text{TOT})}\right) = \text{Var}\left(X_{Y(\text{TOT})}\right) + \left[d_{\text{TOT}}(\kappa_{Y(\text{TOT})})^2\right] \times \text{AW} \tag{A-59}$$

$$\text{Var}\left(\text{Excess}_{Y(\text{FI})}\right) = \text{Var}\left(X_{Y(\text{FI})}\right) + \left[d_{\text{FI}}(\kappa_{Y(\text{FI})})^2\right] \times \text{AW} \tag{A-60}$$

The PSI Rating is the measure used to rank the individual intersections within the output.

Whether the PSI is calculated for expected accident frequency or excess accident frequency, for each site included on the output report, the weighted average observed accident frequency per year for the site will be included on the output report. These values are calculated as follows:

$$K_{i\text{Intersections}(\text{TOT})} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(\text{CT/TOT})}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(\text{TOT})}}\right) \times C_{Y(\text{TOT})} \times \text{AW} \tag{A-141}$$

$$K_{i\text{Intersections}(\text{FS})} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(\text{CT/FS})}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(\text{FI})}}\right) \times C_{Y(\text{FI})} \times \text{AW} \tag{A-142}$$

$$K_{i\text{Intersections}(\text{FI})} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(\text{CT/FI})}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(\text{FI})}}\right) \times C_{Y(\text{FI})} \times \text{AW} \tag{A-143}$$

$$K_{i\text{Intersections}(\text{PDO})} = \left(\left(\frac{\sum_{y=1}^{Y} K_{i,y(\text{CT/TOT})}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(\text{TOT})}}\right) \times C_{Y(\text{TOT})} - \left(\frac{\sum_{y=1}^{Y} K_{i,y(\text{CT/FI})}}{Y_i}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(\text{FI})}}\right) \times C_{Y(\text{FI})}\right) \times \text{AW} \tag{A-144}$$

$$K_{i\text{Intersections}(\text{EPDO})} = K_{i\text{Intersections}(\text{PDO})} + RC_{\text{FI}} K_{i\text{Intersections}(\text{FI})} \tag{A-145}$$

NOTE: If $K_{i\text{Intersections}(\text{FI})} > K_{i\text{Intersections}(\text{TOT})}$, then set $K_{i\text{Intersections}(\text{FI})} = K_{i\text{Intersections}(\text{TOT})}$. Similarly, if $K_{i\text{Intersections}(\text{FS})} > K_{i\text{Intersections}(\text{TOT})}$, then set $K_{i\text{Intersections}(\text{FS})} = K_{i\text{Intersections}(\text{TOT})}$.

This value will be repeated in both columns for average observed accident frequency for the entire site and for the location with the highest potential for safety improvement.

Similarly, whether the PSI is calculated for expected accident frequency or excess accident frequency, for each site included on the output report, the weighted predicted accident frequency for year Y for the site will be included on the output report. These values are calculated as follows:

$$\kappa_{Y,\text{AW}(\text{TOT})} = C_{Y(\text{TOT})} \times P_{\text{CT}(\text{TOT})} \times e^{\alpha} \times \text{MajADT}_Y^{\beta_1} \times \text{MinADT}_Y^{\beta_2} \times \text{AW} \tag{A-146}$$

$$\kappa_{Y,\text{AW}(\text{FI})} = C_{Y(\text{FI})} \times P_{\text{CT}(\text{FI})} \times e^{\alpha} \times \text{MajADT}_Y^{\beta_1} \times \text{MinADT}_Y^{\beta_2} \times \text{AW} \tag{A-147}$$

$$\kappa_{Y,\text{AW}(\text{PDO})} = \kappa_{Y,\text{AW}(\text{TOT})} - \kappa_{Y,\text{AW}(\text{FI})} \tag{A-73}$$

$$\kappa_{Y,\text{AW}(\text{EPDO})} = \kappa_{Y,\text{AW}(\text{PDO})} + RC_{\text{FI}} \kappa_{Y,\text{AW}(\text{FI})} \tag{A-74}$$

NOTE 1: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, and (D) replace $P_{(CT/FI)}$ in Equation (A-147)) with $P_{(CT/FS/FI)}$ as a multiplier.

NOTE 2: If $\kappa_{Y,AW(FI)} > \kappa_{Y,AW(TOT)}$, then set $\kappa_{Y,AW(FI)} = \kappa_{Y,AW(TOT)}$. Similarly, if $\kappa_{Y,AW(FS)} > \kappa_{Y,AW(TOT)}$, then set $\kappa_{Y,AW(FS)} = \kappa_{Y,AW(TOT)}$.

A.1.3 Screening of Ramps

When the user selects basic network screening and the current site list includes ramps, the following calculations are used to rank ramps for future safety improvements. These calculations are similar in principle to those for basic network screening of roadway segments and intersections.

A.1.3.1 Calculations of PSI Based on Expected Accident Frequency on Ramps

The objective for this procedure is to compute the expected number of accidents for a ramp. The procedures for ramps are very similar to those presented in Appendix A.1.1.2.1 for roadway segments and to those presented in Appendix A.1.2.1 for intersections. The main similarities and differences between the procedures for ramps as compared to those for roadway segments and intersections are as follows:

1. The form of the SPFs for ramps is similar to the form of the SPFs for roadway segments.

2. For roadway segments, the procedures account for subsegment lengths. Ramp length is accounted for in the procedures for ramps.

3. For roadway segments, calculations are typically combined for multiple subsegments. For ramps, there are no such components. Ramps are similar to intersections in that each ramp is considered a single site.

Step 1 through *Step 8* describe the calculations for a given ramp.

Step 1: Using the appropriate SPF model parameters, compute for each year ($y = 1, 2,...,Y$) the predicted number of accidents per mile, κ_Y, for TOT and FI accidents as follows:

$$\kappa_{y(TOT)} = SPF_{TOT}\{ADT\} = C_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times ADT_y^{\beta_1} \tag{A-1}$$

$$\kappa_{y(FI)} = SPF_{FI}\{ADT\} = C_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_y^{\beta_1} \tag{A-2}$$

NOTE 1: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, (D) replace $P_{(CT/FI)}$ in Equation (A-2) with $P_{(CT/FS/FI)}$, and (E) proceed as normal for FI calculations.

NOTE 2: If the screening is based upon PDO or EPDO, calculations must be performed for TOT and FI accidents to obtain values for PDO or EPDO accidents. Calculations for PDO or EPDO accidents cannot be based upon calculations from TOT and FS accidents.

NOTE 3: When a site is flagged for inclusion on the output report, the value, κ_Y, is included on the output report under the column heading Predicted Accident Frequency.

NOTE 4: If the ramp length SL_{Ramp} is not available, the site cannot be included in the analysis.

NOTE 5: If $\kappa_{y(FI)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly if $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

Step 2: Using the model predictions computed in *Step 1*, compute the yearly correction factors, C_y, for TOT and FI accidents for years y = 1, 2,...,Y:

$$C_{y(TOT)} = \frac{\kappa_{y(TOT)}}{\kappa_{1(TOT)}} \tag{A-3}$$

$$C_{y(FI)} = \frac{\kappa_{y(FI)}}{\kappa_{1(FI)}} \tag{A-4}$$

NOTE 1: When screening for FS accidents, $C_{y(FS)}$ should not be calculated or used. Instead $C_{y(FI)}$ should be used. In fact, $C_{y(FS)} = C_{y(FI)}$ except when predicted accidents is set to $\kappa_{y(TOT)}$ in Note 5 of *Step 1*.

Step 3: Using κ_1,..., κ_Y and the overdispersion parameter, d, compute the weights, w, for TOT and FI accidents:

$$w_{TOT} = \frac{1}{1 + d_{TOT} \sum_{y=1}^{Y} \kappa_{y(TOT)} \times L} \tag{A-5}$$

$$w_{FI} = \frac{1}{1 + d_{FI} \sum_{y=1}^{Y} \kappa_{y(FI)} \times L} \tag{A-6}$$

NOTE 1: The weights, $w_{(TOT)}$ and $w_{(FI)}$, are always calculated based upon the "all" accidents for TOT and FI severity levels. In other words, for those instances when basic network screening is based upon a certain collision type or types, the predicted value calculated in *Step 1* is scaled, based upon a proportion or a sum of proportions. Rather than using the scaled value of predicted accidents in equations Equation (A-5) and

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Equation (A-6), the predicted value before multiplying by the respective proportion will be used to calculate the weights $w_{(TOT)}$ and $w_{(FI)}$. The same principle applies when the calculations are based upon FS injuries. The weight $w_{(FS)}$ will actually be based upon "all" FI accidents. The rationale for this is because weights, $w_{(TOT)}$ and $w_{(FI)}$, are used in subsequent steps to combine observed accidents and predicted accidents. The weights, $w_{(TOT)}$ and $w_{(FI)}$, are calculated based upon the accuracy/reliability of the SPFs. In concept the accuracy/reliability of the SPF does not change when the screening is based upon certain collision types or FS injury accidents. The same SPFs for TOT and FI accidents are still being used for all calculations, and the accuracy/reliability of the TOT and FI SPFs does not change. If the "scaled" predicted values were used in equations Equation (A-5) and Equation (A-6), then the weights would be adjusted for the wrong reason, not because the accuracy/reliability of the SPFs changed but because the predicted values were scaled as a necessity due to unrelated circumstances.

NOTE 2: In Equation (A-5) and Equation (A-6), L is equal to the ramp length, SL_{RAMP}.

Step 4: Calculate the base EB-adjusted expected number of accidents, X_1, for TOT and FI accidents during Year 1 on a per mile basis:

$$X_{1(TOT)} = w_{TOT}\kappa_{1(TOT)} + \frac{(1-w_{TOT})\sum_{y=1}^{Y}K_{y(TOT)}}{SL_{Ramp}\sum_{y=1}^{Y}C_{y(TOT)}} \qquad (A\text{-}148)$$

$$X_{1(FI)} = w_{FI}\kappa_{1(FI)} + \frac{(1-w_{FI})\sum_{y=1}^{Y}K_{y(FI)}}{SL_{Ramp}\sum_{y=1}^{Y}C_{y(FI)}} \qquad (A\text{-}149)$$

NOTE 1: The observed accidents in Equation (A-148) and Equation (A-149) should be those of the respective collision types and severity levels as specified by the user.

Step 5: Calculate X_Y, the EB-adjusted expected number of accidents for $y = Y$, the last year for which data exist for the site, for TOT, FI, and PDO accidents:

$$X_{Y(TOT)} = X_{1(TOT)}C_{Y(TOT)} \qquad (A\text{-}9)$$

$$X_{Y(FI)} = X_{1(FI)}C_{Y(FI)} \qquad (A\text{-}10)$$

$$X_{Y(PDO)} = X_{Y(TOT)} - X_{Y(FI)} \qquad (A\text{-}11)$$

NOTE: If $X_{Y(FI)} > X_{Y(TOT)}$, then set $X_{Y(FI)} = X_{Y(TOT)}$.

Step 6: To obtain a measure of the precision of these expected accident frequencies, calculate the variance of X_Y for TOT, FI, and PDO accidents:

$$Var(X_{Y(TOT)}) = X_{Y(TOT)}(1 - w_{TOT})\frac{C_{Y(TOT)}}{\sum_{y=1}^{Y}C_{y(TOT)}} \qquad (A\text{-}150)$$

$$Var(X_{Y(FI)}) = X_{Y(FI)}(1 - w_{FI})\frac{C_{Y(FI)}}{\sum_{y=1}^{Y}C_{y(FI)}} \qquad (A\text{-}151)$$

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$$\text{Var}\left(X_{Y(PDO)}\right) = \text{Var}\left(X_{Y(TOT)}\right) + \text{Var}\left(X_{Y(FI)}\right) \tag{A-14}$$

NOTE: If in *Step 5*, $X_{Y(FI)}$ is greater than $X_{Y(TOT)}$ and then $X_{Y(FI)}$ is set equal to $X_{Y(TOT)}$, then set $\text{Var}(X_{Y(FI)}) = \text{Var}(X_{Y(TOT)})$.

When the user specifies that the expected value of the accident frequency is to be unweighted relative to accident severity level, then X_Y and $\text{Var}(X_Y)$ are the final calculations for a given ramp. Proceed to *Step 9*. When the user specifies that the expected value of the accident frequency is to be a cost-weighted estimate (EPDO), proceed to *Step 7*.

Step 7: Calculate the EPDO expected number of accidents using the relative severity weights, SW, for fatal (F), severe injury (SI), nonincapacitating injury (NI), and possible injury (MI) severity levels. To calculate the EPDO expected number of accidents, let RC_{FI} serve as the relative weight of FI accidents as compared to PDO accidents. RC_{FI} is calculated as follows:

$$RC_{FI} = P_F SW_F + P_{SI} SW_{SI} + P_{NI} SW_{NI} + P_{MI} SW_{MI} \tag{A-15}$$

Then, calculate the EPDO expected number of accidents as:

$$X_{Y(EPDO)} = X_{Y(PDO)} + RC_{FI} \times X_{Y(FI)} \tag{A-16}$$

Step 8: Calculate the variance of the EPDO estimate:

$$\text{Var}\left(X_{Y(EPDO)}\right) = \text{Var}\left(X_{Y(TOT)}\right) + (RC_{FI} - 1)^2 \text{Var}(X_{Y(FI)}) \tag{A-17}$$

When the user specifies that the expected value of the accident frequency is to be an EPDO weighted estimate, then $X_{Y(EPDO)}$ and $\text{Var}(X_{Y(EPDO)})$ are the final calculations for a given ramp. Proceed to *Step 9*.

NOTE: Depending on whether the analysis is to include TOT, FI, PDO, or EPDO estimates, all of the calculations in *Step 1* through *Step 8* may not be necessary. Only those pertaining to the selected accident type(s) actually need to be performed.

Step 9: When screening based upon basic network screening using the sliding window approach, if the value of X_Y is greater than or equal to the limiting value for expected accident frequency for ramps, then the ramp is flagged and included in the output. The value of X_Y is the measure used to rank the individual ramp within the output. Thus, for ramps, the PSI $= X_Y$. The ramps for which X_Y is less than the limiting value for expected accident frequency for ramps are not included in the output. When screening based upon basic network screening using the peak searching approach, a ramp is flagged when X_Y is greater than or equal to the limiting value for expected accident frequency for ramps and

the CV is less than CV_{Limit}. Calculate the CV of the expected accident frequency for theramp using Equations (A-18) through (A-21).

NOTE 1: When the user screens by FS or FI accidents, the number of expected fatalities and number of expected injuries will also be included on the output report. To obtain these values, the PSI of a site is multiplied by the corresponding accident rates for the given site subtype. These accident rates are found in the *SafetyAnalyst* database. When the user specifies that the screening is to only consider a certain collision type, the respective accident rate $AccRate_{(F/CT/FS)}$ and $AccRate_{(I/CT/FS)}$ or $AccRate_{(F/CT/FI)}$ and $AccRate_{(I/CT/FI)}$ are obtained from the *SafetyAnalyst* database. When more than one collision type is of interest, the respective accident rates used in Equations (A-126) through (A-129) are calculated by an alternative formula. The number of expected fatalities and injuries is calculated as follows (Note: No. of Expected Fatalities$_{(F/FS)}$ = No. of Expected Fatalities$_{(F/FI)}$):

$$\text{No. of Expected Fatalities}_{(F/FS)} = X_{Y(FI)} \times AccRate_{(F/CT/FI)} \tag{A-126}$$

$$\text{No. of Expected Injuries}_{(I/FS)} = X_{Y(FS)} \times AccRate_{(I/CT/FS)} \tag{A-127}$$

$$\text{No. of Expected Fatalities}_{(F/FI)} = X_{Y(FI)} \times AccRate_{(F/CT/FI)} \tag{A-128}$$

$$\text{No. of Expected Injuries}_{(I/FI)} = X_{Y(FI)} \times AccRate_{(I/CT/FI)} \tag{A-129}$$

NOTE 2: For each site included on the output report, the average observed accident frequency per mile per year for the site will be included on the output report. These values are calculated as follows:

$$K_{iRamps(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times SL_{Ramp_i}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} \tag{A-152}$$

$$K_{iRamps(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FS)}}{Y_i \times SL_{Ramp_i}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-153}$$

$$K_{iRamps(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FI)}}{Y_i \times SL_{Ramp_i}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-154}$$

$$K_{iRamps(PDO)} = \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/TOT)}}{Y_i \times SL_{Ramp_i}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{i,y(CT/FI)}}{Y_i \times SL_{Ramp_i}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-155}$$

$$K_{iRamps(EPDO)} = K_{iRamps(PDO)} + RC_{FI} K_{iRamps(FI)} \tag{A-156}$$

NOTE: If $K_{iRamps>(FI)} > K_{iRamps} > _{(TOT)}$, then set $K_{iRamps} > _{(FI)} = K_{iRamps} > _{(TOT)}$. Similarly, if $K_{iRamps} > _{(FS)} > K_{iRamps>(TOT)}$ then set $K_{iRamps} > _{(FS)} = K_{iRamps} > _{(TOT)}$.

This value will be repeated in both columns for average observed accident frequency for the entire site and for the location with the highest potential for safety improvement.

A.1.3.2 Calculation of PSI Based on Excess Accident Frequency at a Ramp

The procedures for calculating the PSI based on excess accident frequency are very similar to those for calculating the PSI based on expected accident frequency. Excess accident frequency is determined by comparing the SPF predicted accident frequency to the EB-adjusted expected accident frequency. The steps for these calculations are presented below.

Step 1: Using the appropriate SPF model parameters, compute for each year ($y = 1, 2,...,Y$) the predicted number of accidents per mile, κ_Y, for TOT and FI accidents as follows:

$$\kappa_{y(TOT)} = SPF_{TOT}\{ADT\} = C_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times ADT_y^{\beta_1} \tag{A-1}$$

$$\kappa_{y(FI)} = SPF_{FI}\{ADT\} = C_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_y^{\beta_1} \tag{A-2}$$

NOTE 1: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, (D) replace $P_{(CT/FI)}$ in Equation (A-2) with $P_{(CT/FS/FI)}$, and (E) proceed as normal for FI calculations.

NOTE 2: If the screening is based upon PDO or EPDO, calculations must be performed for TOT and FI accidents to obtain values for PDO or EPDO accidents. Calculations for PDO or EPDO accidents cannot be based upon calculations from TOT and FS accidents.

NOTE 3: When a site is flagged for inclusion on the output report, the value, κ_Y, is included on the output report under the column heading Predicted Accident Frequency.

NOTE 4: If the ramp length (SL_{Ramp}) is not available, the site cannot be included in the analysis.

NOTE 5: If $\kappa_{y(FI)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly, if $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

Step 2: Using the model predictions computed in *Step 1*, compute the yearly correction factors, C_y, for TOT and FI accidents for years $y = 1, 2,...,Y$:

$$C_{y(TOT)} = \frac{\kappa_{y(TOT)}}{\kappa_{1(TOT)}} \tag{A-3}$$

$$C_{y(FI)} = \frac{\kappa_{y(FI)}}{\kappa_{1(FI)}} \tag{A-4}$$

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NOTE 1: When screening for FS accidents, $C_{y(FS)}$ should not be calculated or used. Instead $C_{y(FI)}$ should be used. In fact $C_{y(FS)} = C_{y(FI)}$ except when predicted accidents is set to $\kappa_{y(TOT)}$ in Note 5 of *Step 1*.

Step 3: Using $\kappa_1,\ldots,\kappa_Y$ and the overdispersion parameter, d, compute the weights, w, for TOT and FI accidents:

$$w_{TOT} = \frac{1}{1+d_{TOT}\sum_{y=1}^{Y}\kappa_{y(TOT)}\times L} \tag{A-5}$$

$$w_{FI} = \frac{1}{1+d_{FI}\sum_{y=1}^{Y}\kappa_{y(FI)}\times L} \tag{A-6}$$

NOTE 1: The weights, $w_{(TOT)}$ and $w_{(FI)}$, are always calculated based upon the "all" accidents for TOT and FI severity levels. In other words, for those instances when basic network screening is based upon a certain collision type or types, the predicted value calculated in *Step 1* is scaled, based upon a proportion or a sum of proportions. Rather than using the scaled value of predicted accidents in equations Equation (A-5) and Equation (A-6), the predicted value before multiplying by the respective proportion will be used to calculate the weights $w_{(TOT)}$ and $w_{(FI)}$. The same principle applies when the calculations are based upon FS injuries. The weight $w_{(FS)}$ will actually be based upon "all" FI accidents. The rationale for this is because weights, $w_{(TOT)}$ and $w_{(FI)}$, are used in subsequent steps to combine observed accidents and predicted accidents. The weights, $w_{(TOT)}$ and $w_{(FI)}$, are calculated based upon the accuracy/reliability of the SPFs. In concept the accuracy/reliability of the SPF does not change when the screening is based upon certain collision types or FS injury accidents. The same SPFs for TOT and FI accidents are still being used for all calculations, and the accuracy/reliability of the TOT and FI SPFs does not change. If the "scaled" predicted values were used in equations Equation (A-5) and Equation (A-6), then the weights would be adjusted for the wrong reason, not because the accuracy/reliability of the SPFs changed but because the predicted values were scaled as a necessity due to unrelated circumstances.

NOTE 2: In Equation (A-5) and Equation (A-6), L is equal to the ramp length, SL_{RAMP}.

Step 4: Calculate the base EB-adjusted expected number of accidents, X_1, for TOT and FI accidents during Year 1 on a per mile basis:

$$X_{1(TOT)} = w_{TOT}\kappa_{1(TOT)} + \frac{(1-w_{TOT})\sum_{y=1}^{Y}\kappa_{y(TOT)}}{SL_{Ramp}\ \sum_{y=1}^{Y}C_{y(TOT)}} \tag{A-148}$$

$$X_{1(FI)} = w_{FI}\kappa_{1(FI)} + \frac{(1-w_{FI})\sum_{y=1}^{Y}\kappa_{y(FI)}}{SL_{Ramp}\ \sum_{y=1}^{Y}C_{y(FI)}} \tag{A-149}$$

NOTE 1: The observed accidents in Equation (A-81) and Equation (A-82) should be those of the respective collision types and severity levels as specified by the user.

Step 5: Calculate X_Y, the EB-adjusted expected number of accidents for $y = Y$, the last year for which data exist for the site, for TOT, FI, and PDO accidents:

$$X_{Y(TOT)} = X_{1(TOT)} C_{Y(TOT)} \tag{A-9}$$

$$X_{Y(FI)} = X_{1(FI)} C_{Y(FI)} \tag{A-10}$$

$$X_{Y(PDO)} = X_{Y(TOT)} - X_{Y(FI)} \tag{A-11}$$

NOTE: If $X_{Y(FI)} > X_{Y(TOT)}$, then set $X_{Y(FI)} = X_{Y(TOT)}$.

Step 6: To obtain a measure of the precision of these expected accident frequencies, calculate the variance of X_Y for TOT, FI, and PDO accidents:

$$Var\left(X_{Y(TOT)}\right) = X_{Y(TOT)}(1 - w_{TOT}) \frac{C_{Y(TOT)}}{\sum_{y=1}^{Y} C_{y(TOT)}} \tag{A-150}$$

$$Var\left(X_{Y(FI)}\right) = X_{Y(FI)}(1 - w_{FI}) \frac{C_{Y(FI)}}{\sum_{y=1}^{Y} C_{y(FI)}} \tag{A-151}$$

$$Var\left(X_{Y(PDO)}\right) = Var\left(X_{Y(TOT)}\right) + Var\left(X_{Y(FI)}\right) \tag{A-14}$$

NOTE: If in *Step 5*, $X_{Y(FI)}$ is greater than $X_{Y(TOT)}$ and then $X_{Y(FI)}$ is set equal to $X_{Y(TOT)}$, then set $Var(X_{Y(FI)}) = Var(X_{Y(TOT)})$.

Step 7: Calculate the excess accident frequency for all severity levels:

$$Excess_{Y(TOT)} = X_{Y(TOT)} - \kappa_{Y(TOT)} \tag{A-36}$$

$$Excess_{Y(FI)} = X_{Y(FI)} - \kappa_{Y(FI)} \tag{A-37}$$

$$Excess_{Y(PDO)} = Excess_{Y(TOT)} - Excess_{Y(FI)} \tag{A-38}$$

NOTE: If $\kappa_{Y(FI)}$ is greater than $\kappa_{Y(TOT)}$, then set $\kappa_{Y(FI)} = \kappa_{Y(TOT)}$.

Step 8: Calculate the variance of the excess accident frequency for all severity levels.

Knowing that the variance of an SPF-predicted accident frequency is, in general form:

$$Var(\kappa_Y) = d(\kappa_Y)^2 \tag{A-39}$$

Then,

$$Var\left(Excess_{Y(TOT)}\right) = Var\left(X_{Y(TOT)}\right) + d_{TOT}(\kappa_{Y(TOT)})^2 \tag{A-40}$$

$$Var\left(Excess_{Y(FI)}\right) = Var\left(X_{Y(FI)}\right) + d_{TOT}(\kappa_{Y(FI)})^2 \tag{A-41}$$

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$$Var\left(Excess_{Y(PDO)}\right) = Var\left(Excess_{Y(TOT)}\right) + Var\left(Excess_{Y(FI)}\right) \qquad \text{(A-42)}$$

NOTE: If $\kappa_{Y(FI)}$ is greater than $\kappa_{Y(TOT)}$, then set $\kappa_{Y(FI)} = \kappa_{Y(TOT)}$ and $d_{FI} = d_{TOT}$.

When the user specifies that the excess accident frequency is to be unweighted relative to accident severity level, then $Excess_Y$ and $Var(Excess_Y)$ are the final calculations for a given ramp. Proceed to *Step 11*. When the user specifies that the excess accident frequency is to be a cost-weighted estimate (EPDO), proceed to *Step 9*.

