SafetyAnalyst: Software Tools for Safety Management of Specific Highway Sites

White Paper for Module 4—Countermeasure Evaluation

August 2010

1. INTRODUCTION

This white paper documents the benefits and capabilities of the countermeasure evaluation tool in Module 4 of the *SafetyAnalyst* software. An overview summary and the expected benefits are found in Section 1. Section 2 of this paper details the capabilities of *SafetyAnalyst* Module 4. Appendix A presents a detailed description of the analytical procedures found in this module. A complete description of *SafetyAnalyst* capabilities is found in the *SafetyAnalyst* final report (*1*).

1.1 *SafetyAnalyst* Countermeasure Evaluation Overview

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.

1.2 Expected Benefits of the Countermeasure Evaluation Tool

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.

2. CAPABILITIES FOR MODULE 4—COUNTERMEAUSRE EVALUATION

This section of the paper 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 2.1.

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 2.2.

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 2.3.1 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 2.3.2 through 2.3.7 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 2.4. Section 2.5 summerizes the benefits of using Module 4.

2.1 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.

2.2 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 A 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 A.

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.

2.3 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.

2.3.1 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.

2.3.2 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 1). After a dataset is selected, the main interface for the Implemented Countermeasure tool is then shown.

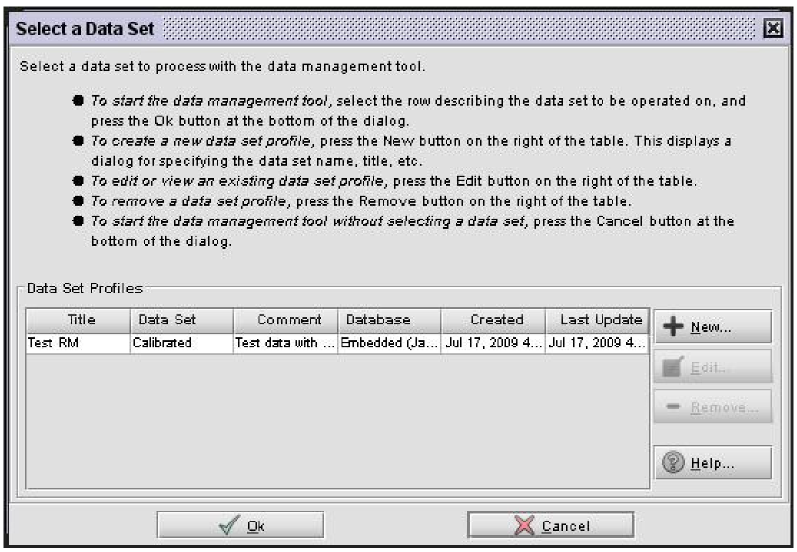


Figure 1. Select a Data Set Dialog in the Implemented Countermeasure Tool

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 2. 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.

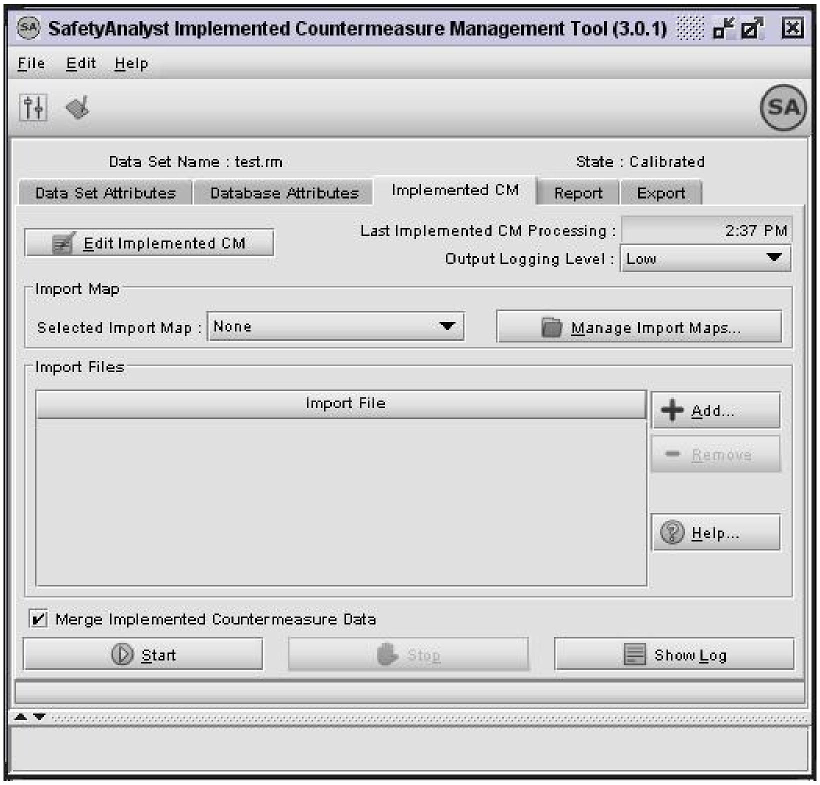


Figure 2. Implemented CM Tab Within the Implemented Countermeasure Tool

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 3, 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 3. 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 4). 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.

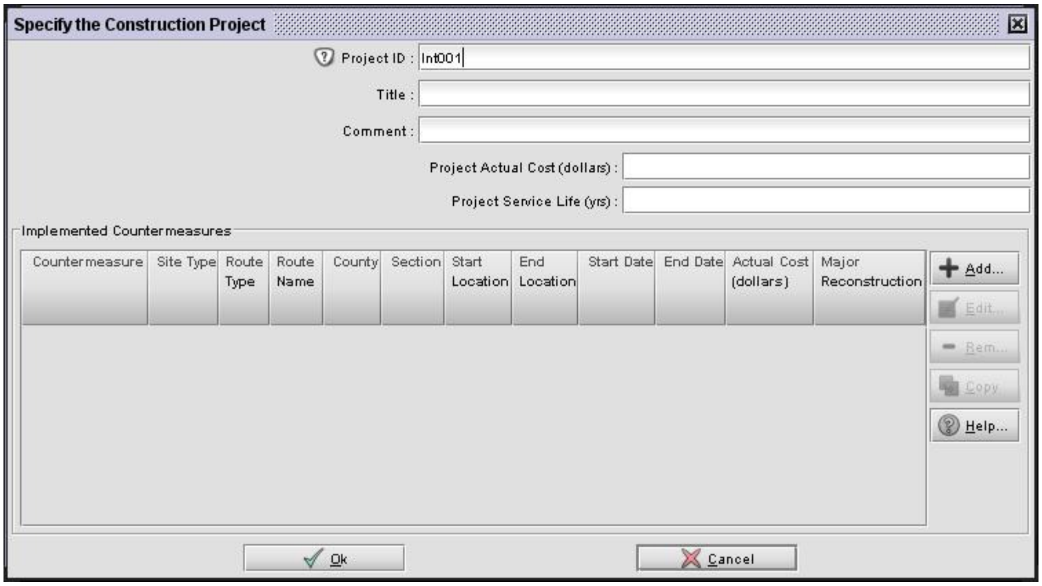


Figure 4. Specify the Construction Project Dialog Within the Implemented Countermeasure Tool

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 5, 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.

