White Paper for Module 3—Economic Appraisal and Priority Ranking
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1. INTRODUCTION

This white paper documents the benefits and capabilities of the economic appraisal and priority ranking tool in Module 3 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 3. 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 Economic Appraisal and Priority Ranking Overview

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

The priority ranking tool in Module 3 of SafetyAnalyst provides a priority ranking of sites and proposed improvement projects based on the benefit and cost estimates determined by the economic appraisal tool. The priority ranking tool can compare the benefits and costs of projects across sites and rank those projects on the basis of cost effectiveness, benefit-cost ratio, or net present value. The priority ranking tool also has the ability to determine an optimal set of projects to maximize safety benefits.
1.2 Expected Benefits of the Economic Appraisal and Priority Ranking Tool

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

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

*SafetyAnalyst* incorporates the best AMFs available to represent the safety effectiveness of specific countermeasures. A wide variety of AMFs have been used by highway agencies across the nation. Many of these AMFs are based on older evaluations that were not well designed and well executed. For example, many of these evaluations may be substantially affected by regression to the mean. *SafetyAnalyst* incorporates the most reliable estimate of the safety benefits for each improvement type, and these estimates may be updated as new research results become available.
2. CAPABILITIES FOR MODULE 3—ECONOMIC APPRAISAL AND PRIORITY RANKING

This section of the paper provides an overview of the capabilities of SafetyAnalyst Module 3, the economic appraisal and priority ranking tools. The purpose of the economic appraisal and priority ranking tools is to conduct an economic analysis for implementing a countermeasure or combination of countermeasures so that monetary expenditures can be prioritized. The module is capable of assessing the economic benefits of countermeasures at a single site assisting a highway agency in setting priorities for safety countermeasures across a network. The types of problems that can be addressed with this module are summarized in Section 2.1.

SafetyAnalyst evaluates whether the proposed improvement(s) are economically efficient through a variety of economic criteria and calculations. All of the criteria address cost and benefits in terms of total accident severity, and some incorporate information from all severity levels when appropriate. Economic calculations for alternative improvements at a site are normalized through present values and equivalent analysis periods so they can be fairly compared. In Section 2.2, the economic criteria used by SafetyAnalyst are explained as well as their advantages and disadvantages.

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

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

Some or all of these data are already included in the SafetyAnalyst databases and can be retrieved as part of the analysis. However, some data are not available and will need to be entered as part of the analysis. Section 2.4.1 details how the data needed for an analysis is assembled as well as sources of any system provided data.

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

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

Sections 2.4.2 through 2.4.5 discuss these features of Module 3.
The primary output from Module 3 is a list of sites with all alternative countermeasures proposed for them with the results of the economic analysis. Other output is available depending on the analysis specified. If priority ranking criteria were specified, another output section provides ranked site and countermeasures lists by these criteria. Similarly, an optimization report is produced if the optimal mix of sites and countermeasures within a limited budget is desired. These reports are discussed in Section 2.5.

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

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

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

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

2.2 Types of Economic Analyses and Choosing Among Them

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

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

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

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

\[
\text{Cost-effectiveness} = \frac{\text{Total Cost}}{\text{Expected Number of Accidents Reduced}} \quad (1)
\]

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

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

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

\[
\text{Benefit-Cost Ratio} = \frac{\text{Benefit}}{\text{Cost}} \quad (2)
\]

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

A disadvantage of the benefit-cost ratio approach is that if multiple benefit and cost terms exist, it is not always clear whether specific terms belong in the numerator or the denominator of the ratio. For example, it is not always clear whether some maintenance costs should be treated as a decrease in the annual safety benefit or should be converted to a present value and treated as an increase in the project cost.
The net benefit approach to economic appraisal assesses projects by benefits minus costs. Some consider this approach to be superior to the benefit-cost ratio approach because it eliminates the issue of whether particular cost items should appear in the numerator or denominator. For this approach, the most desirable improvements are those with the highest net benefit:

\[
\text{Net Benefit} = \text{Benefit} - \text{Costs}
\]  

(3)

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

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

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

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

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

2.3 Performing Economic Analyses in SafetyAnalyst

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

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

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

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

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

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

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

The proposed countermeasure dialog, shown in Figure 1, is divided into three sections: selected sites, available countermeasures for site subtypes and proposed site countermeasures. The selected sites section lists the sites to which countermeasures can be proposed for future implementation. SafetyAnalyst automatically provides a list of available countermeasures (default and user-specified) for potential implementation at a site in the middle section of the dialog. Once the countermeasures are assigned to the selected sites, they will be listed in the Proposed Countermeasure list at the bottom of the dialog.

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

AMFs provide estimates of the expected reduction (or increase) in accident frequency and/or severity after countermeasure implementation. They are used to estimate the number of accidents reduced from implementing the countermeasure or the safety benefits. AMFs are provided for total accident severity and fatal-and-all-injury accident severity and are express as decimal factors. An AMF value of one implies no change in the number of accidents. A value less than one implies a decrease in the anticipated number of accidents expected to occur after implementation (e.g., a value of 0.95 would imply a 5 percent reduction in accident frequency). Conversely, a value greater than one implies an increase in accidents is expected by implementing this countermeasure.
Figure 1. Proposed Countermeasures Dialog in Module 3

Figure 2. Enter/Edit Proposed Countermeasures Dialog in Module 3
AMFs used in SafetyAnalyst are usually represented as a single factor for all sites in a subtype. However, an AMF function is necessary when the incremental effect on safety for a countermeasure varies due to site characteristics at a given site. For example, the value of the AMF for widening lanes along a rural two-lane highway depends upon the lane widths before and after reconstruction and the traffic volume of the facility. Similarly, effectiveness estimates for improving horizontal curves are dependent on the change in curvature. For these types of countermeasures, several iterations of the analysis may be performed to find the best trade-off between safety and cost.

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

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

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

**Enter/Edit Proposed Countermeasure Dialog**

The Enter/Edit Proposed Countermeasure dialog (Figure 2) provides an opportunity to review or edit the information required for a countermeasure’s economic appraisal: an estimate of the countermeasure’s safety effectiveness (AMF), the service life of the countermeasure (or the number of years that safety will be improved at a site resulting from the countermeasure), and the construction cost of implementing the countermeasure. Additionally through this dialog, changes may be made to the implementation location of the countermeasure and the ADT growth factor.

The dialog first requests any site characteristic information needed to calculate the AMF function or cost function for the selected countermeasure, then presents a final summary panel where estimates can be reviewed and edited. Each dialog that appears may be different depending on the type of countermeasure being assigned. For example, more information may be needed to calculate cost by square feet than cost by linear mile. Also, the safety estimate for widening...
shoulders to different lengths may require input for the current site geometric configuration and proposed site geometric configuration.