Step 9: Calculate the EPDO excess accidents using the relative severity weights, SW, for fatal (F), severe injury (SI), nonincapacitating injury (NI), and possible injury (MI) severity levels. To calculate the EPDO excess accidents, let RC_{FI} be the relative severity weight of FI accidents as compared to PDO accidents. RC_{FI} is calculated as follows:

$$RC_{FI} = P_F SW_F + P_{SI} SW_{SI} + P_{NI} SW_{NI} + P_{MI} SW_{MI} \qquad \text{(A-15)}$$

Then, calculate the EPDO excess accidents as:

$$Excess_{Y(EPDO)} = Excess_{Y(PDO)} + RC_{FI} Excess_{Y(FI)} \qquad \text{(A-43)}$$

Step 10: Calculate the variance of the EPDO excess accident estimate:

$$Var\left(Excess_{Y(EPDO)}\right) = Var\left(Excess_{Y(TOT)} + (RC_{FI} - 1)^2 Var\left(Excess_{Y(FI)}\right) \qquad \text{(A-44)}$$

When the user specifies that the excess accident frequency is to be an EPDO weighted estimate, then $Excess_{Y(EPDO)}$ and $Var(Excess_{Y(EPDO)})$ are the final calculations for a given ramp. Proceed to *Step 11*.

NOTE: Depending on whether the analysis is to include TOT, FI, PDO, or EPDO estimates, all of these calculations may not be necessary in *Step 1* through *Step 10*. Only those steps pertaining to the selected accident type(s) actually need to be performed.

Step 11: When screening based upon basic network screening using the sliding window approach, if the value of $Excess_Y$ is greater than or equal to the limiting value for excess accident frequency for ramps, then the ramp is flagged and included in the output. The value of $Excess_Y$ is the measure used to rank the individual ramp within the output. Thus, for ramps, the PSI = $Excess_Y$. The ramps for which $Excess_Y$ is less than the limiting value for expected accident frequency for ramps are not included in the output. When screening based upon basic network screening using the peak searching approach, a ramp is flagged when $Excess_Y$ is greater than or equal to the limiting value for excess accident frequency for ramps and the CV is less than CV_{Limit}. Calculate the CV of the excess accident frequency for the ramp using Equations (A-45) through (A-48).

NOTE 1: When the user screens by FS or FI accidents, the number of excess fatalities and number of excess injuries will also be included on the output report. To obtain these values, the PSI of a site is multiplied by the corresponding accident rates for the given site subtype. These accident rates are found in the *SafetyAnalyst* database. When the user specifies that the screening is to only consider a certain collision type, the respective accident rate $AccRate_{(F/CT/FS)}$ and $AccRate_{(I/CT/FS)}$ or $AccRate_{(F/CT/FI)}$ and $AccRate_{(I/CT/FI)}$ are obtained from the *SafetyAnalyst* database. When more than one collision type is of interest, the respective accident rates used in Equations (A-30A) through (A-30D) are calculated by an alternative formula. The number of excess fatalities and injuries is calculated as follows (Note: No. of Excess Fatalities$_{(F/FS)}$ = No. of Excess Fatalities$_{(F/FI)}$):

$$\text{No. of Excess Fatalities}_{(F/FS)} = Excess_{Y(FI)} \times AccRate_{(F/CT/FI)} \tag{A-135}$$

$$\text{No. of Excess Injuries}_{(I/FS)} = Excess_{Y(FS)} \times AccRate_{(I/CT/FS)} \tag{A-136}$$

$$\text{No. of Excess Fatalities}_{(F/FI)} = Excess_{Y(FI)} \times AccRate_{(F/CT/FI)} \tag{A-137}$$

$$\text{No. of Excess Injuries}_{(I/FI)} = Excess_{Y(FI)} \times AccRate_{(I/CT/FI)} \tag{A-138}$$

NOTE: If No. of Excess Fatalities$_{(F/FS)}$ < 0, then set No. of Excess Fatalities$_{(F/FS)}$ = 0.

NOTE 2: For each site included on the output report, the average observed accident frequency per mile per year for the site will be included on the output report. These values are calculated as follows:

$$K_{iRamps(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times SL_{Ramp_i}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} \tag{A-152}$$

$$K_{iRamps(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FS)}}{Y_i \times SL_{Ramp_i}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-153}$$

$$K_{iRamps(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i \times SL_{Ramp_i}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-154}$$

$$K_{iRamps(PDO)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times SL_{Ramp_i}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{Y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i \times SL_{Ramp_i}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{Y(FI)} \tag{A-155}$$

$$K_{iRamps(EPDO)} = K_{iRamps(PDO)} + RC_{FI} K_{iRamps(FI)} \tag{A-156}$$

NOTE: If $K_{iRamps(FI)} > K_{iRamps(TOT)}$), then set $K_{iRamps(FI)} = K_{iRamps(TOT)}$. Similarly if $K_{iRamps(FS)} > K_{iRamps(TOT)}$, then set $K_{iRamps(FS)} = K_{iRamps(TOT)}$.

This value will be repeated in both columns for average observed accident frequency for the entire site and for the location with the highest potential for safety improvement.

A.1.3.3 Calculation of PSI Rating Weighted by Area Type of Ramp

If ramps are to be ranked based on their area type to account for the differences in costs between urban and rural safety improvement projects, area weights (AW) are applied to the expected accident frequencies or excess accident frequencies to calculate a weighted PSI rating. The values of AW are input by the user for urban and rural areas. By default, AW = 1 for urban sites. Thus, all rural sites are weighted relative to urban sites.

When the weighted PSI Rating is applied to expected accident frequencies, *Step 1* through *Step 9* in Appendix A.1.3.1 are repeated as needed for a given ramp. The area weight, AW, is applied as follows to Equation (A-148) and Equation (A-149) when calculating X_1 in *Step 4*:

$$X_{1(TOT)} = \left[w_{TOT} \kappa_{1(TOT)} + \frac{(1-w_{TOT}) \sum_{y=1}^{Y} \kappa_{y(TOT)}}{SL_{Ramp} \sum_{y=1}^{Y} C_{y(TOT)}} \right] \times AW \qquad (A\text{-}157)$$

$$X_{1(FI)} = \left[w_{FI} \kappa_{1(FI)} + \frac{(1-w_{FI}) \sum_{y=1}^{Y} \kappa_{y(FI)}}{SL_{Ramp} \sum_{y=1}^{Y} C_{y(FI)}} \right] \times AW \qquad (A\text{-}158)$$

Similarly, the variance Equation (A-150) and Equation (A-151) in *Step 6* are adjusted to account for the area weight, AW.

$$Var\left(X_{Y(TOT)}\right) = \left[X_{y(TOT)} (1 - w_{TOT}) \frac{C_{Y(TOT)}}{\sum_{y=1}^{Y} C_{y(TOT)}} \right] \times AW \qquad (A\text{-}159)$$

$$Var\left(X_{Y(FI)}\right) = \left[X_{y(FI)} (1 - w_{FI}) \frac{C_{Y(FI)}}{\sum_{y=1}^{Y} C_{y(FI)}} \right] \times AW \qquad (A\text{-}160)$$

When the weighted PSI Rating is applied to **excess accident frequencies**, *Step 1* through *Step 10* in Appendix A.1.3.2 are repeated as needed for a given intersection. The area weight, AW, is applied as follows to Equation (A-36) and Equation (A-37) when calculating Excess$_Y$ in *Step 7*:

$$Excess_{Y(TOT)} = \left[X_{Y(TOT)} - \kappa_{Y(TOT)} \right] \times AW \qquad (A\text{-}57)$$

$$Excess_{Y(FI)} = \left[X_{Y(FI)} - \kappa_{Y(FI)} \right] \times AW \qquad (A\text{-}58)$$

NOTE: In Equation (A-57) and Equation (A-58), the area weight (AW) has not been applied to $X_{Y(TOT)}$ nor $X_{Y(FI)}$ in previous steps. Therefore, the AW is applied to both terms in the equations.

The variance Equation (A-77) and Equation (A-78) in *Step 8* are also adjusted to account for the area weight.

$$Var\left(Excess_{Y(TOT)}\right) = Var\left(X_{Y(TOT)}\right) + \left[d_{TOT} (\kappa_{Y(TOT)})^2 \right] \times AW \qquad (A\text{-}59)$$

A-66

$$\text{Var}\left(\text{Excess}_{Y(FI)}\right) = \text{Var}\left(X_{Y(FI)}\right) + \left[d_{FI}(\kappa_{Y(FI)})^2\right] \times AW \tag{A-60}$$

The PSI Rating is the measure used to rank the individual ramps within the output.

Whether the PSI is calculated for expected accident frequency or excess accident frequency, for each site included on the output report, the weighted average observed accident frequency per mile per year for the site will be included on the output report. These values are calculated as follows:

$$K_{iRamps(TOT)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times SL_{Ramp}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{y(TOT)} \times AW \tag{A-161}$$

$$K_{iRamps(FS)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FS)}}{Y_i \times SL_{Ramp}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{y(FI)} \times AW \tag{A-162}$$

$$K_{iRamps(FI)} = \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i \times SL_{Ramp}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{y(FI)} \times AW \tag{A-163}$$

$$K_{iRamps(PDO)} = \left(\left(\frac{\sum_{y=1}^{Y} K_{iy(CT/TOT)}}{Y_i \times SL_{Ramp}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(TOT)}}\right) \times C_{y(TOT)} - \left(\frac{\sum_{y=1}^{Y} K_{iy(CT/FI)}}{Y_i \times SL_{Ramp}}\right) \times \left(\frac{Y_i}{\sum_{y=1}^{Y} C_{y(FI)}}\right) \times C_{y(FI)}\right) \times AW \tag{A-164}$$

$$K_{iRamps(EPDO)} = K_{iRamps(PDO)} + RC_{FI} K_{iRamps(FI)} \tag{A-165}$$

NOTE: If $K_{iRamps(FI)} > K_{iRamps(TOT)}$, then set $K_{iRamps(FI)} = K_{iRamps(TOT)}$. Similarly, if $K_{iRamps(FS)} > K_{iRamps(TOT)}$, then set $K_{iRamps(FS)} = K_{iRamps(TOT)}$.

This value will be repeated in both columns for average observed accident frequency for the entire site and for the location with the highest potential for safety improvement.

Similarly, whether the PSI is calculated for expected accident frequency or excess accident frequency, for each site included on the output report, the weighted predicted accident frequency per mile for year Y for the site will be included on the output report. These values are calculated as follows:

$$\kappa_{Y,AW(TOT)} = C_{Y(TOT)} \times e^{\alpha} \times ADT_Y^{\beta_1} \times AW \tag{A-71}$$

$$\kappa_{Y,AW(FI)} = C_{Y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_Y^{\beta_1} \times AW \tag{A-72}$$

$$\kappa_{Y,AW(PDO)} = \kappa_{Y,AW(TOT)} - \kappa_{Y,AW(FI)} \tag{A-73}$$

$$\kappa_{Y,AW(EPDO)} = \kappa_{Y,AW(PDO)} + RC_{FI} \kappa_{Y,AW(FI)} \tag{A-74}$$

NOTE 1: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculation, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents $[P_{(CT/FS/CF)}]$ for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, and (D) include $P_{(CT/FS/FI)}$ in Equation (A-72) as a multiplier.

NOTE 2: If $\kappa_{Y,AW(FI)} > \kappa_{Y,AW(TOT)}$, then set $\kappa_{Y,AW(FI)} = \kappa_{Y,AW(TOT)}$. Similarly, if $\kappa_{Y,AW(FS)} > \kappa_{Y,AW(TOT)}$, then set $\kappa_{Y,AW(FS)} = \kappa_{Y,AW(TOT)}$.

A.2 Screening for High Proportions of Specific Target Accidents

The objective of this screening method is to identify sites that have a higher proportion of specific target accidents than expected and to rank those sites based on the difference between the observed proportion and the expected proportion of the specific target accident. The calculations described in Appendix A.2.1 and Appendix A.2.2 for screening locations for high proportions of specific target accidents apply to one site type for one accident type of interest. This screening methodology cannot be applied to analyze the possibility of multiple accident types being overrepresented. In other words, when screening for high proportions of specific target accident types, the user may only select one accident type of interest. To investigate the possibility of another accident type being overrepresented, a second analysis has to be performed.

The general screening methodology is described below using the following definitions:

Total Accidents

$x_{i(CT)}$ =   observed number of accidents of the collision type of interest at site i for all years of available data

$n_{i(TOT)}$ =   observed number of TOT accidents at site i for all years of available data

$p_{i(CT/TOT)}$ = $x_{i(CT)}/n_{i(TOT)}$ (i.e., the proportion of accidents of the collision type of interest for all TOT accidents)

FI Accidents

$x_{i(CT)}$ =   observed number of FI accidents of the collision type of interest at site i for all years of available data

$n_{i(FI)}$ =   observed number of FI accidents at site i for all years of available data

$p_{i(CT/FI)}$ = $x_{i(CT)}/n_{i(FI)}$ (i.e., the proportion of FI accidents of the collision type interest for all FI accidents)

FS Accidents

$x_{i(CT)}$ =   observed number of FS accidents of the collision type of interest at site i for all years of available data

$n_{i(FS)}$ =   observed number of FS accidents at site i for all years of available data

$p_{i(CT/FS)}$ = $x_{i(CT)}/n_{i(FS)}$ (i.e., the proportion of FS accidents of the collision type of interest for all FS accidents)

PDO Accidents

$x_{i(CT)}$ = observed number of PDO accidents of the collision type of interest at site i for all years of available data

$n_{i(PDO)}$ = observed number of PDO accidents at site i for all years of available data

$p_{i(CT/PDO)}$ = $x_{i(CT)}/n_{i(PDO)}$ (i.e., the proportion of PDO accidents of the collision type of interest for all PDO accidents)

This screening methodology requires a limiting value of the proportion, p_i^*, for the collision type of interest. The value of p_i^* for a given site type, collision type, and severity level is set equal to $P_{(SEV)}$, which is stored in the *SafetyAnalyst* database.

The remainder of this section describes in detail the procedures for screening for high proportions of specific target accidents. Appendix A.2.1 describes the procedures for detecting high proportions of target accident types on roadway segments. Appendix A.2.2 describes the procedures for detecting high proportions of target accident types at intersections. Appendix A.2.3 describes the procedures for detecting high proportions of target accident types at ramps.

A.2.1 Detecting High Proportions of Target Accident Types on Roadway Segments

When screening for high proportions of target accident types on roadway segments, the methodology is very similar to that of the sliding window approach described in Appendix A.1.1.2. Calculations are performed based on observed accidents that occurred within the boundaries of sliding windows. These sliding windows are moved incrementally forward along groups of contiguous roadway segments in similar fashion as described in Appendix A.1.1.2. Rather than repeating the procedures for determining window lengths and positions as described in Appendix A.1.1.2, the primary similarities and differences between the two methodologies are described here.

- In both screening methodologies, all roadway segments in the site list are grouped into contiguous roadway segments. In the sliding window approach, discontinuities in route type, mileposts or route, section identifier signal the end of contiguous sites. In this methodology, discontinuities in roadway class between adjoining roadway segments signal the end of a contiguous group of sites.

- In the sliding window approach, the windows lengths are typically short. For example, a default window length of 0.3 mi is specified. In testing for high proportion of accidents, longer windows are desired. A default window length of 1.0 mi is specified for this screening approach. By default, windows are moved forward incrementally by 0.1 mi in both methodologies.

- In both methodologies, windows are moved forward incrementally until they reach the end of a contiguous set of sites. As the positions of the windows near the end of a contiguous length of roadway segments, the length of the final window along a contiguous set of sites will vary as a function of the window length, the incremental length by which the sliding window is moved forward, and the length of roadway segment that remains between the previous full length window and the end of the roadway segment.

- In both methodologies, when a contiguous group of sites or site is shorter in length than the default window length (e.g., a single site is not contiguous with sites upstream or downstream of it), the length of the window equals the length of the contiguous group. The window for this site will not overlap other windows.

- In both methodologies, all windows that overlap at least some portion of a given roadway segment pertain to that given site.

For a given window, the observed proportion of the target accident (i.e., $p_{i(CT/TOT)}$) is calculated when the following conditions are met:

1. There should be at least two accidents of the specified severity level occurring at the site.

2. There should be at least one collision type accident at the site.

3. There must be beta parameters for the subtype. For the cases in which no beta parameters are available the Test of High Proportions cannot be performed.

The probability that this observed proportion of a specific collision type with $x_{i(CT)}$ and $n_{i(TOT)}$ accidents is higher than the limiting value, p_i^*, is computed as:

$$\text{Prob}\left(p_{i(CT/TOT)} > p_i^* \middle| x_{i(CT)}, n_{i(TOT)}\right) = 1 - \frac{1}{B\left(f + x_{i(CT)}, g + n_{i(TOT)} - x_{i(CT)}\right)} \int_{H=0}^{p_i^*} H^{f + x_{i(CT)} - 1} (1 - H)^{g + n_{i(TOT)} - x_{i(CT)} - 1} dH$$

(A-166)

where $B(f + x_{i(CT)}, g + n_{i(TOT)} - x_{i(CT)})$ is the value of the beta function based on the values of the two parameters inside the parentheses. The *SafetyAnalyst* database includes a table containing the two beta function parameters, f and g, for the site subtypes and collision types (and associated accident-, vehicle-, or person-level data element).

NOTE: When screening is based on a severity level other than Total accidents, proceed as indicated using X_i, n_i, p_i, and p_i^* for the specified severity level.

There are two basic parts to the calculations in Equation (A-166):

- the calculation of the integral

- the calculation of the value of the beta function for given values of f, g, $x_{i(CT)}$, and $n_{i(TOT)}$

The calculation of the integral can be approximated by computing the quantity in Equation (A-167) below for values of H ranging from 0 up to and including p_i^*, in increasing steps of 0.005 (i.e., for H = 0, 0.005, 0.010, 0.015,...., p_i^*).

$$\sum_{H=0}^{p_i} H^{f+x_{i(CT)}-1}(1-H)^{g+n_{i(TOT)}-x_{i(CT)}-1} \qquad \text{(A-167)}$$

The calculation of the beta function can be approximated by computing the quantity in Equation (A-168) below for values of t ranging from 0 up to and including 1, in increasing steps of 0.005 (i.e., for t = 0, 0.005, 0.010, 0.015,...., 1).

$$\sum_{t=0}^{1} t^{f+x_{i(CT)}-1}(1-t)^{g+n_{i(TOT)}-x_{i(CT)}-1} \qquad \text{(A-168)}$$

A window is flagged when the probability, as calculated from Equation (A-166), is greater than the user-defined confidence level (i.e., 1-α). A default Alpha (α) of 0.10 is specified.

To determine the ranking of an individual roadway segment within the site list, sites are ranked based on the difference between the observed proportion of accidents ($p_{i(CT/TOT)}$) and the limiting proportion (p_i^*). From all of the flagged windows that pertain to a given site, the maximum difference between the observed proportion of accidents and the limiting proportion (i.e., Max[Diff{pi - p_i^*}]) is the measure used to rank the individual roadway segment within the site list. Thus, PSI = Max[Diff(pi - p_i^*)]. The PSI and the boundaries of the respective window are included in the main section of the output report. In addition, the boundaries of all flagged windows pertaining to a site are listed under the Additional Windows of Interest column in the output report.

NOTE 1: If more than one window pertaining to a given site has the same Max[Diff(pi - p_i^*)] value, the boundaries of the first window moving incrementally along the site from the beginning of the site to the end of the site (i.e., the window with the smallest milepost values or the furthest upstream window) are included in the main section of the output report (see Review a Network Screening Report of the *SafetyAnalyst* User's Manual. The boundaries of the other windows with values of Max[Diff(pi - p_i^*)] are listed under the Additional Windows of Interest column in the output report.

NOTE 2: If $p_{i(CT/SEV)} < p_i^*$ $_{(CT/SEV)}$, then regardless of the outcome of the statistical test the window is not flagged.

Roadway segment sites that do not have any flagged windows pertaining to them are not included in the output report.

The procedure above is described for TOT accidents. The same procedure is applied for FS, FI and PDO severity levels. Beta parameters and limiting values [$P_{(CT/FS)}$, $P_{(CT/FI)}$, and

$P_{(CT/PDO)}$] for the FS, FI, and PDO severity levels are available in the *SafetyAnalyst* database. Include only those observed accidents that meet the user specified criteria (i.e., collision type and severity level) in the calculations.

A.2.2 Detecting High Proportions of Target Accident Types at Intersections

Calculations for detecting high proportions of target accident types at intersections are performed in a similar fashion as for roadway segments. The primary difference is that the calculations are performed for individual intersections in the site list rather than for windows which pertain to roadway segments. For each intersection, the probability that the proportion of a specific collision type with $x_{i(CT)}$ and $n_{i(TOT)}$ accidents is higher than the limiting value is computed using Equation (A-166). If this probability is greater than the user-defined confidence level, the intersection is flagged and is included in the output report. The difference between the observed proportion of accidents ($p_{i(CT/TOT)}$) and the limiting proportion (p_i^*) is the measure used to rank the individual intersection within the site list. Thus, $PSI = Diff(pi - p_i^*)$. The PSI and the location of the flagged intersection is included in the output report. Intersections that are not flagged are not included in the output report.

A.2.3 Detecting High Proportions of Target Accident Types at Ramps

Calculations for detecting high proportions of target accident types at ramps are performed in a similar fashion as for intersections. For each ramp, the probability that the proportion of a specific collision type with $x_{i(CT)}$ and $n_{i(TOT)}$ accidents is higher than the limiting value, p_i^*, is computed using Equation (A-166). If this probability is greater than the user-defined confidence level, the ramp is flagged and is included in the output report. The difference between the observed proportion of accidents ($p_{i(CT/TOT)}$) and the limiting proportion (p_i^*) is the measure used to rank the individual ramp within the site list. Thus, $PSI = Diff(pi - p_i^*)$. The PSI and the location of the flagged ramp are included in the output report. Ramps that are not flagged are not included in the output report.

A.3 Detecting a Safety Deterioration

The objective of this screening methodology is to identify sites where the mean accident frequency has increased over time to more than what can be attributed to changes in traffic or general trends. Two types of increases can be detected:

- A **steady** but gradual increase in mean accident frequency
- A sudden **increase** in mean accident frequency

Both steady and sudden increases in accident frequency are detected by a statistical test of significance for the difference between the means of two Poisson random variables.

This is the only network screening methodology where sites are identified for their potential for safety improvement, but the sites are not ranked relative to the others. With the other network screening methodologies, all sites included in output report are ranked relative to the others as to their potential for safety improvement.

This screening methodology may be applicable to all site types (i.e., road segments, intersections, and ramps). The methodology can be implemented for TOT, FS, FI, and PDO accident severity levels. The methodology can also be performed for specific collision types or combinations of collision types. When implementing this methodology, include only those observed accidents that meet the user specified criteria (i.e., collision type and severity level) in the calculations.

The remainder of this section describes in detail the procedures for screening for detecting safety deterioration. Appendix A.3.1 describes the procedures for detecting a steady increase in mean accident frequencies. Appendix A.3.2 describes the procedures for detecting sudden increases in mean accident frequencies.

A.3.1 Detecting a Steady Increase in Mean Accident Frequencies

The general process for detecting a steady increase in mean accident frequency is as follows: (1) fit a linear regression model to the data of accident frequency versus year; (2) if the value of the estimated slope is greater than a user-specified limiting value (b_{Limit}), find the time period (year), T*, at which the variance of $\Delta(T)$, the difference between the after and before accident frequencies, is at a minimum; and then (3) determine if the corresponding value of $\Delta(T)$, (i.e., $\Delta(T^*)$, is significantly larger than what it should be as a result of changes in traffic and other factors. All sites which pass this test are flagged.

The data requirements for this screening procedure include:

- The observed accident frequencies for a site

- A limiting value of the slope (b_{Limit}) for a steady increase in mean accident frequency that might be indicative of a safety concern (a default value is provided by *SafetyAnalyst*)

- The nominal level of significance for testing the significance of changes in the mean accident frequency (a default value is provided by *SafetyAnalyst*)

Step 1 through *Step 5* outline the general procedure for detecting a steady increase in mean accident frequencies at a site with at least one observed accident in the accident database. These procedures are not applied to a site with 0 observed accidents. Sites with 0 observed accidents are automatically not included in the output report for this screening methodology. In the procedures detailed below, time periods (years y) are numbered 1, 2,....,T, T + 1,..., L, and the observed accident frequencies in each time period are denoted $K_1, K_2,....., K_L$.

Step 1: Estimate the intercept, a, and the slope, b, using the equations for simple linear regression to fit a straight line to the pairs of data of observed accident frequencies and time periods.

$$b = \frac{\sum_{y=1}^{L} y K_y - L \times \frac{L+1}{2} \times \frac{\sum_{y=1}^{L} K_y}{L}}{L(L+1)(L-1)/12}$$

(A-169)

$$a = \frac{\sum_{y=1}^{L} K_y}{L} - b\frac{L+1}{2}$$

(A-170)

NOTE: If a = 0, then set a = $(\Sigma K_y/L)/2$.

Step 2: Compare the value of the slope (b) to the limiting value (b_{Limit}) for steady increase. If the value of b is greater than b_{Limit}, then the analysis proceeds to *Step 3*. If the value of b is less than b_{Limit} then the site is not flagged, and the analysis of this site is terminated.

Step 3: Calculate the time period, T*, rounding it to the nearest integer value.

$$T^* = (a/b)\left[(1 + bL/a)^{0.5} - 1\right]$$

(A-171)

NOTE: If T* equals 0, then set T* = 1.

Step 4: Determine the value of $\Delta(T^*)$ corresponding to T* calculated above.

$$\Delta(T^*) = \frac{\sum_{(T^*+1)}^{L} K_y}{L - T^*} - \frac{\sum_{1}^{T^*} K_y}{T^*}$$

(A-172)

Step 5: Perform the test of significance according to the procedure shown in Figure A-13 and Figure A-14. Figure A-13 provides the definitions and steps for this test of significance, and Figure A-14 provides a flow chart of the sequential steps. The site is flagged if significance is determined. Significance levels of 0.05 to 0.25, in increments of 0.05, may be selected. Only flagged sites are included in the output for further investigation.