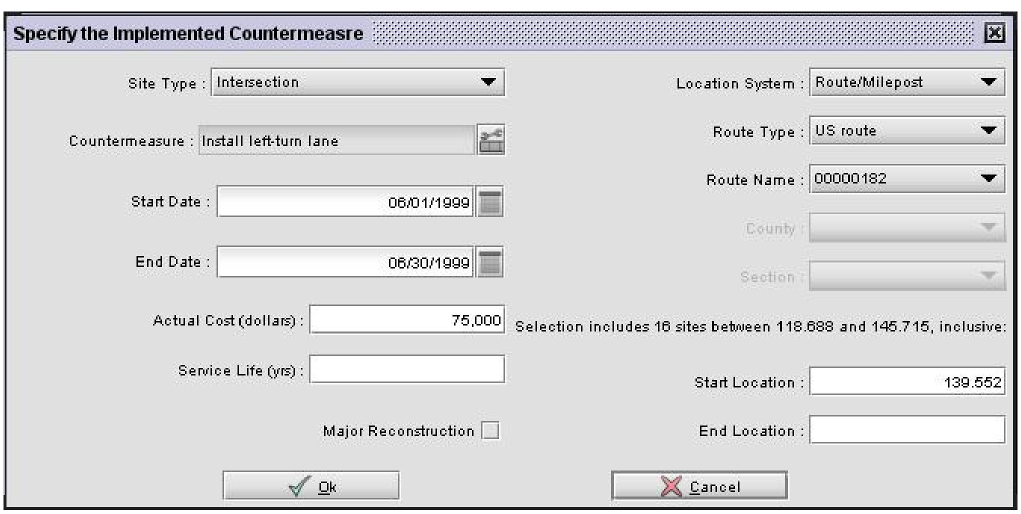


Figure 5. Specify the Implemented Countermeasure Dialog Within the Implemented Countermeasure Tool

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 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.

2.3.3 Specifying Scope and Type of Evaluation

Specifying a countermeasure evaluation begins with selection of the analysis scope and evaluation type. Figure 6 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.

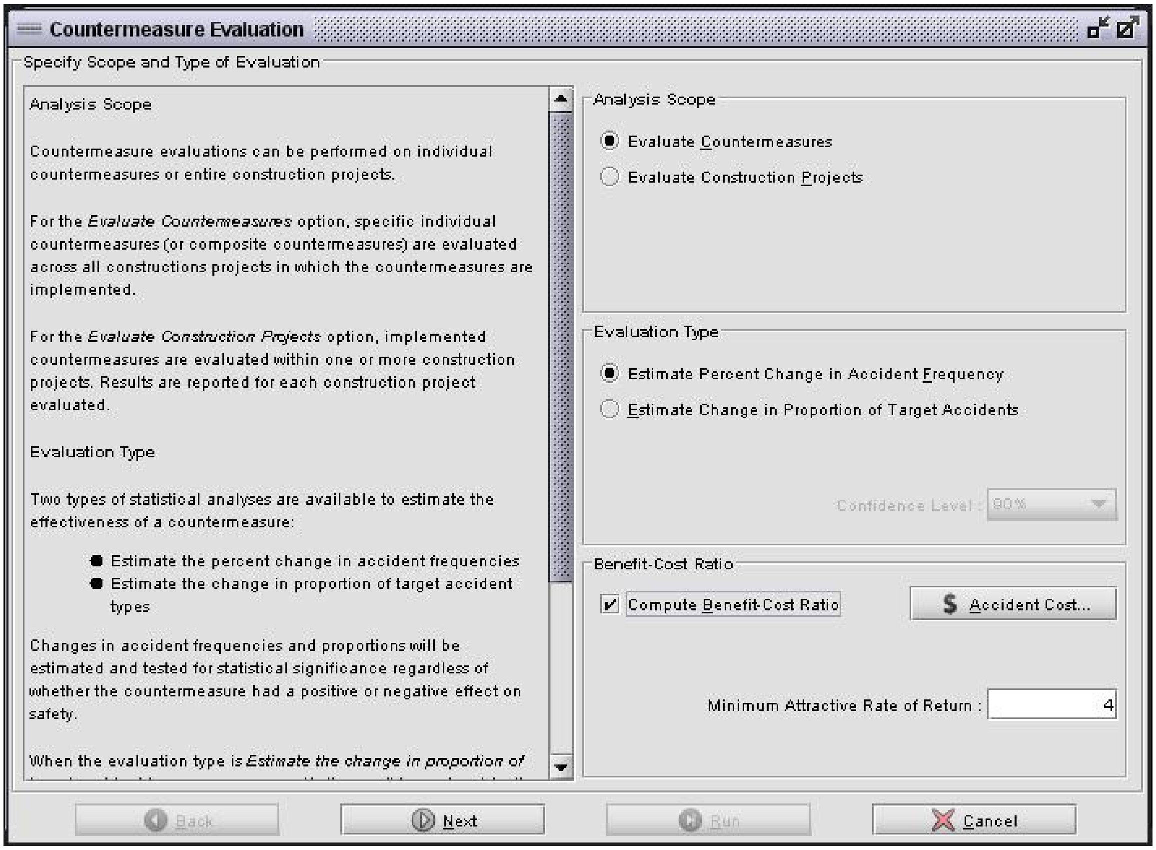


Figure 6. Specify Scope and Type of Evaluation Panel in Module 4

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 2.2. 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 percent and 95 percent 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.

2.3.4 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 7) is used to select the specific implemented countermeasure(s) to be evaluated.

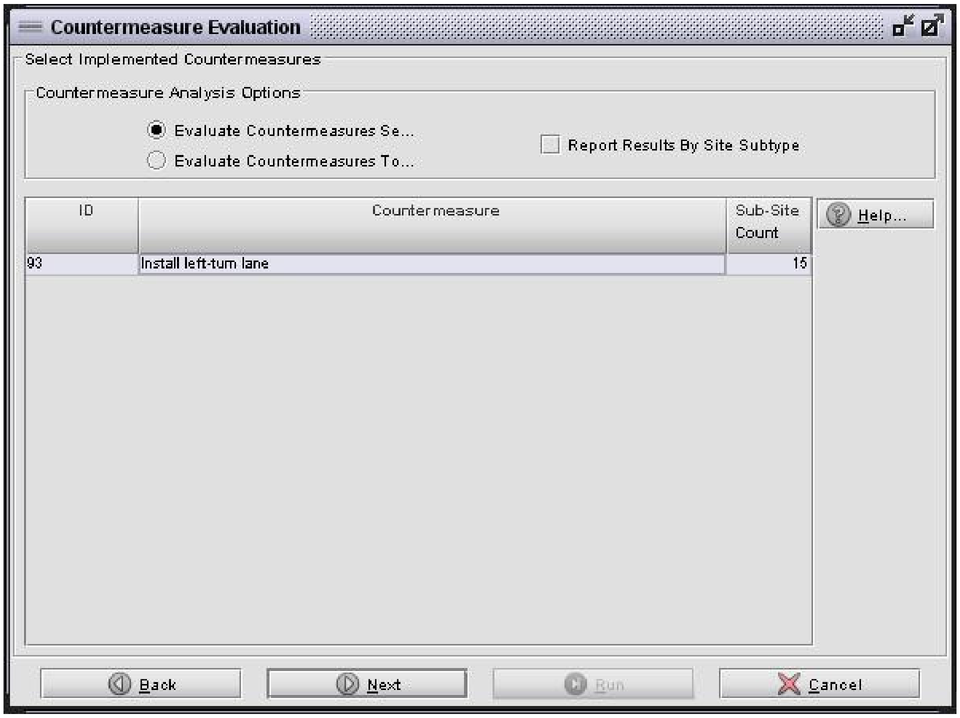


Figure 7. Select Implemented Countermeasures Panel in Module 4

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.