The Enter/Edit Proposed Countermeasure dialog, shown in Figure 2, presents the final values that are used in the economic calculations. Most of the required data have default values that are presented in this dialog. The primary exceptions to this are AMFs. AMF functions and values do not exist for all countermeasures and/or all site subtypes to which they apply since they have only been provided when assessed by safety experts and found to have face validity. When these data (or any other required data) are missing, AMF values will need to be entered by the analyst or no economic analysis will be conducted on the countermeasure. Alternatively, AMF values may be edited globally in the Administration Tool by an individual with administrative rights to the software (1). However, for any required data, the default values may be edited here if there are site specific conditions that warrant it.

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

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

For a countermeasure combination, a summary review panel is presented for each countermeasure in the combination and an additional panel for the combined safety and cost estimates, where each panel is identical to Figure 2. Multiple countermeasures implemented together as a single treatment must have a final cost, service life, and AMF. The final AMF is simply the product of the individual AMFs. The service life of the combined treatment will be the maximum of each individual countermeasure service life.

The cost of a combined treatment is dependent on the service lives. If the service lives are different, an adjustment to the cost must be made. Since the expected benefits have been extended to the maximum service life, the costs should be extended to the same period. Therefore the cost of the countermeasure with the shorter service life is multiplied by a capital recovery factor and a uniform series present worth factor using the different service lives and interest rate. Since this calculation involves a default minimum attractive rate of return, the default value of 4 percent is presented for possible adjustment before presenting the final calculations.
Site List Information Panel

After countermeasures have been proposed for some or all of the sites in the site list, the Site List Information panel should be updated to reflect the number of countermeasures proposed and assigned for each site. Figure 3 shows a typical site list panel ready for analysis in SafetyAnalyst. Each site must have at least one proposed countermeasure to be included in the economic analysis. Also, at least one site must have proposed countermeasures for the analysis to proceed.

2.3.2 Specifying Economic Criteria

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

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

Figure 4 presents a typical input screen on which the analyst specifies the economic criteria for the analysis.

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

Construction costs are computed from the annual construction cost, using the minimum attractive rate of return and service life of the countermeasure. Then the annualized construction cost is grown over the analysis period, using the same interest rate, and brought back to the present value. Basing the construction costs on the analysis period allows for the comparison of countermeasures with different service lives.
Begin an Economic Appraisal by assigning potential countermeasures for each site to be analyzed. Countermeasures can be assigned by selecting a site and then clicking the ‘Edit Proposed Countermeasure’ button. Only those sites for which countermeasures have been assigned will be considered in the analysis. When countermeasures have been assigned to a site, a positive count value in the ‘Proposed CM’ column is displayed.

Figure 3. Site List Information Panel in Module 3

Select up to four economic criteria by which to evaluate proposed countermeasures. When Net Benefit is selected, the user may also choose to optimize the net benefit across all sites and countermeasures. If you plan to optimize the net benefit, the net benefit criterion must be selected on the screen. The optimization options will be presented as you progress through the economic analysis module. For details on these options see Working with Economic Appraisal and Priority Ranking Processes in the Safety Analyst Users Manual.

Figure 4. Typical Input Screen to Specify Economic Criteria in Module 3
Calculations for safety benefits vary by type of criterion. Since benefits are not expressed in monetary terms for the cost-effectiveness criteria, the project benefits are the accidents reduced as a result of a countermeasure. EPDO-based cost-effectiveness is the same as cost-effectiveness except a weighting scheme has been added. When this criterion is selected, the user will have an opportunity to adjust the default weights used in the calculations later in the analysis.

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

2.3.3 Specifying History and Accident Periods

The time periods of the analysis can be specified simultaneously for all sites in the Process Period panel, Figure 5. Selections may be made for the historical time period to use for estimating a site’s average accident frequency as well as the future implementation period, or analysis period, on which safety benefits are based. In SafetyAnalyst, all evaluation periods are considered in entire calendar years, so that there is no seasonal bias in the evaluation data by using partial years. Therefore, all selections made here are based on whole calendar years or yearly units.

By default, the history period includes the 10 most recent available years of data for a site, since the analysis will benefit from using a long-term average for each site. However, selections may be made to specify specific historical data for the analysis. Additionally, the years prior to major reconstruction for any site are excluded by default.
Periods prior to major reconstruction should be excluded from the analysis, and their associated accidents because a site’s estimated average accident frequency is based on its current characteristics and SafetyAnalyst may not account for the differences in the site characteristics between the current conditions and those prior to reconstruction.

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

2.3.4 Specify Weight and Cost Values

If the benefit-cost ratio or net benefits criteria are being evaluated, the Accident Costs Panel (Figure 6) may be used to change the default cost estimates for accidents by severity used in the calculations. The default cost estimates are the Federal Highway Administration estimates for 2009.
If the EPDO-based cost-effectiveness criterion is being evaluated, the Accident Weights Panel (Figure 7) may be used to change the default weight estimates for accidents by severity used in the calculations.

### 2.3.5 Specify Priority Ranking Tables

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

- **Cost-effectiveness**: dollars spent per accident reduced (i.e., the present value of constructing the countermeasure divided by the total number of accidents reduced)
- **EPDO-based cost-effectiveness**: dollars spent per weighted number of accidents reduced (i.e., the present value of constructing the countermeasure divided by a weighted estimate of accidents reduced by severity type)
**Figure 7. Specify Accident Weights in Module 3**

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

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

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

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

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

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

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

One or more of the above criteria, shown in Figure 8, may be selected for the analysis. For each criterion selected, a separate priority ranking Table will be produced for the output report. Two options are available to control the format for each generated table: Countermeasures to Rank and Display Order.
The Countermeasures to Rank option determines whether all countermeasures evaluated at a site will be ranked or just the highest ranked countermeasure for a site. For an analysis of a single site, the All Countermeasures option should be selected. The Display Order option determines the sort order of the criterion: Standard Order or Reverse Order. The Standard Order lists countermeasures from most economically attractive to least. For some criteria, larger values are more economically attractive, whereas, for others, smaller values are more economically attractive.

2.3.6 Specify Optimization Analysis

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

IP is a linear programming technique that maximizes or minimizes an objective function, taking into account integer valued constraints. SafetyAnalyst uses an open-source product, lpsolve, to perform the IP analysis (3).
In SafetyAnalyst, the optimization analysis identified the set of countermeasures for each site that maximizes the total net benefits for all sites considered, subject to the following constraints:

- Only one countermeasure can be selected for each site, including the No Build alternative.
- The total construction cost for the above selected countermeasures does not exceed the available budget.

Figure 9 shows the panel used to specify an optimization analysis.