NOTE: When calculating K_o as indicated in the procedure shown in Figure A-13 the following check needs to be performed on predicted accidents. If $\kappa_{y(FI)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly, if $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

Definitions:
TX   =   length of before period (TX = T*)
TY   =   length of after period (TY = L-T*)
X   =   number of accidents in before period
Y   =   number of accidents in after period

$$K_o = \frac{\dfrac{\sum\limits_{1}^{T^*} \kappa_y}{T^*}}{\dfrac{\sum\limits_{T+1}^{L} \kappa_y}{L - T^*}}$$

Step 1 Calculate the values SUM and θ:
SUM = X+Y
θ   = $K_o TX / (K_o TX + TY)$

Step 2 Set the initial computations:
Set the value of a variable "COUNT" = 0
Set the value of a variable "P" = $(1-\theta)^{SUM}$
If P=0 then P=.00000001
Set F = P
If the value of F for COUNT = 0 is less than ALPHA then proceed to Step 3a. Otherwise proceed to Step 3b.

Step 3a Determination of X:*
If Sum > 25 and (.05 < θ < .95) then
    $X^*=Z[Sum(\theta)(1-\theta)]^{.5} - .5 + (Sum^* \theta)$
(If X* is calculated with this logic, skip remaining calculations in Step 3a and proceed to Step 4)
Set the value of OLDCOUNT = Current value of COUNT
Set the value of OLDP = Current value of P
Set the value of OLDF = Current value of F
The following calculations are done iteratively until F is greater than ALPHA:
Set the new value of COUNT = OLDCOUNT+1
Set the new value of P as = (OLDP) [(SUM-COUNT+1)/COUNT] θ /(1-θ)

If the value of F is less than ALPHA then return to the first action of Step 3a. Otherwise proceed to Step 3b.

Step 3b Determination of X:*
Set X* = 1 less than the current value of COUNT
X* = COUNT -1

Step 4: Compare X to X to determine if site will be flagged:*
If X*<0 then the site will *not* be flagged
If X* >0 and X ?X* then the site will be flagged
If X* >0 and X > X* then the site will *not* be flagged

Figure A-13. Safety Deterioration: Definitions and Steps for Test of Significance
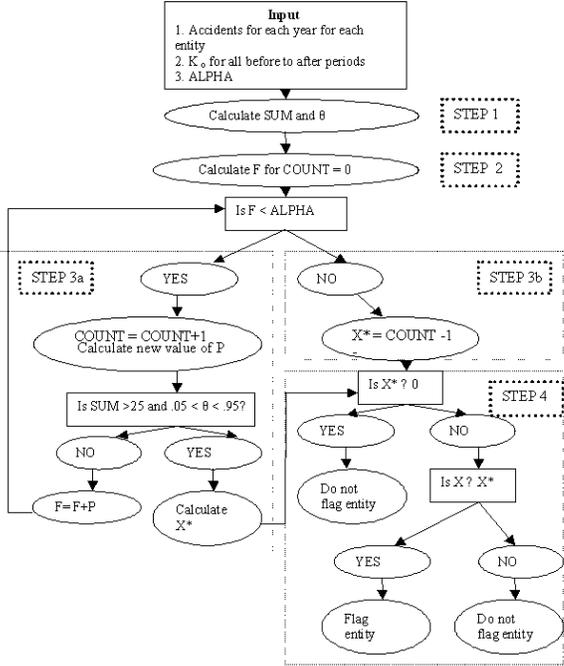
Figure A-14. Safety Deterioration: Definitions and Steps for Test of Significance

A-75

A.3.2 Detecting a Sudden Increase in Mean Accident Frequencies

The general process for detecting a sudden increase in mean accident frequency is to find the critical time period, T*, where there was a sudden percentage increase of size D* in the mean yearly accident frequency. If the size of D* is sufficiently large, that is, equal to or larger than a user specified limiting value D*_Limit, then a test of significance is performed. All sites which pass this test are flagged and are included in the output as lists of sites that warrant further investigation for safety improvement.

The data requirements for performing this screening procedure are similar to those for screening for steady increases in mean accident frequencies with one exception. Rather than specifying a limiting value for the slope, the user specifies a D*_Limit which is the limiting value of a sudden percentage increase in mean accident frequency that might be indicative of a safety concern. The value of D*_Limit is input by the user. A default value for D*_Limit is provided by *SafetyAnalyst*. The steps for this procedure are presented below and are very similar to those of the procedures in Appendix A.3.1.

Step 1 through *Step 5* outline the general procedure for detecting a sudden increase in mean accident frequencies at a site with at least one observed accident in the accident database. These procedures are not applied to a site with 0 observed accidents. Sites with 0 observed accidents are automatically not included in the output report for this screening methodology.

Step 1: Determine the value of Δ(T) for all possible time periods:

$$\Delta(T^*) = \frac{\sum_{(T^*+1)}^{L} K_y}{L-T^*} - \frac{\sum_{1}^{T^*} K_y}{T^*} \qquad \text{(A-172)}$$

Step 2: Find T*, the time period with the largest Δ(T). In case of a tie, choose the smallest T*.

Step 3: Calculate the value of D* corresponding to T*:

$$D^* = 100\frac{\Delta(T^*)I}{T^*} \qquad \text{(A-173)}$$

Step 4: Compare the value of D* to the value of D*_Limit. If the value of D* is greater than or equal to the user-specified limiting value D*_Limit, then the analysis proceeds to *Step 5*. If the value of D* is less than the user-specified limiting value D*_Limit, then the site is not flagged, and the analysis of this site is terminated.

Step 5: Perform the test of significance as presented in Figure A-13 and Figure A-14. The site is flagged if significance is determined. A flagged site is included in the output for further investigation.

NOTE: When calculating K_o as indicated in the procedure shown in Figure A-13 the following check needs to be performed on predicted accidents. If $\kappa_{y(FI)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly, $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

A.3.3 Review, Refinement, and Presentation of List of Flagged Sites

Whether sites are screened for a sudden or a steady increase in mean accident frequency, a list of flagged sites is generated. The user may assess the adequacy of the length of this list based on the user's individual practical and budgetary considerations. If the user determines that too many sites are flagged to be of practical interest, then the user may rerun the analysis and increase the confidence level (i.e., decrease the value of ALPHA) and/or increase the limiting value of b or D^*_{Limit}. If the user determines that too few sites have been flagged, then the user should rerun the analysis and decrease the confidence level (i.e., increase the value of ALPHA) and/or decrease the limiting value of b or D^*_{Limit}.

A.4 Corridor Screening

Corridor screening is a unique approach among the analyses that are performed within Module 1. All other analyses in this module are performed on a site-by-site basis. However, within a corridor analysis, sites are aggregated to investigate the accident history for a group of roadway segments, intersections, and/or ramps. Thus, sites with a common corridor number are analyzed as a single entity.

The user has the option to rank corridors by one or both of two basic measures:

- Accidents/mi/yr
- Accidents/million vehicle miles of travel/yr

Calculations of these two measures are based on observed accidents. The methodology can be implemented for TOT, FS, FI, and PDO accident severity levels. The methodology can also be performed for specific collision types or combinations of collision types. When implementing this methodology, include only those observed accidents that meet the user specified criteria (i.e., collision type and severity level) in the calculations.

Although a corridor is viewed as a single entity, the actual calculations for corridor screening are done on a site-by-site basis. That is, for each roadway segment, intersection, and ramp site that is included in the corridor, accidents are summed on a yearly basis for all sites for the most recent 10 years of data available, the most recent years of data since the most recent date of major reconstruction, or for particular years specified by the user.

When the user selects accidents/mi/yr as the screening measure, the average accidents/mi/yr is calculated for a single corridor as:

$$\text{Average acc/mi/yr} = \frac{\sum_{i=1}^{I}\sum_{y=1}^{Y}\frac{K_{i,y(TOT)}}{Y_i}}{\sum_{i=1}^{I}SL_i} \tag{A-174}$$

where

I   =   total number of sites in the corridor.
Y_i =   total number of years of available data at site i
S_{Li} =   roadway segment length (mi) under consideration at site i. ($S_{Li} = 0$ for all intersection and ramp sites)
$K_{i,y(TOT)}$ =   observed number of TOT accidents at site i during year y

When the user selects accidents/mvmt/yr as the screening measure, the average accidents/mvmt/yr is calculated for a single corridor as:

$$\text{Average acc/mvmt/yr} = \frac{\sum_{i=1}^{I}\sum_{y=1}^{Y}K_{i,y(TOT)}}{\sum_{i=1}^{I}\sum_{y=1}^{Y}\frac{SL_{i,y}\times ADT_{i,y}\times 365}{1,000,000}} \tag{A-175}$$

NOTE 1: In Equation (A-175), accident data are summed in the numerator across all site types included in the corridor (i.e., roadway segments, intersections, and/or ramps)

NOTE 2: In Equation (A-175), segment length data are obtained for roadway segments only. SL = 0 for all intersection and ramp sites.

NOTE 3: The calculations above for average accidents/mi/yr and average accidents/mvmt/yr are illustrated for TOT accidents. The same procedure will be applied for FS, FI, and PDO severity levels and for a given collision type or combinations of collision types.

Corridors are ranked in descending order of the respective overall yearly average values.

Appendix B

Detailed Procedures for *SafetyAnalyst* Module 2— Diagnosis and Countermeasure Selection

APPENDIX B. DETAILED PROCEDURES FOR *SAFETYANALYST* MODULE 2—DIAGNOSIS AND COUNTERMEASURE SELECTION

B.1 Identifying Accident Patterns Using Statistical Procedures

This appendix explains in detail the two statistical procedures used in Module 2 for identifying accident patterns of interest. The statistical procedures are based upon tests for accident frequencies or accident proportions.

B.1.1 Test for Frequencies

Two approaches are available to test whether accident frequencies at a site/project are too large. The approaches are based on comparing the average observed accident frequency and EB-adjusted expected accident frequency to a limiting value, as specified by the user, for a given collision type.

Calculations and tests of average observed accident frequencies and EB-adjusted expected accident frequencies are performed as follows for a given site/project. For roadway segments, these calculations are not necessarily performed for the entire site but are calculated taking into consideration the boundaries of the site as specified by the user. For projects, the calculations are based upon the entire length of each site in the project.

B.1.2 Tests of Average Observed Accident Frequencies

For the specified accident severity level (i.e., TOT, FS, FI, or PDO) and for each observed collision type, calculate the average observed accident frequency as follows:

Step 1a: For roadway segments or ramps.

$$\text{Average acc/mi/yr} = \frac{\sum_{y=1}^{Y} \frac{K_{y(CT)}}{Y}}{SL} \tag{B-1}$$

where:

Y   = total number of years in the analysis period
SL   = roadway segment or ramp length (mi) under consideration
$K_{y(CT)}$ = observed number of accidents of the collision type of interest during year Y. For simplicity of notation, CT may refer to any manner of collision when performing the calculations in Equation (B-1) through Equation (B-26).

NOTE 1: If the entire site is being evaluated, then the roadway segment (or ramp) length for the site is provided in the *SafetyAnalyst* inventory database. If only a portion of the site is being evaluated, then SL for the site must be determined based upon the boundaries (i.e., limits) of the site as specified by the user.

Step 1b: For Intersections.

$$\text{Average acc/yr} = \frac{\sum_{y=1}^{Y} K_{y(CT)}}{Y} \tag{B-2}$$

Step 2: Compare the average observed accident frequency to the limiting value as specified by the user. If the average observed accident frequency is greater than or equal to the limiting value, the collision type is flagged for further consideration.

CALCULATION ADJUSTMENTS FOR PROJECTS: When more than one roadway segment is being considered in the evaluation, then apply Equation (B-3) rather than Equation (B-1) when calculating average observed accident frequencies.

$$\text{Average acc/mi/yr} = \frac{\sum_{i=1}^{I} \sum_{y=1}^{Y} \frac{K_{iy(CT)}}{Y_i}}{\sum_{i=1}^{I} SL_i} \tag{B-3}$$

where:

I   =   total number of sites in the project.
Y_i =   total number of years in the analysis period at site i
SL_i =   roadway segment length (mi) under consideration at site i
$K_{y(CT)}$ =   observed number of accidents of the collision type of interest at site i during year Y. For simplicity of notation, CT may refer to any manner of collision when performing the calculations in Equation (B-1) through Equation (B-26).

NOTE 1: If a project is being evaluated, then i ≥ 2 and the roadway segment lengths for each site in the project are provided in the *SafetyAnalyst* inventory database.

B.1.3 Tests of EB-Adjusted Expected Accident Frequencies

For each observed collision type, calculate the EB-adjusted expected accident frequency as follows:

Step 1a: For roadway segments or ramps using the appropriate SPF model parameters, compute for each year in the analysis period (y = 1, 2, ...,Y) the predicted number of accidents, κ_y, per mile, as follows:

$$\kappa_{y(TOT)} = SPF_{TOT}\{ADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times ADT_y^{\beta_1} \tag{B-4}$$

$$\kappa_{y(FI)} = SPF_{FI}\{ADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_y^{\beta_1} \tag{B-5}$$

NOTE 1: $P_{CT(TOT)}$ and $P_{CT(FI)}$ for the observed collision types are found in the *SafetyAnalyst* database.

NOTE 2: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, (D) replace $P_{CT(FI)}$ in Equation (B-5) with $P_{(CT/FS/FI)}$, and (E) proceed as normal for FI calculations.

NOTE 3: If $\kappa_{y(FI)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly, if $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

Step 1b: For intersections.

Using the appropriate SPF model parameters, compute for each year in the analysis period (y = 1, 2, ...,Y) the predicted number of accidents, κ_y, as follows:

$$\kappa_{y(TOT)} = SPF_{TOT}\{ADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times MajADT_y^{\beta_1} \times MinADT_y^{\beta_2} \tag{B-6}$$

$$\kappa_{y(FI)} = SPF_{FI}\{ADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times MajADT_y^{\beta_1} \times MinADT_y^{\beta_2} \tag{B-7}$$

NOTE 1: $P_{CT(TOT)}$ and $P_{CT(FI)}$ for the observed collision types are found in the *SafetyAnalyst* database.

NOTE 2: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, (D) replace $P_{CT(FI)}$ in Equation (B-7) with $P_{(CT/FS/FI)}$, and (E) proceed as normal for FI calculations.

NOTE 3: If $\kappa_{y(FI)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly, if $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

Step 2: Using the model predictions computed in *Step 1a* or *1b*, compute the yearly correction factors, C_y, for each year in the analysis period (y = 1, 2, ...,Y):

$$C_{y(TOT)} = \frac{\kappa_{y(TOT)}}{\kappa_{1(TOT)}} \tag{B-8}$$

$$C_{y(FI)} = \frac{\kappa_{y(FI)}}{\kappa_{1(FI)}} \tag{B-9}$$

B-3

Step 3: Using $\kappa_1, ..., \kappa_Y$ and the overdispersion parameter, d, compute the weights, w:

$$w_{TOT} = \frac{1}{1 + d_{TOT} \sum_{y=1}^{Y} \kappa_{y(TOT)} \times L} \tag{B-10}$$

$$w_{FI} = \frac{1}{1 + d_{FI} \sum_{y=1}^{Y} \kappa_{y(FI)} \times L} \tag{B-11}$$

NOTE 1: The weights, $w_{(TOT)}$ and $w_{(FI)}$, are always calculated based upon the "all" accidents for TOT and FI severity levels. In other words, for those instances when basic network screening is based upon a certain collision type or types, the predicted value calculated in *Step 1* is scaled, based upon a proportion or a sum of proportions. Rather than using the scaled value of predicted accidents in Equation (B-10) and Equation (B-11), the predicted value before multiplying by the respective proportion will be used to calculate the weights $w_{(TOT)}$ and $w_{(FI)}$. The same principle applies when the calculations are based upon FS injuries. The weight $w_{(FS)}$ will actually be based upon "all" FI accidents. The rationale for this change is because weights, $w_{(TOT)}$ and $w_{(FI)}$, are used in subsequent steps to combine observed accidents and predicted accidents. The weights, $w_{(TOT)}$ and $w_{(FI)}$, are calculated based upon the accuracy/reliability of the SPFs. In concept the accuracy/reliability of the SPF does not change when the screening is based upon certain collision types or FS injury accidents. The same SPFs for TOT and FI accidents are still being used for all calculations, and the accuracy/reliability of the TOT and FI SPFs does not change. If the "scaled" predicted values were used in equations Equation (B-10) and Equation (B-11), then the weights would be adjusted for the wrong reason, not because the accuracy/reliability of the SPFs changed but because the predicted values were scaled as a necessity due to unrelated circumstances.

NOTE 2: In Equation (B-10) and Equation (B-11), L is equal to the segment length, SL for roadway segments, or ramp length, SL_{RAMP} for ramps. For intersections L is set to 1.

Step 4a: For roadway segments, projects, and ramps.

Calculate the base EB-adjusted expected number of accidents, X_1, during Year 1:

$$X_{1(TOT)} = w_{TOT} \kappa_{1(TOT)} SL_i + (1 - w_{TOT}) \frac{\sum_{y=1}^{Y} \kappa_{y(TOT)}}{\sum_{y=1}^{Y} C_{y(TOT)}} \tag{B-12}$$

$$X_{1(FI)} = w_{FI} \kappa_{1(FI)} SL_i + (1 - w_{FI}) \frac{\sum_{y=1}^{Y} \kappa_{y(FI)}}{\sum_{y=1}^{Y} C_{y(FI)}} \tag{B-13}$$

NOTE 1: If the entire site is being evaluated, then the roadway segment length (or ramp length) for the site is provided in the *SafetyAnalyst* inventory database. If only a portion of the site is being evaluated as specified by the user, then SL_i for the site must be determined based upon the boundaries (i.e., limits) of the site that are being considered in the evaluation and the actual boundaries (i.e., limits) of the site.

NOTE 2: If the site is a ramp and ramp length (SL_{Ramp}) is not available, the site cannot be included in the analysis.

NOTE 3: The observed accidents in equations Equation (B-12) and Equation (B-13) should be those of the respective collision types and severity levels as specified by the user.

Step 4b: For intersections

Calculate the base EB-adjusted expected number of accidents, X_1, during Year 1:

$$X_{1(TOT)} = w_{TOT}\kappa_{1(TOT)} + (1-w_{TOT})\frac{\sum_{y=1}^{Y}\kappa_{y(TOT)}}{\sum_{y=1}^{Y}c_{y(TOT)}} \qquad \text{(B-14)}$$

$$X_{1(FI)} = w_{FI}\kappa_{1(FI)} + (1-w_{FI})\frac{\sum_{y=1}^{Y}\kappa_{y(FI)}}{\sum_{y=1}^{Y}c_{y(FI)}} \qquad \text{(B-15)}$$

NOTE: The observed accidents in Equation (B-14) and Equation (B-15) should be of the respective collision types and severity levels as specified by the user.

Step 5: Calculate X_Y, the EB-adjusted expected number of accidents for each year in the analysis period ($y = 1,2, ..., Y$):

$$X_{Y(TOT)} = X_{1(TOT)}c_{Y(TOT)} \qquad \text{(B-16)}$$

$$X_{Y(FI)} = X_{1(FI)}c_{Y(FI)} \qquad \text{(B-17)}$$

Step 6a: For roadway segments and ramps.

Calculate the average EB-adjusted expected accident frequency:

$$\text{Average acc/mi/yr}_{(TOT)} = \frac{\sum_{y=1}^{Y}\frac{X_{y(TOT)}}{Y}}{SL} \qquad \text{(B-18)}$$

$$\text{Average acc/mi/yr}_{(FI)} = \frac{\sum_{y=1}^{Y}\frac{X_{y(FI)}}{Y}}{SL} \qquad \text{(B-19)}$$

$$\text{Average acc/mi/yr}_{(PDO)} = \text{Average acc/mi/yr}_{(TOT)} - \text{Average acc/mi/yr}_{(FI)} \qquad \text{(B-20)}$$

NOTE 1: For ramps, the denominator for Equation (B-18) and Equation (B-19) is SL_{Ramp}.

Step 6b: For Intersections.

Calculate the average EB-adjusted expected accident frequency:

$$\text{Average acc/yr}_{(TOT)} = \sum_{y=1}^{Y}\frac{X_{y(TOT)}}{Y} \qquad \text{(B-21)}$$

$$\text{Average acc/yr}_{(FI)} = \sum_{y=1}^{Y}\frac{X_{y(FI)}}{Y} \qquad \text{(B-22)}$$

$$\text{Average acc/yr}_{(PDO)} = \text{Average acc/yr}_{(TOT)} - \text{Average acc/yr}_{(FI)} \qquad \text{(B-23)}$$

Step 7: Compare the average EB-adjusted expected accident frequency to the limiting value as specified by the user. If the average EB-adjusted expected accident frequency is greater than or equal to the limiting value, the collision type is flagged for further consideration.

CALCULATION ADJUSTMENTS FOR PROJECTS: When more than one roadway segment is being considered in the evaluation, then apply *Steps 1* through *5* to each roadway segment and then apply Equation (B-24) rather than Equation (B-18) when calculating the average EB-adjusted expected accident frequency.

$$\text{Average acc/mi/yr}_{(TOT)} = \frac{\sum_{i=1}^{I} \sum_{y=1}^{Y} \frac{X_{iy(TOT)}}{Y}}{\sum_{i=1}^{I} SL_i} \qquad \text{(B-24)}$$

$$\text{Average acc/mi/yr}_{(FI)} = \frac{\sum_{i=1}^{I} \sum_{y=1}^{Y} \frac{X_{iy(FI)}}{Y}}{\sum_{i=1}^{I} SL_i} \qquad \text{(B-25)}$$

$$\text{Average acc/mi/yr}_{(PDO)} = \text{Average acc/mi/yr}_{(TOT)} - \text{Average acc/mi/yr}_{(FI)} \qquad \text{(B-26)}$$

In summary, the test for frequencies may trigger an investigation into a specific accident pattern ("the test is passed") when either the observed or the EB-expected average frequency exceeds the limiting value.

B.1.4 Test of Proportions

For roadway segments, intersections, and ramps, the following steps describe the procedures for the test of proportions.

Step 1

For a given site/project, severity level, and analysis period of Y years, calculate the proportion of observed accidents for each observed collision type.

$$P_{i(CT/SEV)} = \frac{\sum_{y=1}^{Y} K_{iy(CT)}}{\sum_{y=1}^{Y} K_{iy(SEV)}} \qquad \text{(B-27)}$$

NOTE: The observed accidents are determined based upon the boundaries of the evaluation as specified by the user. For simplicity of notation, CT may refer to any type of accident.

Step 2

Calculate the probability that the observed proportion exceeds the limiting (i.e., statewide) proportion. The probability that the observed proportion of a specific collision type is higher than the limiting value, p_i^*, is computed as:

$$\text{Prob}\left(p_{i(CT/TOT)} > p_i^* \middle| x_{i(CT)}, n_{i(TOT)}\right) = 1 - \frac{1}{B\left(f+x_{i(CT)}, g+n_{i(TOT)}-x_{i(CT)}\right)} \int_{H=0}^{p_i^*} H^{f+x_{i(CT)}-1}(1-H)^{g+n_{i(TOT)}-x_{i(CT)}-1} dH$$

<div align="right">(same as A-166)</div>

where:

Total Accidents

$x_{i(CT)}$	=	observed number of TOT accidents of the collision type of interest at site i for all years of the analysis period
$n_{i(TOT)}$	=	observed number of TOT accidents at site i for all years of the analysis period
$p_{i(CT/TOT)}$	=	$x_{i(CT)}/n_{i(TOT)}$ (i.e., the proportion of accidents of the collision type of interest for all TOT accidents)
$B(f+x_{i(CT)}, g+n_{i(TOT)}-x_{i(CT)})$	=	the value of the beta function based on the values of the two parameters inside the parentheses.

FS Accidents

$x_{i(CT)}$	=	observed number of FS accidents of the collision type of interest at site i for all years of the analysis period.
$n_{i(FS)}$	=	observed number of FS accidents at site i for all years of the analysis period.
$p_{i(CT/FS)}$	=	$x_{i(CT)}/n_{i(FS)}$ (i.e., the proportion of accidents of the collision type of interest for all FS accidents).
$B(f+x_{i(CT)}, g+n_{i(FS)}-x_{i(CT)})$	=	the value of the beta function based on the values of the two parameters inside the parentheses.

FI Accidents

$x_{i(CT)}$	=	observed number of FI accidents of the collision type of interest at site i for all years of the analysis period.
$n_{i(FI)}$	=	observed number of FI accidents at site i for all years of the analysis period.
$p_{i(CT/FI)}$	=	$x_{i(CT)}/n_{i(FI)}$ (i.e., the proportion of accidents of the collision type of interest for all FI accidents).
$B(f+x_{i(CT)}, g+n_{i(FI)}-x_{i(CT)})$	=	the value of the beta function based on the values of the two parameters inside the parentheses.

PDO Accidents

$x_{i(CT)}$	=	observed number of PDO accidents of the collision type of interest at site i for all years of the analysis period.
$n_{i(PDO)}$	=	observed number of PDO accidents at site i for all years of the analysis period.

$p_{i(CT/PDO)}$ $= x_{i(CT)}/n_{i(PDO)}$ (i.e., the proportion of accidents of the collision type of interest for all PDO accidents).

$B(f+x_{i(CT)},g+n_{i(PDO)}-x_{i(CT)}) =$ the value of the beta function based on the values of the two parameters inside the parentheses.

NOTE: When screening is based on a severity level other than Total accidents, proceed as indicated using X_i, n_i, p_i, and p_i^* for the specified severity level.

The Beta distribution parameters defaults for collision types file in the *SafetyAnalyst* database includes two beta function parameters, f and g, for a limited number of site subtypes collision types.

Step 3

Compare the calculated probability to the p-value specified by the user. If the calculated probability equals or exceeds the given value (1 - p), then that specific accident pattern is flagged for further consideration.

NOTE: If $p_{i(CT/SEV)} \geq {}_i^*{}_{(CT/SEV)}$, then regardless of the outcome of the statistical test the window is not flagged.

CALCULATION ADJUSTMENTS FOR PROJECTS: When more than one roadway segment is being considered in the evaluation, apply Equation (B-28) rather than Equation (B-27) in *Step 1* when calculating the observed proportion of the respective accident pattern.

$$P_{(CT/TOT)} = \frac{\sum_{i=1}^{I}\sum_{y=1}^{Y}K_{iy(CT)}}{\sum_{i=1}^{I}\sum_{y=1}^{Y}K_{iy(TOT)}}$$ (B-28)

NOTE 1: When a project is being evaluated, then $i \geq 2$, and I is the total number of sites in the project.

