

***SafetyAnalyst*: Software Tools for  
Safety Management of Specific  
Highway Sites**

**Task K**

**White Paper for  
Module 2—Diagnosis and  
Countermeasure Selection**

**For  
Federal Highway Administration**

**GSA Contract No. GS-23F-0379K  
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**December 2002**

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**White Paper for  
Module 2—Diagnosis and  
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**Prepared by  
Midwest Research Institute  
iTRANS Consulting, Inc.  
Human Factors North, Inc.  
Ryerson Polytechnic University  
Dr. Ezra Hauer**

**For  
Federal Highway Administration  
Office of Safety R&D  
6300 Georgetown Pike  
McLean, Virginia 22101-2296**

**Attn: Mr. Michael Griffith, HSR-20**

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## Preface

This white paper presents a plan for developing functional specifications for *SafetyAnalyst* software Module 2, the diagnosis and countermeasure selection tools, and was prepared for the Federal Highway Administration (FHWA) under the requirements of GSA Contract No. GS-23F-0379K, Task No. DTFH61-01-F-00096. This paper, prepared as part of Task K, summarizes the technical approach to development of the *SafetyAnalyst* diagnosis and countermeasure selection tools. Preparers of this paper include Dr. Alison Smiley, Human Factors North, Inc.; Ms. Geni Bahar, iTRANS Consulting, Inc.; Mr. Douglas W. Harwood and Ms. Ingrid B. Potts, Midwest Research Institute (MRI); Dr. Ezra Hauer; and other members of the *SafetyAnalyst* team.

MIDWEST RESEARCH INSTITUTE

Douglas W. Harwood  
Principal Traffic Engineer

Approved:

Roger Starnes  
Director  
Applied Engineering Division

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# **SAFETYANALYST WHITE PAPER FOR MODULE 2—DIAGNOSIS AND COUNTERMEASURE SELECTION**

## **Section 1 Introduction**

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In April 2001, the Federal Highway Administration (FHWA) entered into a contract with Midwest Research Institute (MRI) to plan and develop a set of software tools for safety management of specific highway sites, known as *SafetyAnalyst*. The *SafetyAnalyst* team also includes iTRANS Consulting, Inc.; Human Factors North, Inc.; Ryerson Polytechnic University; Woodward Communications, Inc.; and Dr. Ezra Hauer. *SafetyAnalyst* will incorporate computerized analytical tools that correspond to the main steps in highway safety management for site-specific improvements. The *SafetyAnalyst* team will first plan and then develop detailed functional specifications for the *SafetyAnalyst* software tools. Under a separate contract, computer software to implement each tool will be developed by a yet-to-be-selected FHWA contractor from the functional specifications.

This white paper, prepared as part of Task J, summarizes the technical approach to development of *SafetyAnalyst* software Module 2, the diagnosis, and countermeasure selection tools. *SafetyAnalyst* will be comprised of four modules, which when packaged together, incorporate the six main steps for highway safety management:

- Module 1. Network screening
- Module 2. Diagnosis and countermeasure selection
- Module 3. Economic appraisal and priority-ranking
- Module 4. Evaluation

Thus, this white paper addresses the technical approach to the second of the four *SafetyAnalyst* modules.

This white paper expands on the material documented in the *SafetyAnalyst* Work Plan (May 2002) and incorporates changes in response to comments from the September 2002 meeting of the Technical Working Group (TWG), providing detailed explanations of the general approach to be followed during *SafetyAnalyst* development, and the diagnosis and countermeasure selection process to be implemented. It serves as a planning document as well as an overview of the module for the software development contractor. This will assure that the most appropriate diagnosis and countermeasure selection methodology will be incorporated in the functional specifications provided to the software development contractor.

This white paper provides a technical overview of the diagnosis and countermeasure selection tools, but it does not constitute a functional specification. The *SafetyAnalyst* team will develop a draft of a detailed functional specification for the diagnosis and countermeasure selection tool in Task L. That draft will be refined in response to FHWA and TWG comments in Task M. The detailed functional specification will then be provided to the software development contractor so that software development work can begin. It is expected that several key aspects of the diagnosis and countermeasure selection tool will remain to be resolved, even when the detailed functional specifications are complete. Thus, some pieces of logic may be incomplete in the functional specifications. Research to resolve these issues will be undertaken in Task E, in parallel with the software development effort.

This document is organized as follows. Following this introduction there is a general overview of the purpose of the diagnosis and countermeasure selection module. The third section discusses the planned capabilities of the module. The fourth section describes the functionality of the main components of the module. The paper concludes with a section on planned development activities. Three appendices are included that provide an example of diagnostic questions for signalized intersections, an example of diagnosis and related countermeasures for signalized intersections, and a list of potential countermeasures.

## Section 2

# Purpose and Use of Diagnosis and Countermeasure Selection Module

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The purpose of the diagnosis and countermeasure selection tools is to guide the user in the diagnosis of safety problems and the selection of a possible array of countermeasures for a specific site. A site evaluated with the diagnosis and countermeasure selection tools may have been selected by the network screening tool or may have been selected by the user on some other basis. Two separate tools, one for diagnosis and one for countermeasure selection, are anticipated, but these separate tools will be combined into a single software module.

Both tools are intended for use by a user who is knowledgeable about safety. In the diagnosis tool, answers to some of the diagnostic questions are not self-evident and depend on expert judgment. Similarly, although the countermeasure tool suggests potential countermeasures, the *SafetyAnalyst* user will make the decision about which countermeasure(s) will actually be implemented. The user may make this decision based on the output of the diagnosis and countermeasure selection tools, or the user may elect to proceed to the economic appraisal and priority ranking tools in making this decision.

The nature of accidents is that they are rare, multi-causal, and random. They generally result from driver errors, which are more likely in some road and traffic environments than others, because of the nature of the task given to the driver in relation to the driver's limitations. Such driver errors occur frequently, but only result in accidents in the rare situations when road and traffic circumstances combine in an unforgiving fashion. More exposure means more accidents. That is, the more drivers carry out a particular task at a particular site (e.g., a left turn on a permissive green at an intersection with limited sight distance) the more likely common driver errors (e.g., inattention) or limitations (e.g., inability to accurately assess oncoming vehicle speed) will result in accidents. Because accidents are rare, it follows that the presence of accident patterns provides compelling evidence of underlying safety deficiencies. Because accidents are random, it also follows that the accident history at a given site will only provide partial information about safety at that site. Experience tells us that:

- Safety deficiencies can contribute to serious accidents, for which there was no evidence by way of a previous pattern.
- Some sites with high numbers of accidents do not have readily identifiable accident patterns.
- There can be evidence in the accident history that a given deficiency has contributed to accidents at one site while at another site, with a similar deficiency, there is no clear pattern of associated accidents.
- A given deficiency can contribute to different accident types.