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

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

The three algorithm options are:

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

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

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

No concerns with encountering SUBOPTIMAL or TIMEOUT messages have yet been encountered with the default values for the parameters discussed above. So, as a practical matter, it is not expected that adjustment of the current default values will be needed.
2.4 Primary Output Report

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

Table 1 presents the results of the economic evaluation for each site and alternative countermeasure. The analysis options that generated this sample output, presented in the upper left corner of the actual output report, are as follows:

- Types of Economic Analyses Performed: Cost-effectiveness, EPDO-based cost-effectiveness, Benefit-cost ratio, Net benefit
- Years of Data Considered: History Period (Available Years 1995 to 2002)
- No major reconstruction occurred at any sites during the history period
- Analysis Period: Implementation Year (2010), Years to Analyze (20)
• Minimum Attractive Rate of Return (Percent): 4
• Accident Costs by Severity: Fatal ($5,800,000), Severe Injury ($402,000), Non-incapacitating Injury ($80,000), Possible Injury ($42,000), Property Damage Only ($4,000)
• EPDO Weights: Fatal (1,450), Severe Injury (100), Non-incapacitating Injury (20), Possible Injury (10), Property Damage Only (1)

The economic appraisal results Table contains many items of interest:

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

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

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

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

Following the overall economic analysis Table are the individual priority ranking tables, one for each criterion selected for analysis. Table 2 illustrates priority ranking of the Number of Total Accidents Reduced. This Table could be modified to only show the highest ranked countermeasure for each site.
<table>
<thead>
<tr>
<th>Proposed site-CM</th>
<th>Site ID</th>
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<th>County</th>
<th>Route</th>
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## Table 2. Priority Ranking: Total Accidents Reduced

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<th>Ending location</th>
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<th>CM start location</th>
<th>CM end location</th>
<th>Total accidents reduced*</th>
<th>Rank</th>
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<td>144.54</td>
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</table>

* These are estimates of the number of accidents reduced and not a guarantee.
The final output report is the optimization result, shown in Table 3. This section of the report identifies the set of proposed countermeasure for each site that maximizes the overall safety benefit of any expenditure, taking into consideration budgetary constraints. The same analysis options to generate the economic results (Table 1) were used to generate this Table with one additional criterion, the Construction Budget of $10,000,000. The safety benefits, construction cost, net benefits, and total accidents reduced are provided for each site and are totaled for all sites.

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

### 2.5 Benefits of SafetyAnalyst’s Economic Appraisal and Priority Ranking Capabilities

The primary benefits of utilizing SafetyAnalyst’s economic analysis and priority ranking capabilities include:

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

Many highway agencies perform economic analyses for proposed projects, but these methods are not always automated. In addition, SafetyAnalyst uses the most recent and most reliable information on the potential safety benefits of specific improvement types.
<table>
<thead>
<tr>
<th>Proposed site-CM</th>
<th>Site ID</th>
<th>Site type</th>
<th>County</th>
<th>Route</th>
<th>Beginning location</th>
<th>Ending location</th>
<th>Countermeasure</th>
<th>CM start location</th>
<th>CM end location</th>
<th>Safety benefits</th>
<th>Construction costs</th>
<th>Net benefit</th>
<th>Total accidents reduced*</th>
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* These are estimates of the number of accidents reduced and not a guarantee.
ACKNOWLEDGEMENT

This white paper was prepared by Midwest Research Institute in MRI Project 110684 as part of FHWA Contract No. DTFH61-09-D-00020, under subcontract to Genex Systems. The authors of this paper are Mr. Douglas W. Harwood, Dr. Dahrren J. Torbic, Ms. Karen R. Richard, and Ms. Melanie M. Knoshaug. Contributor to the development of SafetyAnalyst Module 3 and an earlier version of this white paper include Dr. Emilia Kohlman Rabbani.
3. REFERENCES


Appendix A

Detailed Procedures for *SafetyAnalyst* Module 3—
Economic Appraisal and Priority Ranking
APPENDIX A. DETAILED PROCEDURES FOR SAFETYANALYST
MODULE 3—ECONOMIC APPRAISAL AND
PRIORITY RANKING

This appendix presents the processing algorithms used to perform economic evaluations within SafetyAnalyst. Each economic evaluation relies on computations of annual accidents reduced. The algorithm to perform these computations is explained in Appendix A.1. The basic criteria users can specify to perform economic analyses of countermeasures for a site is discussed in Appendix A.2. The algorithms to estimate the three basic economic criteria are shown in the following sections:

- Appendix A.2.1
- Appendix A.2.2
- Appendix A.2.3

A separate algorithm for mathematical optimization used in priority ranking of sites is presented in Appendix A.2.4.

A.1 Algorithm to Estimate Annual Accidents Reduced

Each economic analysis relies on finding the expected number of accidents reduced by a proposed countermeasure for each year in the analysis period. SafetyAnalyst implements an Empirical Bayes (EB) approach to estimate this quantity.

Table A-1 introduces the terminology used in these procedures.

The following text provides the mathematical steps on how to estimate the expected number of accidents reduced by proposed countermeasure v at site i for each year in the analysis period. The procedures are similar to the EB procedures given in Module 1 for basic network screening (4). When the equation number reads “same as” and is hyphenated, it indicates that the equation is the same as an equation given in Module 1 (4). The number preceding the hyphen indicates that the equation is provided in Appendix A for Module 1, and the number after the hyphen indicates the equation number in that Appendix (4).

Steps 1 through 8 apply to a site and a single countermeasure. When multiple countermeasures or combinations of countermeasures are under evaluation at a site, Steps 1 through 8 will be repeated for each single countermeasure and/or countermeasure combination selected by the user.

When multiple sites are combined into a project, Steps 1 through 8 are performed separately on a site-by-site basis for all sites in a given project as described in Step 9. In Step 10, the results from the individual sites are combined into a single measure of effectiveness for the given project for the given countermeasure. For any given analysis of a project, only one type of countermeasure may be considered at a time.
At a given site during each year, the EB approach takes a weighted average of the observed accident count, \( K \), and the predicted accident frequency, \( \kappa \), in the history period to estimate the EB adjusted expected accident frequency, \( X \), in the history period. This procedure is explained in Steps 1 through 5.

(a) For roadway segments or ramps:

_Step 1a:_ Using the appropriate SPF model parameters, compute for each year in the **history period** (i.e., \( y = 1, 2, ..., Y \)), the predicted number of accidents per mile, \( \kappa_y \), for TOT and FI accidents as follows:

\[
\kappa_{y(TOT)} = SPF_{TOT}(ADT) = c_y(1)1 \times P_{CI}(1)1 \times e^{a} \times ADT_y^{b_2}
\]

(same as A-1)

\[
\kappa_{y(FI)} = SPF_{FI}(ADT) = c_y(1)2 \times P_{CI}(2)2 \times e^{a} \times ADT_y^{b_1}
\]

(same as A-2)