In summary, the test of proportions may trigger an investigation into a specific accident pattern (i.e., "the test is passed") when the observed proportion exceeds the limiting value (i.e., p_i^*) for that accident type with a probability greater or equal to the user specified probability (i.e., 1 - p).

The procedure above is described for TOT accidents. The same procedure will be applied for FS, FI, and PDO severity levels. Beta parameters and limiting values [$P_{(CT/FS)}$, $P_{(CT/FI)}$, and $P_{(CT/PDO)}$] for the FS, FI and PDO severity levels are available in the *SafetyAnalyst* database. Include only those observed accidents that meet the user specified criteria (i.e., collision type and severity level) in the calculations.

Detailed Procedures for *SafetyAnalyst* Module 3— Economic Appraisal and Priority Ranking

APPENDIX C. DETAILED PROCEDURES FOR *SAFETYANALYST* MODULE 3—ECONOMIC APPRAISAL AND PRIORITY RANKING

This appendix presents the processing algorithms used to perform economic evaluations within *SafetyAnalyst*. Each economic evaluation relies on computations of annual accidents reduced. The algorithm to perform these computations is explained in Appendix C.1. The basic criteria users can specify to perform economic analyses of countermeasures for a site is discussed in Appendix C.2. The algorithms to estimate the three basic economic criteria are shown in the following sections:

- Appendix C.2.1
- Appendix C.2.2
- Appendix C.2.3

A separate algorithm for mathematical optimization used in priority ranking of sites is presented in Appendix C.2.4.

C.1 Algorithm to Estimate Annual Accidents Reduced

Each economic analysis relies on finding the expected number of accidents reduced by a proposed countermeasure for each year in the analysis period. *SafetyAnalyst* implements an Empirical Bayes (EB) approach to estimate this quantity.

Table C-1 introduces the terminology used in these procedures.

The following text provides the mathematical steps on how to estimate the expected number of accidents reduced by proposed countermeasure v at site i for each year in the analysis period. The procedures are similar to the EB procedures given in Module 1 for basic network screening. When the equation number reads "same as" and is hyphenated, it indicates that the equation is the same as an equation given in Module 1. The number preceding the hyphen indicates that the equation is provided in Appendix A for Module 1, and the number after the hyphen indicates the equation number in that Appendix.

Steps 1 through *8* apply to a site and a single countermeasure. When multiple countermeasures or combinations of countermeasures are under evaluation at a site, *Steps 1* through *8* will be repeated for each single countermeasure and/or countermeasure combination selected by the user.

When multiple sites are combined into a project, *Steps 1* through *8* are performed separately on a site-by-site basis for all sites in a given project as described in *Step 9*. In *Step 10*, the results from the individual sites are combined into a single measure of effectiveness for the given project for the given countermeasure. For any given analysis of a project, only one type of countermeasure may be considered at a time.

At a given site during each year, the EB approach takes a weighted average of the observed accident count, K, and the predicted accident frequency, κ, in the history period to estimate the EB adjusted expected accident frequency, X, in the history period. This procedure is explained in *Steps 1* through *5*.

(a) For roadway segments or ramps:

Step 1a: Using the appropriate SPF model parameters, compute for each year in the **history period** (i.e., y = 1, 2, ..., Y), the predicted number of accidents per mile, κ_y, for TOT and FI accidents as follows:

$$\kappa_{y(TOT)} = SPF_{TOT}\{ADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times ADT_y^{\beta_1} \qquad \text{(same as A-1)}$$

$$\kappa_{y(FI)} = SPF_{FI}\{ADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_y^{\beta_1} \qquad \text{(same as A-2)}$$

Table C-1. Summary of Nomenclature Used for Economic Appraisals

Term	Explanation
i	Subscript to represent site i
y	Subscript to represent the year y • The first full year of the history period for which data are available or the first year after major reconstruction is year 1 (i.e., y=1) • The last full year of the history period for which accident and ADT data are available is year Y (i.e., y=Y) • By default, Y equals the number of years of available accident and ADT data for the History Period. For example, if History Period End date equals 12/31/1996 and History Period Start date equals 1/1/1993, then the number of years of available accident and ADT data equals 4.
H	Subscript to denote the History period. These are the years for which accident and ADT data are available from the *SafetyAnalyst* inventory database.
F	Subscript to denote the Future analysis period.
M	In calculating the ADT growth factor, M is the value of the calendar year of the History Period End date.
EIY	Expected Implementation Year of a countermeasure (i.e., the first full calendar year after implementation of a countermeasure. The EIY is considered the first year of the analysis period.)
N	Number of years in the analysis period
N	Subscript to denote year in the analysis period, i.e., n = 1, 2, ..., N
TOT	Subscript to denote total accidents
FI	Subscript to denote fatal and all injury accidents
FS	Subscript to denote fatal and severe injury accidents
PDO	Subscript to denote property damage only accidents
ADT_y	ADT during year y (nonintersection sites)
$MajADT_y$	Major road ADT at an intersection during year y
$MinADT_y$	Minor road ADT at an intersection during year y
GF	Average Growth Factor of ADT
SL	Segment length of a site (nonintersection sites), expressed in mi
SPF_{TOT}, SPF_{FI} α, β_1, β_2, d	Safety Performance Function, applicable to a given type of sites. It includes the following regression coefficients (on the log scale) and parameters: • α: intercept • β_1: coefficient of ADT (nonintersection sites) or of MajADT (major road of intersection) • β_2: coefficient of MinADT (minor road of intersection) • d: overdispersion parameter associated with the negative binomial regression NOTE 1: For the interim tool, two SPFs are available for a given type of site: SPF_{TOT} and SPF_{FI}. Each has its own set of parameters.
$PCT_{(TOT)}$, $PCT_{(FI)}$ $cy_{(TOT)}$, $cy_{(FI)}$	• $PCT_{(TOT)}$: proportion of TOT accidents of a specified collision type • $PCT_{(FI)}$: proportion of FI accidents of a specified collision type • $cy_{(TOT)}$: calibration factor for TOT accidents in year y • $cy_{(FI)}$: calibration factor for FI accidents in year y NOTE 2: All coefficients and parameters related to SPFs are obtained from *SafetyAnalyst* system database: SPF Defaults, Calibration Factors, and Accident Distribution Defaults by Collision Type.
K_y	Observed number of accidents during year y
κ_y	Predicted number of accidents using the SPF during year y (expressed on a per mile basis for roadway segments and on a per site basis for intersection and ramp sites)
C_y	Yearly correction factor for year y relative to year 1

Table C-1. Summary of Nomenclature Used for Economic Appraisals (Continued)

W	A weighting factor to combine observed and predicted accident frequencies at a site
X_y	EB-adjusted expected number of accidents during year y
AMF_v	Accident Modification Factor for countermeasure v
$P_F, P_{II}, P_{NI}, P_{MI}$	Proportions of fatal, incapacitating injury, nonincapacitating injury, and possible injury accidents of all FI accidents • F: Subscript to denote fatal accidents • II: Subscript to denote incapacitating injury accidents • NI: Subscript to denote nonincapacitating injury accidents • MI: Subscript to denote possible injury accidents NOTE: These proportions are stored in the Accident Distribution Defaults by Severity Level tables in the *SafetyAnalyst* system database.
$SW_F, SW_{II}, SW_{NI}, SW_{MI}$	Relative severity weights applied to fatal, incapacitating injury, nonincapacitating injury, and possible injury accidents, respectively NOTE: These weights are stored in the EPDO Weight Defaults table in the *SafetyAnalyst* system database.
RC_{FI}	Relative weight of FI accidents as compared to PDO accidents
EPDO	Equivalent Property Damage Only
S_v	Service life of countermeasure v
CC_v	Construction cost of countermeasure v. This is assumed to be the lump sum cost at year EIY of constructing countermeasure v at a site or along an entire project.
ACC_v	Annual cost of constructing countermeasure v at a site based upon the service life of the countermeasure
PCC_v	Present value of constructing countermeasure v at a site based upon the annualized construction cost across the service life of the countermeasure and the analysis period.
R	Annual rate of return
$AC_F, AC_{SI}, AC_{NI}, AC_{MI}, AC_{PDO}$	Relative costs for fatal, severe injury, nonincapacitating injury, possible injury, and PDO accidents, respectively NOTE: These costs are stored in the Accident Costs Defaults table in the *SafetyAnalyst* system database.
AC_{FI}	Relative accident cost of all severity levels of FI accidents

NOTE 1: To calculate the number of FS injury accidents reduced (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) replace $P_{CT(FI)}$, in Equation (A-2) with $P_{(CT/FS/FI)}$, and (D) proceed as normal for FI calculations.

(b) For intersections:

Step 1b: Using the appropriate SPF model parameters, compute for each year in the **history period** (i.e., y = 1, 2, ...,Y), the predicted number of accidents, κ_y, for TOT and FI accidents as follows:

$$\kappa_{Y(TOT)} = SPF_{TOT}\{MajADT, MinADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^\alpha \times MajADT_y^{\beta_1} \times MinADT_y^{\beta_2} \text{(same as A-122)}$$

$$\kappa_{Y(FI)} = SPF_{FI}\{MajADT, MinADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^\alpha \times MajADT_y^{\beta_1} \times MinADT_y^{\beta_2} \text{(same as A-123)}$$

NOTE 2: Although not explicitly shown in Equations (A-1), (A-2), (A-122), and (A-123), SPF_{TOT} and SPF_{FI} each have their own set of parameters, α, β_1, β_2, and overdispersion parameter d.

NOTE 3: $PCT_{(TOT)}$ and $PCT_{(FI)}$ always equal 1.0.

NOTE 4: To calculate the number of FS injury accidents reduced (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default table to

retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) replace $P_{CT(FI)}$, in Equation (A-2) and Equation (A-123) with $P_{(CT/FS/FI)}$, and (D) proceed as normal for FI calculations.

Step 2: Using the model predictions computed in *Step 1a* or *1b*, compute the yearly correction factors, C_y, for TOT and FI accidents for years y = 1, 2, ...,Y in the **history period**:

$$C_{y(TOT)} = \frac{\kappa_{y(TOT)}}{\kappa_{1(TOT)}}$$ (same as A-3)

$$C_{y(FI)} = \frac{\kappa_{y(FI)}}{\kappa_{1(FI)}}$$ (same as A-4)

Step 3: Using κ_1, ..., κ_Y and the overdispersion parameter, d, compute the weights, w, for TOT and FI accidents:

$$w_{TOT} = \frac{1}{1+d_{TOT}\sum_{y=1}^{Y}\kappa_{y(TOT)}\times L}$$ (same as A-5)

$$w_{FI} = \frac{1}{1+d_{FI}\sum_{y=1}^{Y}\kappa_{y(FI)}\times L}$$ (same as A-6)

NOTE: The weights, $w_{(TOT)}$ and $w_{(FI)}$ are always calculated based upon the "all" accidents for TOT and FI severity levels, even when calculations are being made for the number of FS injury accidents reduced. In other words, the weight $w_{(FS)}$ will actually be based upon "all" FI accidents. The rationale for this change is because weights, $w_{(TOT)}$ and $w_{(FI)}$, are calculated based upon the accuracy/reliability of the SPFs. In concept the accuracy/reliability of the SPF does not change when the calculations are being made for FS injury accidents. The same SPFs for FI accidents are still being used for all calculations, and the accuracy/reliability of the FI SPFs does not change. If the "scaled" predicted values were used in Equation (A-6), then the weight would be adjusted for the wrong reason, not because the accuracy/reliability of the SPFs changed but because the predicted values were scaled as a necessity due to unrelated circumstances.

NOTE 2: In Equation (A-5) and Equation (A-6), L is equal to the segment length, SL for roadway segments, or ramp length, SL_{RAMP} for ramps. For intersections L is set to 1.

Step 4: Calculate the base EB-adjusted expected number of accidents, X_1, for TOT and FI accidents during Year 1 of the **history period**:

$$X_{1(TOT)} = w_{TOT}\kappa_{1(TOT)}SL + (1-w_{TOT})\frac{\sum_{y=1}^{Y}\kappa_{y(TOT)}}{\sum_{y=1}^{Y}C_{y(TOT)}}$$ (same as A-75)

$$X_{1(FI)} = w_{FI}\kappa_{1(FI)}SL + (1-w_{FI})\frac{\sum_{y=1}^{Y}\kappa_{y(FI)}}{\sum_{y=1}^{Y}C_{y(FI)}}$$ (same as A-76)

C-4

NOTE 1: For roadway segments, SL equals the length of the site. For ramps, SL = SL$_{\text{Ramps}}$. For intersections, SL = 1.

NOTE 2: If X$_{1(\text{FI})}$ > X$_{1(\text{TOT})}$, then X$_{1(\text{FI})}$ = X$_{1(\text{TOT})}$

Step 5: Calculate the sum of the EB-adjusted expected number of accidents for the **history period** (y = 1, 2, ...,Y) for TOT and FI accidents:

$$X_{H(\text{TOT})} = \sum_{y=1}^{Y} X_{1(\text{TOT})} C_{y(\text{TOT})} \tag{C-1}$$

$$X_{H(\text{FI})} = \sum_{y=1}^{Y} X_{1(\text{FI})} C_{y(\text{FI})} \tag{C-2}$$

The next step is to estimate the expected value of the accident count that would occur during the analysis period, assuming that the countermeasure **will not be** implemented at a site during a given year. This estimate is obtained by adjusting X from the history period for the difference between ADTs in the history and analysis periods and annualizing. The procedure is explained in *Step 6* below.

(a) For roadway segments or ramps:

Step 6a: Assuming that the countermeasure is **not implemented**, calculate for each year of the **analysis period** (i.e., n = 1, 2, ..., N), the EB-adjusted expected number of accidents for TOT and FI accidents.

$$X_{F(\text{TOT})n} = \frac{X_{H(\text{TOT})}}{\sum_{y=1}^{Y} K_{y(\text{TOT})}} \times \left(C_{Y(\text{TOT})} \times P_{CT(\text{TOT})} \times e^{\alpha} \times \left(ADT_Y \times GF^{(\text{BIY}-M+n-1)} \right)^{\beta_1} \right)$$

$$\tag{C-3}$$

$$X_{F(\text{FI})n} = \frac{X_{H(\text{FI})}}{\sum_{y=1}^{Y} K_{y(\text{FI})}} \times \left(C_{Y(\text{FI})} \times P_{CT(\text{FI})} \times e^{\alpha} \times \left(ADT_Y \times GF^{(\text{BIY}-M+n-1)} \right)^{\beta_1} \right)$$

$$\tag{C-4}$$

(b) For intersections:

Step 6b: Assuming that the countermeasure is **not implemented**, calculate for each year of the **analysis period** (i.e., n = 1, 2, ..., N), the EB-adjusted expected number of accidents for TOT and FI accidents.

$$X_{F(\text{TOT})n} = \frac{X_{H(\text{TOT})}}{\sum_{y=1}^{Y} K_{y(\text{TOT})}} \times$$

$$\left(C_{Y(\text{TOT})} \times P_{CT(\text{TOT})} \times e^{\alpha} \times \left(MajADT_Y \times GF^{(\text{BIY}-M+n-1)} \right)^{\beta_1} \times \left(MinADT_Y \times GF^{(\text{BIY}-M+n-1)} \right)^{\beta_2} \right) \tag{C-5}$$

C-5

$$X_{F(FI)n} = \frac{X_{H(FI)}}{\sum_{y=1}^{Y} K_{y(FI)}} \times$$

$$\left(c_{Y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times \left(MajADT_Y \times GF^{(EIY-M+n-1)} \right)^{\beta_1} \times \left(MinADT_Y \times GF^{(EIY-M+n-1)} \right)^{\beta_2} \right) \quad \text{(C-6)}$$

NOTE 1: In the exponent of GF, the values for M and EIY correspond to calendar years. For example, if the History Period End date is December 31, 2002, then the last full calendar year of available data from the *SafetyAnalyst* inventory database is 2002. If the expected year of implementation for the proposed countermeasure is 2003, then the values in the exponent for the growth factor would be M = 2002 and EIY = 2003.

NOTE 2: The value of GF in Equation (C-3) through Equation (C-6) is specified by the user.

NOTE 3: To calculate the number of FS injury accidents reduced (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ration of FI accidents [$P_{(CT/FS/FS)}$] for the given site subtype, (C) include $P_{(CT/FS/FS)}$, in the second term of Equation (C-4) and Equation (C-6) as a multiplier, and (D) proceed as normal for FI calculations. It is assumed that the proportion of FS injury accidents to FI injury accidents was already applied to the denominator of the first term in Equation (C-4) and Equation (C-6) in *Step 1*.

The next step is to estimate the expected value of the accident count that would occur during the analysis period, assuming that the countermeasure **will be** implemented at a site during a given year. This estimate is obtained by adjusting X from the history period for the difference between ADTs in the history and study periods, for the countermeasure's AMF, and annualizing. The procedure is explained in *Step 7* below.

(a) For roadway segments or ramps:

Step 7a: Assuming that countermeasure v is **implemented**, calculate for each year of the **analysis period** (i.e., n = 1, 2, ..., N), the EB-adjusted expected number of accidents for TOT and FI accidents.

$$X_{Fv(TOT)n} = \frac{X_{H(TOT)}}{\sum_{y=1}^{Y} K_{y(TOT)}} \times \left(c_{Y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times \left(ADT_Y \times GF^{(EIY-M+n-1)} \right)^{\beta_1} \times AMF_{v(TOT)} \right) \quad \text{(C-7)}$$

$$X_{Fv(FI)n} = \frac{X_{H(FI)}}{\sum_{y=1}^{Y} K_{y(FI)}} \times \left(c_{Y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times \left(ADT_Y \times GF^{(EIY-M+n-1)} \right)^{\beta_1} \times AMF_{v(FI)} \right) \quad \text{(C-8)}$$

(b) For intersections:

Step 7b: Assuming that countermeasure v is **implemented**, calculate for each year of the **analysis period** (i.e., n = 1, 2, ..., N), the EB-adjusted expected number of accidents for TOT and FI accidents.

$$X_{Fv(TOT)n} = \frac{X_{H(TOT)}}{\sum_{y=1}^{Y} \kappa_{y(TOT)}} \times$$

$$\left(c_{Y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times \left(\text{MajADT}_Y \times \text{GF}^{(EIY-M+n-1)} \right)^{\beta_1} \times \left(\text{MinADT}_Y \times \text{GF}^{(EIY-M+n-1)} \right)^{\beta_2} \times \text{AMF}_{v(TOT)} \right) \quad \text{(C-9)}$$

$$X_{Fv(FI)n} = \frac{X_{H(FI)}}{\sum_{y=1}^{Y} \kappa_{y(FI)}} \times$$

$$\left(c_{Y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times \left(\text{MajADT}_Y \times \text{GF}^{(EIY-M+n-1)} \right)^{\beta_1} \times \left(\text{MinADT}_Y \times \text{GF}^{(EIY-M+n-1)} \right)^{\beta_2} \times \text{AMF}_{v(FI)} \right) \quad \text{(C-10)}$$

NOTE 1: In the exponent of GF, the values for M and EIY correspond to calendar years (see Note 2 of *Step 6*).

NOTE 2: The value for the AMF of a countermeasure is provided from the Countermeasure Default file. When combinations of countermeasures are proposed for implementation, the value of the AMF for the combination is the product of the AMFs of the individual countermeasures.

NOTE 3: To calculate the number of FS injury accidents reduced (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ration of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) include $P_{(CT/FS/FI)}$, in the second term of Equation (C-8) and Equation (C-10) as a multiplier, and (D) proceed as normal for FI calculations. It is assumed that the proportion of FS injury accidents of FI injury accidents was already applied to the denominator of the first term in Equation (C-8) and Equation (C-10) in *Step 1*.

The final step is to compare the estimated accident counts in each year of the study period when the countermeasure would be implemented to the estimated accident counts when the countermeasure would not be implemented. The procedure is explained in *Steps 8* through *10*.

Step 8: For each year in the **analysis period** (i.e., n = 1, 2, ..., N), calculate the expected number of accidents reduced by countermeasure v for TOT, FI, FS, PDO, and EPDO accidents.

$$AR_{v(TOT)n} = X_{F(TOT)n} - X_{Fv(TOT)n} \quad \text{(C-11)}$$

$$AR_{v(FS)n} = X_{F(FS)n} - X_{Fv(FS)n} \quad \text{(C-12)}$$

$$AR_{v(FI)n} = X_{F(FI)n} - X_{Fv(FI)n} \quad \text{(C-13)}$$

$$AR_{v(PDO)n} = AR_{v(TOT)n} - AR_{v(FI)n} \quad \text{(C-14)}$$

NOTE 1: If $AR_{v(FI)n} > AR_{v(TOT)n}$, then $AR_{v(TOT)n} = AR_{v(FI)n}$.

To calculate the EPDO expected number of accidents reduced for each year in the analysis period, use the relative severity weights, SW, for fatal (F), severe injury (SI), nonincapacitating injury (NI), and possible injury (MI) severity levels. Let RC_{FI} be the relative weight of FI accidents as compared to PDO accidents. RC_{FI} is calculated as follows:

$$RC_{FI} = P_F SW_F + P_{SI} SW_{SI} + P_{NI} SW_{NI} + P_{MI} SW_{MI} \qquad \text{(same as A-15)}$$

The EPDO expected number of accidents reduced for each year in the analysis period is then calculated as:

$$AR_{v(EPDO)n} = AR_{v(PDO)n} + RC_{FI} AR_{v(FI)n} \qquad \text{(C-15)}$$

When a roadway segment is being considered as an individual site in the analysis, the expected numbers of accidents reduced for each year in the analysis period (AR_{vn}) are the final calculations for a given site and countermeasure.

NOTE 2: When the user selects to priority rank countermeasures and sites by FS or FI accidents reduced, the number of fatalities and the number of injuries reduced will be included on the output report. For this calculation, the *SafetyAnalyst* database contains data on fatalities per accident and injuries per accident (i.e., $AccRate_{(F/CT/FS)}$, $AccRate_{(I/CT/FS)}$, $AccRate_{(F/CT/FI)}$, and $AccRate_{(I/CT/FI)}$) and is searched to find the corresponding values based on site subtype. Use the sum of the accident rates across all collision types in Equations (C-14A) through (C-14D) to calculate the number of fatalities reduced and the number of injuries reduced as follows:

$$\text{No. of Expected Fatalities Reduced}_{(F/FS)} = \sum_{n=1}^{N} AR_{v(FS)n} \times AccRate_{(F/CT/FS)} \qquad \text{(C-16)}$$

$$\text{No. of Expected Injuries Reduced}_{(I/FS)} = \sum_{n=1}^{N} AR_{v(FS)n} \times AccRate_{(I/CT/FS)} \qquad \text{(C-17)}$$

$$\text{No. of Expected Fatalities Reduced}_{(F/FI)} = \sum_{n=1}^{N} AR_{v(FI)n} \times AccRate_{(F/CT/FI)} \qquad \text{(C-18)}$$

$$\text{No. of Expected Injuries Reduced}_{(I/FI)} = \sum_{n=1}^{N} AR_{v(FI)n} \times AccRate_{(I/CT/FI)} \qquad \text{(C-19)}$$

CALCULATION ADJUSTMENTS FOR PROJECTS: When multiple roadway segments are combined into a project, proceed with *Steps 9* and *10*.

Step 9: Repeat *Steps 1* through *8* for each site i in the project.

NOTE: *Steps 1* through *8* describe the process of calculating the number of annual accidents reduced by a given countermeasure for each year in the analysis period for a given site. In general, a subscript (i) could be added to the equations in each of these steps.

Step 10: For each year in the analysis period (i.e., n = 1, 2, ..., N), calculate the expected number of accidents reduced by countermeasure v for the given project for TOT, FI, FS, PDO, and EPDO accidents by summing over all sites i in the project.

$$AR_{v(TOT)n} = \Sigma_i X_{F(TOT)n} - \Sigma_i X_{Fv(TOT)n} \tag{C-20}$$

$$AR_{v(FS)n} = \Sigma_i X_{F(FS)n} - \Sigma_i X_{Fv(FS)n} \tag{C-21}$$

$$AR_{v(FI)n} = \Sigma_i X_{F(FI)n} - \Sigma_i X_{Fv(FI)n} \tag{C-22}$$

$$AR_{v(PDO)n} = AR_{v(TOT)n} - AR_{v(FI)n} \tag{C-23}$$

$$AR_{v(EPDO)n} = AR_{v(PDO)n} + RC_{FI}AR_{v(FI)n} \tag{C-24}$$

NOTE 1: The EPDO estimates for sites and projects are only utilized in calculating cost-effectiveness.

NOTE 2: When the user selects to priority rank countermeasures and sites by FS or FI accidents reduced, the number of fatalities and the number of injuries reduced will be included on the output report. For this calculation, the *SafetyAnalyst* database contains data on fatalities per accident and injuries per accident (i.e., $AccRate_{(F/CT/FS)}$, $AccRate_{(I/CT/FS)}$, $AccRate_{(F/CT/FI)}$, and $AccRate_{(I/CT/FI)}$) and is searched to find the corresponding values based on site subtype. Use the sum of the accident rates across all collision types in Equations (C-16) through (C-19) to calculate the number of fatalities reduced and the number of injuries reduced as follows:

$$\text{No. of Expected Fatalities Reduced}_{(F/FS)} = \Sigma_{n=1}^{N} AR_{v(FS)n} \times AccRate_{(F/CT/FS)} \tag{C-16}$$

$$\text{No. of Expected Injuries Reduced}_{(I/FS)} = \Sigma_{n=1}^{N} AR_{v(FS)n} \times AccRate_{(I/CT/FS)} \tag{C-17}$$

$$\text{No. of Expected Fatalities Reduced}_{(F/FI)} = \Sigma_{n=1}^{N} AR_{v(FI)n} \times AccRate_{(F/CT/FI)} \tag{C-18}$$

$$\text{No. of Expected Injuries Reduced}_{(I/FI)} = \Sigma_{n=1}^{N} AR_{v(FI)n} \times AccRate_{(I/CT/FI)} \tag{C-19}$$

C.2 Criteria for Economic Evaluations

This section explains the calculations used in the economic analyses, depending upon the economic criteria specified by the user.