Thus, while analysis of accident patterns is critical to addressing safety, it is not sufficient. The diagnosis tool must also encompass other approaches to safety. The diagnostic questions should be 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, and on a highway design and traffic engineering approach, wherein substandard designs, which are known to be associated with accidents at other sites, are identified.

Similarly, countermeasures can be identified based on a particular pattern of accidents, or can be identified based on driver information needs and limitations, and on deficiencies known to lead to accidents at other sites.

## Section 3

# Capabilities Planned for the Diagnosis and Countermeasure Selection Module

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This section identifies the capabilities planned for the diagnosis and countermeasure selection module. Details on how the module will function to achieve the planned capabilities are provided in later sections. Several of these capabilities will require further development and testing in subsequent tasks to determine the need for, and practicality of, implementing them. Users may need the option to customize the module and omit some capabilities if they do not have the data needed to support them.

The capabilities planned for the diagnosis and countermeasure selection tools will include:

- Preparation of collision diagram template
- Plotting of collision diagram
- Identification of accident patterns
- Diagnosis of safety problems through office and field investigations
- Identification and selection of appropriate countermeasures

The first four bullet items in this list constitute the *SafetyAnalyst* diagnosis tool, while the final bullet item constitutes the *SafetyAnalyst* countermeasure selection tool. Figure 1 provides an overview of the process.

# SafetyAnalyst OUTPUTS

## PREPARATION

### Automated Inputs

- geometric design database
- accident record database
- traffic volume database
- accident record database

Collision diagram template

Annotated collision diagram

Table of accident type breakdowns (by factor and maneuver)

### User Inputs

- geometry, traffic control and site characteristics (from design plans and photo log)
- annotations to be displayed
- years of accident data to be displayed used

## PATTERN IDENTIFICATION

- site characteristic information
- statistics on proportions of accidents by site type and factor, crash type, and vehicle maneuver type
- traffic volume information

List of over-represented and most frequent factors, crash types, maneuver types

## SELECTION FOR DIAGNOSIS

Factor/crash type/maneuver patterns for diagnosis based on selection algorithms

- thresholds for selection
- removal of patterns not requiring diagnosis
- addition of patterns requiring diagnosis

## DIAGNOSIS

- site characteristic information
- selected diagnoses

Questions specific to site, factors, maneuvers

Potential diagnoses  
Questions remaining to be answered at the site visit

- answers to questions from office investigation
- observations made at field visit
- review of police reports
- **prioritization of diagnoses**
- **removal of diagnoses not considered relevant**

## COUNTERMEASURES

- selected diagnoses

Potential countermeasures for selected diagnoses

Countermeasure contra-indications

Selected potential countermeasures

Cost-effective countermeasures (addressed in Module 3)

- countermeasures already in place
- removal of impractical countermeasures
- removal of contra-indicated countermeasures

Figure 1. Overview of Planned Capabilities

## Section 4

# Functional Approach to the Module

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This section outlines the anticipated functional approach to the diagnosis and countermeasure selection module in a level of detail that provides an overview of the logical framework for the software.

### 4.1 Overview of Basic Functionality

The following list outlines the basic functionality of the diagnosis and countermeasure selection module. More detail on each function is provided in subsequent sections. For each specific location to be investigated, the module will perform the following sequence of steps:

1. Prepare collision diagram template
2. Plot collision diagram
3. Identify accident patterns
4. Diagnose safety problems
5. Identify and select appropriate countermeasures

Step 4 will be performed interactively with the user, who will provide information from office and field investigations. It is also expected that the module will have a “help” function that will provide background material related to the various analytical functions.

### 4.2 Input Options

The primary user-supplied inputs to the *SafetyAnalyst* diagnostic and countermeasure selection tools are:

- Specific location to be investigated
- Geometry
- Traffic control
- Other site characteristics as required for the collision diagram template
- Specific years of accident data needed, based on the timing of significant changes to the site that may have affected accident patterns
- User review of the lanes in which particular accidents are displayed on collision diagrams

- Responses to *SafetyAnalyst* questions posed as part of the office and field investigations
- Final selections of potential safety concerns based on the diagnostic investigation
- Selection of one or more countermeasures to address those concerns from lists provided by *SafetyAnalyst*

The diagnosis and countermeasure selection tools will make extensive use of an agency's accident, geometry, traffic control, and traffic volume data, so that some of the above inputs can be supplied automatically.

In addition, there are a number of default values that may be modified by knowledgeable users. These include:

- Items to display for each accident
- Criteria for threshold values for (1) observed accident frequency and (2) excess of the observed frequency of specific accident types over the expected frequency
- Expected proportions of specific accident types (e.g., wet-pavement accidents), potential for safety improvement (PSI) values for specific accident types, and/or accident severity for specific roadway segments or intersection legs

### 4.3 Prepare Collision Diagram Template

The first step in diagnosis of safety problems at a particular site is to generate a template on which accidents can be plotted. Two general methods for developing a collision diagram template are available:

- Automated retrieval of data from *SafetyAnalyst* geometry and traffic control files
- Plotting from user-supplied data

A combination of these approaches can be used; in other words, the user should be able to supply data to supplement or override the data obtained from the geometry and traffic control files. Some of this information will be used to create the template for the collision diagram.

For automated data retrieval, the user describes the coordinates of the site or corridor using the location reference system for the highway agency's roadway data. The system will then retrieve geometry and traffic control data from the available databases. For intersections, the variables on which the template will be based include:

- Number of intersection legs
- Number of through lanes on each leg

- Left- and right-turn lanes (or shared turn lanes) on each leg (if available)
- Presence/absence of raised/painted/depressed median on each approach

Other geometric features could be added to the collision diagram template, if available.