<table>
<thead>
<tr>
<th>Term</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( i )</td>
<td>Subscript to represent site ( i )</td>
</tr>
</tbody>
</table>
| \( y \) | Subscript to represent the year \( y \)  
- The first full year of the history period for which data are available or the first year after major reconstruction is year 1 (i.e., \( y = 1 \))  
- The last full year of the history period for which accident and ADT data are available is year \( Y \) (i.e., \( y = Y \))  
- By default, \( Y \) equals the number of years of available accident and ADT data for the History Period. For example, if History Period End date equals 12/31/1996 and History Period Start date equals 1/1/1993, then the number of years of available accident and ADT data equals 4. |
| \( H \) | Subscript to denote the History period. These are the years for which accident and ADT data are available from the SafetyAnalyst inventory database. |
| \( F \) | Subscript to denote the Future analysis period. |
| \( M \) | In calculating the ADT growth factor, \( M \) is the value of the calendar year of the History Period End date. |
| \( EIY \) | Expected Implementation Year of a countermeasure (i.e., the first full calendar year after implementation of a countermeasure. The EIY is considered the first year of the analysis period.) |
| \( N \) | Number of years in the analysis period |
| \( N \) | Subscript to denote year in the analysis period, i.e., \( n = 1, 2, ..., N \) |
| \( TOT \) | Subscript to denote total accidents |
| \( FI \) | Subscript to denote fatal and all injury accidents |
| \( FS \) | Subscript to denote fatal and severe injury accidents |
| \( PDO \) | Subscript to denote property damage only accidents |
| \( ADT_y \) | ADT during year \( y \) (nonintersection sites) |
| \( MajADT_y \) | Major road ADT at an intersection during year \( y \) |
| \( MinADT_y \) | Minor road ADT at an intersection during year \( y \) |
| \( GF \) | Average Growth Factor of ADT |
| \( SL \) | Segment length of a site (nonintersection sites), expressed in mi |
| \( SPF_{TOT}, SPF_{FI} \) | Safety Performance Function, applicable to a given type of sites. It includes the following regression coefficients (on the log scale) and parameters:  
- \( a \): intercept  
- \( \beta_1 \): coefficient of ADT (nonintersection sites) or of MajADT (major road of intersection)  
- \( \beta_2 \): coefficient of MinADT (minor road of intersection)  
- \( d \): overdispersion parameter associated with the negative binomial regression |

**NOTE 1:** For the interim tool, two SPFs are available for a given type of site: SPF_TOT and SPF_FI. Each has its own set of parameters.
Table A-1. Summary of Nomenclature Used for Economic Appraisals (Continued)

<table>
<thead>
<tr>
<th>Term</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$PCT_{TOT}$, $PCT_{FI}$</td>
<td>Proportion of TOT accidents of a specified collision type</td>
</tr>
<tr>
<td>$c_{yTOT}$, $c_{yFI}$</td>
<td>Calibration factor for TOT accidents in year $y$</td>
</tr>
</tbody>
</table>

NOTE 2: All coefficients and parameters related to SPFs are obtained from Safety Analyst system database: SPF Defaults, Calibration Factors, and Accident Distribution Defaults by Collision Type.

<table>
<thead>
<tr>
<th>Term</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_y$</td>
<td>Number of accidents observed during year $y$</td>
</tr>
<tr>
<td>$\kappa_y$</td>
<td>Predicted number of accidents using the SPF during year $y$ (expressed on a per mile basis for roadway segments and on a per site basis for intersection and ramp sites)</td>
</tr>
<tr>
<td>$C_y$</td>
<td>Yearly correction factor for year $y$ relative to year 1</td>
</tr>
<tr>
<td>$W$</td>
<td>A weighting factor to combine observed and predicted accident frequencies at a site</td>
</tr>
<tr>
<td>$X_y$</td>
<td>EB-adjusted expected number of accidents during year $y$</td>
</tr>
<tr>
<td>AMF, $v$</td>
<td>Accident Modification Factor for countermeasure $v$</td>
</tr>
</tbody>
</table>

NOTE: These proportions are stored in the Accident Distribution Defaults by Severity Level tables in the Safety Analyst system database.

<table>
<thead>
<tr>
<th>Term</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{F}, P_{II}, P_{NI}, P_{MI}$</td>
<td>Proportions of fatal, incapacitating injury, nonincapacitating injury, and possible injury accidents of all FI accidents</td>
</tr>
</tbody>
</table>

NOTE: These proportions are stored in the Accident Distribution Defaults by Severity Level tables in the Safety Analyst system database.

<table>
<thead>
<tr>
<th>Term</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW, $F$, SW, $II$, SW, $NI$, SW, $MI$</td>
<td>Relative severity weights applied to fatal, incapacitating injury, nonincapacitating injury, and possible injury accidents, respectively</td>
</tr>
</tbody>
</table>

NOTE: These weights are stored in the EPDO Weight Defaults Table in the Safety Analyst system database.

<table>
<thead>
<tr>
<th>Term</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC</td>
<td>Relative weight of FI accidents as compared to PDO accidents</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Term</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>EP, $v$</td>
<td>Equivalent Property Damage Only</td>
</tr>
<tr>
<td>$S_v$</td>
<td>Service life of countermeasure $v$</td>
</tr>
<tr>
<td>$C_{Cv}$</td>
<td>Construction cost of countermeasure $v$. This is assumed to be the lump sum cost at year $E Y$ of constructing countermeasure $v$ at a site or along an entire project.</td>
</tr>
<tr>
<td>$A_{CC}$</td>
<td>Annual cost of constructing countermeasure $v$ at a site based upon the service life of the countermeasure</td>
</tr>
<tr>
<td>$PCC_v$</td>
<td>Present value of constructing countermeasure $v$ at a site based upon the annualized construction cost across the service life of the countermeasure and the analysis period.</td>
</tr>
<tr>
<td>$R$</td>
<td>Annual rate of return</td>
</tr>
<tr>
<td>$A_{AC}, A_{ACII}, A_{ACNI}, A_{ACMI}, A_{ACPDO}$</td>
<td>Relative costs for fatal, severe injury, nonincapacitating injury, possible injury, and PDO accidents, respectively</td>
</tr>
</tbody>
</table>

NOTE: These costs are stored in the Accident Costs Defaults Table in the Safety Analyst system database.

<table>
<thead>
<tr>
<th>Term</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$AC_v$</td>
<td>Relative accident cost of all severity levels of FI accidents</td>
</tr>
</tbody>
</table>

NOTE 1: To calculate the number of FS injury accidents reduced (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{CT/FS/FI}$] for the given site subtype, (C) replace $P_{CT(FI)}$, in Equation (A-2) with $P_{CT/FS/FI}$, and (D) proceed as normal for FI calculations.

(b) For intersections:

Step 1b: Using the appropriate SPF model parameters, compute for each year in the history period (i.e., $y = 1, 2, ..., Y$), the predicted number of accidents, $\kappa_y$, for TOT and FI accidents as follows:

$$\kappa_y(TOT) = \text{SPF}_{TOT} \cdot \left(\alpha_{TOT} \cdot c_{yTOT} \cdot a^x \cdot \text{MinADT}_{y}^{\beta_1} \cdot \text{MinADT}_{y}^{\beta_2}\right)$$ (same as A-122)

$$\kappa_y(FI) = \text{SPF}_{FI} \cdot \left(\alpha_{FI} \cdot c_{yFI} \cdot a^x \cdot \text{MinADT}_{y}^{\beta_1} \cdot \text{MinADT}_{y}^{\beta_2}\right)$$ (same as A-123)
**NOTE 2:** Although not explicitly shown in Equations (A-1), (A-2), (A-122), and (A-123), SPF_{TOT} and SPF_{FI} each have their own set of parameters, $\alpha$, $\beta_1$, $\beta_2$, and overdispersion parameter $d$.