2.3.5 Specifying History and Accident Periods

With the panel for Specifying Analysis Period Constraints (Figure 8), 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.

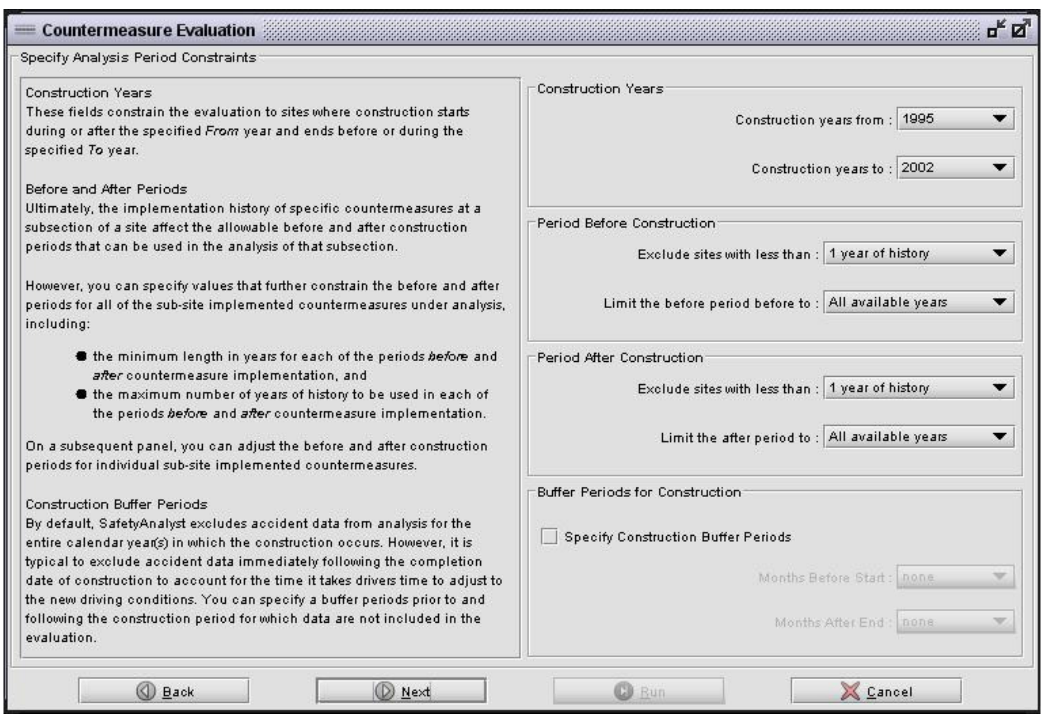


Figure 8. Specify Analysis Period Panel in Module 4

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.

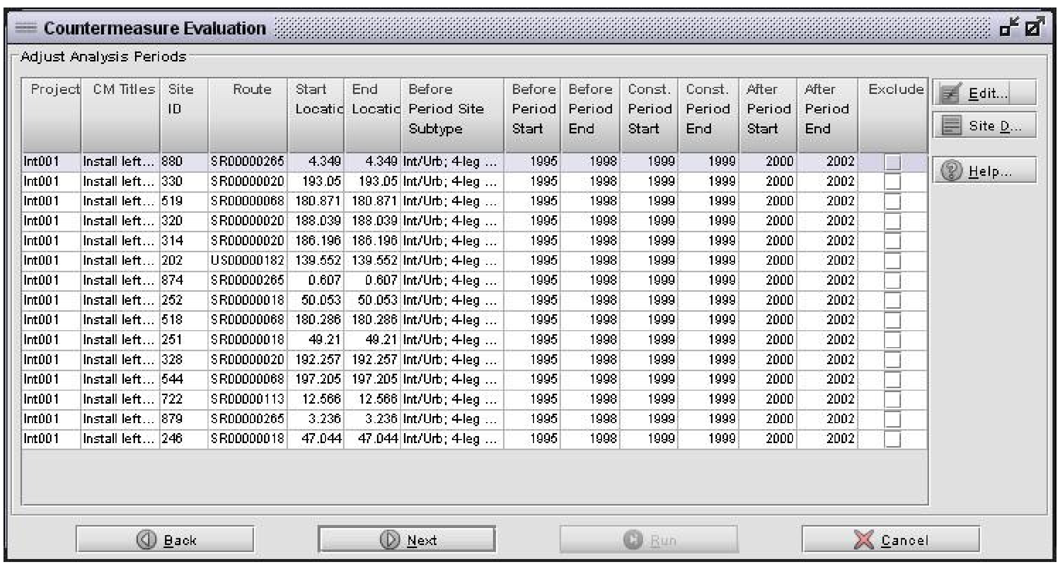
When multiple countermeasures are being evaluated, it is expected that they were constructed at the same time. However, *SafetyAnalyst* also allows them to be evaluated together if there is a short time period between them, as long as their combined construction period does not exceed 3 years.

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.

2.3.6 Adjust Analysis Periods and Costs (Optional)

SafetyAnalyst provides the opportunity to adjust the analysis periods for each site individually (Figure 9). 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.



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	

Figure 9. 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 10) 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.

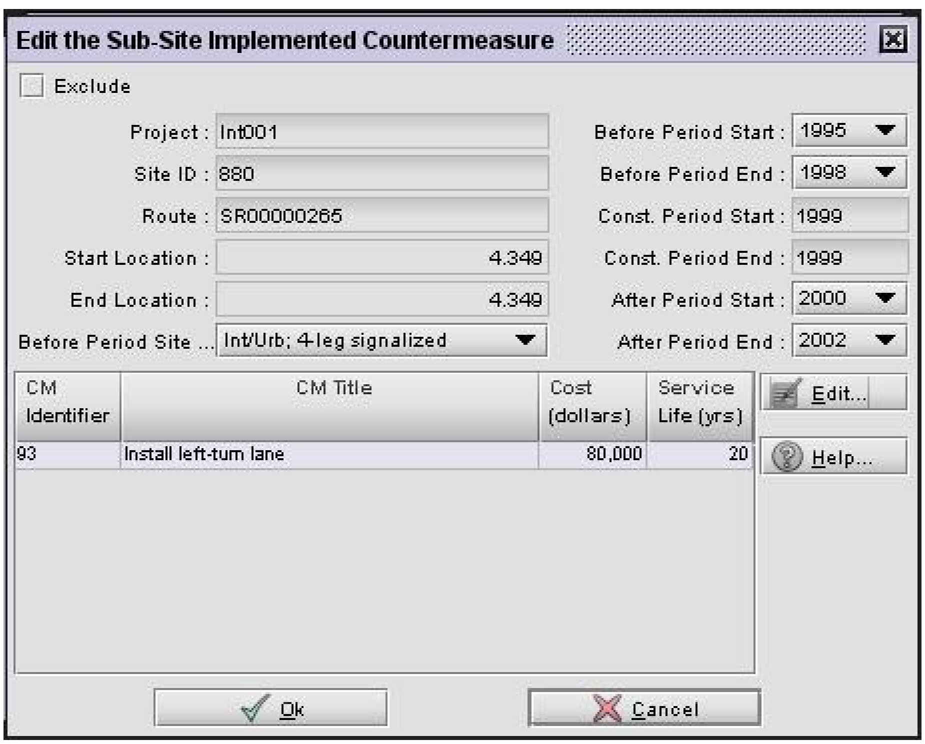


Figure 10. Edit the Sub-Site Implemented Countermeasure Dialog

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.

