SafetyAnalyst: Software Tools for Safety Management of Specific Highway Sites

White Paper for Module 2—Diagnosis and Countermeasure Selection

August 2010

1. INTRODUCTION

This white paper documents the benefits and capabilities of the diagnosis and countermeasure selection tool in Module 2 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 2. 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* Diagnosis and Countermeasure Selection Overview

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

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

1.2 Expected Benefits of the Diagnosis and Countermeasure Selection Tool

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

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

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

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

2. CAPABILITIES FOR MODULE 2—DIAGNOSIS AND COUNTERMEASURE SELECTION

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

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

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

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

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

The end result of the diagnostic process is a list of potential countermeasures that, if implemented at the site, could serve to mitigate particular accident patterns. The decision as to which countermeasure or countermeasures will be implemented needs expert judgment and is made by the analyst, and not by the software. The analyst may make this decision based on the output of the diagnosis and countermeasure selection tools, or the analyst may elect to proceed to the economic appraisal and priority ranking tools (i.e., Module 3 [*1*, *2*]) for additional input to make this decision. The analyst should also consider all other available information on site-specific conditions and highway agency policies and experience in deciding which countermeasure(s) to implement.

This module is intended for use by an analyst knowledgeable about safety. As part of the diagnostic process, answers to some of the diagnostic questions are not self-evident and depend on expert judgment. Similarly, although through the expert system *SafetyAnalyst* suggests potential countermeasures based upon responses input by the analyst, the decision as to which countermeasure or countermeasures will actually be implemented or will be considered further through economic analyses is made by the analyst. The analyst should have some knowledge of the countermeasure before making this decision.

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

2.1 Diagnosis—Identification of Accident Patterns of Interest

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

- Accident summary statistics
- Collision diagrams
- Statistical tests

Figure 1 shows the input screen where the analyst specifies which approach will be used to identify accident patterns of interest. The analyst is encouraged to use more than one approach.

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

- **Analysis Direction**: The analyst has the option to include only those accidents that occurred in a given direction.
- **Accident Severity**: The analyst selects from four primary accident severity levels upon which to base the analysis: total (TOT) accidents, fatal and all injury (FI) accidents, fatal and severe injury (FS) accidents, and property-damage-only (PDO) accidents.
- **Analysis Limits**: For roadway segments, the analyst may include those accidents that occurred along the entire portion of the site, or only a limited portion of the site, by specifying start and end locations. These limits are not applicable when the site is an intersection or a ramp.

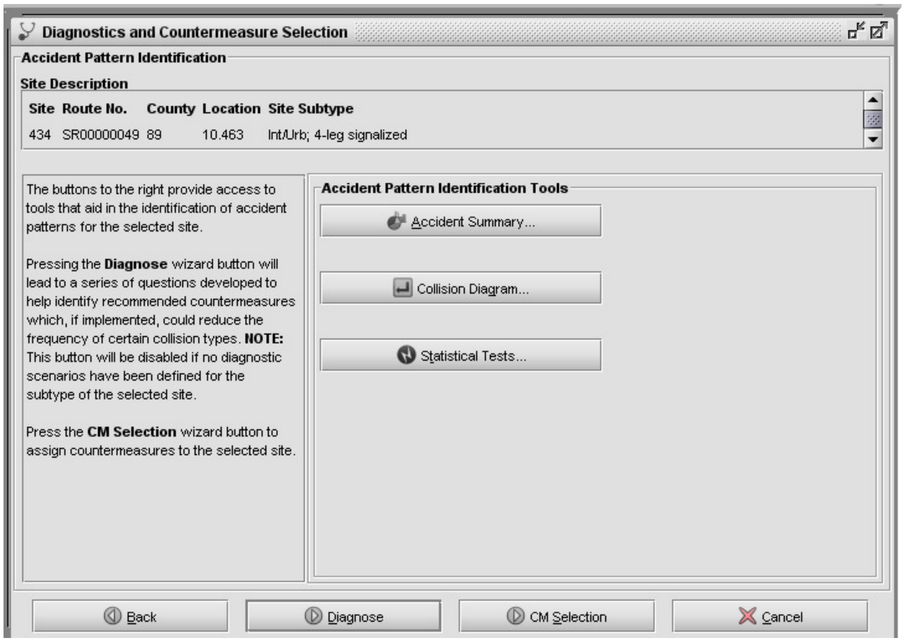

Figure 1. Module 2—Input Screen to Select Diagnostic Tools for Identifying Accident Patterns of Interest

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

Figure 2 presents the input screen where the analyst specifies these four filtering parameters for the analysis.

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

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

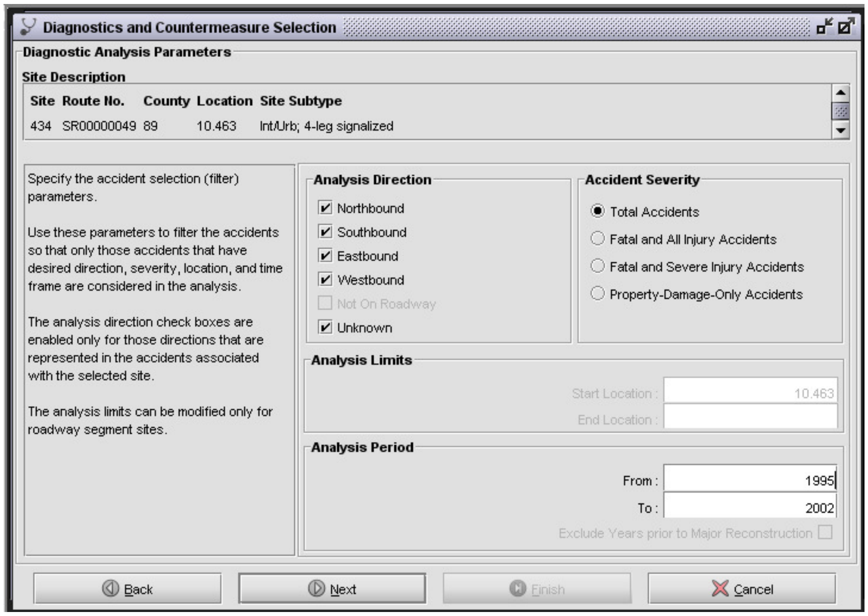

Figure 2. Module 2—Input Screen With Filtering Parameters for Use in Identifying Accident Patterns of Interest