C.2.1 Algorithm to Estimate Cost-Effectiveness

In evaluating a countermeasure based upon the cost-effectiveness criterion, the cost-effectiveness of the countermeasure is expressed in terms of dollars spent per accident reduced. Countermeasures with lower cost per accident reduced are more likely to maximize the benefits of an improvement program than countermeasures with higher cost per accident reduced. Calculation of the cost-effectiveness ratio is dependent upon the service life of a countermeasure, the analysis period being considered, construction costs, and the expected accidents reduced as a result of the countermeasure.

Calculating the cost-effectiveness ratio consists of three phases:

- The first phase involves estimating the expected number of accidents reduced by a given countermeasure for the given site or project (AR_{vn}). This procedure is described in Appendix (C.10).

- The second phase involves calculating the present value of the construction costs for implementing a countermeasure (PCC_v). These calculations are described next in *Steps 1* through *3*.

- The accident predictions and the construction costs are combined in the final phase (see *Step 4* below).

Step 1: Calculate the lump sum construction cost (CC_v) for implementing countermeasure v at site (or project) i during year EIY.

Procedures for calculating the construction cost (CC_v) for implementing a countermeasure at a given site are provided in Section 3.7. In some cases the construction cost for implementing a countermeasure is a fixed cost. In other cases, the construction cost is a function of the site characteristics.

Step 2: Calculate the annual construction cost for implementing countermeasure v at site (or project) i given the service life (S_v) of the countermeasure and the annual rate of return (R).

$$ACC_v = CC_v \times \frac{R(1+R)^{S_v}}{(1+R)^{S_v}-1} \tag{C-25}$$

Step 3: Calculate the present value of the construction cost (PCC_v) for implementing countermeasure v at site (or project) i based upon the annualized construction cost (ACC_v), the annual rate of return (R), and the analysis period (N).

$$PCC_v = ACC_v \times \frac{(1+R)^N-1}{R(1+R)^N} \tag{C-26}$$

Step 4: Calculate the cost-effectiveness of countermeasure v (CE_v) at site (or project) i for the entire analysis period for TOT and EPDO accidents.

$$CE_{v(TOT)} = \frac{PCC_v}{\sum_{n=1}^{N} AR_{v(TOT)n}} \tag{C-27}$$

$$CE_{v(EPDO)} = \frac{PCC_v}{\sum_{n=1}^{N} AR_{v(EPDO)n}} \tag{C-28}$$

NOTE: The calculations above assume the proposed countermeasure will be implemented along the entire site. *SafetyAnalyst* also estimates the cost-effectiveness of a proposed countermeasure installed along a portion or subsegment of a site. The calculations as described above are performed in the exact same manner taking into consideration the boundaries of the proposed countermeasure as defined by the analyst.

C.2.2 Algorithm to Estimate Benefit-Cost Ratio

The benefit-cost ratio is the ratio of the present safety benefit of a countermeasure to its construction costs. For a countermeasure to be economically justified by this criterion, its benefit-cost ratio should be greater than 1.0. The most desirable countermeasures are those with the highest benefit-cost ratios.

Calculating the benefit-cost ratio consists of four phases:

- The first phase involves estimating the expected number of accidents reduced by a given countermeasure for the given site or project (AR_{vn}). This procedure is described in Appendix C.1.

- The second phase involves calculating the present value of the safety benefits of the countermeasure at the given site or project (PSB_v). These calculations are described below in *Steps 1 and 2*.

- The third phase involves calculating the present value of the construction cost for implementing countermeasure v at site or project i (PCC_v). These calculations are described in Appendix C.2.1.

- The final phase involves calculating the ratio of the present values of the safety benefits to the construction costs (see *Step 3* below).

Step 1: Calculate the relative accident cost for all severity levels of FI accidents (AC_{FI}). This relative cost is calculated by taking a weighted average of the accident cost values and the statewide accident proportion values for the respective accident severity levels as follows:

$$AC_{FI} = P_F AC_F + P_{SI} AC_{SI} + P_{NI} AC_{NI} + P_{MI} AC_{MI} \qquad \text{(C-29)}$$

Step 2: Calculate the present value of safety benefits of countermeasure v at site (or project) i by calculating the monetary present value of the estimated annual accidents reduced for the analysis period.

$$PSB_v = \sum_{n=1}^{N} \frac{AR_{v(PDO)n} \times AC_{PDO}}{(1+R)^{EIY-M+n-1}} + \sum_{n=1}^{N} \frac{AR_{v(FI)} \times AC_{FI}}{(1+R)^{EIY-M+n-1}} \qquad \text{(C-30)}$$

Step 3: Calculate the benefit-cost ratio for countermeasure v at site (or project) i:

$$BC_v = \frac{PSB_v}{PCC_v} \qquad \text{(C-31)}$$

NOTE: The calculations above assume the proposed countermeasure will be implemented along the entire site. SafetyAnalsyt also estimates the benefit-cost ratio of a proposed countermeasurre installed along a portion or subsegment of a site. The calculations as

described above are performed in the exact same manner taking into consideration the boundaries of the proposed countermeasure as defined by the analyst.

C.2.3 Algorithm to Estimate Net Benefits

The net benefits criterion assesses countermeasures via the difference between safety benefits and construction costs. For a countermeasure to be economically justified by this criterion, the net benefits should be greater than zero. For this approach, the most desirable improvements are those with the highest net benefits.

Calculating the net benefits criterion consists of four phases:

- The first phase involves estimating the expected number of accidents reduced by a given countermeasure for the given site or project (AR_{vn}). This procedure is described in Appendix C.1.

- The second phase involves calculating the present value of the safety benefits of the countermeasure at the given site or project (PSB_v). These calculations are described in Appendix C.2.2.

- The third phase involves calculating the present value of the construction cost for implementing countermeasure v at site or project i (PCC_v). These calculations are described in Appendix C.2.1.

- The final phase involves calculating the difference between the present value of the safety benefits and the present value of the construction costs (see *Step 1* below).

Step 1: Calculate the net benefits for countermeasure v at site (or project) i:

$$NB_v = PSB_v - PCC_v \qquad \text{(C-32)}$$

NOTE: The calculations above assume the proposed countermeasures will be implemented along the entire site. *SafetyAnalyst* also estimates the net benefits of a proposed countermeasure installed along a portion or subsegment of a site. The calculations as described above are performed in the exact same manner taking into consideration the boundaries of the proposed countermeasrue as defined by the analyst.

C.2.4 Maximizing Net Benefits of an Improvement Program

In *SafetyAnalyst* the user can maximize the net benefits across all sites and countermeasures under evaluation, taking into consideration budgetary constraints. This optimization is performed using Integer Programming (IP). IP is a linear programming technique in which some, or all, of the decision variables are restricted to integer values. The integer program for Module 3, which optimizes the net benefits criterion, can be determined with the following equation:

$$\text{Maximize TB} = \sum_i \sum_v NB_{iv} Z_{iv} \tag{C-33}$$

subject to the following constraints:

$$\sum_v Z_{1v} = 1 \tag{C-34}$$

$$\sum_v Z_{2v} = 1 \tag{C-35}$$

$$\sum Z_{iv} = 1 \tag{C-36}$$

$$\sum_i \sum_v PCC_{iv} Z_{iv} \leq B \tag{C-37}$$

where:

TB = total benefits from all selected countermeasures

Z_{iv} = a decision variable whose value is 1 if countermeasure v at site (or project) i is selected as part of the optimum solution; and 0 if countermeasure v at site (or project) i is not selected as part of the optimum solution. For each site (or project), exactly one countermeasure (or combination of countermeasures) should be selected.

B = improvement budget or maximum funding available for countermeasures implemented at sites in the current site list.

Equation (C-33), which represents the total benefits (TB) to be maximized, is the objective function of the integer program. Changing the decision values in the sum-product of the net benefit and decision values optimizes the target value, or total benefits.

Equation (C-34) through Equation (C-37) represent the constraints on the objective function. They require that one and only one countermeasure (or combinations of countermeasures) can be selected for each site. The last inequality constrains the total construction costs of countermeasures not to exceed the available budget.

Before optimization processing begins, the user inputs the total budget available from which countermeasures can be financed. The following steps are taken to obtain the final solution from the optimization program.

Step 1: Create the Do Nothing or No Build alternative (countermeasure) for each site in the current site list. For this alternative, NB = 0.

Step 2: Perform reduction algorithm on list of sites and countermeasures.

Since the computations involved for integer programming are quite labor intensive and repetitive, the list of possible sites and countermeasures can be reduced before submitting them to the optimization program. Countermeasures for a site can be deleted if:

- NB
- A countermeasure alternative for a site dominates another countermeasure alternative for the same site. Countermeasure 1 dominates Countermeasure 2 when Countermeasure 1 costs less ($PCC_1 \leq PCC_2$) and has greater benefits ($PSB_1 \geq PSB_2$) than Countermeasure 2. In this determination, the Do Nothing alternative should never be eliminated.

Step 3: Create decision variable (true/false indicator) for each site and its associated countermeasures in the list and set the value to false (or zero).

Step 4: Set parameters/create variables for optimization program.

- Choose to maximize target value, or the sum-product of the economic criterion and decision variable, for all sites and their associated countermeasures in the list, by changing values of the decision variable.

- Add constraint to limit decision variable to 1 or 0.

- For each site, add constraint to choose only one alternative, or the sum of the decision variables, for a site = 1.

- Add constraint to limit total construction cost (sum-product of construction cost and decision variable for all sites and their associated countermeasures in list) to the user-entered budget.

NOTE: This step indicates that only one alternative may be chosen for a site. This alternative could be the implementation of a single countermeasure or a combination of countermeasures. During the analysis of a combination of countermeasures, the combination is treated as a single countermeasure by (1) multiplying the AMFs of the individual countermeasures to get a single AMF value, (2) adding the construction costs of the individual countermeasures to get a single construction cost (except when service lives are different, (3) taking the maximum service life for the individual countermeasures to get a single service life.

Step 5: Execute optimization program.

The final solution of the optimization program has a one (or true value) in the decision variable for the sites and their associated countermeasures selected by the program.

The optimization calculations are performed using LP Solve which is commercially available. In using this program, default values need to be set for the following parameters:

- Percent tolerance of true optimum solution
- Maximum time to run optimization program
- Maximum iterations to perform in finding solution

The user has the ability to modify the default values.

NOTE: The calculations above assume the proposed countermeasure will be implemented along the entire site. *SafetyAnalyst* also maximizes the net benefits of proposed countermeasures installed along a portion or subsegment of sites. The calculations as described above are performed in the exact same manner taking into consideration the boundaries of the proposed countermeasure as defined by the analyst.

C.2.5 Reporting of Other Ranking Criteria

In addition to providing results based upon cost-effectiveness (CE_y), benefit-cost ratio (BC_y), and net benefits (NB_y), additional ranking criteria that may be reported include:

- Construction costs (PCC_y)
- Safety benefits (PSB_y)
- Number of TOT, FS, and FI accidents reduced (Ar_y)

Detailed Procedures for *SafetyAnalyst* Module 4— Countermeasure Evaluation

APPENDIX D. DETAILED PROCEDURES FOR *SAFETYANALYST* MODULE 4— COUNTERMEAUSRE EVALUATION

D.1 Procedures for Evaluating Countermeasures

D.1.1 Algorithm to Estimate Percent Change in Total, FI, FS, and PDO Accident Frequency

SafetyAnalyst implements the Empirical Bayes (EB) approach to estimate the percent change in accident frequency due to an implemented countermeasure. The EB approach is the only known approach that can be practically implemented in before-after evaluations that directly addresses regression to the mean. The basic steps in the EB approach are as follows:

1. Estimate the number of accidents in the BEFORE period.

2. Estimate the number of accidents in the AFTER period in the absence of a treatment.

3. Compare the observed number of accidents after the treatment is implemented to the estimated number of accidents in the after period in the absence of a treatment.

Table D-1 presents the nomenclature used in the Module 4 algorithms.

D.1.1.1 EB Estimation of the Number of Accidents in the Before Period

For each site i in the site list, the EB approach takes a weighted average of the observed accident count, K_i, and the predicted accident frequency, κ_i, in the before period to estimate the EB adjusted expected accident frequency, X_i, in the before period. This procedure is explained in *Step 1* through *Step 7*.

(a) For roadway segments or ramps:

Step 1a: Using the appropriate SPF model parameters, compute for each <u>before</u> year $(y = 1, 2,...,Y)$ the predicted number of accidents, κ_{iy}, per mile, for TOT and FI accidents for site i:

$$\kappa_{iy(TOT)} = SPF_{TOT}\{ADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times ADT_{iy}^{\beta_1} \tag{D-1}$$

$$\kappa_{iy(FI)} = SPF_{FI}\{ADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_{iy}^{\beta_1} \tag{D-2}$$

(b) For intersections:

Step 1b: Using the appropriate SPF model parameters, compute for each before year ($y = 1$, 2,...,Y) the predicted number of accidents, κ_{iy}, for TOT and FI accidents at intersection i:

$$\kappa_{iy(TOT)} = SPF_{TOT}\{MajADT, MinADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times MajADT_{iy}^{\beta_1} \times MinADT_{iy}^{\beta_2} \quad \text{(D-3)}$$

$$\kappa_{iy(FI)} = SPF_{FI}\{MajADT, MinADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times MajADT_{iy}^{\beta_1} \times MinADT_{iy}^{\beta_2} \quad \text{(D-4)}$$

Table D-1. Summary of Nomenclature Used for Countermeasure Evaluation (Module 4)

Term	Explanation
i	Subscript to represent site (or project) i
y	Subscript to represent the year y; the last year in the before period is year Y.
BT	Subscript indicating the before treatment period
AT	Subscript indicating the after treatment period
TOT	Subscript to denote total accidents
FI	Subscript to denote fatal and all injury accidents
FS	Subscript to denote fatal and severe injury accidents
PDO	Subscript to denote property damage only accidents
CT	Subscript to denote any collision type
$YEARS_{BT,i}$	Number of years in before treatment period at site i (thus, $YEARS_{BT,i}$ corresponds to Y)
$YEARS_{AT,i}$	Number of years in after treatment period at site i
ADT_{iy}	ADT at site i during year y (nonintersection sites)
$MajADT_{iy}$	Major road ADT at intersection i during year y
$MinADT_{iy}$	Minor road ADT at intersection i during year y
SL_i	Segment length of site l (nonintersection sites), expressed in mi
SPF_{TOT}, SPF_{FI} $\square$, $\square_1$, $\square_2$, d	Safety Performance Function, applicable to a given type of sites. It includes the following regression coefficients (on the log scale) and parameters: - $\square$: intercept - $\square_1$: coefficient of ADT (nonintersection sites) or of MajADT (major road of intersection) - $\square_2$: coefficient of MinADT (minor road of intersection) - d: overdispersion parameter associated with the negative binomial regression (expressed on a per mile basis for nonintersection sites) **NOTE 1:** Two SPFs are available for a given type of site: SPF_{TOT} and SPF_{FI}. Each has its own set of parameters.
$P_{CT(TOT)}$, $P_{CT(FI)}$, $P_{(CT/FS/FI)}$ $c_{y(TOT)}$, $c_{y(FI)}$	- $P_{CT(TOT)}$: proportion of TOTAL accidents of a specified collision type - $P_{CT(FS/FI)}$: proportion of FI accidents of a specified collision type - $P_{CT(FI)}$: proportion of FS accidents of a specified collision type to all FI accidents - $c_{y(TOT)}$: calibration factor for TOTAL accidents in year y - $c_{y(FI)}$: calibration factor for FI accidents in year y - **NOTE 2:** All coefficients and parameters related to SPFs are provided in the master SafetyAnalyst database.
K_{iy}	Observed number of accidents during before period at site i during before year y
K_i	Observed number of accidents during before period at site i, summed over all before years
L_{iy}	Observed number of accidents during after period at site i during after year y
L_i	Observed number of accidents during after period at site i, summed over all after years
$\square_y$	Predicted number of accidents during the before period using the SPF at site i during before year y
$\square$	Predicted number of accidents during the before period using the SPF at site i, summed over all before years
w_i	A weighting factor to combine observed and predicted accident frequencies at site i
X_{iy}	EB-adjusted expected number of accidents during the before period at site i during before year y
X_i	EB-adjusted expected number of accidents during the before period at site i, summed over all before years
$\square$	Final EB expected number of accidents during the after period in the absence of treatment at site i, summed over all after years
$\square$	Expected number of accidents during the after period in the presence of treatment at site i, summed over all after years. This quantity equals L_i
r_i	Adjustment factor to account for differences between before and after period durations and between before and after traffic volumes at site i
$\square$	Estimate of the effectiveness of a treatment at site i
$\square$	Overall estimate of the effectiveness of a treatment at sites of a specific type
E_i	Estimated percentage before-to-after accident change at site i.
E	Overall estimated percentage before-to-after accident change at sites of a specific type
E(X)	Expected value (mean) of a random variable X
Var(X)	Variance of a random variable X
STD(X)	Standard deviation of a random variable X; $Var(X) = [STD(X)]^2$

D-2

NOTE 1: When the user specifies that the evaluation is to only consider a certain collision type, the respective proportion or proportions of $P_{CT(TOT)}$ and $P_{CT(FI)}$ are obtained from the SafetyAnalyst system database. When the collision type of interest is "all" TOT accidents, then $P_{CT(TOT)} = 1$; similarly, when the accident type of interest is "all" FI accidents, then $P_{CT(FI)} = 1$.

NOTE 2: If multiple collision types are selected for analysis, then $P_{CT(TOT)}$ and $P_{CT(FI)}$ are the sum of the individual proportions pertaining to the selected collision types.

NOTE 3: If the evaluation is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents $[P_{(CT/FS/FI)}]$ for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, (D) replace $P_{CT(FI)}$ in Equation (D-2) and Equation (D-4) with $P_{(CT/FS/FI)}$, and (E) proceed as normal for FI calculations.

Step 2: Sum the number of accidents across all before years at site i for TOT and FI accidents.

$$\kappa_{i(TOT)Before} = \sum_{y(Before\ Years)} \kappa_{iy(TOT)} \tag{D-5}$$

$$\kappa_{i(FI)Before} = \sum_{y(Before\ Years)} \kappa_{iy(FI)} \tag{D-6}$$

NOTE: These computations will be used in *Step 10*.

Step 3: Using the model predictions computed in *Step 1a* or *Step 1b*, compute the yearly correction factors, C_{iy}, for TOT and FI accidents for years y = 1, 2,...,Y:

$$C_{iy(TOT)} = \frac{\kappa_{iy(TOT)}}{\kappa_{i1(TOT)}} \tag{D-7}$$

$$C_{iy(FI)} = \frac{\kappa_{iy(FI)}}{\kappa_{i1(FI)}} \tag{D-8}$$

Step 4: Using κ_{i1},..., κ_{iy} (for before years) and the overdispersion parameter, d, compute the weights, w_i, for TOT and FI accidents:

$$w_{TOT} = \frac{1}{1+d_{TOT}\sum_{y=1}^{Y}\kappa_{y(TOT)}\times SL_i} \tag{D-9}$$

$$w_{FI} = \frac{1}{1+d_{FI}\sum_{y=1}^{Y}\kappa_{y(FI)}\times SL_i} \tag{D-10}$$

NOTE 1: The weights, $w_{(TOT)}$ and $w_{(FI)}$, are always calculated based upon the "all" accidents for TOT and FI severity levels. In other words, for those instances when the countermeasure evaluation is based upon a certain collision type or types, the predicted value calculated in *Step 1* is scaled, based upon a proportion or a sum of proportions. Rather than using the scaled value of predicted accidents in Equation (D-9) and Equation (D-10), the predicted value before multiplying by the respective proportion will be used to calculate the weights $w_{(TOT)}$ and $w_{(FI)}$. The same principle applies when the calculations are based upon FS injuries. The weight $w_{(FS)}$ will actually be based upon "all" FI accidents. The rationale for this is because weights, $w_{(TOT)}$ and $w_{(FI)}$ are calculated based upon the accuracy/reliability of the SPFs. In concept the accuracy/reliability of the SPF does not change when the screening is based upon certain collision type or FS injury accidents. The same SPFs for TOT and FI accidents are still being used for all calculations, and the accuracy/reliability of the TOT and FI SPFs does not change. If the "scaled" predicted values were used in Equation (D-9) and Equation (D-10), then the weights would be adjusted for the wrong reason, not because the accuracy/reliability of the SPFs changed but because the predicted values were scaled as a necessity due to unrelated circumstances.

NOTE 2: For intersections, set $SL_i = 1$.

Step 5: Calculate the EB-adjusted expected number of accidents, X_{iy}, for TOT and FI accidents for each year in the before period (i.e., $y = 1,2...,Y$) at site i:

$$X_{iy(TOT)} = \left[w_{i(TOT)} \kappa_{iy(TOT)} SL_i + \left(1 - w_{i(TOT)}\right) \frac{\sum_{y=1}^{Y} \kappa_{iy(TOT)}}{\sum_{y=1}^{Y} C_{iy(TOT)}} \right] \times C_{iy(TOT)} \qquad \text{(D-11)}$$

$$X_{iy(FI)} = \left[w_{i(FI)} \kappa_{iy(FI)} SL_i + \left(1 - w_{i(FI)}\right) \frac{\sum_{y=1}^{Y} \kappa_{iy(FI)}}{\sum_{y=1}^{Y} C_{iy(FI)}} \right] \times C_{iy(FI)} \qquad \text{(D-12)}$$

NOTE 1: For intersections, set $SL_i = 1$.

NOTE 2: If $X_{iy(FI)} > X_{iy(TOT)}$, then set $X_{iy(FI)} = X_{iy(TOT)}$.

NOTE 3: The observed accidents in Equation (D-11) and Equation (D-12) should be those of the respective collision types and severity levels as specified by the user.

Step 6: For each year in the before period (i.e., $y = 1,2...,Y$), calculate the EB-adjusted expected number of accidents, X_{iy}, for PDO accidents at site i:

$$X_{iy(PDO)} = X_{iy(TOT)} - X_{iy(FI)} \qquad \text{(D-13)}$$

NOTE: Calculations for PDO accidents must be based upon calculations for TOT and FI accidents. Calculations for PDO accidents cannot be based upon calculation from TOT and FS accidents.

Step 7: Calculate the EB-adjusted expected number of accidents, X_i, for the entire before period at site i for TOT, FI, and PDO accidents:

$$X_{i(TOT)} = \sum_{y(\text{Before Years})} X_{iy(TOT)} \tag{D-14}$$

$$X_{i(FI)} = \sum_{y(\text{Before Years})} X_{iy(FI)} \tag{D-15}$$

$$X_{i(PDO)} = \sum_{y(\text{Before Years})} X_{iy(PDO)} \tag{D-16}$$

D.1.1.2 EB Estimation of the Number of Accidents in the After Period in the Absence of Treatment

The objective of this step is to estimate π_i, the expected value of the accident count that would have occurred during the after period had the improvement not been implemented at site i. This estimate is obtained by adjusting X_i from the before period for the difference between before and after ADTs and between before and after number of years. The procedure is explained in *Step 8* through *Step 11*.

(a) For roadway segments or ramps:

Step 8a: Using the appropriate SPF model parameters, compute for each **after** year y the predicted number of accidents, κ_{iy}, for TOT and FI accidents at site i:

$$\kappa_{iy(TOT)} = SPF_{TOT}\{ADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times ADT_{iy}^{\beta_1} \tag{D-1}$$

$$\kappa_{iy(FI)} = SPF_{FI}\{ADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_{iy}^{\beta_1} \tag{D-2}$$

(b) For intersections:

Step 8b: Using the appropriate SPF model parameters, compute for each **after** year y the predicted number of accidents, κ_{iy}, for TOT and FI accidents at intersection i:

$$\kappa_{iy(TOT)} = SPF_{TOT}\{MajADT, MinADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times MajADT_{iy}^{\beta_1} \times MinADT_{iy}^{\beta_2} \tag{D-3}$$

$$\kappa_{iy(FI)} = SPF_{FI}\{MajADT, MinADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times MajADT_{iy}^{\beta_1} \times MinADT_{iy}^{\beta_2} \tag{D-4}$$

NOTE: If the evaluation is based upon FS , then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, (D) replace $P_{CT(FI)}$ in Equation (D-2) and Equation (D-4) with $P_{(CT/FS/FI)}$, and (E) proceed as normal for FI calculations.

D-5

Step 9: Sum the number of accidents across all after years at site i for TOT and FI accidents.

$$\kappa_{i(TOT)After} = \sum_{y(After\ Years)} \kappa_{iy(TOT)} \tag{D-17}$$

$$\kappa_{i(FI)After} = \sum_{y(After\ Years)} \kappa_{iy(FI)} \tag{D-18}$$

Step 10: For TOT and FI accidents, calculate the adjustment factor to account for the duration of the after period and traffic changes relative to the before period at site i as:

$$r_{i(TOT)} = \frac{\kappa_{i(TOT)After}}{\kappa_{i(TOT)Before}} \tag{D-19}$$

$$r_{i(FI)} = \frac{\kappa_{i(FI)After}}{\kappa_{i(FI)Before}} \tag{D-20}$$

Step 11: Calculate the total expected number of TOT, FI, and PDO accidents during the after period had the improvement not been made at site i as:

$$\pi_{i(TOT)} = X_{i(TOT)} \times r_{i(TOT)} \tag{D-21}$$

$$\pi_{i(FI)} = X_{i(FI)} \times r_{i(FI)} \tag{D-22}$$

$$\pi_{i(PDO)} = \pi_{i(TOT)} - \pi_{i(FI)} \tag{D-23}$$

NOTE 1: If $\pi_{i(FI)} > \pi_{i(TOT)}$, then set $\pi_{i(FI)} = \pi_{i(TOT)}$.

NOTE 2: If $\pi_{i(PDO)} = 0$ then $\pi_{i(PDO)} = 0.01$

CALCULATION ADJUSTMENT FOR PROJECTS: When a countermeasure is evaluated as a project consisting of a number of roadway segments, perform all calculations in *Step 8* through *Step 11* for each roadway segment and then sum the values of $\lambda_{i(TOT)}$, $\lambda_{i(FI)}$, and $\lambda_{i(PDO)}$, obtained in Equation (D-21) through Equation (D-23), respectively, over all sites included in that project. These values, Sum($\lambda_{i(TOT)}$), Sum($\lambda_{i(FI)}$), and Sum($\lambda_{i(PDO)}$), should then be substituted for $\lambda_{i(TOT)}$, $\lambda_{i(FI)}$, and $\lambda_{i(PDO)}$, respectively, in subsequent calculations.