2.3.7 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 11 presents a typical input screen to specify the accident severity level for the analysis.

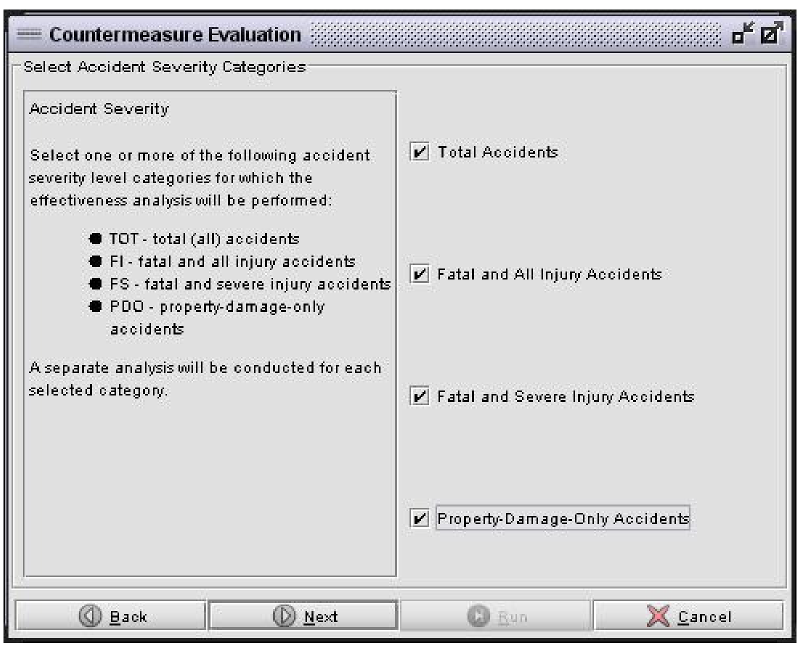


Figure 11. Select Accident Severity Panel in Module 4

2.3.8 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.