2.1.1 Accident Summary Statistics

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

- Accident month
- Accident severity level
- Accident time of day
- Alcohol/drug involvement
- Bicycle indicator
- Collision type (Accident type and manner of collision)
- Contributing circumstances, environment
- Contributing circumstances, road
- Day of week
- Driver age
- Driveway indicator
- First harmful event
- Initial direction of travel
- Light condition
- Number of vehicles involved
- Pedestrian indicator
- Relationship to junction
- Roadway surface condition
- Run-off road indicator

- School bus indicator
- Tow-away indicator
- Vehicle configuration
- Vehicle maneuver/action
- Vehicle turning movement
- Weather condition
- Work zone related

The analyst can specify three separate ways to display the accident data: tables, bar charts, and pie charts. In tabular form, accident frequencies are provided by year and totals, observed proportions/percentages are provided for the site, and statewide proportions are provided when available. On bar charts, observed accident frequencies are shown by year. On pie charts, total accident frequencies are illustrated along with observed proportions. Table 1 and Figures 3 and 4 present sample accident summary statistics for accident type and manner of collision. In this sample data, rear-end accidents appear to be an accident pattern of interest for further investigation, based both on the frequency of occurrence and given that rear-end accidents account for approximately 68 percent of the accidents at the given site and at similar sites rear-end accidents account for approximately 56 percent of the accidents.

Table 1. Module 2—Sample Accident Summary Statistics for Accident Type Manner of Collision for an Urban 4-Leg Signalized Intersection (Tabular Form)

Description	1995	1996	1997	1998	1999	2000	2001	2002	Total	Observed percent	Average percent
Collision with bicyclist	0	0	0	0	2	0	1	0	3	3	1
Collision with fixed object	0	1	0	0	0	0	0	0	1	1	2
Collision with other object	0	0	0	0	0	1	0	0	1	1	1
Overturn	0	0	1	0	0	0	0	0	1	1	0
Fire or explosion	0	0	0	0	0	0	0	1	1	1	0
Rear-end	9	11	6	8	6	7	11	7	65	68	56
Angle	1	1	3	2	4	1	4	0	16	17	25
Sideswipe, same direction	0	1	0	0	0	0	0	0	1	1	4
Other multiple-vehicle collision	2	0	2	0	1	1	1	0	7	7	5
Total Accidents	12	14	12	10	13	10	17	8	96	100	100

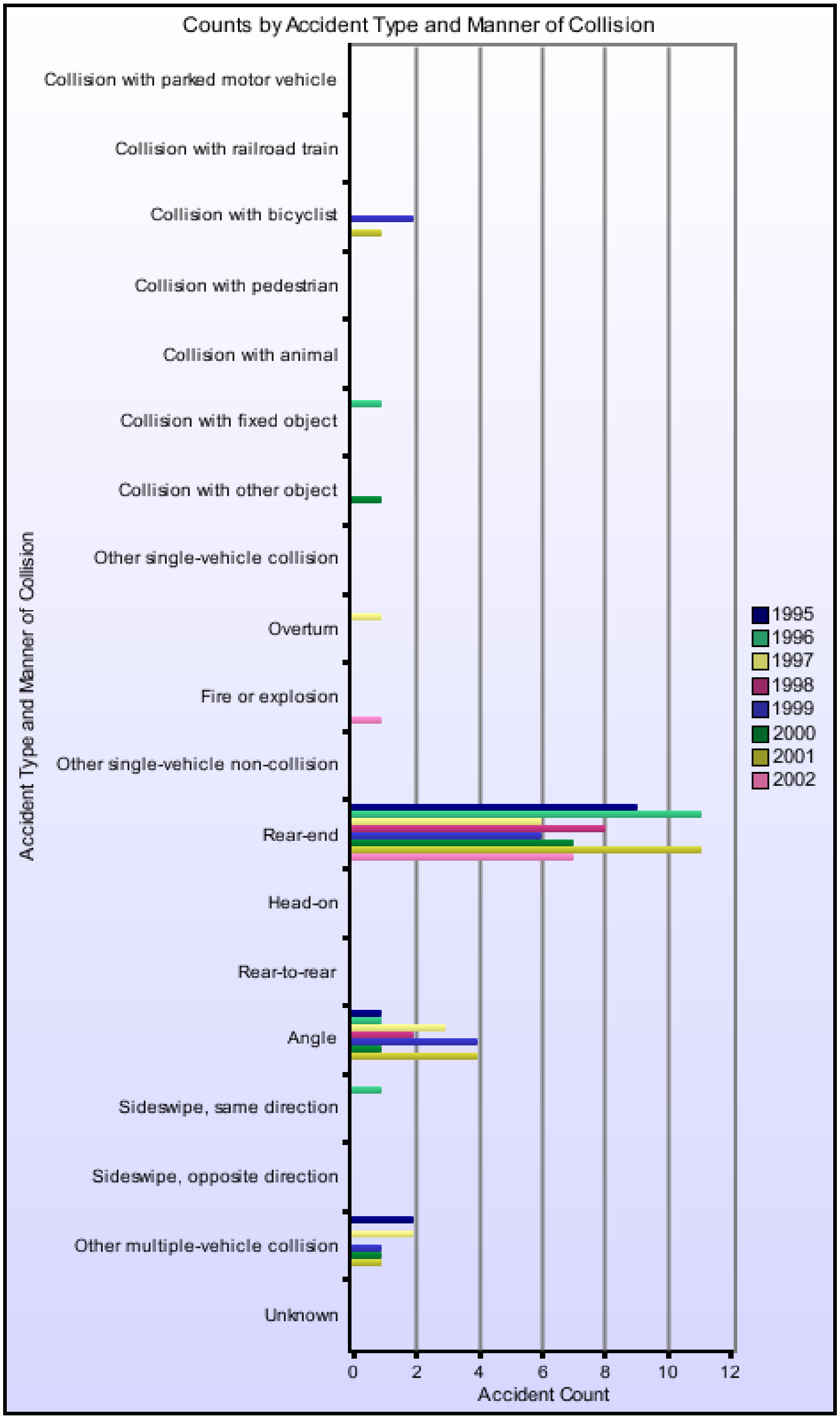

Figure 3. Module 2—Sample Accident Summary Statistics for Accident Type Manner of Collision for an Urban 4-Leg Signalized Intersection (Bar Chart)