**NOTE 3:** PCT_{TOT} and PCT_{FI} always equal 1.0.

**NOTE 4:** To calculate the number of FS injury accidents reduced (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default Table to retrieve the proportion of FS accidents as a ratio of FI accidents $[P_{(CT/FS/FI)}]$ for the given site subtype, (C) replace $P_{CT(FI)}$, in Equation (A-2) and Equation (A-123) with $P_{(CT/FS/FI)}$, and (D) proceed as normal for FI calculations.

**Step 2:** Using the model predictions computed in *Step 1a* or *1b*, compute the yearly correction factors, $C_y$, for TOT and FI accidents for years $y = 1, 2, \ldots, Y$ in the **history period**:

\[
C_y(TOT) = \frac{k_y(TOT)}{k_y(TOT)} \quad \text{(same as A-3)}
\]

\[
C_y(FI) = \frac{k_y(FI)}{k_y(FI)} \quad \text{(same as A-4)}
\]

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

\[
w_{TOT} = \frac{1}{1 + d(C_y(TOT))^2 C_y(TOT)} \quad \text{(same as A-5)}
\]

\[
w_{FI} = \frac{1}{1 + d(C_y(FI))^2 C_y(FI)L} \quad \text{(same as A-6)}
\]

**NOTE:** The weights, $w_{TOT}$ and $w_{FI}$ are always calculated based upon the “all” accidents for TOT and FI severity levels, even when calculations are being made for the number of FS injury accidents reduced. In other words, the weight $w_{FI}$ will actually be based upon “all” FI accidents. The rationale for this change is because weights, $w_{TOT}$ and $w_{FI}$, are calculated based upon the accuracy/reliability of the SPFs. In concept the accuracy/reliability of the SPF does not change when the calculations are being made for FS injury accidents. The same SPFs for FI accidents are still being used for all calculations, and the accuracy/reliability of the FI SPFs does not change. If the “scaled” predicted values were used in Equation (A-6), then the weight would be adjusted for the wrong reason, not because the accuracy/reliability of the SPFs changed but because the predicted values were scaled as a necessity due to unrelated circumstances.

**NOTE 2:** In Equation (A-5) and Equation (A-6), L is equal to the segment length, SL for roadway segments, or ramp length, SL-RAMP for ramps. For intersections L is set to 1.

**Step 4:** Calculate the base EB-adjusted expected number of accidents, $X_1$, for TOT and FI accidents during Year 1 of the **history period**:
\[ X_{1(TOT)} = w_{TOT} \sum_{y=1}^{Y} X_{y(TOT)} C_{y(TOT)} + (1 - w_{TOT}) \sum_{y=1}^{Y} X_{y(TOT)} C_{y(TOT)} \]  
(same as A-75)

\[ X_{1(FI)} = w_{FI} \sum_{y=1}^{Y} X_{y(FI)} C_{y(FI)} + (1 - w_{FI}) \sum_{y=1}^{Y} X_{y(FI)} C_{y(FI)} \]  
(same as A-76)

**NOTE 1:** For roadway segments, SL equals the length of the site. For ramps, SL = SL\textsubscript{Ramps}. For intersections, SL = 1.

**NOTE 2:** If \( X_{1(FI)} > X_{1(TOT)} \), then \( X_{1(FI)} = X_{1(TOT)} \).

**Step 5:** Calculate the sum of the EB-adjusted expected number of accidents for the **history period** \((y = 1, 2, ..., Y)\) for TOT and FI accidents:

\[ X_{H(TOT)} = \sum_{y=1}^{Y} X_{y(TOT)} C_{y(TOT)} \]  
(A-1)

\[ X_{H(FI)} = \sum_{y=1}^{Y} X_{y(FI)} C_{y(FI)} \]  
(A-2)

The next step is to estimate the expected value of the accident count that would occur during the analysis period, assuming that the countermeasure will not be implemented at a site during a given year. This estimate is obtained by adjusting \( X \) from the history period for the difference between ADTs in the history and analysis periods and annualizing. The procedure is explained in **Step 6** below.

(a) For roadway segments or ramps:

**Step 6a:** Assuming that the countermeasure is **not implemented**, calculate for each year of the **analysis period** \((i.e., n = 1, 2, ..., N)\), the EB-adjusted expected number of accidents for TOT and FI accidents.

\[ X_{P(TOT)n} = \frac{X_{H(TOT)}}{\sum_{y=1}^{Y} X_{y(TOT)}} \times \left( c_{y(TOT)} \times P_{CT(TOT)} \times e^{a} \times (ADT_{y} \times GP^{(EY-N+n-1)})^{b_{2}} \right) \]  
(A-3)

\[ X_{P(FI)n} = \frac{X_{H(FI)}}{\sum_{y=1}^{Y} X_{y(FI)}} \times \left( c_{y(FI)} \times P_{CT(FI)} \times e^{a} \times (ADT_{y} \times GP^{(EY-N+n-1)})^{b_{2}} \right) \]  
(A-4)

(b) For intersections:

**Step 6b:** Assuming that the countermeasure is **not implemented**, calculate for each year of the **analysis period** \((i.e., n = 1, 2, ..., N)\), the EB-adjusted expected number of accidents for TOT and FI accidents.
\[ X_{F\text{TOT}}(n) = \frac{X_{H\text{TOT}}(n)}{\sum_{y=1}^{Y} X_{H\text{TOT}}(y)} \times \left( c_{Y\text{TOT}}(n) \times P_{CT\text{TOT}}(n) \times e^{\alpha} \times \left( \text{MaxADT}_{T} \times GF(\text{EIY} - \text{M} - n + 1) \right)^{C_2} \times \left( \text{MinADT}_{T} \times GF(\text{EIY} - \text{M} - n + 1) \right)^{C_3} \right) \] (A-5)

\[ X_{F\text{FIO}}(n) = \frac{X_{H\text{FIO}}(n)}{\sum_{y=1}^{Y} X_{H\text{FIO}}(y)} \times \left( c_{Y\text{FIO}}(n) \times P_{CT\text{FIO}}(n) \times e^{\alpha} \times \left( \text{MaxADT}_{I} \times GF(\text{EIY} - \text{M} - n + 1) \right)^{C_2} \times \left( \text{MinADT}_{I} \times GF(\text{EIY} - \text{M} - n + 1) \right)^{C_3} \right) \] (A-6)

**NOTE 1:** In the exponent of GF, the values for M and EIY correspond to calendar years. For example, if the History Period End date is December 31, 2002, then the last full calendar year of available data from the Safety Analyst inventory database is 2002. If the expected year of implementation for the proposed countermeasure is 2003, then the values in the exponent for the growth factor would be \( M = 2002 \) and \( EIY = 2003 \).