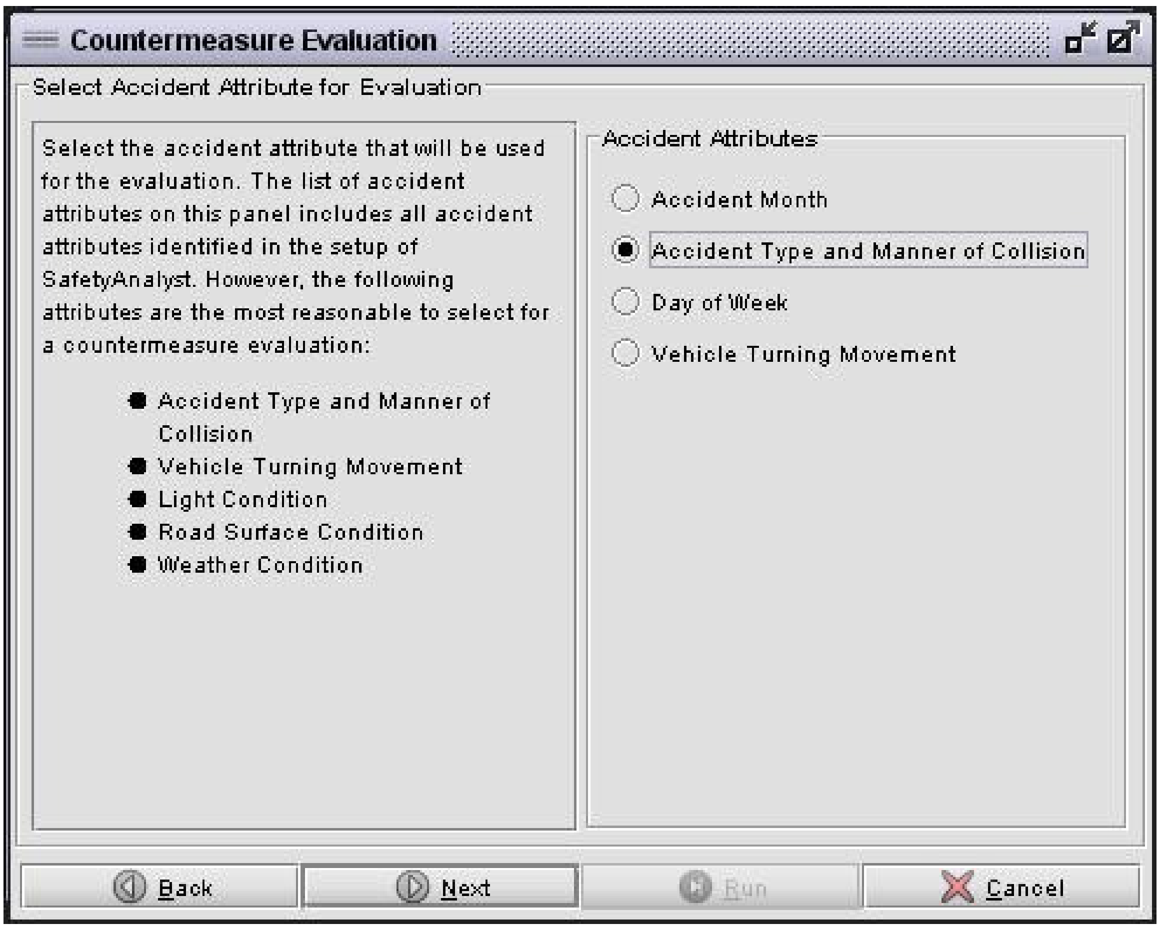


Figure 12. Select Accident Category Panel in Module 4

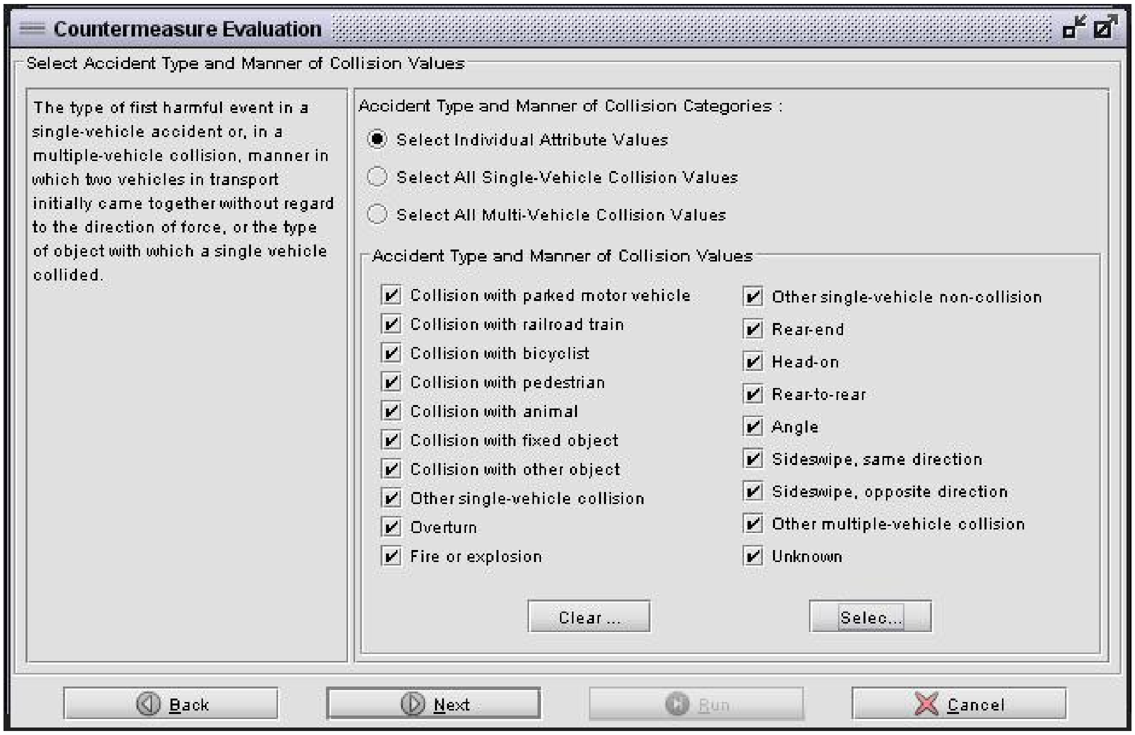


Figure 13. Select Accident Attribute Values Panel in Module 4

2.4 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 1 show no statistically significant change in accident frequency, but this is the expected result for sites where no countermeasure was actually implemented.

Table 1 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:

- 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 1. 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 estimate 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 2 shows the total accident table for this sample.

Table 2. 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 3) and Benefit Cost by Site (Table 4). 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 3. 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 4. 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

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 2 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.

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

Table 5 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 5. 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 (*2*).

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 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 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 6). This table illustrates sites for which the largest differences in proportions occurred.

Table 6. 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

2.5 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 (*2*). 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 (*2*).

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Appendix A

Detailed Procedures for *SafetyAnalyst* Module4—Countermeasure Evaluation

APPENDIX A. DETAILED PROCEDURES FOR *SAFETYANALYST* MODULE 4—COUNTERMEAUSRE EVALUATION

A.1 Procedures for Evaluating Countermeasures

A.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 A-1 presents the nomenclature used in the Module 4 algorithms.

A.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:

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

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

(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:

$$\kappa_{iy(TOT)} = SPF_{TOT}\{MajADT, MinADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times MajADT_{iy}^{\beta_1} \times MinADT_{iy}^{\beta_2} \quad \text{(A-3)}$$

$$\kappa_{iy(FI)} = SPF_{FI}\{MajADT, MinADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times MajADT_{iy}^{\beta_1} \times MinADT_{iy}^{\beta_2} \quad \text{(A-4)}$$

Table A-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 I (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 (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
κ_{iy}	Predicted number of accidents during the before period using the SPF at site i during before year y
κ_i	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
π_i	Final EB expected number of accidents during the after period in the absence of treatment at site i, summed over all after years
λ_i	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
θ_i	Estimate of the effectiveness of a treatment at site i
θ	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; $Var(X) = [STD(X)]^2$

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 (A-2) and Equation (A-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.

$$\kappa_{i(TOT)Before} = \sum_{y(Before\ Years)} \kappa_{iy(TOT)} \tag{A-5}$$

$$\kappa_{i(FI)Before} = \sum_{y(Before\ Years)} \kappa_{iy(FI)} \tag{A-6}$$

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:

$$C_{iy(TOT)} = \frac{\kappa_{iy(TOT)}}{\kappa_{i1(TOT)}} \tag{A-7}$$

$$C_{iy(FI)} = \frac{\kappa_{iy(FI)}}{\kappa_{i1(FI)}} \tag{A-8}$$

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:

$$w_{TOT} = \frac{1}{1 + d_{TOT}\sum_{y=1}^{Y}\kappa_{y(TOT)} \times SL_i} \tag{A-9}$$

$$w_{FI} = \frac{1}{1 + d_{FI}\sum_{y=1}^{Y}\kappa_{y(FI)} \times SL_i} \tag{A-10}$$

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 (A-9) and Equation (A-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 (A-9) and Equation (A-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:

$$X_{iy(TOT)} = \left[w_{i(TOT)}\kappa_{iy(TOT)}SL_i + \left(1 - w_{i(TOT)}\right)\frac{\sum_{y=1}^{Y}\kappa_{iy(TOT)}}{\sum_{y=1}^{Y}C_{iy(TOT)}}\right] \times C_{iy(TOT)} \qquad \text{(A-11)}$$

$$X_{iy(FI)} = \left[w_{i(FI)}\kappa_{iy(FI)}SL_i + \left(1 - w_{i(FI)}\right)\frac{\sum_{y=1}^{Y}\kappa_{iy(FI)}}{\sum_{y=1}^{Y}C_{iy(FI)}}\right] \times C_{iy(FI)} \qquad \text{(A-12)}$$

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 (A-11) and Equation (A-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:

$$X_{iy(PDO)} = X_{iy(TOT)} - X_{iy(FI)} \qquad \text{(A-13)}$$

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:

$$X_{i(TOT)} = \sum_{y(\text{Before Years})} X_{iy(TOT)} \qquad \text{(A-14)}$$

$$X_{i(FI)} = \sum_{y(\text{Before Years})} X_{iy(FI)} \qquad \text{(A-15)}$$

$$X_{i(PDO)} = \sum_{y(\text{Before Years})} X_{iy(PDO)} \qquad \text{(A-16)}$$

A.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:

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

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

(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:

$$\kappa_{iy(TOT)} = SPF_{TOT}\{MajADT, MinADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times MajADT_{iy}^{\beta_1} \times MinADT_{iy}^{\beta_2} \quad \text{(A-3)}$$

$$\kappa_{iy(FI)} = SPF_{FI}\{MajADT, MinADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times MajADT_{iy}^{\beta_1} \times MinADT_{iy}^{\beta_2} \quad \text{(A-4)}$$

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 (A-2) and Equation (A-4) with $P_{(CT/FS/FI)}$, and (E) proceed as normal for FI calculations.

Step 9: Sum the number of accidents across all after years at site i for TOT and FI accidents.

$$\kappa_{i(TOT)After} = \sum_{y(After\ Years)} \kappa_{iy(TOT)} \quad \text{(A-17)}$$

$$\kappa_{i(FI)After} = \sum_{y(After\ Years)} \kappa_{iy(FI)} \quad \text{(A-18)}$$

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:

$$r_{i(TOT)} = \frac{\kappa_{i(TOT)After}}{\kappa_{i(TOT)Before}} \quad \text{(A-19)}$$

$$r_{i(FI)} = \frac{\kappa_{i(FI)After}}{\kappa_{i(FI)Before}} \quad \text{(A-20)}$$

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:

$$\pi_{i(TOT)} = X_{i(TOT)} \times r_{i(TOT)} \quad \text{(A-21)}$$

$$\pi_{i(FI)} = X_{i(FI)} \times r_{i(FI)} \quad \text{(A-22)}$$

$$\pi_{i(PDO)} = \pi_{i(TOT)} - \pi_{i(FI)} \quad \text{(A-23)}$$

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 (A-21) through Equation (A-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.