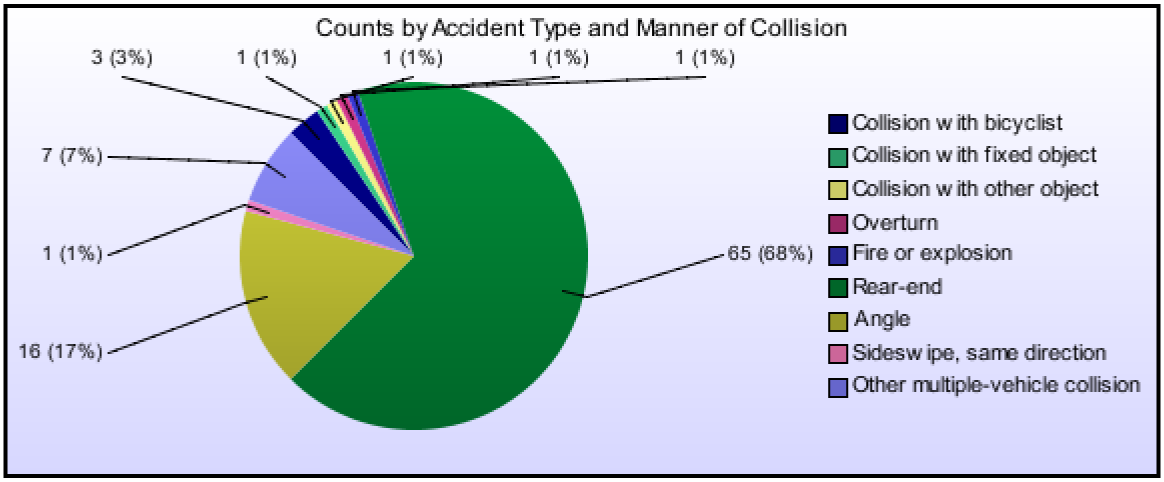

Figure 4. Module 2—Sample Accident Summary Statistics for Accident Type Manner of Collision for an Urban 4-Leg Signalized Intersection (Pie Chart)

2.1.2 Collision Diagrams

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

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

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

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

Figure 5 illustrates a sample collision diagram. In this collision diagram, the schematics are annotated with accident severity levels. The legend depicts the meaning of each schematic. Given the frequency of rear-end accidents at this particular location, rear-end accidents appear to be an accident pattern of interest that the analyst may wish to investigate further as part of the diagnostic and countermeasure selection process.

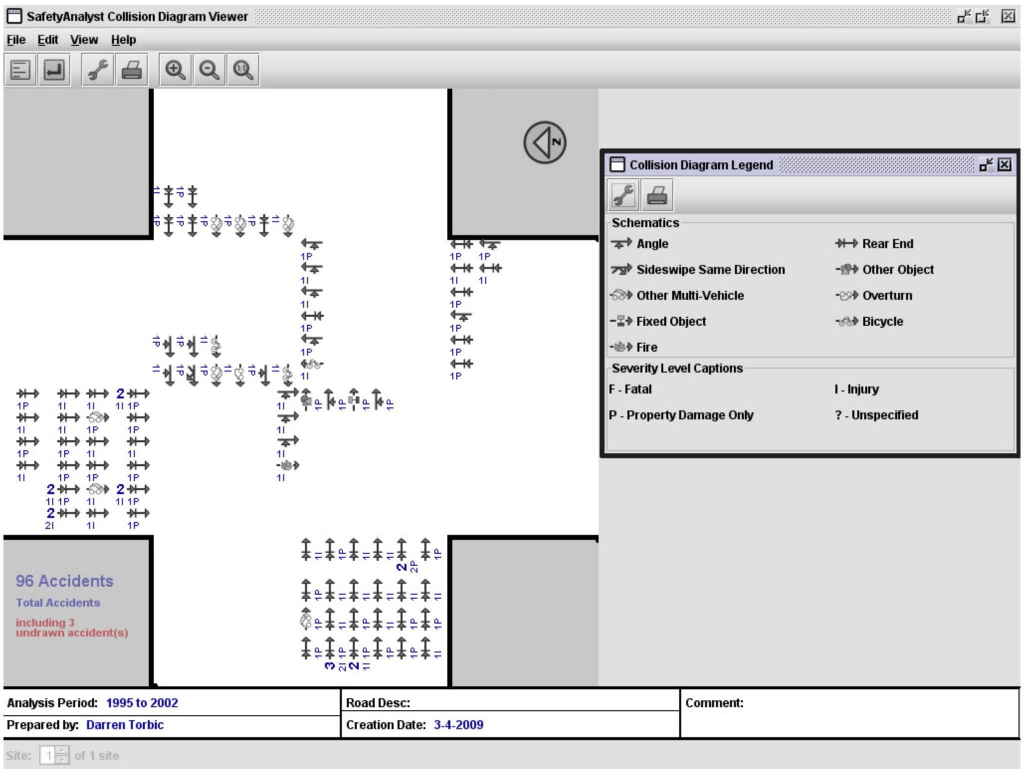

Figure 5. Module 2—Sample Collision Diagram for an Urban 4-Leg Signalized Intersection

2.1.3 Statistical Tests

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

2.1.3.1 Test of Accident Frequencies

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

Table 2 presents the results of a test of frequencies. In this example, a limiting value of one accident/yr was specified. The first column in Table 2 displays the collision types. Columns 2 and 3 present the following:

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

  The value for the Average Observed Accident Frequency presented in the output for the test of frequencies in Module 2 is slightly different than the Average Observed Accidents for Entire Site and the Average Observed Accidents for that portion of the site identified as having the greatest potential for safety improvement as presented in the Module 1 outputs for the "Peak Searching" and "Sliding Window" network screening methodologies (*3*). The primary difference is that the Average Observed Accident Frequency as calculated in Module 2 is based on the entire analysis period. This is an average frequency for the middle of the analysis period, assuming the ADT grows yearly. For example, say the analysis period is from 2003 through 2007. The average observed accident frequency would essentially provide an estimate for the Year 2005, because of the differences in ADT. If the ADT was the same for every year in the analysis period, then the simple average value would be applicable to every year. The Average Observed Accidents for Entire Site and the Average Observed Accidents as calculated in Module 1 are scaled to the final year of the analysis period (*3*). In Module 1, this scaling is necessary so that all accident frequencies (i.e., observed, predicted, and expected) are comparable to one another (*3*).