For roadway segments, the key variables for the template will include:

- Length of roadway segment
- Number of lanes
- Dedicated lanes (i.e., left or right turn lanes)
- Medians (painted, raised, or depressed)
- Key locations (e.g., intersections, jurisdictional boundaries on each roadway segment)

The collision diagram template will then be annotated with information on:

- Roadway or street names
- Traffic control devices
- Speed limits (to the extent they are available in *SafetyAnalyst* databases)
- Traffic volumes, including turning movements, peaking characteristics, pedestrian and cyclist volumes, and truck volumes and percentages

All annotations will be set up so that the user can view them selectively, or hide them (e.g., there might be separate layers for accidents and for other types of information). This can be facilitated by the tool or by the use of a particular GIS software package.

For information that is not available electronically, users will be able to manually input that information with the keyboard. This capability will also allow annotation of the collision diagram template with data that are not typically available electronically, such as orientation (north/south/east/west), geometry, driveways, land use, and operating speeds. The user may obtain such information from design plans or photologs. Aerial photographs would also be valuable in understanding the conditions at a given location. The manual data entry capability will also allow users to edit the data available from electronic files should those data prove to be inaccurate or inappropriate.

Based on feedback from others who have attempted to build a diagnostic tool, it is critical to “reward” the user quickly with information. Therefore it is proposed that the first output of the diagnosis preparation stage will be the template for the site being analyzed showing basic information, such as number of lanes and dedicated turn lanes as well as all annotations to be used (e.g., street names, traffic control devices, and speed limits.) The user can then review this template for accuracy before proceeding with the diagnosis. The *SafetyAnalyst* user should have the capability to print a copy of the site

template or to save it to a file, along with the data used to generate it. This capability should be available for all the outputs of the diagnosis.

## 4.4 Plot Collision Diagram

Once the collision diagram template is prepared, *SafetyAnalyst* will have the capability to pull the accident data for the site into the diagram. Accidents will be displayed graphically, with each vehicle involved shown so as to indicate its direction of travel and intended maneuver. It may be necessary to limit the graphical display to a maximum of two vehicles per accident. Naturally, the accuracy of the collision diagram will be dependent on the accuracy of the accident data. Problems with inaccurate or missing data are almost inherent when working with a large accident database.

The level of detail in reporting accidents varies among state highway agencies; some databases include variables that others do not. For example, the lane in which an accident took place is not always available. Where such information is not available, *SafetyAnalyst* will have to use a set of rules to plot the most likely position, based on the accident type (e.g., a left-turn accident at an intersection will likely involve a vehicle in the left-turn lane and a vehicle in the opposing through lane). Where there are two or more lanes in each direction, and where there is a database of scanned police reports available, the system should allow the user to access the schematic for each accident so as to confirm the “best guess” of the location that was made by *SafetyAnalyst*.

Each accident configuration will be annotated with the data available in the accident database. Due to space restrictions, not all such data can be displayed on the collision diagram. Default variables will be selected for display. These defaults might include accident time, date, road surface, weather, light conditions, driver ages, and severity. The user can elect to change these defaults or to view “hidden” information, also available from the accident database, such as unsafe action/contributing factors.

The *SafetyAnalyst* user will select the specific calendar years of data to be retrieved from a menu that shows the full period for which data are available. The user will be encouraged to consider as many years of data as practical, but the user may be required to limit the time period considered because of previous improvements. The accident data will come from the highway agency traffic accident files included in *SafetyAnalyst*. The accident data will not be passed to the diagnostic tool from the network screening tool, but will be retrieved using logic that is the same as (or similar to) that used to retrieve data for the network screening tool. The accident data for each calendar year will be contained in a separate data layer, so that data for all years retrieved, or any specific year or combination of years, can be displayed.

In retrieving accident data, *SafetyAnalyst* will produce tables of accident type breakdowns and display them to the user. These tables should, as a minimum, include breakdowns by severity, accident type, vehicle maneuver, and calendar year. These

tables could be supplemented with average values for these accident types and maneuvers for equivalent facilities in that state or highway jurisdiction.

## **4.5 Identify Accident Patterns**

Once the collision diagram and the tables of accident data have been prepared and displayed, the user will then identify accident patterns by carrying out the following steps:

- Assessment of factors which apply to all accidents at the site under investigation and are related to road condition, driver characteristics, time of day, season, etc., to determine which are most commonly occurring and which, if any, are over-represented
- Assessment of the crash types to determine which are most commonly occurring and which, if any, are over-represented
- Assessment of the vehicle maneuvers to determine which are most commonly occurring and which, if any, are over-represented

### **4.5.1 Accident Characteristics**

It is anticipated that all states will have information on the following characteristics from the accident report form:

- Time of day
- Day of the week
- Month
- Pavement condition (e.g., wet, slippery)
- Light conditions
- Weather (e.g., raining, fog)
- Driver age
- Driver contributing factors (e.g., excessive speed, improper turn)

Some states will have additional characteristics such as driver condition, presence of work zone, etc. In this portion of the diagnosis, all accidents at the site will be considered.

The statistical procedures for this review have not yet been developed, but will be based on comparison to expected proportions of specific accident types determined from individual state statistics appropriate to the class of roadway and site type (intersection/four lane corridor) being analyzed. Over-representation would be indicated

by having a greater proportion of accidents with a particular condition at the site in question (e.g., wet pavement) than at other similar sites in the state. The statistical procedures to determine over-representation will probably incorporate an EB approach. A list of over-represented accident types (irrespective of the vehicle maneuver involved) will be displayed to the user. The over-representations identified will assist both in the diagnosis and the selection of countermeasures. For example, an over-representation of accidents in darkness, compared to similar sites in the state without lighting, would suggest consideration of lighting or better delineation as countermeasures. Estimates of over-representation in comparison to other similar sites will be more useful for some global factors than for others (e.g., pavement condition vs. direction of travel of vehicles involved). Direction of travel should be checked for over-representation in comparison with traffic volumes at that site.

For some global characteristics, it would be more useful to know the most frequent conditions. In most cases, the majority of accidents will happen during periods of greatest exposure (i.e., rush hour, weekdays, dry weather) and data on most frequent conditions will confirm this. Knowing the most common circumstances is important in focusing the user's attention on those accident types.