A.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:

$$\lambda_{i(TOT)} = L_{i(TOT)} = \sum_{y(\text{After Years})} L_{iy(TOT)} \quad \text{(A-24)}$$

$$\lambda_{i(FI)} = L_{i(FI)} = \sum_{y(\text{After Years})} L_{iy(FI)} \quad \text{(A-25)}$$

$$\lambda_{i(PDO)} = L_{i(PDO)} = \sum_{y(\text{After Years})} L_{iy(PDO)} \quad \text{(A-26)}$$

NOTE 1: If the user selected to analyze FS accidents, then the observed accident frequencies in Equation (A-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 (A-24) through Equation (A-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 (A-21) through Equation (A-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:

$$\theta_{i(TOT)} = \frac{\lambda_{i(TOT)}}{\pi_{i(TOT)}} \quad \text{(A-27)}$$

$$\theta_{i(FI)} = \frac{\lambda_{i(FI)}}{\pi_{i(FI)}} \quad \text{(A-28)}$$

$$\theta_{i(PDO)} = \frac{\lambda_{i(PDO)}}{\pi_{i(PDO)}} \quad \text{(A-29)}$$

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:

$$E_{i(TOT)} = 100\left(\theta_{i(TOT)} - 1\right) \quad \text{(A-30)}$$

$$E_{i(FI)} = 100\left(\theta_{i(FI)} - 1\right) \quad \text{(A-31)}$$

$$E_{i(PDO)} = 100\left(\theta_{i(PDO)} - 1\right) \quad \text{(A-32)}$$

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:

$$\theta_{(TOT)} = \frac{\Sigma \lambda_{i(TOT)}}{\Sigma \pi_{i(TOT)}} = \frac{\lambda_{(TOT)}}{\pi_{(TOT)}} \quad \text{(A-33)}$$

$$\theta_{(FI)} = \frac{\Sigma \lambda_{i(FI)}}{\Sigma \pi_{i(FI)}} = \frac{\lambda_{(FI)}}{\pi_{(FI)}} \quad \text{(A-34)}$$

$$\theta_{(PDO)} = \frac{\Sigma \lambda_{i(PDO)}}{\Sigma \pi_{i(PDO)}} = \frac{\lambda_{(PDO)}}{\pi_{(PDO)}} \quad \text{(A-35)}$$

where all summations are performed over all sites and/or projects in the site list.

However, the use of θ in Equation (A-33) through Equation (A-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 (A-11) and Equation (A-12):

$$Var(X_{iy(TOT)}) = X_{iy(TOT)}(1 - w_{i(TOT)})\frac{C_{iy(TOT)}}{\sum_{y=1}^{Y} C_{iy(TOT)}} \quad \text{(A-36)}$$

$$Var(X_{iy(FI)}) = X_{iy(FI)}(1 - w_{i(FI)})\frac{C_{iy(FI)}}{\sum_{y=1}^{Y} C_{iy(FI)}} \quad \text{(A-37)}$$

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:

$$Var(\pi_{(TOT)}) = \sum_i \left[r_{i(TOT)}^2 \sum_{y(BeforeYears} Var(X_{iy(TOT)}) \right] \quad \text{(A-38)}$$

$$Var(\pi_{(FI)}) = \sum_i \left[r_{i(FI)}^2 \sum_{y(BeforeYears} Var(X_{iy(FI)}) \right] \quad \text{(A-39)}$$

$$Var(\pi_{(PDO)}) = Var(\pi_{(TOT)}) + Var(\pi_{(FI)}) \quad \text{(A-40)}$$

NOTE: Because FI accidents are a subset of TOT accidents, the calculation in Equation (A-40), which assumes statistical independence of TOT and FI accidents, is only an approximation. In fact, Equation (A-40) overestimates $Var(X_{iy(PDO)})$.

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 $Var(\pi_{iy(TOT)})$, $Var(\pi_{iy(FI)})$, and $Var(\pi_{iy(PDO)})$ obtained in Equation (A-38) through Equation (A-40) in each before year y, respectively, over all sites included in that project. These values, $Sum[Var(\pi_{iy(TOT)})]$, $Sum[Var(\pi_{iy(FI)})]$, and $Sum[Var(\pi_{iy(PDO)})]$ in each before year y, should then be substituted for $Var(\pi_{iy(TOT)})$, $Var(\pi_{iy(FI)})$, and $Var(\pi_{iy(PDO)})$, respectively, in each before year y, in subsequent calculations.

Step 18: Calculate the final adjusted overall effectiveness, θ*, for TOT, FI, and PDO accidents:

$$\theta^*_{(TOT)} = \frac{\theta_{(TOT)}}{1+\frac{Var(\pi_{(TOT)})}{\pi^2_{(TOT)}}} \tag{A-41}$$

$$\theta^*_{(FI)} = \frac{\theta_{(FI)}}{1+\frac{Var(\pi_{(FI)})}{\pi^2_{(FI)}}} \tag{A-42}$$

$$\theta^*_{(PDO)} = \frac{\theta_{(PDO)}}{1+\frac{Var(\pi_{(PDO)})}{\pi^2_{(PDO)}}} \tag{A-43}$$

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:

$$E_{(TOT)} = 100\left(\theta^*_{(TOT)} - 1\right) \tag{A-44}$$

$$E_{(FI)} = 100\left(\theta^*_{(FI)} - 1\right) \tag{A-45}$$

$$E_{(PDO)} = 100\left(\theta^*_{(PDO)} - 1\right) \tag{A-46}$$

NOTE: It is also important in the EB evaluation to estimate the precision of the treatment effectiveness shown in Equation (A-44) through Equation (A-46). This is done by calculating the variance of the ratios shown in Equation (A-33) through Equation (A-35) and of the quantities in Equation (A-24) through Equation (A-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 (A-38) through Equation (A-40).

Step 20: Calculate the variance of λ for TOT, FI, and PDO accidents as:

$$Var(\lambda_{(TOT)}) = \sum_i \sum_{y(After\ Years)} L_{iy(TOT)} \tag{A-47}$$

$$Var(\lambda_{(FI)}) = \sum_i \sum_{y(After\ Years)} L_{iy(FI)} \tag{A-48}$$

$$Var(\lambda_{(PDO)}) = \sum_i \sum_{y(After\ Years)} L_{iy(PDO)} \tag{A-49}$$

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 (A-48) would include FS accidents for the respective collision type(s).