  In summary, the average observed accident frequency calculated in Module 2 for tests for frequencies is the simple average observed accident frequency for the middle of the analysis period, and the average observed accident frequency calculated in Module 1 for "Peak Searching" and "Sliding Window" network screening methodologies are for the final year of the analysis period (*3*). For roadway segments and ramps, the units for this measure are acc/mi/yr. For intersections, the units are acc/yr.

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

  The value for the Average EB-Adjusted Accident Frequency presented in the output for the test of frequencies in Module 2 is very similar to the Expected Accident Frequency for that portion of the site identified as having the greatest potential for safety improvement as presented in the Module 1 outputs for the "Peak Searching" and "Sliding Window" network screening methodologies (*3*). In both cases an Empirical Bayes approach is used for calculating the accident frequency. However, as discussed above for the Average Observed Accident Frequency, the Average EB-Adjusted Accident Frequency as calculated in Module 2 is based on the entire analysis period, where as Expected Accident Frequency as calculated in Module 1 is scaled to the final year of the analysis period(*3*). In Module 1, this scaling is necessary so that all accident frequencies (i.e., observed, predicted, and expected) are comparable to one another (*3*).

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

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

Table 2 shows the combined results for test of frequencies and test of proportions. An explanation of the test of proportions is presented below.

2.1.3.2 Test of Accident Proportions

The objective of this test is to identify accident types that are over-represented at a location based upon the proportions of observed accidents at the given location compared to the proportion of accidents at similar locations. The primary rationale for this test is that diagnosing safety concerns by strictly focusing on accident frequencies (i.e., average observed and EB-Adjusted Accident Frequencies) only tells a portion of the issue. Some sites may experience high accident frequencies, but given the exposure levels (i.e., average daily traffic) and current site conditions, the safety experience may be what would be expected. However, it may also be the case that a particular type of accident is occurring more often at a given location than is typically expected.

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

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

This may be assessed by comparing accident proportions rather than frequencies. By comparing observed proportions of particular accident types at a given location to proportions at similar locations, over representation of particular accident types can be determined and identified as accident patterns of interest for further investigation. The opposite may also be true. A site may experience relatively few accidents, but based upon the accident patterns at the site, the site can still be effectively treated with a countermeasure to reduce particular types of accidents that may be occurring.

The general approach for the test of proportions is similar to the methodology used in Module 1 to perform network screening based on a high proportion of specific accident type (*3*). Given the distribution of accident types at the given location, the observed proportions of accident types at the location are compared to accident proportions at similar locations. When the probability that the observed proportion of the particular accident type at the site is greater than what is expected for similar sites, the accident type is highlighted for potential further investigation. The analyst specifies the desired confidence level for the statistical validity of the test to assess the probability that the observed proportion of a particular accident type is greater than the proportion at similar sites.

Table 2 above presents the results of both the test of frequencies and test of proportions. In this example, a 90-percent confidence level was specified. Columns 4, 5, and 6 of Table 2 present the following information related to the test of proportions:

- **Observed Proportion (Column 4):** The observed proportion presented in this column on the output report is the proportion of accidents for each specific collision type, relative to all accidents for the given severity level that occurred at the site.
- **Limiting Proportion (Column 5):** The limiting proportion presented in this column on the output report is the proportion of accidents for each specific collision type, relative to all accidents for the given severity level, but it is based upon accident data distributions for sites of the same site subtype.
- **Probability Observed Proportion Exceeds Limiting Proportion (Column 6):** This column on the output report presents the probability that the observed proportion is greater than the limiting proportion. Collision types are highlighted in this column if the probability is greater than or equal to the confidence level (i.e., 1-α) specified by the analyst.

In the sample output in Table 2, rear-end and overturn accidents are highlighted in Column 6 because there is at least a 90-percent probability that the observed proportion for each specific collision type is greater than the limiting proportion. Given that the observed proportion of overturn accidents is relatively small (i.e., less than 1 percent of the total accidents at the site), overturn type accidents at this location are probably not of too much concern. This is also reflected by the frequency level for overturn type accidents. However, rear-end accidents account for approximately 69 percent of the total accidents at this location. At similar locations, rear-end accidents typically account for about 56 percent of the total accidents which suggests that rear-end accidents are slightly over represented at this particular location. Also, given the frequency of rear-end accidents at this particular location, rear-end accidents appear to be an accident pattern of interest that the analyst may wish to investigate further as part of the diagnostic and countermeasure selection process.

2.2 Diagnostic Investigation and Countermeasure Selection

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

All diagnostic scenarios presented in *SafetyAnalyst* have a general format. Each scenario is characterized under a particular title, site type, site subtype, attributes, accident pattern, vehicle maneuvers, circumstance statement, scenario background rationale, and diagnostic questions. The analyst selects which diagnostic scenario or scenarios related to the accident type of interest to review.

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

A total of 393 diagnostic scenarios are incorporated in *SafeyAnalyst*. Diagnostic scenarios are available for roadway segments and intersections. Diagnostic scenarios have not been developed for ramps. For roadway segments, diagnostic scenarios are available for rural and urban two-lane roads and multilane divided and undivided highways (i.e., nonfreeways). Diagnostic scenarios have not been developed for urban one-way arterials, or freeways. For intersections, diagnostic scenarios are available for rural and urban three- and four-leg intersections with minor-road STOP control or signal control. Diagnostic scenarios have not been developed for intersections with all-way STOP control. Table 3 presents a summary of the *SafetyAnalyst* site subtypes for which diagnostic scenarios have been developed. The number presented in the Yes column under Diagnostic Scenarios Available indicates the number of diagnostic scenarios that have been developed for the respective site subtype. Table 4 presents the details/logic for a single scenario related to dilemma zone issues. The scenario is for an urban, four-leg signalized intersection and addresses rear-end accidents. All other scenarios have been developed with a similar format.

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

Upon completing the review of the diagnostic scenario or scenarios, the analyst is presented with a list of countermeasures for potential implementation and/or for further economic analysis within Module 3 (*2*). Prior to completing the diagnostic investigation for a site, the analyst has the opportunity to revise the list of countermeasures by (a) removing countermeasures from the list and (b) including other countermeasures that may not have been identified during the review of diagnostic scenarios.