The first output of the pattern identification stage will be:

- List of over-represented characteristics in accidents
- List of most frequent characteristics in accidents

## 4.5.2 Collision Types

The user will continue the diagnosis by focusing on predominant accident types, as defined in the creation of the collision diagram. First, the crash types (e.g. run-off-road, rear-end), in order of frequency, will be determined. Then, the proportion of various crash types will be compared to the proportion of crashes of that type at other similar sites.

The identification of over-representation using proportions has an advantage and a disadvantage. The advantage is that traffic information is not needed. The disadvantage is that the proportion can be misleading; for example, if a large proportion of night-time accidents is a result of fewer than expected day-time accidents rather than of a true night-time accident problem. Therefore, it is best to use traffic volumes if at all possible. If this is not possible (e.g., side road traffic at low-volume intersections), it may be necessary to use proportions.

In the analysis for over-representation, or excess of frequency over what is expected, AADT values provided in the generation of the collision diagram will be used to set default values, which can be changed by users with access to safety performance functions for their state and site type. Through the use of AADT values to set the criterion, it will be possible to identify crash types that are over-represented. For

example, more right-angle accidents than expected, given entering AADTs, may lead to diagnostic suggestions to make turning movement counts or check for conspicuity of the stop sign. The criterion based on the excess of observed frequency over expected frequency will also identify crash types involving only a few accidents, but only in cases where these would be unexpected given the AADT.

The second output of the pattern identification stage will be:

- List of over-represented collision types in accidents
- List of most frequent collision types in accidents

### **4.5.3 Vehicle Maneuvers**

The user will then continue the diagnosis by focusing on predominant accident types with respect to the vehicle maneuvers involved (i.e., through, right turn, left turn, passing, reversing), as defined in the creation of the collision diagram. First, the most frequent vehicle maneuvers involved in accidents will be determined. Then, the proportion of various maneuvers will be compared to the proportion of maneuvers of that type involved in accidents at other similar sites.

The third output of the pattern identification stage will be:

- List of over-represented maneuver types in accidents
- List of most frequent maneuver types in accidents

### **4.5.4 Criteria for Selecting Patterns for Further Investigation**

Formal criteria will be used to suggest to the user which accident patterns warrant further investigation. The network screening paper suggests several procedures for identifying hazardous locations and elements including:

- Rank sites by expected accident frequency
- Rank sites by weighted expected accident frequency
- Rank sites by excess accident frequency
- Rank sites by weighted excess accident frequency
- Rank sites by prospective cost-effectiveness
- Screen sites for over-representations of specific accident types

These methods can be applied to the next level of detail, the accident patterns to be diagnosed. For example, wet weather accidents or run-off-road accidents might be

selected for diagnosis on the basis of being very frequent, over-represented, or likely to have more prospect for cost-effective countermeasures.

With respect to the expected frequency criterion, although the accident patterns may be typical of such sites (e.g., rear-end accidents at a signalized intersection), and the site may be operating “normally” in terms of accident patterns, the occurrence of a sufficient number of accidents of a particular type means attention should be given to any potential countermeasures for that type of accident. Thus, accident frequency is an important criterion, even if there are not more accidents than expected.

With respect to the accident severity (weighted expected) criterion, fatal and serious injury accidents often add pressure to select a site for improvements. However, users should be cautioned against focusing on such accidents exclusively. The same driver error that results in a property-damage-only accident in one circumstance can result in a fatality in another. For example, the precise timing of a vehicle running through a stop sign relative to a vehicle on an intersecting path determines where on the vehicle, and on the occupants, the impact occurs and whether injuries and fatalities result. Severity should exert only its appropriate influence.

The *SafetyAnalyst* user will have the flexibility to initiate diagnosis for specific accident types, even if formal criterion for initiating diagnosis is not met. The user also should be given the option of ignoring certain accident types, for example, if these accident types have recently been addressed with new countermeasures.

When the site selected for diagnosis is a corridor extending several miles, it is very possible that significant accident patterns will be overlooked. For example, a single sharp curve in the section might generate a cluster of run-off-road accidents. However, when the entire corridor is considered, the number of run-off-road accidents could be within normal range for the corridor as a whole. To identify locations with over-representation of particular vehicle maneuver types or conditions, a moving average approach should be used (Kononov, 2002). The white paper for Network Screening has described the approach that the Colorado project (Hauer et al., 2002) is testing for the selection of a road section length and its impact on identification of problem locations. The same approach, if considered to be appropriate, will be very applicable for diagnosis as well.

No matter what criterion is used to select a pattern for diagnosis, frequency, or over-representation, it may be necessary to set a threshold. At an intersection with 50 accidents per year, one might set a threshold of five accidents of a particular type before initiating diagnosis. Where only one or two accidents of a given type have occurred, diagnosis may or may not be useful. It depends on the type of accident. On the one hand experience tells us that a safety deficiency may be revealed by a single serious accident, at a site with no previous history of such accidents. On the other hand, some accidents result from such an unusual combination of circumstances that they are unlikely to happen again.

The output from the accident pattern identification stage is a list of accident types (over-represented conditions or crash types or maneuver types or very frequently occurring conditions or maneuver types), and their specific locations (e.g., approach on an intersection, segment of a corridor) for diagnosis. The user will be able to edit this list, adding or removing particular accident patterns, before proceeding to diagnosis.

## 4.6 Diagnose Safety Problems

The purpose of the diagnosis is to perform a detailed investigation specific to the site and accident patterns of concern. The diagnosis procedures should be viewed as an aid to the *SafetyAnalyst* user in understanding the reasons why accidents occur at the location and selecting appropriate countermeasures to reduce those accidents, rather than as a software tool that produces “answers” without any consideration or knowledge on the part of the *SafetyAnalyst* user. The diagnostic approach assumes that the user is an experienced highway safety professional with an understanding of accident causation and prevention. To emphasize this point, the *SafetyAnalyst* user for diagnostic reviews is referred to in this section as the *SafetyAnalyst* investigator.