D.1.1.3 Estimation of Countermeasure Effectiveness and Its Precision

The primary objective of the before-after evaluation is to compare the **observed** number of accidents after the treatment is implemented to the **expected** number of accidents in the after period, had the countermeasure not been implemented. This provides an estimate of the overall safety effectiveness of the countermeasure, expressed as a percent change in the accident frequency. It is also important to estimate the precision of the treatment effectiveness. The procedure is explained in *Step 12* through *Step 24*.

Step 12: Obtain the best estimate of the expected accident frequency during the entire after period after the treatment is implemented at site i. This estimate, λ_i, for TOT, FI, and PDO accidents is the observed accident frequency after treatment, L_i, that is:

$$\lambda_{i(TOT)} = L_{i(TOT)} = \sum_{y(After\ Years)} L_{iy(TOT)} \qquad (D\text{-}24)$$

$$\lambda_{i(FI)} = L_{i(FI)} = \sum_{y(After\ Years)} L_{iy(FI)} \qquad (D\text{-}25)$$

$$\lambda_{i(PDO)} = L_{i(PDO)} = \sum_{y(After\ Years)} L_{iy(PDO)} \qquad (D\text{-}26)$$

NOTE 1: If the user selected to analyze FS accidents, then the observed accident frequencies in Equation (D-25) would include FS accidents for the respective collision type(s).

CALCULATION ADJUSTMENT FOR PROJECTS: When a countermeasure is evaluated as a project consisting of a number of roadway segments, perform the calculations in *Step 12* for each roadway segment and then sum the values of $\lambda_{i(TOT)}$, $\lambda_{i(FI)}$, and $\lambda_{i(PDO)}$, obtained in Equation (D-24) through Equation (D-26), respectively, over all sites included in that project. These values, $Sum(\lambda_{i(TOT)})$, $Sum(\lambda_{i(FI)})$, and $Sum(\lambda_{i(PDO)})$, should then be substituted for $\lambda_{i(TOT)}$, $\lambda_{i(FI)}$, and $\lambda_{i(PDO)}$, respectively, in subsequent calculations.

NOTE 2: While X_i in the before period is determined as a weighted average of the expected and observed accident frequencies (κ_i and K_i, respectively), the observed accident frequency for the after period, L_i, is not combined as a weighted average with an expected accident frequency.

Step 13: Using the values of λ_i and π_i in Equation (D-21) through Equation (D-26), determine the customary estimate of the effectiveness (or odds ratio) of the treatment at site or project i, θ_i, for TOT, FI, and PDO accidents as:

$$\theta_{i(TOT)} = \frac{\lambda_{i(TOT)}}{\pi_{i(TOT)}} \qquad (D\text{-}27)$$

$$\theta_{i(FI)} = \frac{\lambda_{i(FI)}}{\pi_{i(FI)}} \qquad (D\text{-}28)$$

$$\theta_{i(PDO)} = \frac{\lambda_{i(PDO)}}{\pi_{i(PDO)}} \qquad (D\text{-}29)$$

Step 14: Although the overall countermeasure effectiveness is based on the results obtained from all sites or projects within the set, an indication of the effectiveness at a single site or single project, expressed as a percentage accident change, can be calculated as follows:

D-7

$$E_{i(TOT)} = 100\big(\theta_{i(TOT)} - 1\big) \tag{D-30}$$

$$E_{i(FI)} = 100\big(\theta_{i(FI)} - 1\big) \tag{D-31}$$

$$E_{i(PDO)} = 100\big(\theta_{i(PDO)} - 1\big) \tag{D-32}$$

Step 15: The overall effectiveness of countermeasure XYZ implemented at similar sites or projects is determined by summing and then combining values of λ_i and π_i across all sites and/or projects in the site list. The overall treatment effectiveness is calculated as:

$$\theta_{(TOT)} = \frac{\Sigma\lambda_{i(TOT)}}{\Sigma\pi_{i(TOT)}} = \frac{\lambda_{(TOT)}}{\pi_{(TOT)}} \tag{D-33}$$

$$\theta_{(FI)} = \frac{\Sigma\lambda_{i(FI)}}{\Sigma\pi_{i(FI)}} = \frac{\lambda_{(FI)}}{\pi_{(FI)}} \tag{D-34}$$

$$\theta_{(PDO)} = \frac{\Sigma\lambda_{i(PDO)}}{\Sigma\pi_{i(PDO)}} = \frac{\lambda_{(PDO)}}{\pi_{(PDO)}} \tag{D-35}$$

where all summations are performed over all sites and/or projects in the site list.

However, the use of θ in Equation (D-33) through Equation (D-35) is not recommended because even if the calculated values λ and π are unbiased estimators of the expected number of accidents during the after period in the presence or absence of treatment, respectively, the ratio λ/π is a biased estimator of θ. Although this bias is often small, removing it is a worthwhile precaution (Hauer, 1997). To obtain an approximately unbiased estimator for θ, proceed as follows:

Step 16: Calculate the variance of the EB-adjusted expected number, X_{iy}, of TOT, FI, and PDO accidents for each site i and year y calculated in Equation (D-11) and Equation (D-12):

$$Var\big(X_{iy(TOT)}\big) = X_{iy(TOT)}\big(1 - w_{i(TOT)}\big)\frac{C_{iy(TOT)}}{\sum_{y=1}^{Y}C_{iy(TOT)}} \tag{D-36}$$

$$Var\big(X_{iy(FI)}\big) = X_{iy(FI)}\big(1 - w_{i(FI)}\big)\frac{C_{iy(FI)}}{\sum_{y=1}^{Y}C_{iy(FO)}} \tag{D-37}$$

NOTE: $X_{iy(FI)} > X_{iy(TOT)}$ (in *Step 5*), then set $Var(X_{iy(FI)}) = Var(X_{iy(TOT)})$.

Step 17: Calculate the variance of π for TOT, FI, and PDO accidents as:

$$Var(\pi_{(TOT)}) = \sum_i \left[r_{i(TOT)}^2 \sum_{y(BeforeYears} Var(X_{iy(TOT)}) \right] \tag{D-38}$$

D-8

$$\text{Var}(\pi_{(FI)}) = \sum_i \left[r_{i(FI)}^2 \sum_{y(BeforeYears)} \text{Var}(X_{iy(FI)}) \right] \qquad \text{(D-39)}$$

$$\text{Var}(\pi_{(PDO)}) = \text{Var}(\pi_{(TOT)}) + \text{Var}(\pi_{(FI)}) \qquad \text{(D-40)}$$

NOTE: Because FI accidents are a subset of TOT accidents, the calculation in Equation (D-40), which assumes statistical independence of TOT and FI accidents, is only an approximation. In fact, Equation (D-40) overestimates $\text{Var}(X_{iy(PDO)})$.

Calculation Adjustment for Projects: When a countermeasure is evaluated as a project consisting of a number of roadway segments, perform the calculations in *Step 17* for each roadway segment in each before year y. Then sum the values of $\text{Var}(\pi_{iy(TOT)})$, $\text{Var}(\pi_{iy(FI)})$, and $\text{Var}(\pi_{iy(PDO)})$ obtained in Equation (D-38) through Equation (D-40) in each before year y, respectively, over all sites included in that project. These values, $\text{Sum}[\text{Var}(\pi_{iy(TOT)})]$, $\text{Sum}[\text{Var}(\pi_{iy(FI)})]$, and $\text{Sum}[\text{Var}(\pi_{iy(PDO)})]$ in each before year y, should then be substituted for $\text{Var}(\pi_{iy(TOT)})$, $\text{Var}(\pi_{iy(FI)})$, and $\text{Var}(\pi_{iy(PDO)})$, respectively, in each before year y, in subsequent calculations.

Step 18: Calculate the final adjusted overall effectiveness, θ^*, for TOT, FI, and PDO accidents:

$$\theta_{(TOT)}^* = \frac{\theta_{(TOT)}}{1 + \frac{\text{Var}(\pi_{(TOT)})}{\pi_{(TOT)}^2}} \qquad \text{(D-41)}$$

$$\theta_{(FI)}^* = \frac{\theta_{(FI)}}{1 + \frac{\text{Var}(\pi_{(FI)})}{\pi_{(FI)}^2}} \qquad \text{(D-42)}$$

$$\theta_{(PDO)}^* = \frac{\theta_{(PDO)}}{1 + \frac{\text{Var}(\pi_{(PDO)})}{\pi_{(PDO)}^2}} \qquad \text{(D-43)}$$

Step 19: The effectiveness of countermeasure XYZ implemented at all sites and/or projects in the site list can then be expressed as a percentage accident change in the form:

$$E_{(TOT)} = 100(\theta_{(TOT)}^* - 1) \qquad \text{(D-44)}$$

$$E_{(FI)} = 100(\theta_{(FI)}^* - 1) \qquad \text{(D-45)}$$

$$E_{(PDO)} = 100(\theta_{(PDO)}^* - 1) \qquad \text{(D-46)}$$

NOTE: It is also important in the EB evaluation to estimate the precision of the treatment effectiveness shown in Equation (D-44) through Equation (D-46). This is done by calculating the variance of the ratios shown in Equation (D-33) through Equation (D-35) and of the quantities in Equation (D-24) through Equation (D-26), for TOT, FI, and PDO

accidents. To that effect, the variances of λ and π are necessary. The variances of $\pi_{(TOT)}$, $\pi_{(FI)}$, and $\pi_{(PDO)}$ were already calculated in Equation (D-38) through Equation (D-40).

Step 20: Calculate the variance of λ for TOT, FI, and PDO accidents as:

$$Var(\lambda_{(TOT)}) = \sum_{i} \sum_{y(After\ Years)} L_{iy(TOT)} \tag{D-47}$$

$$Var(\lambda_{(FI)}) = \sum_{i} \sum_{y(After\ Years)} L_{iy(FI)} \tag{D-48}$$

$$Var(\lambda_{(PDO)}) = \sum_{i} \sum_{y(After\ Years)} L_{iy(PDO)} \tag{D-49}$$

NOTE 1: No adjustments are necessary in this step to account for projects.

NOTE 2: If the user selected to analyze FS accidents, then the observed accident frequencies in Equation (D-48) would include FS accidents for the respective collision type(s).

Step 21: The variance of $\theta*$ is estimated for TOT, FI, and PDO accidents as:

$$Var(\theta^*_{(TOT)}) \cong \frac{\theta^2_{(TOT)} \left[\frac{Var(\lambda_{(TOT)})}{\lambda^2_{(TOT)}} + \frac{Var(\pi_{(TOT)})}{\pi^2_{(TOT)}} \right]}{\left[1 + \frac{Var(\pi_{(TOT)})}{\pi^2_{(TOT)}} \right]^2} \tag{D-50}$$

$$Var(\theta^*_{(FI)}) \cong \frac{\theta^2_{(FI)} \left[\frac{Var(\lambda_{(FI)})}{\lambda^2_{(FI)}} + \frac{Var(\pi_{(FI)})}{\pi^2_{(FI)}} \right]}{\left[1 + \frac{Var(\pi_{(FI)})}{\pi^2_{(FI)}} \right]^2} \tag{D-51}$$

$$Var(\theta^*_{(PDO)}) \cong \frac{\theta^2_{(PDO)} \left[\frac{Var(\lambda_{(PDO)})}{\lambda^2_{(PDO)}} + \frac{Var(\pi_{(PDO)})}{\pi^2_{(PDO)}} \right]}{\left[1 + \frac{Var(\pi_{(PDO)})}{\pi^2_{(PDO)}} \right]^2} \tag{D-52}$$

NOTE: When $\lambda_{TOT} = 0$, $\lambda_{FI} = 0$, or $\lambda_{PDO} = 0$, then Equation (D-50), Equation (D-51), and Equation (D-52) will become:

$$Var(\theta^*_{(TOT)}) \cong \frac{\left[\frac{Var(\pi_{(TOT)})}{\pi^2_{(TOT)}} \right]}{\left[1 + \frac{Var(\pi_{(TOT)})}{\pi^2_{(TOT)}} \right]} \tag{Alternate D-50}$$

$$\text{Var}(\theta^*_{(FI)}) \cong \frac{\left| \dfrac{\text{Var}(\pi_{(FI)})}{\pi^2_{(FI)}} \right|}{\left[1 + \dfrac{\text{Var}(\pi_{(FI)})}{\pi^2_{(FI)}} \right]} \qquad \text{(Alternate D-51)}$$

$$\text{Var}(\theta^*_{(PDO)}) \cong \frac{\left| \dfrac{\text{Var}(\pi_{(PDO)})}{\pi^2_{(PDO)}} \right|}{\left[1 + \dfrac{\text{Var}(\pi_{(PDO)})}{\pi^2_{(PDO)}} \right]} \qquad \text{(Alternate D-52)}$$

Step 22: To obtain a measure of the precision of θ* for TOT, FI, and PDO accidents, calculate the standard error of θ* as the square root of its variance:

$$\text{SE}(\theta^*_{(TOT)}) = \sqrt{\text{Var}(\theta^*_{(TOT)})} \qquad \text{(D-53)}$$

$$\text{SE}(\theta^*_{(FI)}) = \sqrt{\text{Var}(\theta^*_{(FI)})} \qquad \text{(D-54)}$$

$$\text{SE}(\theta^*_{(PDO)}) = \sqrt{\text{Var}(\theta^*_{(PDO)})} \qquad \text{(D-55)}$$

Step 23: Using the relationship between E and θ* as shown in Equation (D-44) through Equation (D-46) for TOT, FI, and PDO accidents, the standard error of the treatment effectiveness, E, is calculated as:

$$\text{SE}(E_{(TOT)}) = 100 \times \text{SE}(\theta^*_{(TOT)}) \qquad \text{(D-56)}$$

$$\text{SE}(E_{(FI)}) = 100 \times \text{SE}(\theta^*_{(FI)}) \qquad \text{(D-57)}$$

$$\text{SE}(E_{(PDO)}) = 100 \times \text{SE}(\theta^*_{(PDO)}) \qquad \text{(D-58)}$$

Step 24: Assess the statistical significance of E by calculating the ratio E/(SE(E)) for TOT, FI, and PDO accidents. Compare its absolute value to either 1.7 or 2.0. Conclusion concerning $E_{(TOT)}$, $E_{(FI)}$, or $E_{(PDO)}$ may be drawn as follows:

- Abs[E/(SE(E))]

- Abs[E/(SE(E))] ≥ 1.7 indicates significant countermeasure effect at the (approximate) 90 percent confidence level

- Abs[E/(SE(E))] ≥ 2.0 indicates significant countermeasure effect at the (approximate) 95 percent confidence level

All computations shown in this section apply to estimating a percent change in either TOT or FI accidents, and by difference, PDO. Similar estimations can be carried out for specific collision types. Details on how to compute E and SE(E) in this case are given next.

D-11

NOTE: The calculations above assume the countermeasure was implemented along the entire site. SafetyAnalyst also estimates the safety effectiveness of a countermeasure installed along a portion or subsegment of a site. The calculations as described above are performed in the exact same manner taking into consideration the boundaries of the implemented countermeasure.

D.1.2 Algorithm to Estimate Percent Change in Frequency of a Target Collision Type

The Module 4 inputs provided by the user to estimate the percent change in accident frequency of a target accident due to an implemented countermeasure are similar to the user inputs described in Appendix D.1.1. Also, the actual calculations for estimating the percent change in accident frequency of a target collision type(s) are very similar to the procedure described in Appendix D.1.1. Several notes concerning notation for estimating the percent change in frequency of a target collision type are as follows:

- Let "CT" denote the subscript for collision types.

- For practical purposes, assume that the collision type of interest is a proportion of TOT accidents (i.e., $P_{CT(TOT)}$). Calculations for proportions of FI accidents will be identical, with the appropriate substitutions made.

- If the screening is based upon FS, include $P_{(CT/FS/FI)}$, in equations to predict FI calculations and proceed as normal for FI accidents. Also observed accident frequencies would include FS accidents for the respective collision type(s).

- Borrowing from the terminology used in Appendix D.1.1, let $K_{iy(CT)}$ denote the **observed** accident frequencies of the selected collision type during a **before** year y at site i. Similarly, let $L_{iy(CT)}$ denote the **observed** accident frequencies of the selected collision type during an **after** year y at site i.

Step A: Using the proportion $P_{CT(TOT)}$, calculate the EB-adjusted expected accident frequency for the collision type of interest, $X_{i(CT)}$, at site or project i in the before period using *Step 1a* or *Step 1b* and Equation (D-7), Equation (D-9), Equation (D-11), and Equation (D-14), substituting the subscript CT for TOT in all equations.

NOTE: No adjustment is made to the overdispersion parameter, d_{TOT}, in Equation (D-9).

Step B: Using the proportion $P_{CT(TOT)}$, calculate the number of CT accidents, $\pi_{i(CT)}$, at site or project i in the after period in the absence of treatment using *Step 8a* or *Step 8b* and Equation (D-17), Equation (D-19), and Equation (D-21), substituting the subscript CT for TOT in all equations.

Step C: Obtain the best estimate of the expected CT accident frequency, $\kappa_{i(CT)}$, during the entire after period after the treatment is implemented at site or project i using Equation (D-24) and substituting the subscript CT for TOT.

At this point, one could simply carry out the remaining computations shown in Equation (D-27), Equation (D-30), Equation (D-33), Equation (D-36), Equation (D-38), Equation (D-41), Equation (D-44), Equation (D-47), Equation (D-50), Equation (D-53), and Equation (D-56). However, since proportions of specific collision types are estimated, care needs to be taken to ensure that the final EB estimated proportions do add up to one. The following example calculations demonstrate an adjustment procedure as it would apply to multiple-vehicle (MV) and single-vehicle (SV) total accidents. This procedure would also apply to other subsets of collision types. The procedure is explained in *Step D* through *Step G*. For this procedure, to evaluate any selected collision type, the computations for its complement (i.e., all other collision types combine) must be performed as well.

Step D: Let $\pi_{i(TOT)}$, $\pi_{i(SV)}$, and $\pi_{i(MV)}$ denote the EB expected number of TOT, SV, and MV accidents during the after period in the absence of treatment, all are calculated using Equation (D-21) as explained in *Step B*. Since these computations were performed independently of each other, the expected SV and MV accident frequencies most probably will not sum to the expected TOT accident frequency. In other words,

$$\pi_{i(SV)} + \pi_{i(MV)} \neq \pi_{i(TOT)} \tag{D-59}$$

Calculate a correction, AF_i, so that the two sides of Equation (D-59) become equal.

$$AF_i = \frac{\pi_{i(TOT)}}{\pi_{i(SV)} + \pi_{i(MV)}} \tag{D-60}$$

Step E: Calculate the adjusted expected SV and MV accident frequencies, $adj(\pi_i)$, as follows:

$$adj\left(\pi_{i(SV)}\right) = AF_i \times \pi_{i(SV)} \tag{D-61}$$

$$adj\left(\pi_{i(MV)}\right) = AF_i \times \pi_{i(MV)} \tag{D-62}$$

It can be easily shown that:

$$adj\left(\pi_{i(SV)}\right) + adj\left(\pi_{i(MV)}\right) = AF_i\left(\pi_{i(SV)} + \pi_{i(MV)}\right) = \pi_{i(TOT)} \tag{D-63}$$

Step F: Proceed with the estimation of the effectiveness of a countermeasure with regard to a specific collision type CT (e.g., SV or MV total accidents) by performing the calculations in *Step 13* through *Step 23*, substituting $adj(\pi_{i(CT)})$ for $\pi_{i(CT)}$ in the appropriate equations.

Step G: Although all substitutions of $adj(\pi_{i(CT)})$ for $\pi_{i(CT)}$ are straight forward, it should be noted that after adjustment, the variance of $adj(\pi_{i(CT)})$ in Equation (D-38) becomes:

D-13

$$adj\left(\pi_{i(SV)}\right) + adj\left(\pi_{i(MV)}\right) = AF_i\left(\pi_{i(SV)} + \pi_{i(MV)}\right) = \pi_{i(TOT)} \qquad \text{(D-64)}$$

D.1.3 Algorithm to Estimate Change in Proportion of a Target Collision Type

This section presents the statistical technique implemented to evaluate before-after changes in proportions of specific target accident types. Using the notation shown in Table D-1, let $K_{iy(TOT)}$ denote the observed number of TOT accidents at site i during **before** treatment year y. Similarly, let $K_{iy(CT)}$ be the observed number of TOT accidents of a specific collision type at site i during **before** treatment year y. In the same fashion, let $L_{iy(TOT)}$ denote the observed number of TOT accidents at site i during **after** treatment year y. Similarly, let $L_{iy(CT)}$ denote the observed number of TOT accidents of the same collision type at site i during **after** treatment year y.

CALCULATION ADJUSTMENT FOR PROJECTS: When a countermeasure is evaluated at a project consisting of a number of roadway segments, first sum the values of $K_{iy(TOT)}$ and $K_{iy(CT)}$ across all sites within the project, separately for each before year y. These values, $Sum(K_{iy(TOT)})$ and $Sum(K_{iy(CT)})$, should then be substituted for $K_{iy(TOT)}$ and $K_{iy(CT)}$, respectively, in each before year y. The same rule applies to the after treatment accidents, $L_{iy(TOT)}$ and $L_{iy(CT)}$. Alternatively, the totals across all before years, $K_{i(CT)}$ and $K_{i(TOT)}$, and the totals across all after years, $L_{i(CT)}$ and $L_{i(TOT)}$, may be summed across all sites in a project as the implementation year will necessarily be the same for all sites in a project. When dealing with projects, the subscript, i, used for a site simply applies to a project.

NOTE 1: The number of years before and after treatment are no assumed to be equal for a given site (i.e., $YEARS_{BT,i} \neq YEARS_{AT,i}$). In addition, the number of before (or after) years is not necessarily the same across sites of a given site subtype (i.e., $YEARS_{BT,i} \neq YEARSBT,j$ and $YEARS_{AT,i} \neq YEARSAT,j$ for $i \neq j$).

NOTE 2: The calculations that follow apply to any collision type, be it a subset of TOT accidents or FI accidents.

Let $P_{i(CT)B}$ be the before treatment proportion of observed accidents of a specific target accident type of total accidents at site or project i across all before years. $P_{i(CT)B}$ is calculated as follows:

$$P_{i(CT)B} = \frac{\displaystyle\sum_{YEARS_{BT,i}} K_{iy(CT)}}{\displaystyle\sum_{YEARS_{BT,i}} K_{iy(TOT)}} \qquad \text{(D-65)}$$

where $YEARS_{BT,i}$ is the number of years in the before treatment period at site i.

Similarly, let $P_{i(CT)A}$ be the after treatment proportion of observed accidents of the same target accident type of total accidents at site or project i across all after years. $P_{i(CT)A}$ is calculated as follows:

$$P_{i(CT)A} = \frac{\displaystyle\sum_{YEARS_{AT,i}} L_{iy(CT)}}{\displaystyle\sum_{YEARS_{AT,i}} L_{iy(TOT)}} \tag{D-66}$$

where $YEARS_{AT,i}$ is the number of years in the after treatment period at site i.

Next, the difference between the after and before proportions at each site i is calculated as follows:

$$P_{i(CT)Diff} = P_{i(CT)A} - P_{i(CT)B} \tag{D-67}$$

At this point, an average proportion before treatment and an average proportion after treatment can be calculated across all I sites as follows:

$$AvgP_{(CT)B} = \frac{1}{I}\sum_{i=1}^{I} P_{i(CT)B} \tag{D-68}$$

$$AvgP_{(CT)A} = \frac{1}{I}\sum_{i=1}^{I} P_{i(CT)A} \tag{D-69}$$

Similarly, an average difference between after and before proportions can be calculated as:

$$AvgP_{(CT)Diff} = \frac{1}{I}\sum_{i=1}^{I} P_{i(CT)Diff} \tag{D-70}$$

One may proceed and test the differences in proportions [calculated in Equation (D-67)] and compare them statistically to zero by means of a paired t test. However, the differences in proportions do not necessarily come from a normal distribution. In addition, a number of differences may be equal to zero and would skew the t test. Thus, a nonparametric approach is used to assess whether the treatment affected the proportion of accidents of the collision type under consideration. In statistical terms, this is done by calculating the average difference in proportions across all sites and a confidence interval around that difference at a pre-specified confidence level (e.g., 95%). The statistical test performed is the Wilcoxon signed rank test, a nonparametric test that does not require that the differences, $P_{i(CT)Diff}$, follow a normal distribution. Although this test is rather conservative, it is also relatively insensitive to outliers in the data (Hollander and Wolfe, 1973). This is done using the procedure described in *Step 1* through *Step 5a*, which demonstrate how to

conclude whether the treatment had a statistically significant effect on the proportion of a specific collision type.

Step 1: Take the absolute value of the nonzero $P_{i(CT)Diff}$. For simplicity of notation, let Z_i denote the absolute value of $P_{i(CT)Diff}$, thus:

$$Z_i = abs\left(P_{i(CT)Diff}\right), for\ i = 1, ..., I^*$$
(D-71)

NOTE: When $Z_i = 0$, exclude the corresponding sites and adjust the number of sites to be the number of nonzero differences. Let I* denote the adjusted sample size in this case.

Step 2: Rank in ascending order the I* Z_i values. When multiple Z_i have the same value (i.e., tied), use the average rank as the rank of each tied Z_i. For example, if three Z_i values are identical and would rank, say, 12, 13, and 14, use 13 as the rank for each. If the ranks would be, say, 15 and 16, use 15.5 as the rank for each. Let R_i designate the rank of Z_i in the joint ranking.