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

Table 3. Module 2—SafetyAnalyst Site Subtypes for Which Diagnostic Scenarios Have Been Developed

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

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

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

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

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

Diagnostic Question(s):

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

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

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

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

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

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

2.3 Primary Output Report

The primary output report from Module 2 includes:

- A list of countermeasures for potential implementation and/or further economic analysis in Module 3 (*2*);
- A summary of the detailed diagnostic scenarios reviewed during the investigation; and
- A list of office and/or field procedures to gather information which will help in responding to diagnostic questions for which the analyst did not readily know the answer.

Table 5 presents a sample output table from a Module 2 analysis that lists the potential countermeasures identified by diagnostic review of two scenarios. In addition to listing the countermeasure, this table includes:

- **Contraindication:** This column on the output report presents any potential negative impact that could be experienced due to the implementation of the countermeasure.
- **Recommended By:** This column on the output report indicates the scenario ID for all diagnostic scenarios that were reviewed and resulted in identification of the particular countermeasure. More than one scenario ID can be shown in this column. When the value in this column is User, this indicates that the countermeasure was selected by the analyst and was not identified through the review of diagnostic scenarios.
- **Accident Pattern:** This column on the output report indicates the accident pattern that the countermeasure was identified to mitigate.
- record exists that indicates the respective countermeasure has been implemented at the site. If a record exists which indicates that the countermeasure has been implemented at the site, the column will indicate Yes, Otherwise, the column will indicate No.

Table 6 presents the potential diagnostic scenarios that have been reviewed and could have been reviewed given the site subtype, accident pattern of interest, and vehicle maneuvers (for intersections). In this portion of the output report, those diagnostic scenarios that were reviewed in detail are presented first. The responses to the specific questions are provided, along with the

Table 5. Module 2—Example of Countermeasures Report

Countermeasure	Contraindication	Recommended by*	Accident pattern(s)	Implemented
Provide signal coordination	Only aids mainline	16	Rear-end	no
Add advanced detection	May increase delay	16	Rear-end	no
Install dilemma detection system		16	Rear-end	no
Improve change plus clearance interval	May increase delay	16	Rear-end	no
Narrow cross section by reducing number of approach lanes	Reduced capacity	18	Rear-end	no
Reduce speed limit on approaches		18	Rear-end	no
Increase enforcement to reduce speed on intersection approach		18	Rear-end	no
Narrow cross section by physically narrowing lanes		18	Rear-end	no
Change streetscape to increase stimulation of peripheral vision		18	Rear-end	no
Restrict movements to right-in and right-out at the access using channelizing island	Accidents may migrate with changes in volume patterns	18	Rear-end	no
Improve sight distance to intersection		User	user-selected CM	no
Improve sight distance to traffic signal		User	user-selected CM	no

* A scenario ID ending in 'u' indicates the countermeasure was user-selected and is not a result of the diagnosis.

identified countermeasures or procedures. The latter portion of this output lists those diagnostic scenarios that the analyst did not review. In Table 6, Diagnostic Scenario 16 related to the dilemma zone was reviewed in detail along with Diagnostic Scenario 18 related to speeds. Eight other diagnostic scenarios related to rear-end accidents involving two through movements were not reviewed in detail.

The final portion of the output report provides procedures for gathering information, either in the office or in the field, that will be useful for answering a diagnostic question for which the analyst did not initially know the answer. Some of the procedures are very basic, while others are more complicated and detailed. Table 7 lists two procedures that resulted from an unknown response for a question generated while reviewing Scenario 18 related to speed.

Table 6. Module 2—Example of Report Presenting Potential Diagnoses

3.3.1 Diagnosis 16: Dilemma Zone

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Evaluation Status: Complete

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

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

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

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

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

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

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

3.3.2 Diagnosis 18: Speeds Too High

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

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

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

Rationale:
A wide cross-section and wide lanes contribute to a road message that high speeds are acceptable. High operating speeds may occur at intersections near freeway exits or on freeway to highway transitions. Drivers from the freeway have adapted to traveling at higher speeds,

Table 6. Module 2—Example of Report Presenting Potential Diagnoses (Continued)

and require several minutes to transition to lower speeds. Even when drivers are aware that this transition is required, it can take several minutes for drivers to adapt and reduce their speed. High operating speeds are a concern for vulnerable road users, such as pedestrians and bicyclists. Accesses near the intersection are a concern when operating speeds are high, for vehicles slowing, stopping, or turning into or out of the access.

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

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

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

3.3.3 Diagnosis 17: Traffic Congestion (Queuing)

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

3.3.4 Diagnosis 19: Inadequate Signal Visibility

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

3.3.5 Diagnosis 20: Inadequate Guidance for Drivers

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

3.3.6 Diagnosis 21: Accesses/Driveways

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

3.3.7 Diagnosis 22: Bus Stops Near Intersection

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

Table 6. Module 2—Example of Report Presenting Potential Diagnoses (Continued)

3.3.8 Diagnosis 23: Pedestrian Movements

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

3.3.9 Diagnosis 24: Downgrade

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Not Evaluated

3.3.10 Diagnosis 25: Road Surface Condition/Drainage

Accident Pattern: Rear-end

Vehicle Maneuvers: 2 thru

Attribute: Wet weather

Not Evaluated

Table 7. Module 2—Example of Report With Description of Recommended Procedures

3.4 Measure 85th Percentile Speed (See ITE Traffic Engineering Handbook)

85^{th} percentile speed measurement.

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

3.5 Visit Site

Visit the site to obtain information.

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

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

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

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

- The diagnostic scenarios guide analysts toward identifying countermeasures for potential implementation or further economic analysis.
- Highway agencies may add, delete, or modify the questions included in the diagnostic scenarios and the potential countermeasures suggested in response to specific answers to those questions.
- *SafetyAnalyst* does not make the final selection of countermeasures for potential implementation or further economic analysis; it is the analyst that makes the final selection. *SafetyAnalyst* is only a tool that the analyst can utilize during diagnostic investigations to help identify potential countermeasures. Once the analyst selects specific countermeasures, those selections can be entered into *SafetyAnalyst* for further consideration in Module 3 (*2*).