**NOTE 2:** The value of GF in Equation (A-3) through Equation (A-6) is specified by the user.

**NOTE 3:** To calculate the number of FS injury accidents reduced (A) select and use FI SPF$s$ and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ration of FI accidents \( P_{CT/FIS/FS} \) for the given site subtype, (C) include \( P_{CT/FIS/FS} \), in the second term of Equation (A-4) and Equation (A-6) as a multiplier, and (D) proceed as normal for FI calculations. It is assumed that the proportion of FS injury accidents to FI injury accidents was already applied to the denominator of the first term in Equation (A-4) and Equation (A-6) in Step 1.

The next step is to estimate the expected value of the accident count that would occur during the analysis period, assuming that the countermeasure **will be** implemented at a site during a given year. This estimate is obtained by adjusting X from the history period for the difference between ADTs in the history and study periods, for the countermeasure's AMF, and annualizing. The procedure is explained in Step 7 below.

(a) For roadway segments or ramps:

*Step 7a*: Assuming that countermeasure v is **implemented**, calculate for each year of the analysis period (i.e., \( n = 1, 2, \ldots, N \)), the EB-adjusted expected number of accidents for TOT and FI accidents.

\[ X_{F\text{vTOT}}(n) = \frac{X_{H\text{TOT}}(n)}{\sum_{y=1}^{Y} X_{H\text{TOT}}(y)} \times \left( c_{Y\text{TOT}}(n) \times P_{CT\text{TOT}}(n) \times e^{\alpha} \times \left( \text{ADT}_{T} \times GF(\text{EIY} - \text{M} - n + 1) \right)^{C_2} \times \text{AMF}_{v(TOT)} \right) \] (A-7)

\[ X_{F\text{vFIO}}(n) = \frac{X_{H\text{FIO}}(n)}{\sum_{y=1}^{Y} X_{H\text{FIO}}(y)} \times \left( c_{Y\text{FIO}}(n) \times P_{CT\text{FIO}}(n) \times e^{\alpha} \times \left( \text{ADT}_{I} \times GF(\text{EIY} - \text{M} - n + 1) \right)^{C_2} \times \text{AMF}_{v(FIO)} \right) \] (A-8)

(b) For intersections:
Step 7b: Assuming that countermeasure \( v \) is implemented, calculate for each year of the analysis period (i.e., \( n = 1, 2, ..., N \)), the EB-adjusted expected number of accidents for TOT and FI accidents.

\[
X_{Fv(TOT)n} = \frac{X'H(TOT)}{\Sigma_y'Zv(TOT)} \times \left( c_{v(TOT)} \times P_{R(TOT)} \times e^a \times (M_0ADF)P \times GF^{(EIV-M+n-s-1)} \right) \times \left( (M_0ADF)P \times GF^{(EIV-M+n-s-1)} \right) \times AMF_{v(TOT)}
\]  
(A-9)

\[
X_{Fv(FI)n} = \frac{X'H(FI)}{\Sigma_y'Zv(FI)} \times \left( c_{v(FI)} \times P_{R(FI)} \times e^a \times (M_0ADF)P \times GF^{(EIV-M+n-s-1)} \right) \times \left( (M_0ADF)P \times GF^{(EIV-M+n-s-1)} \right) \times AMF_{v(FI)}
\]  
(A-10)

**Note 1:** In the exponent of GF, the values for \( M \) and EIY correspond to calendar years (see Note 2 of Step 6).

**Note 2:** The value for the AMF of a countermeasure is provided from the Countermeasure Default file. When combinations of countermeasures are proposed for implementation, the value of the AMF for the combination is the product of the AMFs of the individual countermeasures.

**Note 3:** To calculate the number of FS injury accidents reduced (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ration of FI accidents \( P_{(CT/FS/FI)} \) for the given site subtype, (C) include \( P_{(CT/FS/FI)} \) in the second term of Equation (A-8) and Equation (A-10) as a multiplier, and (D) proceed as normal for FI calculations. It is assumed that the proportion of FS injury accidents of FI injury accidents was already applied to the denominator of the first term in Equation (A-8) and Equation (A-10) in Step 1.

The final step is to compare the estimated accident counts in each year of the study period when the countermeasure would be implemented to the estimated accident counts when the countermeasure would not be implemented. The procedure is explained in Steps 8 through 10.

Step 8: For each year in the analysis period (i.e., \( n = 1, 2, ..., N \)), calculate the expected number of accidents reduced by countermeasure \( v \) for TOT, FI, FS, PDO, and EPDO accidents.

\[
AR_{v(TOT)n} = X_{Fv(TOT)n} - X_{Fv(TOT)n}
\]  
(A-11)

\[
AR_{v(FI)n} = X_{Fv(FI)n} - X_{Fv(FI)n}
\]  
(A-12)

\[
AR_{v(FD)n} = X_{Fv(FD)n} - X_{Fv(FD)n}
\]  
(A-13)

\[
AR_{v(PDO)n} = AR_{v(TOT)n} - AR_{v(FI)n}
\]  
(A-14)

**Note 1:** If \( AR_{v(FI)n} > AR_{v(TOT)n} \), then \( AR_{v(TOT)n} = AR_{v(FI)n} \).
To calculate the EPDO expected number of accidents reduced for each year in the analysis period, use the relative severity weights, $SW$, for fatal (F), severe injury (SI), nonincapacitating injury (NI), and possible injury (MI) severity levels. Let $RC_{FI}$ be the relative weight of FI accidents as compared to PDO accidents. $RC_{FI}$ is calculated as follows:

$$RC_{FI} = P_F SW_F + P_{SI} SW_{SI} + P_{MI} SW_{MI}$$

(same as A-15)

The EPDO expected number of accidents reduced for each year in the analysis period is then calculated as:

$$AR_v(EPDO)_n = AR_v(PODO)_n + RC_{FI} AR_v(FI)_n$$

(A-15)

When a roadway segment is being considered as an individual site in the analysis, the expected numbers of accidents reduced for each year in the analysis period ($AR_v$) are the final calculations for a given site and countermeasure.

**NOTE 2:** When the user selects to prioritize rank countermeasures and sites by FS or FI accidents reduced, the number of fatalities and the number of injuries reduced will be included on the output report. For this calculation, the SafetyAnalyst database contains data on fatalities per accident and injuries per accident (i.e., AccRate$_{(F/CT/FS)}$, AccRate$_{(I/CT/FS)}$, AccRate$_{(F/CT/FI)}$, and AccRate$_{(I/CT/FI)}$) and is searched to find the corresponding values based on site subtype. Use the sum of the accident rates across all collision types in Equations (A-14A) through (A-14D) to calculate the number of fatalities reduced and the number of injuries reduced as follows:

$$\text{No. of Expected Fatalities Reduced}_{(F/FS)} = \sum_{i=1}^{N} AR_v(F/F)_n \times \text{AccRate}_(F/CT/FS)$$

(A-16)

$$\text{No. of Expected Injuries Reduced}_{(I/FS)} = \sum_{i=1}^{N} AR_v(I/F)_n \times \text{AccRate}_(I/CT/FS)$$

(A-17)

$$\text{No. of Expected Fatalities Reduced}_{(F/FS)} = \sum_{i=1}^{N} AR_v(F/F)_n \times \text{AccRate}_(F/CT/FI)$$

(A-18)

$$\text{No. of Expected Injuries Reduced}_{(I/FS)} = \sum_{i=1}^{N} AR_v(I/F)_n \times \text{AccRate}_(I/CT/FI)$$

(A-19)

**CALCULATION ADJUSTMENTS FOR PROJECTS:** When multiple roadway segments are combined into a project, proceed with Steps 9 and 10.