Step 21: The variance of θ^* is estimated for TOT, FI, and PDO accidents as:

$$\mathrm{Var}(\theta^*_{(TOT)}) \cong \frac{\theta^2_{(TOT)}\left[\frac{\mathrm{Var}(\lambda_{(TOT)})}{\lambda^2_{(TOT)}}+\frac{\mathrm{Var}(\pi_{(TOT)})}{\pi^2_{(TOT)}}\right]}{\left[1+\frac{\mathrm{Var}(\pi_{(TOT)})}{\pi^2_{(TOT)}}\right]^2} \quad \text{(A-50)}$$

$$\mathrm{Var}(\theta^*_{(FI)}) \cong \frac{\theta^2_{(FI)}\left[\frac{\mathrm{Var}(\lambda_{(FI)})}{\lambda^2_{(FI)}}+\frac{\mathrm{Var}(\pi_{(FI)})}{\pi^2_{(FI)}}\right]}{\left[1+\frac{\mathrm{Var}(\pi_{(FI)})}{\pi^2_{(FI)}}\right]^2} \quad \text{(A-51)}$$

$$\mathrm{Var}(\theta^*_{(PDO)}) \cong \frac{\theta^2_{(PDO)}\left[\frac{\mathrm{Var}(\lambda_{(PDO)})}{\lambda^2_{(PDO)}}+\frac{\mathrm{Var}(\pi_{(PDO)})}{\pi^2_{(PDO)}}\right]}{\left[1+\frac{\mathrm{Var}(\pi_{(PDO)})}{\pi^2_{(PDO)}}\right]^2} \quad \text{(A-52)}$$

NOTE: When $\lambda_{TOT} = 0$, $\lambda_{FI} = 0$, or $\lambda_{PDO} = 0$, then Equation (A-50), Equation (A-51), and Equation (A-52) will become:

$$\mathrm{Var}(\theta^*_{(TOT)}) \cong \frac{\left[\frac{\mathrm{Var}(\pi_{(TOT)})}{\pi^2_{(TOT)}}\right]}{\left[1+\frac{\mathrm{Var}(\pi_{(TOT)})}{\pi^2_{(TOT)}}\right]} \quad \text{(Alternate A-50)}$$

$$\mathrm{Var}(\theta^*_{(FI)}) \cong \frac{\left[\frac{\mathrm{Var}(\pi_{(FI)})}{\pi^2_{(FI)}}\right]}{\left[1+\frac{\mathrm{Var}(\pi_{(FI)})}{\pi^2_{(FI)}}\right]} \quad \text{(Alternate A-51)}$$

$$\mathrm{Var}(\theta^*_{(PDO)}) \cong \frac{\left[\frac{\mathrm{Var}(\pi_{(PDO)})}{\pi^2_{(PDO)}}\right]}{\left[1+\frac{\mathrm{Var}(\pi_{(PDO)})}{\pi^2_{(PDO)}}\right]} \quad \text{(Alternate A-52)}$$

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:

$$\mathrm{SE}(\theta^*_{(TOT)}) = \sqrt{\mathrm{Var}(\theta^*_{(TOT)})} \quad \text{(A-53)}$$

$$\mathrm{SE}(\theta^*_{(FI)}) = \sqrt{\mathrm{Var}(\theta^*_{(FI)})} \quad \text{(A-54)}$$

$$\mathrm{SE}(\theta^*_{(PDO)}) = \sqrt{\mathrm{Var}(\theta^*_{(PDO)})} \quad \text{(A-55)}$$

Step 23: Using the relationship between E and θ* as shown in Equation (A-44) through Equation (A-46) for TOT, FI, and PDO accidents, the standard error of the treatment effectiveness, E, is calculated as:

$$\mathrm{SE}(E_{(TOT)}) = 100 \times \mathrm{SE}(\theta^*_{(TOT)}) \quad \text{(A-56)}$$

$$SE(E_{(FI)}) = 100 \times SE(\theta^*_{(FI)}) \quad \text{(A-57)}$$

$$SE(E_{(PDO)}) = 100 \times SE(\theta^*_{(PDO)}) \quad \text{(A-58)}$$

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.

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.

A.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 A.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 A.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 A.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 (A-7), Equation (A-9), Equation (A-11), and Equation (A-14), substituting the subscript CT for TOT in all equations.

NOTE: No adjustment is made to the overdispersion parameter, d_{TOT}, in Equation (A-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 (A-17), Equation (A-19), and Equation (A-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 (A-24) and substituting the subscript CT for TOT.

At this point, one could simply carry out the remaining computations shown in Equation (A-27), Equation (A-30), Equation (A-33), Equation (A-36), Equation (A-38), Equation (A-41), Equation (A-44), Equation (A-47), Equation (A-50), Equation (A-53), and Equation (A-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 (A-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,

$$\pi_{i(SV)} + \pi_{i(MV)} \neq \pi_{i(TOT)} \qquad \text{(A-59)}$$

Calculate a correction, AF_i, so that the two sides of Equation (A-59) become equal.

$$AF_i = \frac{\pi_{i(TOT)}}{\pi_{i(SV)} + \pi_{i(MV)}} \qquad \text{(A-60)}$$

Step E: Calculate the adjusted expected SV and MV accident frequencies, $adj(\pi_i)$, as follows:

$$adj\left(\pi_{i(SV)}\right) = AF_i \times \pi_{i(SV)} \qquad \text{(A-61)}$$

$$\text{adj}(\pi_{i(MV)}) = AF_i \times \pi_{i(MV)} \tag{A-62}$$

It can be easily shown that:

$$\text{adj}(\pi_{i(SV)}) + \text{adj}(\pi_{i(MV)}) = AF_i\,(\pi_{i(SV)} + \pi_{i(MV)}) = \pi_{i(TOT)} \tag{A-63}$$

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 (A-38) becomes:

$$\text{adj}(\pi_{i(SV)}) + \text{adj}(\pi_{i(MV)}) = AF_i\,(\pi_{i(SV)} + \pi_{i(MV)}) = \pi_{i(TOT)} \tag{A-64}$$

A.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 A-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:

$$P_{i(CT)B} = \frac{\sum_{YEARS_{BT,i}} K_{iy(CT)}}{\sum_{YEARS_{BT,i}} K_{iy(TOT)}} \qquad \text{(A-65)}$$

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:

$$P_{i(CT)A} = \frac{\sum_{YEARS_{AT,i}} L_{iy(CT)}}{\sum_{YEARS_{AT,i}} L_{iy(TOT)}} \qquad \text{(A-66)}$$

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:

$$P_{i(CT)Diff} = P_{i(CT)A} - P_{i(CT)B} \qquad \text{(A-67)}$$

At this point, an average proportion before treatment and an average proportion after treatment can be calculated across all I sites as follows:

$$AvgP_{(CT)B} = \frac{1}{I}\sum_{i=1}^{I} P_{i(CT)B} \qquad \text{(A-68)}$$

$$AvgP_{(CT)A} = \frac{1}{I}\sum_{i=1}^{I} P_{i(CT)A} \qquad \text{(A-69)}$$

Similarly, an average difference between after and before proportions can be calculated as:

$$AvgP_{(CT)Diff} = \frac{1}{I}\sum_{i=1}^{I} P_{i(CT)Diff} \qquad \text{(A-70)}$$

One may proceed and test the differences in proportions [calculated in Equation (A-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:

$$Z_i = abs\left(P_{i(CT)Diff}\right), \text{for } i = 1, \ldots, I^* \tag{A-71}$$

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:

$$\Psi_i = \begin{cases} 1 \ if \ P_{i(CT)Diff} > 0 \\ 0 \ if \ P_{i(CT)Diff} < 0 \end{cases} \tag{A-72}$$

Step 4: Form the I* products $R_1\Psi_1, \ldots, R_{I^*}\Psi_{I^*}$, and calculate the statistic T^+, the sum of the positive signed ranks as follows:

$$T^+ = \sum_{i=1}^{I^*} R_i \Psi_i \tag{A-73}$$

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:

$$T^+ \geq t(\alpha_2, I^*) \text{ or } T^+ \leq \frac{I^*(I^*+1)}{2} - t(\alpha_1, I^*) \tag{A-74}$$

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 A-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 A-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	Number of Sites (I*)											
	4	5	6	7	8	9	10	11	12	13	14	15
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 $P(T^+ \geq x)$. Thus if x is such that $P(T^+ \geq x) = \alpha$, then $t(\alpha, I^*) = x$.