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3. REFERENCES

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Appendix A

Detailed Procedures for *SafetyAnalyst* Module 2—Diagnosis and Countermeasure Selection

APPENDIX A. DETAILED PROCEDURES FOR *SAFETYANALYST* MODULE 2—DIAGNOSIS AND COUNTERMEASURE SELECTION

A.1 Identifying Accident Patterns Using Statistical Procedures

This appendix explains in detail the two statistical procedures used in Module 2 for identifying accident patterns of interest. The statistical procedures are based upon tests for accident frequencies or accident proportions.

A.1.1 Test for Frequencies

Two approaches are available to test whether accident frequencies at a site/project are too large. The approaches are based on comparing the average observed accident frequency and EB-adjusted expected accident frequency to a limiting value, as specified by the user, for a given collision type.

Calculations and tests of average observed accident frequencies and EB-adjusted expected accident frequencies are performed as follows for a given site/project. For roadway segments, these calculations are not necessarily performed for the entire site but are calculated taking into consideration the boundaries of the site as specified by the user. For projects, the calculations are based upon the entire length of each site in the project.

A.1.2 Tests of Average Observed Accident Frequencies

For the specified accident severity level (i.e., TOT, FS, FI, or PDO) and for each observed collision type, calculate the average observed accident frequency as follows:

Step 1a: For roadway segments or ramps.

$$\text{Average acc/mi/yr} = \frac{\sum_{y=1}^{Y} \frac{K_{y(CT)}}{Y}}{SL} \qquad \text{(A-1)}$$

where:

Y = total number of years in the analysis period.
SL = roadway segment or ramp length (mi) under consideration.
$K_{y(CT)}$ = observed number of accidents of the collision type of interest during Year Y. For simplicity of notation, CT may refer to any manner of collision when performing the calculations in Equation (A-1) through Equation (A-26).

NOTE 1: If the entire site is being evaluated, then the roadway segment (or ramp) length for the site is provided in the *SafetyAnalyst* inventory database. If only a portion of the site is being evaluated, then SL for the site must be determined based upon the boundaries (i.e., limits) of the site as specified by the user.

Step 1b: For Intersections.

$$\text{Average acc/yr} = \frac{\sum_{y=1}^{Y} K_{y(CT)}}{Y} \tag{A-2}$$

Step 2: Compare the average observed accident frequency to the limiting value as specified by the user. If the average observed accident frequency is greater than or equal to the limiting value, the collision type is flagged for further consideration.

CALCULATION ADJUSTMENTS FOR PROJECTS: When more than one roadway segment is being considered in the evaluation, then apply Equation (A-3) rather than Equation (A-1) when calculating average observed accident frequencies.

$$\text{Average acc/mi/yr} = \frac{\sum_{i=1}^{I} \sum_{y=1}^{Y} \frac{K_{i,y(CT)}}{Y_i}}{\sum_{i=1}^{I} SL_i} \tag{A-3}$$

where:

I	=	total number of sites in the project.
Y_i	=	total number of years in the analysis period at site i.
SL_i	=	roadway segment length (mi) under consideration at site i.
$K_{y(CT)}$	=	observed number of accidents of the collision type of interest at site i during Year Y. For simplicity of notation, CT may refer to any manner of collision when performing the calculations in Equation (A-1) through Equation (A-26).

NOTE 1: If a project is being evaluated, then i ≥ 2 and the roadway segment lengths for each site in the project are provided in the *SafetyAnalyst* inventory database.

A.1.3 Tests of EB-Adjusted Expected Accident Frequencies

For each observed collision type, calculate the EB-adjusted expected accident frequency as follows:

Step 1a: For roadway segments or ramps using the appropriate SPF model parameters, compute for each year in the analysis period (y = 1, 2, ...,Y) the predicted number of accidents, κ_y, per mile, as follows:

$$\kappa_{y(TOT)} = SPF_{TOT}\{ADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times ADT_y^{\beta_1} \tag{A-4}$$

$$\kappa_{y(FI)} = SPF_{FI}\{ADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times ADT_y^{\beta_1} \quad \text{(A-5)}$$

NOTE 1: $P_{CT(TOT)}$ and $P_{CT(FI)}$ for the observed collision types are found in the *SafetyAnalyst* database.

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

NOTE 3: If $\kappa_{y(FI)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly, if $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

Step 1b: For intersections.

Using the appropriate SPF model parameters, compute for each year in the analysis period (y = 1, 2, ...,Y) the predicted number of accidents, κ_y, as follows:

$$\kappa_{y(TOT)} = SPF_{TOT}\{ADT\} = c_{y(TOT)} \times P_{CT(TOT)} \times e^{\alpha} \times MajADT_y^{\beta_1} \times MinADT_y^{\beta_2} \quad \text{(A-6)}$$

$$\kappa_{y(FI)} = SPF_{FI}\{ADT\} = c_{y(FI)} \times P_{CT(FI)} \times e^{\alpha} \times MajADT_y^{\beta_1} \times MinADT_y^{\beta_2} \quad \text{(A-7)}$$

NOTE 1: $P_{CT(TOT)}$ and $P_{CT(FI)}$ for the observed collision types are found in the *SafetyAnalyst* database.

NOTE 2: If the screening is based upon FS, then (A) select and use FI SPFs and equations for the calculations, (B) use the Accident Distribution Default data to retrieve the proportion of FS accidents as a ratio of FI accidents [$P_{(CT/FS/FI)}$] for the given site subtype, (C) if more than one collision type is included in the analysis, sum the $P_{(CT/FS/FI)}$, (D) replace $P_{CT(FI)}$ in Equation (A-7) with $P_{(CT/FS/FI)}$, and (E) proceed as normal for FI calculations.

NOTE 3: If $\kappa_{y(FI)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FI)} = \kappa_{y(TOT)}$. Similarly, if $\kappa_{y(FS)} > \kappa_{y(TOT)}$, then set $\kappa_{y(FS)} = \kappa_{y(TOT)}$.