Two types of diagnostic activities will be undertaken: office and field investigations. These investigations will involve interaction between the *SafetyAnalyst* diagnostic expert system and the investigator. *SafetyAnalyst* will obtain accident and location data assembled in previous steps or from databases. Where data are not available, *SafetyAnalyst* will query the investigator for those data. For each location, *SafetyAnalyst* will provide a list of questions that asks the investigator to obtain data and provide a response. In some cases, the questions will be easily answered by anyone with knowledge of the site. In other cases, the questions will require an experienced investigator (e.g., “Is the superelevation adequate for the curve?”). For each set of questions, two methods of obtaining responses from the investigator may be used. These are:

- Interactively, with the investigator providing a response to each question as it arises
- Through a displayed or printed list of questions that the investigator can consider off-line and then enter responses to *SafetyAnalyst*

From an expert systems viewpoint, the interactive method is more efficient, because the system will ask only those questions for which a need is indicated by the responses to previous questions. However, particularly for field investigations, the interactive approach may not be practical, since it will be desirable to make a single trip to the field. An interactive field investigation will be possible if a laptop computer containing the *SafetyAnalyst* diagnostic module is available for field use. In any event, it is anticipated that the majority of the diagnosis will occur in the office, during which potential diagnoses will be made and potential countermeasures identified. This will leave a limited list of unanswered questions for the field investigation.

## 4.6.1 Office Investigation

For each over-represented or frequent characteristic and vehicle maneuver type, identified in the first steps of the diagnosis procedures, a series of diagnostic statements or questions, specific to the site and to the characteristic or vehicle maneuver will be presented to the investigator. The statements and questions will be framed in such a way that the investigator is provided a rationale for why the issue is being raised. Consideration should be given to allowing the investigator to click on an “expand” function, which will give a more detailed explanation, together with a brief summary of the research literature support, and other potential references to provide the investigator with additional information.

As an example, for rear-end accidents at an intersection, the system will automatically check for the following conditions exist at the intersection:

- Signalization
- Type of signal (e.g., fixed-time isolated, fixed-time coordinated, semi-actuated, fully actuated, fixed cycle time with traffic actuated splits)
- Short clearance interval (all red plus yellow)
- Cycle time
- Signal coordination
- Speeds over 40 mph—long distance detection
- Grade over X %—accidents on the approach with a downgrade
- Over-representation of wet-pavement accidents
- High turning volume but no dedicated lane

Some of these conditions can be identified from available data, but many databases will lack these data. The lack of availability of these data will initiate queries to the investigator for the missing information.

Each condition that is present will lead to a set of diagnostic questions and to diagnoses. For example, where inputs have indicated rear-end accidents at a downgrade approach to an intersection, a diagnostic question might be:

Is the grade near the stop line greater than X %?

If the answer to this question is affirmative, diagnosis from the office investigation might be that rear-end accidents are more likely when the grade works against the driver, making stopping distances longer than usual. This issue would automatically be flagged as a diagnosis for further investigation in the field. The investigator could be asked to rate such diagnoses as high, medium, low, or unknown importance with respect to the site visit and/or countermeasure selection.

An example of a diagnostic question for single-vehicle accidents on a horizontal curve is as follows:

When drivers reach a curve, which is much sharper than curves on the preceding road section, especially if they are unfamiliar, they can be surprised and find themselves approaching it at too high a speed. Is the curvature of the accident site unusually sharp in relation to the previous several miles of road section?

An investigator familiar with the road network may be able to answer this question on the basis of his or her own knowledge, or by using a photolog or accessing design drawings. If the answer to this question is no, then it will not be flagged as a diagnosis for further investigation. Otherwise, it will be flagged and will be included in items to investigate further during the site visit.

An investigator not familiar with the site, or unable to determine the answer through available documentation, may have to add this issue to the list of questions accumulated for the site visit, or may be reminded to search for vertical and horizontal alignment plans to check on the road geometry.

Since a site may have been previously investigated because of safety issues, the investigator should be asked about any countermeasures already in place, so that these are not suggested by the expert system. An example of such a diagnostic question is:

Rear-end accidents are more likely when drivers are caught in the “dilemma zone.” This is longer at high speeds. Has long distance detection, which delays the signal change until vehicles are out of the dilemma zone, been implemented, and recently verified to be operating correctly at this intersection?

The investigator will answer the questions to the best of his/her ability given the information available prior to visiting the site. The program will prompt the investigator to search for answers within the office. If the investigator is able (the issue of training and experience is very relevant here), the investigator can indicate which issues are of high, medium, or low importance and can have the list of diagnostic issues printed in order of importance. The list will include diagnoses as well as questions to be answered at the site visit. The list of questions will be customized to the office investigation outcome for the specific site.

For certain accident patterns, it may be desirable for the office investigation to include a review of hard-copy police accident reports for the specific accidents that constitute that pattern. It would be desirable to conduct such a review on-line, interactively with the automated collision diagram discussed earlier. However, not all jurisdictions will have hard-copy police accident reports available in electronic or scanned form for linking to the collision diagram. Therefore, in some states, such a

review would need to be conducted off-line as part of the office investigation. The *SafetyAnalyst* diagnostic tool will be capable of generating a list of accident report numbers to be reviewed (i.e., the accidents that constitute the accident pattern of interest) and a list of factors to look for in the review of those reports. The results of the review would be entered into *SafetyAnalyst* by the investigator for further consideration.

Appendix A presents diagnostic questions for over-represented maneuvers that might occur at signalized intersections. Each diagnostic question is framed to lead to a diagnosis and each diagnosis is framed to lead to a countermeasure. The diagnostic questions are intended to cover typical accident scenarios, rather than rare and unusual situations. In order to avoid presenting irrelevant questions, the investigator will first be asked a few questions that characterize the site, prior to diagnosis. If the site is a site identified by Module 1 (Network Screening), most of these characteristics will be known to the *SafetyAnalyst* system in the process of developing the collision diagram. Other answers will be found in state databases accessible to *SafetyAnalyst*. If the answers are not supplied automatically, the software will request the information from the investigator. For intersections, the following basic information will be used to streamline the diagnostic questions:

- Intersection layout
- Cross section of approaching roads
- Alignment of approaching roads
- Proximity to other intersections along each approach
- Traffic control device (fixed-timed, actuated, scoot, etc)
- RTR permitted or not
- Pedestrian counts (ballpark estimates only)
- Entering traffic volumes (ballpark estimates only)
- Adjacent land use type (urban commercial, urban residential, suburban commercial, suburban residential, industrial, rural–town, rural–country)
- Presence of illumination

For corridors, the basic information used to streamline the questions is:

- Number of through lanes in each direction
- AADT
- Adjacent land use
- Lane widths
- Presence of dedicated lanes
- Purpose of dedicated lanes (turning, passing, HOV)
- Length of dedicated lanes

- Alignment (horizontal curve radius and design speed, vertical curve lengths, grades, stopping sight distance, intersection sight distance)
- Shoulder width
- Shoulder treatment
- Curb type
- Access points per mile
- Intersection spacing
- Presence of illumination

Once the data is assembled, it will be displayed to the investigator for confirmation. The software will then initiate the diagnosis, eliminating questions unlikely to be relevant, or modifying the order so that questions less likely to be relevant are presented last.