Step 3: Define the indicator variable, Ψ_i, as:

$$\Psi_i = \begin{cases} 1\ if\ P_{i(CT)Diff} > 0 \\ 0\ if\ P_{i(CT)Diff} < 0 \end{cases}$$
(D-72)

Step 4: Form the I* products $R_1\Psi_1$, ..., $R_{I^*}\Psi_{I^*}$, and calculate the statistic T^+, the sum of the positive signed ranks as follows:

$$T^+ = \sum_{i=1}^{I^*} R_i \Psi_i$$
(D-73)

Step 5: Assess the statistical significance of T^+ using a two-sided significance test at the α level of significance as follows:

- Conclude that the treatment is statistically significant if:

$$T^+ \geq t(\alpha_2, I^*)\ or\ T^+ \leq \frac{I^*(I^*+1)}{2} - t(\alpha_1, I^*)$$
(D-74)

where $\alpha \approx \alpha_1 + \alpha_2$.

- Conclude that the treatment is not statistically significant otherwise

The quantities $t(\alpha_1, I^*)$ and $t(\alpha_2, I^*)$ are obtained from the table of critical values for the Wilcoxon signed rank test partially reproduced in Figure D-1. Generally, α_1 and α_2 are approximately equal to $\alpha/2$. Choose the values for α_1 and α_2 so that $\alpha_1 + \alpha_2$ is closest to a in Figure D-1 and α_1 and α_2 are each closest to $\alpha/2$. Often, $\alpha_1 = \alpha_2$ are the closest values to $\alpha/2$.

x	4	5	6	7	8	9	10	11	12	13	14	15
						Number of Sites (I*)						
10	0.062											
13		0.094										
14		0.062										
17			0.109									
18			0.078									
19			0.047									
22				0.109								
23				0.078								
24				0.055								
28					0.098							
29					0.074							
30					0.055							
34						0.102						
35						0.082						
36						0.064						
37						0.049						
41							0.097					
42							0.080					
43							0.065					
44							0.053					
48								0.103				
49								0.087				
50								0.074				
51								0.062				
52								0.051				
56									0.102			
57									0.088			
58									0.076			
59									0.065			
60									0.055			
64										0.108		
65										0.095		
66										0.084		
67										0.073		
68										0.064		
69										0.055		
70										0.047		
73											0.108	
74											0.097	
75											0.086	
76											0.077	
77											0.068	
78											0.059	
79											0.052	
83												0.104
84												0.094
85												0.084
86												0.076
87												0.068
88												0.060
89												0.053
90												0.047

[a] For a given I*, the table entry for the point x is P(T ≥ x). Thus if x is such that P(T ≥ x) = α, then t(α,I*) = x.

Figure D-1. Upper Tail Probabilities for the Wilcoxon's Signed Rank T^+ Statistic (I* = 4 to 10)[a] (Hollander and Wolfe, 1973)

Figure D-1 presents only an excerpt of the full table of critical values shown in Hollander and Wolfe (1973). A range of significance levels (α), approximately 0.10 to 0.20, has been selected to test a change in proportion of a target collision type. Although 0.05 to 0.10 are more typical levels, 0.20 has also been included to account for the fact that the Wilcoxon signed rank test is a conservative test, that is, it is difficult to detect a significant effect when it is present. Figure D-1 shows one-sided probability levels; since the test performed here is a two-sided test, the values in Figure D-1 correspond to $\alpha/2$, with values ranging from 0.047 to 0.109 (corresponding to 0.094/2 to 0.218/2).

LARGE SAMPLE APPROXIMATION: Figure D-1 provides critical values for T^+ for values of I* = 4 to 15 in increments of 1. Thus a minimum I* of four sites is required to perform this test. In those cases where I* exceeds 15, a large sample approximation is used to test the significance of T^+. The following steps show the approach.

Step 4a: Calculate the quantity T* as follows:

$$T^* = \frac{T^+ - E_o(T^+)}{[Var_o(T^+)]^{\frac{1}{2}}} \tag{D-75}$$

where

$$E_o(T^+) = I^*(I^* + 1)/4 \tag{D-76}$$

and

$$Var_o(T^+) = [I^*(I^* + 1) - \tfrac{1}{2}\sum_{j=1}^{g} t_j(t_j - 1)(t_j + 1)]/24 \tag{D-77}$$

where g = number of tied groups and t_j = size of tied group j.

Step 5a: Assess the statistical significance of T* using a two-sided test at the α level of significance as follows:

- Conclude that the treatment is statistically significant if:

$$T^* \geq z_{\alpha/2} \text{ or } T^* \leq -z_{\alpha/2} \tag{D-78}$$

where $z_{(\alpha/2)}$ is the upper tail probability for the standard normal distribution. Selected values of $z_{(\alpha/2)}$ are as follows:

α	$Z_{(\alpha/2)}$
0.05	1.960
0.10	1.645
0.15	1.440
0.20	1.282

Figure D-2. α vs. $z_{(\alpha/2)}$

- Conclude that the treatment is not statistically significant otherwise.

Once the statistical significance of the treatment effect has been established at the pre-selected significance level, a, the next step is to estimate the average difference between

the after and before proportions (i.e., treatment effect), $P_{(CT)Diff}$, and construct a confidence interval around that estimate. This is done using the procedure described in *Step 6* through *Step 10a*.

NOTE: The calculations in *Step 6* through *Step 9a* are performed regardless of the statistical significance of T^+ or T^*.

Step 6: Form the $M = I^*(I^*+1)/2$ averages $[P_{i(CT)Diff} + P_{j(CT)Diff}]/2$, $i \leq j = 1,...,I^*$ where I^* is the number of nonzero differences [see Equation (D-71)].

Step 7: Let $W^{(1)} \leq ... \leq W^{(M)}$ denote the M ordered values of

$$[P_{i(CT)Diff} + P_{j(CT)Diff}]/2 \tag{D-79}$$

Step 8: Estimate the treatment effect, $P_{(CT)Diff}$, as the median of the M ordered

$W^{(1)} \leq ... \leq W^{(M)}$ values as follows:

- If M is odd, say $M = 2k+1$, then

$$P_{(CT)Diff} = W^{(k+1)} \tag{D-80}$$

- If M is even, say $M = 2k$, then

$$P_{(CT)Diff} = [W^{(k)} + W^{(k+1)}]/2 \tag{D-81}$$

Obtain a symmetric two-sided confidence interval for $P_{(CT)Diff}$ with confidence level 1-α as follows:

Step 9: From Figure D-1, obtain $t(\alpha/2,I^*)$ and calculate the integer C_a.

$$C_\alpha = [I^*(I^* + 1)/2] + 1 - t(\alpha/2, I^*) \tag{D-82}$$

LARGE SAMPLE APPROXIMATION: When I^* exceeds 15, Figure D-1 will no longer provide the necessary critical values. In this case, the computations in *Step 9* will be replaced with the following:

Step 9a: Approximate C_α by the integer closest to:

$$C_\alpha \approx \frac{I^*(I^*+1)}{4} - z_{(\alpha/2)}\left[\frac{I^*(I^*+1)(2I^*+1)}{24}\right]^{1/2} \tag{D-85}$$

D-19

where $z_{(\alpha/2)}$ is the upper tail probability for the standard normal distribution (see $z_{(\alpha/2)}$ values in *Step 5a*).

Step 10: From the M ordered values, $W^{(1)} \leq \ldots \leq W^{(M)}$, select the lower and upper confidence limits, $LLP_{(CT)Diff}$ and $ULP_{(CT)Diff}$, as follows:

$$LLP_{(CT)Diff} = W^{(C_\alpha)} \tag{D-83}$$

$$ULP_{(CT)Diff} = W^{(M+1-C_\alpha)} \tag{D-84}$$

In summary, this procedure provides a means of estimating the following:

- A simple average proportion of a specific target collision type **before** treatment
- A simple average proportion of a specific target collision type **after** treatment
- A simple average difference in after minus before proportions
- An estimate of the median treatment effect and its statistical significance
- A confidence interval of the estimated median treatment effect

NOTE: The calculations above assume the countermeasure was implemented along the entire site. SafetyAnalyst also estimates the safety effectiveness of a countermeasure installed along a portion or subsegment of a site. The calculations as described above are performed in the exact same manner taking into consideration the boundaries of the implemented countermeasure.

D.1.4 Benefit Cost Analysis

This section presents the benefit cost calculations that are performed based upon a percent change in total accident frequencies. The benefit-cost ratio calculations are based upon the economic algorithm for the benefit-cost ratio described in Appendix C with some minor adjustments as described below.

Computation of Annual Accidents Reduced

The first modification is that an alternative equation replaces the algorithm described in Appendix C.1, which provides the procedures used to calculate the Annual Accidents Reduced in Module 3. In Module 4, the Annual Accidents Reduced will be determined by using the Expected number of Accidents Without Treatment and the Percentage Reduction values, found in Columns 6 and 8 of the output report, by the following computation:

$$AR_{i(TOT)} = \pi_{i(TOT)} \times (-1) \times \left(\frac{E_{i(TOT)}}{100}\right) \times \left(\frac{S_v}{Years_{ATi}}\right) \tag{D-86}$$

where:

$AR_{i(TOT)}$ = the annual accidents reduced for site i

$\pi_{i(TOT)}$ = the expected number of total accidents without treatment for site i (found in Column 6 of Table 2 in the output report)

$E_{i(TOT)}$ = the percentage reduction in total accidents for site i (found in Column 8 of Table 2 in the output report)

S_v = the service life of countermeasure v

$Years_{ATi}$ = the number of years in the after period for site i

Actual Construction Cost

The second modification to the benefit-cost ratio calculation will be the use of the actual construction cost ($ACTC_i$) instead of the default or calculated construction cost (CC_i) used to calculate the Annual Construction Cost (ACC_i) in Equation (C-25) for Module 3. This value should be entered at the time of the analysis by the user if it has not been previously entered in the implemented countermeasure record. Equation (C-25) becomes:

$$ACC_i = ACTC_i \times \frac{R(1+R)^{S_v}}{(1+R)^{S_v}-1} \qquad \text{(D-87)}$$

The next modification to the benefit-cost ratio calculations is to the present value of the construction cost (PCC_i) as determined with Equation (C-26). For this computation, the service life of the countermeasure (S_v) should be substituted for the number of years in the analysis period (N). Equation (C-26) becomes:

$$PCC_i = ACC_i \times \frac{(1+R)^{S_v}-1}{R(1+R)^{S_v}} \qquad \text{(D-88)}$$

During the analysis of a combination of countermeasures, the combination is treated as a single countermeasure by taking the maximum service life for the individual countermeasures to get a single service life. The construction costs of the individual countermasures are added together to get a single construction cost, except when service lives are different as described next.

Combined Costs for Multiple Countermeasures

If a multiple countermeasure is considerd for which all of the individual countermeasures have the same service life then $ACTC_i$ for the multiple countermasure is the sum of the $ACTC_i$'s for the individual countemeasure.

If a multiple countermeasure is considered for which the indidvidual countermeasures have different service lives, the ACTC$_i$ for the multiple countermeasrue is calculated by adding the cost of the countermeasure with the longest service life to the cost of the countermeasure with shorter service life multiplied by a capital recovery factor and an uniform series present worth factor (USPWF) as shown below. This example illustrates combining two countermeasures, with A designating the countermeasure with the longer service life and B designating the countermeasure with the shorter service life:

$$(ACTC_i)_{A+B} = (ACTC_i)_A + (ACTC_i)_B \times CRF(R, S_B) \times USPWF(R, S_A) \tag{D-89}$$

$$CRF(R, S_B) = \frac{R(1+R)^{S_B}}{(1+R)^{S_B}-1} \tag{D-90}$$

$$USPWF(R, S_A) = \frac{(1+R)^{S_A}-1}{R(1+R)^{S_A}} \tag{D-91}$$

If a third countermeasure (C) were added which also had a service life less than countermeasure A, another term would be added to Equation (D-89) as follows:

$$+(ACTC_i)_C \times CRF(R, S_C) \times USPWF(R, S_A) \tag{D-92}$$

where:

R $\quad$ = Annual rate of return
S$_A$ $\quad$ = Service life of countermeasure A
S$_B$ $\quad$ = Service life of countermeasure B
CRF $\quad$ = Capital recovery factor
USPWF = Uniform series present worth factor

Computation of the Benefit-Cost Ratio for Each Site

The final modification to the benefit-cost ratio calculation will be the replacement of the accident cost used in Equation (C-30), the calculation of the present value of the safety benefits. The accident cost for use in the computation is determined as:

$$AC_{i(TOT)} = \left(\frac{\pi_{i(FI)}}{\pi_{i(FI)}+\pi_{i(PDO)}}\right)AC_{FI} + \left(\frac{\pi_{i(PDO)}}{\pi_{i(FI)}+\pi_{i(PDO)}}\right)AC_{PDO} \tag{D-93}$$

The present value of the safety benefits for site i will then be computed as:

D-22

$$PSB_i = \frac{AR_{i(TOT)}AC_{i(TOT)}}{(1+R)^{S_v}}$$ (D-94)

The benefit-cost ratio is computed in a manner equivalent to Equation (C-31):

$$BC_i = \frac{PSB_i}{PCC_i}$$ (D-95)

Computation of the Benefit-Cost Ratio for All Sites

The benefit-cost ratio for all sites is computed as:

$$BC = \frac{\sum_{i=1}^{I} PSB_i}{\sum_{i=1}^{I} PCC_i}$$ (D-96)

Computation of the Benefit-Cost Ratio for Projects

The benefit-cost ratio of a construction project is calculated as described above for a countermeasure or combination of countermeasures with the following changes. The benefit-cost summary table on the output report will include a Project column calculated by using the project cost and project service life provided by the user in the implemented countermeasure record. When cost is provided at the countermeasure level, an All Sites column will also be included on this table. This column will be calculated using the cost and service life of the countermeasure(s) as described above. When a project cost is not provided by the user, then the sum of the cost of the individual countermeasures will be used as a project cost. If the project service life is not provied, then the maximum service life of all the indivivual countermeasures will be used. So for the project column the following equations will replace Equation (D-86), Equation (D-87), Equation (D-88), Equation (D-94), and Equation (D-96) respectively.

$$AR_{i(TOT)} = \pi_{i(TOT)} \times (-1) \times \left(\frac{B_{i(TOT)}}{100}\right) \times \left(\frac{S_p}{Years_{ATi}}\right)$$ (D-97)

$$ACC_p = ACTC_p \times \frac{R(1+R)^{S_p}}{(1+R)^{S_p}-1}$$ (D-98)

D-23

$$PCC_p = ACC_p \times \frac{(1+R)^{S_p} - 1}{R(1+R)^{S_p}}$$ (D-99)

$$PSB_i = \frac{AR_{i(TOT)} AC_{i(TOT)}}{(1+R)^{S_p}}$$ (D-100)

$$BC = \frac{\sum_{i=1}^{I} PSB_i}{PCC_p}$$ (D-101)

where

S_p = the service life of the project. If the project service life is not available, then the maximum service life of all the countermeasures should be used.

$ACTC_p$ = the actual construction cost of the project. If the project cost is not provided then, the sum of the cost of individual countermeasures should be used.

Appendix E

Default Safety Performance Functions Used in *SafetyAnalyst*

APPENDIX E. DEFAULT SAFETY PERFORMANCE FUNCTIONS USED IN *SAFETYANALYST*

This appendix presents the Safety Performance Functions (SPFs) developed and provided for use in *SafetyAnalyst* and explains their calibration. These SPFs are used as defaults in *SafetyAnalyst* to predict the safety performance of specific site subtypes. Highway agencies may, if they wish, develop their own SPFs and provide them for use in *SafetyAnalyst*. The development of such SPFs is described in Appendix F.

The SPFs used as defaults in *SafetyAnalyst* were developed using available data for four states from the FHWA Highway Safety Information System (HSIS). The states whose data files were used, and the years of data used for each state are as follows:

- California (1997 to 2001)
- Minnesota (1995 to 1999)
- Ohio (1997 to 1999)
- Washington (1993 to 1996)

The HSIS data files from these states included roadway segment characteristics, intersection characteristics, ramp characteristics, and accident data.

The SPFs have been developed to predict accident frequency as a function of annual average daily traffic (AADT) volume alone. For roadway segments and ramps, the independent variable representing traffic volume is the AADT of the roadway segment or ramp. For intersections, two independent variables represent traffic volume, the AADTs of the two intersection roads (classified as the major and minor road, where the major road is typically the road with the higher AADT).

For roadway segments and ramps, the length is included as a scale factor.

For all of the SPFs developed, the dependent variable (i.e., the variable whose value is predicted by the model) is accident frequency per year on the roadway segment, intersection, or ramp of interest. SPFs have been developed both for total (TOT) accident frequency (all accident severity levels combined) and for fatal and injury (FI) accidents. FI accidents include all accidents in which a fatality occurred and all accidents in which a personal injury of any severity level occurred (i.e., FI accidents include fatal accidents and accidents involving injuries of the A, B, and C severity levels).

SPFs have not been developed to estimate the frequency of fatal and severe injury (FS) accidents or property-damage-only (PDO) accidents.

Separate SPFs have been developed for 17 subtypes of roadway segments, 12 subtypes of intersections, and 16 subtypes of ramps. The use of separate models for each site subtype is more desirable than trying to account for the differences in accident frequency between site subtypes with explicit variables included in the models.

In developing the SPFs for *SafetyAnalyst*, the following functional forms were used for roadway segments, intersections, and ramps, respectively.

Roadway Segments:

$$\kappa = e^{\alpha} \times ADT^{\beta_1} \times SL \tag{E-1}$$

where: κ = predicted accident frequency per mile per year
ADT = average daily traffic (veh/day)
SL = segment length (mi)

Intersections:

$$\kappa = e^{\alpha} \times MajADT^{\beta_1} \times MinADT^{\beta_2} \tag{E-2}$$

where: κ = predicted accident frequency per intersection per year
MajADT = average daily traffic on the major road (veh/day)
MinADT = average daily traffic on the minor road (veh/day)

Ramps: where: κ = predicted accident frequency per ramp per year

ADT = average daily traffic (veh/day)
SL_{Ramp} = ramp length (mi)

$$\kappa = e^{\alpha} \times ADT^{\beta_1} \times SL_{Ramp} \tag{E-3}$$

In all three equations, α, β_1, and β_2 represent the regression parameters that are estimated from the available data.

The SPFs were developed with negative binomial (NB) regression using the SAS GENMOD software package. NB regression was used because it is appropriate for data with low—frequency observations, like accident data, and data that are overdispersed (i.e., data for which the variance exceeds the mean). For each data set used in modeling, an overdispersion parameter (d) has been quantified, indicating the extent to which the mean accident frequency is exceeded by the variance of accident frequency. The goodness of fit of the NB regression models is represented by the Freeman—Tukey R^2 coefficient (R_{FT}^2).

The SPFs developed for use in SafetyAnalyst are valid only for application to the states and time periods for which they were developed. However, *SafetyAnalyst* includes a calibration procedure that allows SPFs developed for one particular state and one particular time period to be applied to other states and time periods. When SPFs provided with

SafetyAnalyst are subsequently calibrated for application to a different state and time period using a state's own accident data, useful safety predictions are obtained.

Tables E-1 through E-6 show the estimated parameters of the SPFs provided in *SafetyAnalyst*. Tables E-1 and E-2 provide information concerning the SPFs developed for roadway segments. The first two columns show the site subtype, and the third column shows the state from which data were used to develop the model. Columns 4 and 5 show the estimated regression parameters α and β_1, respectively. Column 6 shows the estimated overdispersion parameter (d). Column 7 shows the goodness of fit of the regression model. Column 8 shows the total length of sites (i.e., mi) used to calibrate the model, and Column 9 shows the maximum AADT used to calibrate the model.

Tables E-3 and E-4 provides information concerning the SPFs developed for intersections. The first two columns show the site subtype, and the third column shows the state from which data were used to develop the model. Columns 4, 5, and 6 show the estimated regression parameters α, β_1, and β_2, respectively. Column 7 shows the estimated overdispersion parameter (d). Column 8 shows the goodness of fit of the regression model. Column 9 shows the total number of sites used to calibrate the model, and Column 10 and 11 shows the maximum AADTs of the major and minor roads, respectively, used to calibrate the model.

Tables E-5 and E-6 provides information concerning the SPFs developed for ramps. The first two columns show the site subtype, and the third column shows the state from which data were used to develop the model. Columns 4 and 5 show the estimated regression parameters α and β_1, respectively. Column 6 shows the estimated overdispersion parameter (d). Column 7 shows the goodness of fit of the regression model. Column 8 shows the total number of sites (i.e., mi) used to calibrate the model, and Column 9 shows the maximum AADT used to calibrate the model. In Tables E-5 and E-6, note that for rural free-flow loop off-ramps, only a model predicting TOT accidents was developed. No model predicting FI accidents for this site subtype was developed.

The SPFs used in *SafetyAnalyst* are calibrated prior to their use to predict safety performance. Calibration is performed separately for each site subtype and each year of data. This calibration process is performed each time new data are added to the *SafetyAnalyst* data base. Calibration occurs automatically when new data are added and no intervention by the user is needed.

The calibration process computes a calibration factor, C, as the ratio of the sum of the observed accidents for all sites if a particular site subtype and during a particular year to the sum of the predicted accidents determined by applying the SPF to each individual site of that particular site subtype for the traffic volume level applicable to that particular year. Then, whenever that SPF is used in *SafetyAnalyst*, the predicted accident frequency, κ, is multiplied by applicable calibration factor, C.

E-3

Table E-1. SPFs for Total Accidents on Roadway Segments

Site subtype code	Site subtype description	State	Regression coefficients LogIntercept(□)	Regression coefficients LogAADT(□$_t$)	Over-dispersion parameter (d)	R$_{FT}^2$ (%)	Total length of sites (mi)	Maximum AADT (veh/day)
101	Rural two - lane highway segments	OH	−3.63	0.53	0.50	72.5	12,412	30,025
102	Rural multilane undivided highway segments	NC	−3.17	0.49	0.53	46.5	308	42,638
103	Rural multilane divided highway segments	MN	−5.05	0.66	0.32	49.8	467	31,188
104	Rural freeway segments - 4 lanes	MN	−6.82	0.81	0.17	88.0	379	60,621
105	Rural freeway segments - 6+ lanes	CA	−8.28	0.94	0.09	84.3	201	190,403
106	Rural freeway segments within an interchange area - 4 lanes	MN	−7.76	0.97	0.15	65.0	90	60,621
107	Rural freeway segments within an interchange area - 6+ lanes	CA	−9.63	1.06	0.21	46.1	238	197,798
151	Urban two - lane arterial segments	OH	−7.16	0.84	4.40	13.6	1,504	29,850
152	Urban multilane undivided arterial segments	WA	−10.24	1.29	0.85	23.5	194	57,901
153	Urban multilane divided arterial segments	OH	−11.85	1.34	5.91	1.4	327	77,735
154	Urban one - way arterial segments	MN	−3.53	0.60	1.38	4.1	170	23,628
155	Urban freeway segments - 4 lanes	WA	−7.85	1.00	0.99	9.2	126	151,038
156	Urban freeway segments - 6 lanes	WA	−5.96	0.78	0.48	53.5	35	241,255
157	Urban freeway segments - 8+ lanes	WA	−16.24	1.67	0.45	43.1	15	223,088
158	Urban freeway segments within an interchange area - 4 lanes	WA	−11.23	1.30	0.81	40.9	156	241,255
159	Urban freeway segments within an interchange area - 6 lanes	WA	−11.25	1.28	0.60	56.1	83	255,154
160	Urban freeway segments within an intersection area - 8+ lanes	WA	−26.76	2.58	0.52	51.6	31	233,323

NOTE: The SPFs shown in this table use the functional form shown in Equation (E-1).

Table E-2. SPFs for Fatal and Injury Accidents on Roadway Segments

Site subtype code	Site subtype description	State	Regression coefficients LogIntercept(□)	Regression coefficients LogAADT(□$_t$)	Over-dispersion parameter (d)	R$_{FT}^2$ (%)	Total length of sites (mi)	Maximum AADT (veh/day)
101	Rural two - lane highway segments	OH	−4.86	0.53	0.67	59.9	12,412	30,025
102	Rural multilane undivided highway segments	NC	−4.20	0.50	0.53	45.9	308	42,638
103	Rural multilane divided highway segments	MN	−7.46	0.72	0.09	37.2	467	31,188
104	Rural freeway segments - 4 lanes	MN	−8.82	0.89	0.16	82.2	379	60,621
105	Rural freeway segments - 6+ lanes	CA	−10.25	1.03	0.09	82.8	201	190,403
106	Rural freeway segments within an interchange area - 4 lanes	MN	−8.86	0.96	0.24	53.1	90	60,621
107	Rural freeway segments within an interchange area - 6+ lanes	CA	−10.48	1.04	0.20	45.3	238	197,798
151	Urban two - lane arterial segments	OH	−8.84	0.89	4.54	14.0	1,504	29,850
152	Urban multilane undivided arterial segments	WA	−12.07	1.39	0.81	25.8	194	57,901
153	Urban multilane divided arterial segments	OH	−14.87	1.52	5.81	2.2	327	77,735
154	Urban one - way arterial segments	MN	−5.15	0.65	1.45	11.1	170	23,628
155	Urban freeway segments - 4 lanes	WA	−8.82	1.02	1.15	12.8	126	151,038
156	Urban freeway segments - 6 lanes	WA	−7.60	0.85	0.54	46.4	35	241,255
157	Urban freeway segments - 8+ lanes	WA	−19.16	1.85	0.52	39.9	15	223,088
158	Urban freeway segments within an interchange area - 4 lanes	WA	−12.89	1.38	0.79	38.1	156	241,255
159	Urban freeway segments within an interchange area - 6 lanes	WA	−13.62	1.42	0.55	56.0	83	255,154
160	Urban freeway segments within an intersection area - 8+ lanes	WA	−25.63	2.42	0.53	48.9	31	233,323

NOTE: The SPFs shown in this table use the functional form shown in Equation (E-1).