Step 2: Using the model predictions computed in *Step 1a* or *1b*, compute the yearly correction factors, C_y, for each year in the analysis period (y = 1, 2, ...,Y):

$$C_{y(TOT)} = \frac{\kappa_{y(TOT)}}{\kappa_{1(TOT)}} \quad \text{(A-8)}$$

$$C_{y(FI)} = \frac{\kappa_{y(FI)}}{\kappa_{1(FI)}} \quad \text{(A-9)}$$

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

$$w_{TOT} = \frac{1}{1+d_{TOT}\sum_{y=1}^{Y}\kappa_{y(TOT)}\times L} \quad \text{(A-10)}$$

$$w_{FI} = \frac{1}{1+d_{FI}\sum_{y=1}^{Y}\kappa_{y(FI)}\times L} \quad \text{(A-11)}$$

NOTE 1: The weights, $w_{(TOT)}$ and $w_{(FI)}$, are always calculated based upon the "all" accidents for TOT and FI severity levels. In other words, for those instances when basic network screening is based upon a certain collision type or types, the predicted value calculated in *Step 1* is scaled, based upon a proportion or a sum of proportions. Rather than using the scaled value of predicted accidents in Equation (A-10) and Equation (A-11), the predicted value before multiplying by the respective proportion will be used to calculate the weights $w_{(TOT)}$ and $w_{(FI)}$. The same principle applies when the calculations are based upon FS injuries. The weight $w_{(FS)}$ will actually be based upon "all" FI accidents. The rationale for this change is because weights, $w_{(TOT)}$ and $w_{(FI)}$, are used in subsequent steps to combine observed accidents and predicted accidents. The weights, $w_{(TOT)}$ and $w_{(FI)}$, are calculated based upon the accuracy/reliability of the SPFs. In concept the accuracy/reliability of the SPF does not change when the screening is based upon certain collision types or FS injury accidents. The same SPFs for TOT and FI accidents are still being used for all calculations, and the accuracy/reliability of the TOT and FI SPFs does not change. If the "scaled" predicted values were used in equations Equation (A-10) and Equation (A-11), then the weights would be adjusted for the wrong reason, not because the accuracy/reliability of the SPFs changed but because the predicted values were scaled as a necessity due to unrelated circumstances.

NOTE 2: In Equation (A-10) and Equation (A-11), L is equal to the segment length, SL for roadway segments, or ramp length, SL_{RAMP} for ramps. For intersections L is set to 1.

Step 4a: For roadway segments, projects, and ramps.

Calculate the base EB-adjusted expected number of accidents, X_1, during Year 1:

$$X_{1(TOT)} = w_{TOT}\kappa_{1(TOT)}SL_i + (1 - w_{TOT})\frac{\sum_{y=1}^{Y}K_{y(TOT)}}{\sum_{y=1}^{Y}C_{y(TOT)}} \quad \text{(A-12)}$$

$$X_{1(FI)} = w_{FI}\kappa_{1(FI)}SL_i + (1 - w_{FI})\frac{\sum_{y=1}^{Y}K_{y(FI)}}{\sum_{y=1}^{Y}C_{y(FI)}} \quad \text{(A-13)}$$

NOTE 1: If the entire site is being evaluated, then the roadway segment length (or ramp length) for the site is provided in the *SafetyAnalyst* inventory database. If only a portion of the site is being evaluated as specified by the user, then SL_i for the site must be determined based upon the boundaries (i.e., limits) of the site that are being considered in the evaluation and the actual boundaries (i.e., limits) of the site.

NOTE 2: If the site is a ramp and ramp length (SL_{Ramp}) is not available, the site cannot be included in the analysis.

NOTE 3: The observed accidents in equations Equation (A-12) and Equation (A-13) should be those of the respective collision types and severity levels as specified by the user.

Step 4b: For intersections

Calculate the base EB-adjusted expected number of accidents, X_1, during Year 1:

$$X_{1(TOT)} = w_{TOT}\kappa_{1(TOT)} + (1 - w_{TOT})\frac{\sum_{y=1}^{Y} K_{y(TOT)}}{\sum_{y=1}^{Y} C_{y(TOT)}} \quad \text{(A-14)}$$

$$X_{1(FI)} = w_{FI}\kappa_{1(FI)} + (1 - w_{FI})\frac{\sum_{y=1}^{Y} K_{y(FI)}}{\sum_{y=1}^{Y} C_{y(FI)}} \quad \text{(A-15)}$$

NOTE: The observed accidents in Equation (A-14) and Equation (A-15) should be of the respective collision types and severity levels as specified by the user.

Step 5: Calculate X_Y, the EB-adjusted expected number of accidents for each year in the analysis period (y = 1,2, ..., Y):

$$X_{Y(TOT)} = X_{1(TOT)} C_{Y(TOT)} \quad \text{(A-16)}$$

$$X_{Y(FI)} = X_{1(FI)} C_{Y(FI)} \quad \text{(A-17)}$$

Step 6a: For roadway segments and ramps.

Calculate the average EB-adjusted expected accident frequency:

$$\text{Average acc/mi/yr}_{(TOT)} = \frac{\sum_{y=1}^{Y} \frac{X_{y(TOT)}}{Y}}{SL} \quad \text{(A-18)}$$

$$\text{Average acc/mi/yr}_{(FI)} = \frac{\sum_{y=1}^{Y} \frac{X_{y(FI)}}{Y}}{SL} \quad \text{(A-19)}$$

$$\text{Average acc/mi/yr}_{(PDO)} = \text{Average acc/mi/yr}_{(TOT)} - \text{Average acc/mi/yr}_{(FI)} \quad \text{(A-20)}$$

NOTE 1: For ramps, the denominator for Equation (A-18) and Equation (A-19) is SL_{Ramp}.

Step 6b: For Intersections.

Calculate the average EB-adjusted expected accident frequency:

$$\text{Average acc/yr}_{(TOT)} = \sum_{y=1}^{Y} \frac{X_{y(TOT)}}{Y} \quad \text{(A-21)}$$

$$\text{Average acc/yr}_{(FI)} = \sum_{y=1}^{Y} \frac{X_{y(FI)}}{Y} \quad \text{(A-22)}$$

$$\text{Average acc/yr}_{(PDO)} = \text{Average acc/yr}_{(TOT)} - \text{Average acc/yr}_{(FI)} \quad \text{(A-23)}$$

Step 7: Compare the average EB-adjusted expected accident frequency to the limiting value as specified by the user. If the average EB-adjusted expected accident frequency is greater than or equal to the limiting value, the collision type is flagged for further consideration.