**Step 9:** Repeat Steps 1 through 8 for each site $i$ in the project.

**NOTE:** Steps 1 through 8 describe the process of calculating the number of annual accidents reduced by a given countermeasure for each year in the analysis period for a given site. In general, a subscript (i) could be added to the equations in each of these steps.

**Step 10:** For each year in the analysis period (i.e., $n = 1, 2, ..., N$), calculate the expected number of accidents reduced by countermeasure $v$ for the given project for TOT, FI, FS, PDO, and EPDO accidents by summing over all sites $i$ in the project.
NOTE 1: The EPDO estimates for sites and projects are only utilized in calculating cost-effectiveness.

NOTE 2: When the user selects to priority rank countermeasures and sites by FS or FI accidents reduced, the number of fatalities and the number of injuries reduced will be included on the output report. For this calculation, the SafetyAnalyst database contains data on fatalities per accident and injuries per accident (i.e., AccRate_{FS/CT/FS}, AccRate_{I/CT/FS}, AccRate_{FS/CT/FI}, and AccRate_{I/CT/FI}) and is searched to find the corresponding values based on site subtype. Use the sum of the accident rates across all collision types in Equations (A-16) through (A-19) to calculate the number of fatalities reduced and the number of injuries reduced as follows:

\[
\text{No. of Expected Fatalities Reduced}_{(FS/CT/FS)} = \sum_{n=1}^{N} AR_{v(FS)}n \times \text{AccRate}_{(FS/CT/FS)}
\]  
(A-16)

\[
\text{No. of Expected Injuries Reduced}_{(FS/CT/FS)} = \sum_{n=1}^{N} AR_{v(FS)}n \times \text{AccRate}_{(I/CT/FS)}
\]  
(A-17)

\[
\text{No. of Expected Fatalities Reduced}_{(FS/CT/FI)} = \sum_{n=1}^{N} AR_{v(FS)}n \times \text{AccRate}_{(FS/CT/FI)}
\]  
(A-18)

\[
\text{No. of Expected Injuries Reduced}_{(FS/CT/FI)} = \sum_{n=1}^{N} AR_{v(FS)}n \times \text{AccRate}_{(I/CT/FI)}
\]  
(A-19)

A.2 Criteria for Economic Evaluations

This section explains the calculations used in the economic analyses, depending upon the economic criteria specified by the user.

A.2.1 Algorithm to Estimate Cost-Effectiveness

In evaluating a countermeasure based upon the cost-effectiveness criterion, the cost-effectiveness of the countermeasure is expressed in terms of dollars spent per accident reduced. Countermeasures with lower cost per accident reduced are more likely to maximize the benefits of an improvement program than countermeasures with higher cost per accident reduced. Calculation of the cost-effectiveness ratio is dependent upon the service life of a countermeasure, the analysis period being considered, construction costs, and the expected accidents reduced as a result of the countermeasure.

Calculating the cost-effectiveness ratio consists of three phases:
The first phase involves estimating the expected number of accidents reduced by a given countermeasure for the given site or project ($AR_{vn}$). This procedure is described in Appendix (A.10).

The second phase involves calculating the present value of the construction costs for implementing a countermeasure ($PCC_v$). These calculations are described next in Steps 1 through 3.

The accident predictions and the construction costs are combined in the final phase (see Step 4 below).

**Step 1:** Calculate the lump sum construction cost ($CC_v$) for implementing countermeasure $v$ at site (or project) $i$ during year EIY.

In some cases the construction cost for implementing a countermeasure is a fixed cost. In other cases, the construction cost is a function of the site characteristics.

**Step 2:** Calculate the annual construction cost for implementing countermeasure $v$ at site (or project) $i$ given the service life ($S_v$) of the countermeasure and the annual rate of return ($R$).

$$ACC_v = CC_v \times \frac{R(1+R)^S_v}{(1+R)^N-1}$$  \hspace{1cm} (A-25)

**Step 3:** Calculate the present value of the construction cost ($PCC_v$) for implementing countermeasure $v$ at site (or project) $i$ based upon the annualized construction cost ($ACC_v$), the annual rate of return ($R$), and the analysis period ($N$).

$$PCC_v = ACC_v \times \frac{(1+R)^N-1}{R(1+R)^N}$$  \hspace{1cm} (A-26)

**Step 4:** Calculate the cost-effectiveness of countermeasure $v$ ($CE_v$) at site (or project) $i$ for the entire analysis period for TOT and EPDO accidents.

$$CE_{v(TOT)} = \frac{PCC_v}{\sum_{n=2}^{N} AR_{vn(TOT)}}$$  \hspace{1cm} (A-27)

$$CE_{v(EPUO)} = \frac{PCC_v}{\sum_{n=2}^{N} AR_{vn(EPUO)}}$$  \hspace{1cm} (A-28)

**NOTE:** The calculations above assume the proposed countermeasure will be implemented along the entire site. *Safety Analyst* also estimates the cost-effectiveness of a proposed countermeasure installed along a portion or subsegment of a site. The calculations as described above are performed in the exact same manner taking into consideration the boundaries of the proposed countermeasure as defined by the analyst.
A.2.2 Algorithm to Estimate Benefit-Cost Ratio

The benefit-cost ratio is the ratio of the present safety benefit of a countermeasure to its construction costs. For a countermeasure to be economically justified by this criterion, its benefit-cost ratio should be greater than 1.0. The most desirable countermeasures are those with the highest benefit-cost ratios.

Calculating the benefit-cost ratio consists of four phases:

- The first phase involves estimating the expected number of accidents reduced by a given countermeasure for the given site or project (AR_{vi}). This procedure is described in Appendix A.1.
- The second phase involves calculating the present value of the safety benefits of the countermeasure at the given site or project (PSB_{v}). These calculations are described below in Steps 1 and 2.
- The third phase involves calculating the present value of the construction cost for implementing countermeasure v at site or project i (PCC_{v}). These calculations are described in Appendix A.2.1.
- The final phase involves calculating the ratio of the present values of the safety benefits to the construction costs (see Step 3 below).