For example, diagnostic questions for a pattern of rear-end accidents at a signalized intersection include:

- Are there bus stops?
- Are bays provided?
- Are pedestrians violating traffic signals to catch buses?

These would be high priority questions for an intersection identified as being in a central business district with high pedestrian counts. They would be low priority questions for a suburban residential intersection with moderate pedestrian counts. They would not be asked for a rural signalized intersection with low pedestrian counts. For each diagnostic question, the conditions under which it is high, medium, and low priority must be established.

Each series of questions will culminate in a diagnosis. There may be more than one diagnosis for a given accident pattern. We anticipate that many investigators will discontinue the diagnosis process once they feel they have identified a satisfactory explanation for the accident pattern. For example, the user investigating rear-end accidents at an isolated rural intersection may be inclined to stop once the possibility of long distance detection is considered, and not continue on to discover that there is a lane drop at the intersection which is contributing to these accidents. A short-form preview of the upcoming questions would help to avoid investigators stopping prematurely.

Where practical, a field investigation will follow the office investigation. However, this may not always occur. The site may be isolated or it may simply be too expensive to visit all the sites being diagnosed. In order to allow for the need to develop countermeasures without the benefit of a site visit, and in order to maximize the value of the field investigation, the *SafetyAnalyst* investigator should already have in mind potential countermeasures at the end of the office investigation. Consequently, once a

diagnosis is proposed, on the basis of answers to the diagnostic questions, potential countermeasures linked to that diagnosis will also be proposed. Appendix B presents four potential diagnoses for rear-end accidents at signalized intersections and, in each case, proposed countermeasures.

The output of the office investigation diagnosis stage will be in the form of an interim report comprising all assembled information, such as:

- Collision diagram with all characteristics (traffic devices, geometrics, etc.) to be taken to the site if that investigation will take place
- List of accident patterns to be diagnosed, annotated with the season and time of the week and of the day, if any, that the accidents are most prevalent
- List of questions about the site that could not be answered in the office
- List of initial diagnoses
- List of potential countermeasures to be considered in the field

#### **4.6.2 Field Investigation**

Based on the results of the office investigation, *SafetyAnalyst* will produce a set of instructions for a field investigation at the location of interest. This will include:

- Outline of how to conduct the site investigation as a function of the type of site (e.g., roadway segment, intersection, ramp)
- List of issues particular to that site, its accident patterns, and over-represented conditions (e.g., wet-pavement or older driver accidents)
- List of questions concerning the site characteristics
- List of questions concerning the driver (or other road user) tasks
- List of questions concerning operational issues
- Suggested techniques for carrying out diagnostic studies at the site

*SafetyAnalyst* will include a text box in which the user can insert any text that they wish to have appear on all printed output. For example, this could include a reminder concerning safety procedures to be followed in field studies.

The outline of the site investigation will draw the investigator's attention to the predominant accident types and the need to investigate the site by carrying out the same vehicle maneuvers (as long as they are legal) that are implicated in the accidents. The investigator will be encouraged to consider road user information needs, visual search, workload, and expectancy issues related to the particular task. The tasks considered will include:

- Through movement

- Right turns
- Left turns
- Curve negotiation
- Overtaking
- Merging
- Lane changing

Each of these tasks will be considered at signalized and unsignalized intersections, and on corridors.

The effectiveness of the site investigation will be greatly improved if a laptop computer containing *SafetyAnalyst* tools is available for interactive application while on site. The on-site question list generated during the office investigation will suggest what times of the day/week/year are most prevalent so that the site can be visited at those times (e.g., during winter or during night-time hours).

In some cases, the reasons that a particular accident pattern occurs at a site may not be evident to the investigator, even after a full review using *SafetyAnalyst*. In these situations, an office and site investigation by a multi-disciplinary team may be appropriate. It will be the investigator's responsibility to ascertain the need for assembling a multi-disciplinary team of professionals.

**Site Characteristics:** The *SafetyAnalyst* investigator will be asked to check critical site characteristics, which are not known in any of the databases accessible by the system or by the investigator prior to the site visit. For example, for accidents involving negotiating an off ramp with a low design speed, the following questions may be asked:

- Is the curve superelevated?
- Are shoulders provided?
- What is the grade of the ramp?
- What is the length of the ramp and what type of traffic control device is installed?
- How is the pavement surface friction?
- Are speed measurements available or are they obtainable during the visit?

**Driver Task Characteristics:** The investigator will be asked about the driver's task. For the off ramp described above, questions might include:

- Is the curvature of the off ramp such that it would surprise an unfamiliar driver?
- Is the curvature of the off ramp visible at a distance that would allow a driver to decelerate comfortably?

- Does the curve become sharper?
- Is the signing for the exit legible and placed far enough in advance of the exit for the unfamiliar driver to read it, change lanes smoothly and decelerate adequately?

**Operational Issues:** The investigator will also be asked about operational issues that may affect safety at the site. For example, for the off ramp described above, the following questions may be asked:

- Is the superelevation adequate for prevailing speeds?
- Do queues form on a regular basis?
- Are the queues affecting the approach visibility or weaving?