Figure A-1. Upper Tail Probabilities for the Wilcoxon's Signed Rank T^+ Statistic (I* = 4 to 10)$_a$ (Hollander and Wolfe, 1973)

Figure A-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 A-1 shows one-sided probability levels; since the test performed here is a two-sided test, the values in Figure A-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 A-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:

$$T^* = \frac{T^+ - E_o(T^+)}{[Var_o(T^+)]^{\frac{1}{2}}} \quad \text{(A-75)}$$

where

$$E_o(T^+) = I^*(I^*+1)/4 \quad \text{(A-76)}$$

and

$$Var_o(T^+) = [I^*(I^*+1) - \tfrac{1}{2}\textstyle\sum_{j=1}^{g} t_j(t_j-1)(t_j+1)]/24 \quad \text{(A-77)}$$

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:

$$T^* \geq z_{\alpha/2} \text{ or } T^* \leq -z_{\alpha/2} \quad \text{(A-78)}$$

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 A-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 $[P_{i(CT)Diff} + P_{j(CT)Diff}]/2$, $i \le j = 1,\ldots,I^*$ where I^* is the number of nonzero differences [see Equation (A-71)].

Step 7: Let $W^{(1)} \le \ldots \le W^{(M)}$ denote the M ordered values of

$$\left[P_{i(CT)Diff} + P_{j(CT)Diff}\right]/2 \qquad \text{(A-79)}$$

Step 8: Estimate the treatment effect, $P_{(CT)Diff}$, as the median of the M ordered

$W^{(1)} \le \ldots \le W^{(M)}$ values as follows:

- If M is odd, say M = 2k+1, then

$$P_{(CT)Diff} = W^{(k+1)} \qquad \text{(A-80)}$$

- If M is even, say M = 2k, then

$$P_{(CT)Diff} = \left[W^{(k)} + W^{(k+1)}\right]/2 \qquad \text{(A-81)}$$

Obtain a symmetric two-sided confidence interval for $P_{(CT)Diff}$ with Confidence Level $1-\alpha$ as follows:

Step 9: From Figure A-1, obtain $t(\alpha/2, I^*)$ and calculate the integer C_a.

$$C_\alpha = [I^*(I^* + 1)/2] + 1 - t(\alpha/2, I^*) \qquad \text{(A-82)}$$

LARGE SAMPLE APPROXIMATION: When I* exceeds 15, Figure A-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:

$$C_\alpha \approx \frac{I^*(I^*+1)}{4} - z_{(\alpha/2)}\left[\frac{I^*(I^*+1)(2I^*+1)}{24}\right]^{1/2} \qquad \text{(A-85)}$$

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, $W^{(1)} \leq ... \leq W^{(M)}$, select the lower and upper confidence limits, $LLP_{(CT)Diff}$ and $ULP_{(CT)Diff}$, as follows:

$$LLP_{(CT)Diff} = W^{(C_\alpha)} \quad \text{(A-83)}$$

$$ULP_{(CT)Diff} = W^{(M+1-C_\alpha)} \quad \text{(A-84)}$$

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.

A.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 the procedures used to calculate the Annual Accidents Reduced in Module 3 (*2*). 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:

$$AR_{i(TOT)} = \pi_{i(TOT)} \times (-1) \times \left(\frac{E_{i(TOT)}}{100}\right) \times \left(\frac{S_V}{Years_{ATi}}\right) \quad \text{(A-86)}$$

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 (*2*). 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:

$$ACC_i = ACTC_i \times \frac{R(1+R)^{S_v}}{(1+R)^{S_v}-1} \quad \text{(A-87)}$$

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:

$$PCC_i = ACC_i \times \frac{(1+R)^{S_v}-1}{R(1+R)^{S_v}} \quad \text{(A-88)}$$

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

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:

$$(ACTC_i)_{A+B} = (ACTC_i)_A + (ACTC_i)_B \times CRF(R, S_B) \times USPWF(R, S_A) \quad \text{(A-89)}$$

$$CRF(R, S_B) = \frac{R(1+R)^{S_B}}{(1+R)^{S_B}-1} \quad \text{(A-90)}$$

$$USPWF(R, S_A) = \frac{(1+R)^{S_A}-1}{R(1+R)^{S_A}} \quad \text{(A-91)}$$

If a third countermeasure (C) were added which also had a service life less than countermeasure A, another term would be added to Equation (A-89) as follows:

$$+(ACTC_i)_C \times CRF(R, S_C) \times USPWF(R, S_A) \quad \text{(A-92)}$$

where:

R	=	Annual rate of return
S_A	=	Service life of countermeasure A
S_B	=	Service life of countermeasure B
CRF	=	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:

$$AC_{i(TOT)} = \left(\frac{\pi_{i(FI)}}{\pi_{i(FI)}+\pi_{i(PDO)}}\right)AC_{FI} + \left(\frac{\pi_{i(PDO)}}{\pi_{i(FI)}+\pi_{i(PDO)}}\right)AC_{PDO} \quad \text{(A-93)}$$

The present value of the safety benefits for site i will then be computed as:

$$PSB_i = \frac{AR_{i(TOT)}AC_{i(TOT)}}{(1+R)^{S_V}} \quad \text{(A-94)}$$

The benefit-cost ratio is computed in a manner equivalent to Equation (C-31):

$$BC_i = \frac{PSB_i}{PCC_i} \quad \text{(A-95)}$$

Computation of the Benefit-Cost Ratio for All Sites

The benefit-cost ratio for all sites is computed as:

$$BC = \frac{\sum_{i=1}^{I} PSB_i}{\sum_{i=1}^{I} PCC_i} \quad \text{(A-96)}$$

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 (A-86), Equation (A-87), Equation (A-88), Equation (A-94), and Equation (A-96) respectively.

$$AR_{i(TOT)} = \pi_{i(TOT)} \times (-1) \times \left(\frac{E_{i(TOT)}}{100}\right) \times \left(\frac{S_p}{Years_{ATi}}\right) \quad \text{(A-97)}$$

$$ACC_p = ACTC_p \times \frac{R(1+R)^{S_p}}{(1+R)^{S_p}-1} \quad \text{(A-98)}$$

$$PCC_p = ACC_p \times \frac{(1+R)^{S_p}-1}{R(1+R)^{S_p}} \quad \text{(A-99)}$$

$$PSB_i = \frac{AR_{i(TOT)} AC_{i(TOT)}}{(1+R)^{S_p}} \quad \text{(A-100)}$$

$$BC = \frac{\sum_{i=1}^{I} PSB_i}{PCC_p} \quad \text{(A-101)}$$

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.