Table E-3. SPFs for Total Accidnts at Intersections

Site subtype code	Site subtype description	State	Regression coefficients LogIntercept (β_0)	Regression coefficients LogAADT$_{maj}$ (β_1)	Regression coefficients LogAADT$_{min}$ (β_2)	Over-dispersion parameter (d)	R_{FT}^2 (%)	Number of sites	Max AADT$_{maj}$ (veh/day)	Max AADT$_{min}$ (veh/day)
201	Rural three - leg intersections with minor - road STOP control	MN	−8.78	0.71	0.24	1.07	13.3	1,706	28,500	27,000
202	Rural three - leg intersections with all - way STOP control	MN	−12.37	1.22	0.27	0.47	41.0	41	25,300	6,803
203	Rural three - leg intersections with signal control	MN	−6.57	0.66	0.20	0.33	26.0	136	36,400	11,500
204	Rural four - leg intersections with minor - road STOP control	MN	−8.96	0.65	0.47	0.70	29.9	2,114	35,500	26,700
205	Rural four - leg intersections with all - way STOP control	MN	−12.37	1.22	0.27	0.47	41.0	41	25,300	6,803
206	Rural four - leg intersections with signal control	MN	−6.57	0.66	0.20	0.33	26.0	136	36,400	11,500
251	Urban three - leg intersections with minor - road STOP control	MN	−5.35	0.34	0.28	1.28	5.9	397	68,000	18,900
252	Urban three - leg intersections with all - way STOP control	MN	−12.37	1.22	0.27	0.47	41.0	41	25,300	6,803
253	Urban three - leg intersections with signal control	MN	−9.85	0.97	0.18	0.23	41.4	33	50,000	25,807
254	Urban four - leg intersections with minor - road STOP control	MN	−3.12	0.27	0.16	0.86	7.6	333	58,870	81,000
255	Urban four - leg intersections with all - way STOP control	MN	−12.37	1.22	0.27	0.47	41.0	41	25,300	6,803
256	Urban four - leg intersections with signal control	MN	−3.47	0.42	0.14	0.32	26.4	418	75,000	81,000

NOTE: The SPFs shown in this table use the functional form shown in Equation (E-2).

Table E-4. SPFs for Fatal and Injury Accident Intersections

Site subtype code	Site subtype description	State	Regression coefficients LogIntercept (β_0)	Regression coefficients LogAADT$_{maj}$ (β_1)	Regression coefficients LogAADT$_{min}$ (β_2)	Over-dispersion parameter (d)	R_{FT}^2 (%)	Number of eites	Max AADT$_{maj}$ (veh/day)	Max AADT$_{min}$ (veh/day)
201	Rural three - leg intersections with minor - road STOP control	MN	−9.35	0.71	0.21	1.23	9.1	1,706	28,500	27,000
202	Rural three - leg intersections with all - way STOP control	MN	−10.02	1.27	−0.22	0.89	24.8	41	25,300	6,803
203	Rural three - leg intersections with signal control	MN	−7.83	0.75	0.14	0.50	21.5	136	36,400	11,500
204	Rural four - leg intersections with minor - road STOP control	MN	−9.36	0.66	0.40	0.00	14.6	2,114	35,500	26,700
205	Rural four - leg intersections with all - way STOP control	MN	−10.02	1.27	−0.22	0.89	24.8	41	25,300	6,803
206	Rural four - leg intersections with signal control	MN	−7.83	0.75	0.14	0.50	21.5	136	36,400	11,500
251	Urban three - leg intersections with minor - road STOP control	MN	−8.45	0.49	0.39	1.23	8.1	397	68,000	18,900
252	Urban three - leg intersections with all - way STOP control	MN	−10.02	1.27	−0.22	0.89	24.8	41	25,300	6,803
253	Urban three - leg intersections with signal control	MN	−10.22	0.91	0.21	0.27	36.2	33	50,000	25,807
254	Urban four - leg intersections with minor - road STOP control	MN	−4.35	0.29	0.19	0.99	5.7	333	58,870	81,000
255	Urban four - leg intersections with all - way STOP control	MN	−10.02	1.27	−0.22	0.89	24.8	41	25,300	6,803
256	Urban four - leg intersections with signal control	MN	−5.11	0.49	0.16	0.30	29.5	418	75,000	81,000

NOTE: The SPFs shown in this table use the functional form shown in Equation (E-2).

Table E-5. SPFs for Total Accidetns on Ramps

Site subtype code	Site subtype description	State	Regression coefficients LogIntercept(□)	Regression coefficients LogAADT(□i)	Over-dispersion parameter (d)	R_{FT}^2 (%)	Total length of sites (mi)	Maximum AADT (veh/day)
301	Rural diamond off - ramps	WA	−3.07	0.46	1.34	10.2	59	19,907
302	Rural diamond on - ramps	WA	−2.16	0.19	1.86	0.9	30	9,342
303	Rural parclo loop off - ramps	WA	−1.15	0.26	0.12	11.3	2	6,613
304	Rural parclo loop on - ramps	WA	−5.59	0.82	0.97	14.2	2	13,480
305	Rural free - flow loop off - ramps	WA	−5.10	0.78	1.69	25.2	3	19,907
306	Rural free - flow loop on - ramps	WA	−1.17	0.35	2.32	6.8	4	29,767
307	Rural free - flow outer connection ramps	WA	−2.83	0.49	0.86	11.4	15	20,709
308	Rural direct and semidirect connection ramps	WA	−3.21	0.56	1.74	11.3	14	96,716
351	Urban diamond off - ramps	WA	−3.52	0.54	1.15	7.5	28	19,907
352	Urban diamond on - ramps	WA	−8.20	1.03	1.21	19.8	26	25,077
353	Urban parclo loop off - ramps	WA	−1.15	0.26	0.12	11.3	2	6,613
354	Urban parclo loop on - ramps	WA	−5.59	0.82	0.97	14.2	2	13,480
355	Urban free - flow loop off - ramps	WA	−4.60	0.73	1.32	27.1	3	19,907
356	Urban free - flow loop on - ramps	WA	−0.55	0.29	2.42	4.0	3	29,767
357	Urban free - flow outer connection ramps	WA	−3.50	0.57	0.77	11.1	11	20,709
358	Urban direct and semidirect connection ramps	WA	−1.28	0.35	1.47	5.6	11	96,716

NOTE: The SPFs shown in this table use the functional form shown in Equation (E-3).

Table E-6. SPFs for Fatal and Injury Accident Ramps

Site subtype code	Site subtype description	State	Regression coefficients LogIntercept(□)	Regression coefficients LogAADT(□i)	Over-dispersion parameter (d)	R_{FT}^2 (%)	Total length of sites (mi)	Maximum AADT (veh/day)
301	Rural diamond off - ramps	WA	−4.54	0.47	2.66	2.8	31	14,525
302	Rural diamond on - ramps	WA	−8.12	0.86	0.98	9.1	55	25,077
303	Rural parclo loop off - ramps	WA	−4.29	0.59	0.94	18.4	3	19,907
304	Rural parclo loop on - ramps	WA	−1.30	0.24	1.02	4.1	4	29,767
305	Rural free - flow loop off - ramps	WA	−4.29	0.59	0.94	18.4	3	19,907
306	Rural free - flow loop on - ramps	WA	−1.30	0.24	1.02	4.1	4	29,767
307	Rural free - flow outer connection ramps	WA	−4.89	0.61	0.27	12.3	15	20,709
308	Rural direct and semidirect connection ramps	WA	−4.22	0.55	1.39	9.4	14	96,716
351	Urban diamond off - ramps	WA	−3.86	0.47	1.94	3.0	28	19,907
352	Urban diamond on - ramps	WA	−7.99	0.86	0.69	9.6	26	25,077
353	Urban parclo loop off - ramps	WA	−3.68	0.53	0.67	19.3	3	19.907
354	Urban parclo loop on - ramps	WA	−1.34	0.24	1.20	3.2	3	29,767
355	Urban free - flow loop off - ramps	WA	−3.68	0.53	0.67	19.3	3	19,907
356	Urban free - flow loop on - ramps	WA	−1.34	0.24	1.20	3.2	3	29,767
357	Urban free - flow outer connection ramps	WA	−6.12	0.75	0.39	12.9	11	20,709
358	Urban direct and semidirect connection ramps	WA	−2.50	0.37	1.37	4.7	11	96,716

NOTE: The SPFs shown in this table use the functional form shown in Equation (E-3).

Guidance for *SafetyAnalyst* Users on Developing Safety Performance Functions for Individual Highway Agencies

APPENDIX F. GUIDANCE FOR *SAFETYANALYST* USERS ON DEVELOPING SAFETY PERFORMANCE FUNCTIONS FOR INDIVIDUAL HIGHWAY AGENCIES

F.1 Introduction

This appendix provides guidance on the development of safety performance functions (SPFs) for use with the *SafetyAnalyst* software. SPFs are provided in *SafetyAnalyst* and automatically calibrated using each agency's data, so it is not necessary for agencies to develop their own SPFs. However, since some agencies may prefer to implement *SafetyAnalyst* using SPFs developed with their own agency's data; this memo provides guidance on the appropriate procedures for SPF development. SPFs are regression relationships between target accident frequencies and traffic volumes that can be used to predict the expected long-term accident frequency for a site. SPFs are used in the EB methodologies that estimate the safety performance of sites in several of the analytical tools provided with *SafetyAnalyst*. Thus, SPFs are essential to the functioning of those tools.

F.2 What SPFs Are Needed?

Within *SafetyAnalyst*, SPFs are needed for three types of sites (roadway segments, intersections, and ramps) and for several subtypes of those site types. Site type and subtypes are based upon roadway characteristics and other site characteristics. The site types and subtypes for which SPFs are needed are as follows:

Roadway Segments

- Rural two-lane highway segments
- Rural multilane undivided highway segments
- Rural multilane divided highway segments
- Rural freeway segments—4 lanes
- Rural freeway segments—6+ lanes
- Rural freeway segments within an interchange area—4 lanes
- Rural freeway segments within an interchange area—6+ lanes
- Urban two-lane arterial segments
- Urban multilane undivided arterial segments
- Urban multilane divided arterial segments
- Urban one-way arterial segments
- Urban freeway segments—4 lanes
- Urban freeway segments—6 lanes
- Urban freeway segments—8+ lanes

- Urban freeway segments within an interchange area—4 lanes
- Urban freeway segments within an interchange area—6 lanes
- Urban freeway segments within an interchange area—8+ lanes

Intersections

- Rural three-leg intersections with minor-road STOP control
- Rural three-leg intersections with signal control
- Rural four-leg intersections with minor-road STOP control
- Rural four-leg intersections with all-way STOP control
- Rural four-leg intersections with signal control
- Urban three-leg intersections with minor-road STOP control
- Urban three-leg intersections with signal control
- Urban four-leg intersections with minor-road STOP control
- Urban four-leg intersections with all-way STOP control
- Urban four-leg intersections with signal control

Ramps

- Rural diamond off-ramps
- Rural diamond on-ramps
- Rural parclo loop off-ramps
- Rural parclo loop on-ramps
- Rural free-flow loop off-ramps
- Rural free-flow loop on-ramps
- Rural direct or semidirect connection ramps
- Urban diamond off-ramps
- Urban diamond on-ramps
- Urban parclo loop off-ramps
- Urban parclo loop on-ramps
- Urban free-flow loop off-ramps
- Urban free-flow loop on-ramps
- Urban direct or semidirect connection ramps

For each site subtype, SPFs are needed both for total (TOT) (i.e., all accident severity levels combined) and fatal-and-injury (FI) (i.e., all accidents in which a fatality occurred and all accidents in which a personal injury of any severity level occurred) accidents. No SPFs are needed to estimate the frequency of fatal and severe injury (FS) accidents and property-damage-only (PDO) accidents. For FS accident frequencies, estimates are calculated within *SafetyAnalyst* by using the FI SPF multiplied by the proportion of FS accidents out of all FI accidents. Similarly, when PDO accident frequency values are

needed, they are determined within *SafetyAnalyst* as the difference between TOT and FI accident frequencies.

F.3 Functional Form of SPFs

The SPFs needed for *SafetyAnalyst* predict accident frequency as a function of annual average daily traffic (ADT) volume alone. For roadway segments and ramps, the independent variable representing traffic volume is the ADT of the roadway segment or ramp. For intersections, two independent variables represent traffic volume, the ADTs of the two intersecting roads (classified as the major and minor road, where the major road is typically defined as the road with the higher ADT).

The dependent variable of the SPFs (i.e., the variable whose value is predicted by the model) is accidents per mile per year for roadway segments and ramps and accidents per year for intersections.

The functional form for roadway segment SPFs is:

$$\kappa = e^{\alpha} \times ADT^{b} \tag{F-1}$$

where:
κ   =   predicted number of target accidents per mile per year
ADT =   average annual daily traffic volume (veh/day) for the roadway segment for both directions of travel combined

Since κ is expressed in terms of target accidents per mile per year, Equation (F-1) is equivalent to:

$$N = e^{\alpha} \times ADT^{b} \times L \tag{F-2}$$

where:
N =   predicted number of target accidents per site per year
L =   length (in miles) of the roadway segment

The functional form for intersection SPFs is:

$$\kappa = e^{\alpha} \times MajADT^{b} \times MinADT^{c} \tag{F-3}$$

where:
κ   =   predicted number of target accidents per intersection per year
MajADT =   average annual daily traffic volume on the major road (veh/day) for both directions of travel combined

MinADT = average annual daily traffic volume on the minor road (veh/day) for both directions of travel combined

The functional form for ramp SPFs is:

$$\kappa = e^{\alpha} \times ADT^{b} \qquad\qquad\qquad (F\text{-}4)$$

where:
κ = predicted number of target accidents per mile per year
ADT = average annual daily traffic volume (veh/day) for the ramp

Since κ is expressed in terms of target accidents per mile per year, Equation (F-4) is equivalent to:

$$N = e^{\alpha} \times ADT^{b} \times L \qquad\qquad\qquad (F\text{-}5)$$

where:
N = predicted number of target accidents per site per year
L = length (in miles) of the ramp

In all three equations, a, b, and c represent the regression parameters that are estimated from the available data.

Since the default SPFs provided within *SafetyAnalyst* were developed using data from multiple states, a calibration procedure is included as part of the data import and preprocessing procedures. Yearly calibration factors are calculated within *SafetyAnalyst* during the data import and preprocessing procedures using an agency's own accident and traffic volume data and the default SPFs provided with *SafetyAnalyst*. The calibration factors are intended to account for differences in accident patterns in different geographical areas that are not directly addressed by the SPFs and provide accident predictions that are comparable to the estimates that a highway agency would obtain from SPFs developed using its own accident records system. The yearly calibration factor for a given year and site subtype is calculated as the ratio of the sum of observed accidents for all sites for a specific site subtype to the sum of the predicted accidents for the same sites using the ADT and accident count values for that year. When an agency develops its own SPFs for use within *SafetyAnalyst*, the yearly calibration factors for use with these agency defined SPFs are by definition 1.0.

F.4 Data Needs for Development of SPFs

All of the data needed for the creation of SPFs is the same data that is needed to operate and use the *SafetyAnalyst* software. As a result, it is highly recommended that an agency import their data into *SafetyAnalyst*, run the preprocessing programs on the data, then

export the data for use in the development of SPFs. Alternatively, users may independently create the necessary data as described in the remaining part of this section.

The creation of SPFs requires data on the location information, roadway characteristics, traffic volumes, and accidents. Each of these types of data and their processing requirements are described next.

The roadway characteristics, which should be the current characteristics at a site, are used to define the site types and subtypes identified in the first section of this document. The logic and data used to create the subtypes in *SafetyAnalyst* out of agency data are described in the Site Subtype Assignment document on the *SafetyAnalyst* Wiki. Please note that *SafetyAnalyst* does this assignment automatically with agency data when importing the data. However, users will have to assign site subtypes themselves when using their own data to develop SPFs. Additionally, segment length data is needed for roadway segments and ramps. Sites with missing length should not be used to develop SPFs. Finally, roadway segments may also require some additionally processing based on their geometrics.

Regression models for roadway segments rely on observed accidents at a site. As roadway accidents occur infrequently over a period of time, statistically significant regression models for roadway segments are often only obtained by considering roadway segments of a certain minimal length, usually between 0.04 and 0.1 mi. For some agencies to obtain valid models, smaller roadway segment records may need to be combined into longer roadway segments to meet that minimum length; such longer segments should be as homogeneous as possible with respect to key variables such as: area type, terrain, functional class, number of through lanes, auxiliary lanes, lane width, median type, median width, shoulder type, shoulder width, access control, driveway density, ADT, posted speed limit, two-way vs. one-way operation, bikeway, and interchange influence area.

Traffic volume data should be supplied for each calendar year for which accident data are used in *SafetyAnalyst*. For roadway segments, traffic volume should be for both directions, as the SPFs predict accidents for both directions. Some states keep separate records for traffic volumes and accidents in each direction of travel on divided highways. If a state develops an SPF for one direction of travel on a divided highway in the following form:

$$\kappa = e^{\alpha} \times ADT_{oneway}^{b} \qquad\qquad (F-6)$$

It should be converted to a two-directional SPF for use in *SafetyAnalyst* as follows:

$$\kappa = 2(0.5)^{b} \times e^{\alpha} \times ADT^{b} \qquad\qquad (F-7)$$

where value of the intercept term would be entered into *SafetyAnalyst* as $2(0.5)^{b}e^{\alpha}$.

For intersections, yearly ADT are needed for both the major and minor roads, where the major road is generally defined to be the road with the highest ADT. If two major-or

minor-road legs of an intersection have different ADTs, the higher of the two ADT values should be used. Years for which ADT are missing can be estimated by interpolation or extrapolation. Sites that are missing ADT information for all years should be excluded from SPF development.

Location information is needed for sites to match/merge accidents records to the sites. Accidents should be assigned to only one site and be related to the type of site. For example, roadway segments should not be matched with any intersection-related or ramp-related accidents. Accidents that occur at an intersection (within the curbline limits) or that are classified as intersection-related and occur within 250 ft of an intersection should be assigned to the intersection. Accidents should be assigned to roadway segments and ramps by matching the location information. If an accident occurs on the point between two roadway segments then it should be assigned to either the beginning segment or ending segment so that all similarly situated accidents are assigned in the same way. If an agency has difficulty in following these rules for accident assignment exactly because of data limitations, they should be followed as closely as possible.

Accident data should also include information on the severity of the accident. All reported accidents, including fatal, injury, and property-damage-only accidents should be included in the development of the total accident SPFs. The accident severity data should then be used to identify which accidents should be considered in the development of fatal and injury SPFs. Accident data should be provided for a minimum of 3 years (preferably five) up to a maximum of 10 years. The historical accident data should include whole calendar years for each year of data.

F.5 Statistical Assumptions and Software

SPFs are usually developed with negative binomial regression analysis, but can be developed with Poisson regression analysis, depending on the relationship between the mean and variance in the data. When accident frequency data have the same mean and variance, then accident frequency follows a Poisson distribution. Alternatively, when the accident variance exceeds the mean, or the data are overdispersed, then accident frequency follows a negative binomial (NB) distribution. In fact, the variance of a NB distribution is a function of its mean (i.e., the mean plus a dispersion parameter multiplied by the square of the mean). In this way, when the dispersion parameter nears zero, the NB distribution approaches the Poisson distribution. Since most accident frequencies are overdispersed, NB regression is typically used. However, Poisson regression is an acceptable substitute if the dispersion parameter is near zero.

The parameters of these distributions can be indirectly estimated using a generalized linear model to obtain the model regression coefficients shown in the functional form section of this document. Generalized linear models are extensions of conventional linear models where the dependant variable is related to the linear independent variables through a nonlinear link function and the dependent variable is generated from a distribution function in the exponential family. Several commercially available statistical software packages

offer generalized linear model procedures that can be used to estimate the regression coefficients. In particular, the use of the procedure, PROC GENMOD, (*10*) of the statistical package SAS will be described in this section.

There are two methods of obtaining the regression models with the PROC GENMOD procedure. The first method models yearly accident counts while the second method models summary accident count data. For the yearly accident count models, the relationship in accidents at a site across years (temporal correlation) can be accounted for in the model by using a repeated measures correlation structure. General estimating equations (GEE) using a compound symmetry covariance structure can be used to determine the final regression parameter estimates. For the summary accident count data, the model regression coefficients are estimated by the method of maximum likelihood using a ridge-stabilized Newton-Raphson algorithm. The asymptotic normality of maximum likelihood estimates is used to obtain test of significance of the parameters and goodness of fit measures for the models. To perform an analysis in these procedures, several data items will need to be specified: dataset, dependent variable and distribution, independent variable(s), link function, and offset factor.

The dataset used for yearly accident counts should be organized as one record for each available year of data for each site. The dataset for the summary accident data should be organized as one record per site. Both datasets should contain the site subtype, dependent variables, independent variable(s), and offset factor. The minimum number of sites needed for model convergence is dependent on a number of accidents occurring at the sites. Site types that experience relatively high accident frequencies, such as urban intersections, will require fewer sites and/or fewer years of accident history. In contrast, rural roadway segments generally need more sites and/or more years of accident history.

Poisson and negative binomial regression are performed with a log link function, which is sometimes referred to as loglinear modeling. A log linear relationship between the accidents and ADT ensures that predictions from the fitted model are positive.

The dependent variables, or variables whose values are predicted by the model, are the number of TOT or FI accidents that are predicted to have occurred at each site during the history period. Consequently, for SPF development in *SafetyAnalyst* there should be two accident variables in the dataset, one containing the count of all (i.e., TOT) accidents and one containing a similar count of fatal and injury (i.e., FI) accidents. However, individual models are to be created for each dependent variable. These variables should contain yearly accident counts for the first method and total counts occurring at the site during the history period for the summary method.

Traffic volume(s) are the only independent variable(s) considered in the SPF forms shown in Equations (F-1) through (F-3). As shown in these equations, these variables have a nonlinear relationship with predicted accidents. As a result, the natural logarithm of these variables should be used in the modeling procedure rather than the actual values. Again, these values should be yearly values for the first method and the logarithm of the average

value for the summary method. There does not need to be a placeholder variable in the data for the intercept, as it is automatically provided by the software.

The offset factor, or scale factor, serves to normalize the predicted accidents to a per mile per year basis, since accident frequencies, not accident rates, are used in the model. For roadway segments and ramps, the natural logarithm of the length of the segment multiplied by the number of accident calendar years is included as a scale factor for the summary method. Intersections use the natural logarithm of the number of accident calendar years as a scale factor for the summary method so predicted accidents are given on a per site per year basis. Since the yearly accident count model is already predicting accidents on a per year basis, only the length variables are needed as an offset in this modeling method.

Once the dataset has been assembled for regression analysis, and the usual data quality checks for outliers and model assumptions are conducted, the following SAS code may be used to generate the SPF model coefficients:

Yearly Method:

PROC GENMOD; BY SiteSubtype; MODEL TotAcc=logADT/LINK=Log DIST=NEGBIN OFFSET=logLength; repeated subject=SiteID/ type=CS;

Summary Method:

PROC GENMOD; BY SiteSubtype; MODEL TotAcc=logADT/LINK=Log DIST=NEGBIN OFFSET=logLengthYrs;

In these specifications, TotAcc and logADT are the dependent and independent variables (respectively) defined in the dataset, logLength and logLengthYrs are the offset values defined in the dataset, DIST = option specifies the negative binomial distribution, LINK = option specifies log-linear regression model, SiteID is the unique site number in the dataset that ties yearly records together, CS (Compound Symmetry) is the covariance structure type, and the BY SiteSubtype option creates a separate model for each change in value of the SiteSubtype variable defined in the dataset.

Several other options are available that could be specified in the above statements to control the algorithm and display additional statistics (e.g., type I tests, type III tests, confidence intervals, etc.). In particular, using the combined options of DIST = NEGBIN SCALE = 0 NOSCALE in the summary method, can test for overdispersion in a Poisson model. Overdispersion is assessed by testing whether the negative binomial dispersion parameter is equal to zero (i.e., when the negative binomial distribution is equivalent to the Poisson distribution).

Model convergence, goodness-of-fit, and statistical significance of the coefficients can be assessed with the output automatically generated by the software. While all of the details

of these components cannot be described in this document, some basic guidelines on excluding models for use in *SafetyAnalyst* are provided in the remainder of this section.

Coefficients from models that do not converge should not be used in *SafetyAnalyst*. Nonconvergence of the Newton-Raphson algorithm can occur for some datasets. Poor performance can be the result of a number of factors: ill-conditioned data (e.g., data that are extremely large or extremely small), a nonpositive definite Hessian matrix can indicate linear dependencies among the parameters, model misspecification, or violations of the error assumptions. (The general estimating equations can fail for similar reasons including nonconvergence of the covariance estimate.) However, the most probable explanation for nonconvergence is lack of event data (i.e., small accident counts). Asymptotic or large sample inference used by this procedure, which is based on maximizing the likelihood function, may not be appropriate in situations where the total number of accidents in any site subtype group is small. For those groupings, exact Poisson regression is a more statistically valid approach to get regression estimates and p-values. However, this capability is not currently provided in this procedure, rather LogXact 4.1 software should be used.

There are several goodness-of-fit statistics available for the summary procedure. However, the preferred fit statistics used by transportation researchers are usually calculated from output generated by the procedure rather than the procedure itself. For example, the Freeman-Tukey R^2 coefficient (R_{FT}^2) (*11*) has been presented in Appendix E for the SPFs that have been developed for *SafetyAnalyst*. This goodness-of-fit statistic is not available within the software procedure and must be calculated outside of the procedure. As observed in Appendix E, selection of models for use with *SafetyAnalyst* was not limited by the value of this goodness-of-fit statistic, particularly if it was the only available model. However, an agency developing their own SPFs may compare and consider this goodness-of-fit statistic when choosing between their own SPFs or the ones provided by *SafetyAnalyst*.

Coefficient estimates provided by the procedure should be assessed by their magnitude and direction as well as their statistical significance. For example, a negative coefficient for ADT, indicating accidents decrease as ADT increase, is probably never appropriate. Also, the significance level used to assess coefficient estimates is more relaxed in transportation research. A significance level of 10 percent is generally used to assess coefficient estimates for ADT on roadways, ramps, and the major road of intersections. However, a significance level of 20 percent is usually considered for minor road ADT on intersections.

Finally, the estimate of the dispersion parameter should always be positive since the Empirical Bayes procedures in SafetyAnalyst rely on a positive dispersion parameter. A negative value will sometimes occur when overdispersion is not present in the data. Overdispersion may be absent when most sites have nonzero accident counts, such as high accident locations or longer roadway segments. In these situations, remodel the data assuming a small positive constant dispersion parameter, like 0.1.