**On-Site Diagnostic Studies:** Standard methods for carrying out specific studies will be developed and documented. For example, if the accident pattern suggests too many right-angle accidents at a signalized intersection and that red-light running is suspected, the site investigation may focus on the amount of red-light running and approach speed. There should perhaps be a standard procedure for everyone to follow in describing a potential red-light running problem and the measurement of approach speed distribution. Similarly, there should be a standard procedure for sight distance determination, pavement friction measurement, etc. An assembly of such standard procedures should be part of the tool. This does not mean that each site investigation must entail an expensive study. It only means that if a study is required, it follows a standard procedure. A source document for such studies would be the Manual of Traffic Engineering Studies (1994), or equivalent agency-specific engineering study guidelines. Other sources for standard techniques may also exist.

### 4.6.3 Output of Office and Field Investigations

The output of the office and field investigations will be a report including a list of diagnoses. This list is determined from data obtained from databases, gathered by the investigator, and from expert judgments made by the investigator. The diagnostic tool is intended as an aid and a guide to diagnosis and not as a substitute for expert assessments. The diagnostic list will be used to generate potential countermeasures for the site.

In the documentation of the office and field investigations, either using a laptop at the site or later in the office, investigators will indicate potential safety concerns based on the diagnoses, in order of priority. It is expected that most of the diagnostic work will take place in the office, and that, in only some cases, field visits will be made. Therefore, potential countermeasures will be considered during the office investigation. A site investigation is always preferable, but may not be possible because of schedule or financial constraints. Investigators will be able to move directly from diagnosis and countermeasure identification in Module 2 to economic appraisal and priority ranking of those countermeasures in Module 3.

## 4.7 Select Countermeasures

Appendix C shows a list of countermeasures that will be included in the *SafetyAnalyst* software. This is not an exhaustive list—additions are expected based on review and alpha and beta testing of the software. In addition, it should be recognized that countermeasures change over time as new traffic control devices are developed and as new approaches to safety evolve. For example, traffic calming and roundabouts are two countermeasures that might not have been considered only five years ago. It is anticipated that *SafetyAnalyst* will be updated regularly and that recommended countermeasures will be added (or removed) as research demonstrates their effectiveness. *SafetyAnalyst* users will have the capability to customize the countermeasure list.

Countermeasures for implementation will be selected by the *SafetyAnalyst* investigator, not by the *SafetyAnalyst* software itself. Countermeasure selection involves multiple technical and budgetary considerations that are not appropriate for automated decision making; selection of countermeasures is a critically important activity that requires real experience and training. However, the *SafetyAnalyst* countermeasure selection tool can assist investigators in identifying candidate improvements that address the diagnoses. This tool will also assist in reviewing those potential countermeasures to identify the most appropriate countermeasure, or set of countermeasures, for a particular site.

Once the diagnoses pertinent to each accident pattern have been identified in the office and field investigations, potential countermeasures pertinent to each diagnosis will be suggested by *SafetyAnalyst* to the investigator. If there is a field visit and the investigators have access to the system while in the field, they can consider both the diagnosis and potential solution as part of the field review. Thus, the potential use of *SafetyAnalyst* tools in a laptop at the site provides a greater ability to consider the practicality of specific countermeasures.

*SafetyAnalyst* will perform a preliminary benefit-cost appraisal using the procedures described in Module 3 and will inform the user of the maximum countermeasure cost level above which no countermeasure would be cost effective even if it reduced *all* accidents or enough accidents to decrease a high observed accident frequency to the expected value.

The *SafetyAnalyst* investigator will be informed of which of the countermeasures under consideration have known and reliable effectiveness measures, such as accident modification factors (AMFs). Where there are known AMFs, a brief summary of the circumstances in which they were obtained will be provided. This will allow the investigator to assess how relevant the AMF is to the site in question. *SafetyAnalyst* investigators will need to be aware that many potential countermeasures will not have quantitative AMFs, but *SafetyAnalyst* will guide investigators toward those potential countermeasures whose safety effectiveness is more certain.

For each concern identified through the diagnostic process, a list of potential countermeasures will be selected. If more than one concern has been identified at the site, more than one countermeasure list will be generated. Countermeasures that appear on more than one list should receive heightened attention. The investigator will be asked to flag those countermeasures that are practical, given physical constraints at the site (e.g., right-of-way needs or interference with existing development) and the financial constraints for improving the site (e.g., major reconstruction may not be feasible). Background information on each countermeasure will be available as part of *SafetyAnalyst* to assist in this winnowing process.

Next, based on the countermeasures selected by the investigator for further consideration, contraindications, if applicable, will be presented to the investigator (e.g., no rumble strips in residential areas). The investigator will be asked to perform a further winnowing of countermeasures based on these contra-indications.

A final list of potential countermeasures will then be presented to the investigator. At this point, the investigator will have several options:

- Select a specific countermeasure (or combination of countermeasures) for implementation
- Tentatively select a specific countermeasure (or combination of countermeasures) for implementation, subject to the results of an economic analysis with the *SafetyAnalyst* economic appraisal and priority ranking tool

## 4.8 Output Options

The expected outputs of the *SafetyAnalyst* diagnostic and countermeasure selection tools are as follows:

- Collision diagram template of the site under investigation annotated with design, operational and environmental information
- Collision diagram of the site annotated with accident characteristics
- List of most frequent characteristics (e.g., wet pavement, young drivers)
- List of over-represented characteristics which may contribute to a particular accident pattern at a particular site
- List of most frequent crash types (e.g., run-off-road)
- List of over-represented crash types
- List of most frequent accident maneuvers (e.g., left turns)
- List of over-represented accident maneuvers
- List of diagnostic questions/statements for the office investigation

- List of accident report numbers for which hard-copy police accident reports should be reviewed
- List of potential diagnoses and potential countermeasures
- List of diagnostic issues for the field investigation
- List of potential safety concerns in order of priority identified by the investigator from the diagnoses
- List of potential countermeasures that address the identified concerns and have been selected by the investigator for implementation (or for further consideration with subsequent tools)
- Report in bullet point form containing the following sections for each site investigated:
  - site description
    - frequency of accident characteristics, types, and maneuvers including their degree of over-representation
    - potential safety concerns based on the office and field investigations
    - selected countermeasures

The report is intended to document the investigation for the highway agency records. It may be released, if desired, to document the investigation to other interested parties.



## Section 5

# Planned Development Activities

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This section itemizes planned development activities, with a view to planning the next steps and scheduling the work to be done over the course of the project.