CALCULATION ADJUSTMENTS FOR PROJECTS: When more than one roadway segment is being considered in the evaluation, then apply *Steps 1* through *5* to each roadway segment and then apply Equation (A-24) rather than Equation (A-18) when calculating the average EB-adjusted expected accident frequency.

$$\text{Average acc/mi/yr}_{(TOT)} = \frac{\sum_{i=1}^{I}\sum_{y=1}^{Y}\frac{x_{i,y(TOT)}}{Y}}{\sum_{i=1}^{I} SL_i} \quad \text{(A-24)}$$

$$\text{Average acc/mi/yr}_{(FI)} = \frac{\sum_{i=1}^{I}\sum_{y=1}^{Y}\frac{x_{i,y(FI)}}{Y}}{\sum_{i=1}^{I} SL_i} \quad \text{(A-25)}$$

$$\text{Average acc/mi/yr}_{(PDO)} = \text{Average acc/mi/yr}_{(TOT)} - \text{Average acc/mi/yr}_{(FI)} \quad \text{(A-26)}$$

In summary, the test for frequencies may trigger an investigation into a specific accident pattern ("the test is passed") when either the observed or the EB-expected average frequency exceeds the limiting value.

A.1.4 Test of Proportions

For roadway segments, intersections, and ramps, the following steps describe the procedures for the test of proportions.

Step 1

For a given site/project, severity level, and analysis period of Y years, calculate the proportion of observed accidents for each observed collision type.

$$P_{i\,(CT/SEV)} = \frac{\sum_{y=1}^{Y} K_{iy(CT)}}{\sum_{y=1}^{Y} K_{iy(SEV)}} \quad \text{(A-27)}$$

NOTE: The observed accidents are determined based upon the boundaries of the evaluation as specified by the user. For simplicity of notation, CT may refer to any type of accident.

Step 2

Calculate the probability that the observed proportion exceeds the limiting (i.e., statewide) proportion. The probability that the observed proportion of a specific collision type is higher than the limiting value, p_i^*, is computed as:

$$Prob\left(p_{i(CT/TOT)} > p_i^* \middle| x_{i(CT)}, n_{i(TOT)}\right) = 1 - \frac{1}{B\left(f+x_{i(CT)}, g+n_{i(TOT)}-x_{i(CT)}\right)} \int_{H=0}^{p_i^*} H^{f+x_{i(CT)}-1}(1-H)^{g+n_{i(TOT)}-x_{i(CT)}-1} dH$$

(same as A-166)

where:

Total Accidents

$x_{i(CT)}$	=	observed number of TOT accidents of the collision type of interest at site i for all years of the analysis period.
$n_{i(TOT)}$	=	observed number of TOT accidents at site i for all years of the analysis period.
$p_{i(CT/TOT)}$	=	$x_{i(CT)}/n_{i(TOT)}$ (i.e., the proportion of accidents of the collision type of interest for all TOT accidents).
$B(f+x_{i(CT)},g+n_{i(TOT)}-x_{i(CT)})$	=	the value of the beta function based on the values of the two parameters inside the parentheses.

FS Accidents

$x_{i(CT)}$	=	observed number of FS accidents of the collision type of interest at site i for all years of the analysis period.
$n_{i(FS)}$	=	observed number of FS accidents at site i for all years of the analysis period.
$p_{i(CT/FS)}$	=	$x_{i(CT)}/n_{i(FS)}$ (i.e., the proportion of accidents of the collision type of interest for all FS accidents).
$B(f+x_{i(CT)},g+n_{i(FS)}-x_{i(CT)})$	=	the value of the beta function based on the values of the two parameters inside the parentheses.

FI Accidents

$x_{i(CT)}$	=	observed number of FI accidents of the collision type of interest at site i for all years of the analysis period.
$n_{i(FI)}$	=	observed number of FI accidents at site i for all years of the analysis period.
$p_{i(CT/FI)}$	=	$x_{i(CT)}/n_{i(FI)}$ (i.e., the proportion of accidents of the collision type of interest for all FI accidents).
$B(f+x_{i(CT)},g+n_{i(FI)}-x_{i(CT)})$	=	the value of the beta function based on the values of the two parameters inside the parentheses.

PDO Accidents

$x_{i(CT)}$ = observed number of PDO accidents of the collision type of interest at site i for all years of the analysis period.

$n_{i(PDO)}$ = observed number of PDO accidents at site i for all years of the analysis period.

$p_{i(CT/PDO)}$ = $x_{i(CT)}/n_{i(PDO)}$ (i.e., the proportion of accidents of the collision type of interest for all PDO accidents).

$B(f+x_{i(CT)},g+n_{i(PDO)}-x_{i(CT)})$ = the value of the beta function based on the values of the two parameters inside the parentheses.

NOTE: When screening is based on a severity level other than Total accidents, proceed as indicated using X_i, n_i, p_i, and p_i^* for the specified severity level.

The Beta distribution parameters defaults for collision types file in the *SafetyAnalyst* database includes two beta function parameters, f and g, for a limited number of site subtypes collision types.

Step 3

Compare the calculated probability to the p-value specified by the user. If the calculated probability equals or exceeds the given value (1 - p), then that specific accident pattern is flagged for further consideration.

NOTE: If $p_{i(CT/SEV)}\ {}_{i}^{*}{}_{(CT/SEV)}$, then regardless of the outcome of the statistical test the window is not flagged.

CALCULATION ADJUSTMENTS FOR PROJECTS: When more than one roadway segment is being considered in the evaluation, apply Equation (A-28) rather than Equation (A-27) in *Step 1* when calculating the observed proportion of the respective accident pattern.

$$P_{(CT/TOT)} = \frac{\sum_{i=1}^{I}\sum_{y=1}^{Y}K_{iy(CT)}}{\sum_{i=1}^{I}\sum_{y=1}^{Y}K_{iy(TOT)}} \qquad \text{(A-28)}$$

NOTE 1: When a project is being evaluated, then $i \geq 2$, and I is the total number of sites in the project.

In summary, the test of proportions may trigger an investigation into a specific accident pattern (i.e., "the test is passed") when the observed proportion exceeds the limiting value (i.e., p_i^*) for that accident type with a probability greater or equal to the user specified probability (i.e., 1 - p).

The procedure above is described for TOT accidents. The same procedure will be applied for FS, FI, and PDO severity levels. Beta parameters and limiting values [$P_{(CT/FS)}$, $P_{(CT/FI)}$, and $P_{(CT/PDO)}$] for the FS, FI and PDO severity levels are available in the *SafetyAnalyst* database. Include only those observed accidents that meet the user specified criteria (i.e., collision type and severity level) in the calculations.