**Step 1:** Calculate the relative accident cost for all severity levels of FI accidents (AC_{F1}). This relative cost is calculated by taking a weighted average of the accident cost values and the statewide accident proportion values for the respective accident severity levels as follows:

\[ AC_{F1} = P_2 AC_F + P_{22} AC_{21} + P_{N1} AC_{N1} + P_{NN} AC_{NN} \]  
(A-29)

**Step 2:** Calculate the present value of safety benefits of countermeasure v at site (or project) i by calculating the monetary present value of the estimated annual accidents reduced for the analysis period.

\[ PSB_v = \sum_{n=1}^{N} \frac{AR_{vi} \times FDI_{n} \times AC_{F1}}{(1+r)^{(n-1)}} + \sum_{n=1}^{N} \frac{AR_{vi} \times FDI \times P_{n} \times AC_{n}}{(1+r)^{(n-1)}} \]  
(A-30)

**Step 3:** Calculate the benefit-cost ratio for countermeasure v at site (or project) i:

\[ BC_v = \frac{PSB_v}{PCC_v} \]  
(A-31)

**Note:** The calculations above assume the proposed countermeasure will be implemented along the entire site. SafetyAnalyst also estimates the benefit-cost ratio of a proposed countermeasure installed along a portion or subsegment of a site. The calculations as described above are performed in the exact same manner taking into consideration the boundaries of the proposed countermeasure as defined by the analyst.
A.2.3 Algorithm to Estimate Net Benefits

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

Calculating the net benefits criterion consists of four phases:

- The first phase involves estimating the expected number of accidents reduced by a given countermeasure for the given site or project \(AR_v\). This procedure is described in Appendix A.1.
- The second phase involves calculating the present value of the safety benefits of the countermeasure at the given site or project \(PSB_v\). These calculations are described in Appendix A.2.2.
- The third phase involves calculating the present value of the construction cost for implementing countermeasure \(v\) at site or project \(i\) \(PCC_v\). These calculations are described in Appendix A.2.1.
- The final phase involves calculating the difference between the present value of the safety benefits and the present value of the construction costs (see Step 1 below).

\textit{Step 1:} Calculate the net benefits for countermeasure \(v\) at site (or project) \(i\):

\[NB_v = PSB_v - PCC_v\]  

\textit{NOTE:} The calculations above assume the proposed countermeasures will be implemented along the entire site. \textit{SafetyAnalyst} also estimates the net benefits of a proposed countermeasure installed along a portion or subsegment of a site. The calculations as described above are performed in the exact same manner taking into consideration the boundaries of the proposed countermeasure as defined by the analyst.

A.2.4 Maximizing Net Benefits of an Improvement Program

In \textit{SafetyAnalyst} the user can maximize the net benefits across all sites and countermeasures under evaluation, taking into consideration budgetary constraints. This optimization is performed using Integer Programming (IP). IP is a linear programming technique in which some, or all, of the decision variables are restricted to integer values. The integer program for Module 3, which optimizes the net benefits criterion, can be determined with the following equation:

\[\text{Maximize } TB = \sum_i \sum_v NB_{iv} Z_{iv}\]  

subject to the following constraints:
\[
\begin{align*}
\sum v Z_{iv} &= 1 \\
\sum v Z_{iv} &= 1 \\
\sum Z_{iv} &= 1 \\
\sum_i Z_{iv} p_{CC} &\leq B
\end{align*}
\]  

where:

\[TB = \text{total benefits from all selected countermeasures}\]
\[Z_{iv} = \text{a decision variable whose value is 1 if countermeasure } v \text{ at site (or project) } i \text{ is selected as part of the optimum solution; and 0 if countermeasure } v \text{ at site (or project) } i \text{ is not selected as part of the optimum solution. For each site (or project), exactly one countermeasure (or combination of countermeasures) should be selected.}\]
\[B = \text{improvement budget or maximum funding available for countermeasures implemented at sites in the current site list.}\]

Equation (A-33), which represents the total benefits (TB) to be maximized, is the objective function of the integer program. Changing the decision values in the sum-product of the net benefit and decision values optimizes the target value, or total benefits.

Equation (A-34) through Equation (A-37) represent the constraints on the objective function. They require that one and only one countermeasure (or combinations of countermeasures) can be selected for each site. The last inequality constrains the total construction costs of countermeasures not to exceed the available budget.

Before optimization processing begins, the user inputs the total budget available from which countermeasures can be financed. The following steps are taken to obtain the final solution from the optimization program.

\textit{Step 1: Create the Do Nothing or No Build alternative (countermeasure) for each site in the current site list. For this alternative, }NB = 0.\n
\textit{Step 2: Perform reduction algorithm on list of sites and countermeasures.}\n
Since the computations involved for integer programming are quite labor intensive and repetitive, the list of possible sites and countermeasures can be reduced before submitting them to the optimization program. Countermeasures for a site can be deleted if:

- \text{NB}
- \text{A countermeasure alternative for a site dominates another countermeasure alternative for the same site. Countermeasure 1 dominates Countermeasure 2 when Countermeasure 1 costs less (}PCC_1 \leq PCC_2\text{) and has greater benefits (}PSB_1 \geq PSB_2\text{) than Countermeasure 2. In this determination, the Do Nothing alternative should never be eliminated.}\n
Step 3: Create decision variable (true/false indicator) for each site and its associated countermeasures in the list and set the value to false (or zero).

Step 4: Set parameters/create variables for optimization program.

- Choose to maximize target value, or the sum-product of the economic criterion and decision variable, for all sites and their associated countermeasures in the list, by changing values of the decision variable.
- Add constraint to limit decision variable to 1 or 0.
- For each site, add constraint to choose only one alternative, or the sum of the decision variables, for a site = 1.
- Add constraint to limit total construction cost (sum-product of construction cost and decision variable for all sites and their associated countermeasures in list) to the user-entered budget.

Note: This step indicates that only one alternative may be chosen for a site. This alternative could be the implementation of a single countermeasure or a combination of countermeasures. During the analysis of a combination of countermeasures, the combination is treated as a single countermeasure by (1) multiplying the AMFs of the individual countermeasures to get a single AMF value, (2) adding the construction costs of the individual countermeasures to get a single construction cost (except when service lives are different, (3) taking the maximum service life for the individual countermeasures to get a single service life.

Step 5: Execute optimization program.

The final solution of the optimization program has a one (or true value) in the decision variable for the sites and their associated countermeasures selected by the program.

The optimization calculations are performed using LP Solve which is commercially available. In using this program, default values need to be set for the following parameters:

- Percent tolerance of true optimum solution
- Maximum time to run optimization program
- Maximum iterations to perform in finding solution

The user has the ability to modify the default values.

Note: The calculations above assume the proposed countermeasure will be implemented along the entire site. SafetyAnalyst also maximizes the net benefits of proposed countermeasures installed along a portion or subsegment of sites. The calculations as described above are performed in the exact same manner taking into consideration the boundaries of the proposed countermeasure as defined by the analyst.
A.2.5 Reporting of Other Ranking Criteria

In addition to providing results based upon cost-effectiveness ($CE_y$), benefit-cost ratio ($BC_y$), and net benefits ($NB_y$), additional ranking criteria that may be reported include:

- Construction costs ($PCC_y$)
- Safety benefits ($PSB_y$)
- Number of TOT, FS, and FI accidents reduced ($Ar_y$)