### 5.1 Technical Development

The following activities are anticipated for development of the *SafetyAnalyst* diagnosis and countermeasure selection tools:

- Develop a list of site types (also required for network screening)
- Interact/liase with network screening tool development to provide guidance on desired output of the screening process with respect to site geometry, cross-section elements, traffic movements, accident profiles, etc.
- Using HSIS data, and other available state data, determine how collision diagram templates can be generated from typical state highway geometry databases
- Using the police accident report form, develop a list of accident characteristics (e.g., wet roads, night time, young drivers, speeding too fast for conditions)
- Develop a list of accident types (e.g., angle, run off road, head-on)
- Develop a list of accident types with respect to vehicle maneuver (e.g., right turn, through, left turn, overtaking)
- Develop values for expected proportions for specific accident types
- Develop statistical procedures to determine whether particular accident types are over-represented at particular sites
- Develop a set of rules to transform accident characteristics available in computerized data (direction of travel, vehicle maneuver, accident type, contributing factors) into accident configurations plotted in the correct lanes on a collision diagram
- Develop a list of diagnostic questions related to site types and accident patterns for office and field investigations
- For each diagnostic question, develop a rationale for why that issue should be considered in relation to a specific site type and accident pattern
- For each diagnostic question, develop the site characteristics for which that question is high, medium, or low priority or not relevant
- Develop a list of diagnoses appropriate for particular site types and accident patterns based on the answers to the diagnostic questions

- Develop procedures for carrying out field visits, and in particular the driver tasks to be considered and the information processing requirements and driver expectancies for each task
- Develop standard methods for carrying out specific field operational studies, (e.g., documenting a red light running problem, measuring an approach speed distribution, measuring sight distance)
- Develop a description of each countermeasure that can be accessed by the *SafetyAnalyst* user
- Develop countermeasures appropriate to each diagnosis
- Determine the target accidents for each countermeasure
- For each countermeasure, provide AMFs where available, as well as information on the circumstances in which the AMF's were calculated
- Develop a list of contraindications for each countermeasure
- Spend four days with safety specialists from four states, one day with each, to obtain information on the process currently followed for high profile hazardous sites (identified either through current network screening processes or through media attention), for reconstruction where safety is to be addressed and for minor safety investigations. In each case, it would be helpful to know how much time the analyst currently spends, what information is generally obtained in the course of the analysis, and how much of what he or she currently does could be automated to result in time savings. These observations would also help identify where the value added aspects of *SafetyAnalyst* would be of most interest to analysts.
- Test the planned diagnostic procedures by using at least three examples of each site-type/accident-pattern combination of interest to ensure that all key office and field diagnostic questions have been identified and that all reasonable concerns and countermeasures have been suggested
- Develop a help function for the diagnostic module

Diagnostic procedures in *SafetyAnalyst* will address, at a minimum, the following facility types:

- Signalized intersections
- Unsignalized intersections (primarily intersections with two-way stop control)
- Rural two-lane highway roadway segments
- Rural multilane highway roadway segments
- Rural freeway roadway segments
- Urban/suburban arterial roadway segments
- Urban freeway roadway segments

Consideration will also be given to possible inclusion of other facility types such as interchange ramps, rural local road segments, urban/suburban collector street segments, and urban/suburban local street segments, but this will depend on time and resources.

Approximately half of serious accidents occur at intersections. Therefore, we recommend beginning with development and testing of diagnostic procedures with signalized intersections using the approach shown in Appendices A and B of this white paper. A decision will need to be reached as to how many of the facility types identified above should be incorporated in the interim tool to be developed for release in 2004. One possible approach would be to include only signalized intersections so that we get some user experience with the module before completing its development. However, there may not be sufficient time between 2004 and 2006 to complete development of diagnostic procedures for all of the other facility types of interest. Therefore, it may be that the interim tool should include diagnostic procedures for several facility types including at least one intersection type and one roadway segment type. The scope of the interim and final diagnostic tools is under active consideration and will be discussed with the Technical Working Group (TWG) at their upcoming meeting.

## 5.2 General Issues to be Resolved

There are a number of general issues in the development of the *SafetyAnalyst* diagnosis and countermeasure selection module that still need to be resolved. Some of these have been mentioned previously but are repeated here for completeness.

- What is the base level of information required to use *SafetyAnalyst*?
- Who is the target user for the interim diagnosis and countermeasure selection module? For the final module? In particular, assuming that state agencies are the primary users, to what extent should the diagnosis and countermeasure selection module be applicable to local agencies?
- Should “expert users” be treated differently from less expert users?
- Do the planned diagnosis and countermeasure selection capabilities meet the expectations of potential users?
- Should the system have the ability to look at partial years of accident data (e.g., after an improvement has taken place)?
- Should a ballpark cost be provided for each potential countermeasure suggested during the office investigation to allow the user to eliminate those that are impractical due to cost?



## Section 6

### References

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Hauer, E., J. Kononov, B. Allery and M. Griffith. "Screening the Road Network for Sites with Promise," Transportation Research Record, in press (presented at the TRB annual meeting, January 2002).

Kononov, J. "Use of Direct Diagnostics and Pattern Recognition Methodologies in Identifying Locations With Potential for Accident Reductions," Transportation Research Record, in press (presented at the TRB annual meeting, January 2002).

*Manual of Traffic Engineering Studies*, Institute of Transportation Engineers (ITE), 1994.



## **Appendix A**

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# **Diagnostic Questions for Maneuvers at a Signalized Intersection**

# Rear-End Accidents

## Contributing Factors

Rear end accidents occur due to speed differences between vehicles and/or conflicting decisions when signals turn to amber (caution) and due to drivers being surprised that the vehicle ahead slows and stops

## Diagnostic Issues

1. Is the signal isolated? If yes, is operating speed over 40 mph? If operating speed is unknown, is there a high-speed road nearby? If operating speed is high, is there long distance detection?
2. Considering both approaches, is the intersection one of a sequence of signalized intersections? If yes, are the signals uncoordinated with each other so that traffic stops and starts frequently?
3. Is the signal activated and changing too frequently?
4. Are there access points near the intersection? If yes, are the road name signs inconspicuous or placed too close to the intersection for the unfamiliar driver to see them in time to safely maneuver to the access point?
5. Are there bus stops? Are bays provided? Are pedestrians violating traffic signals to catch buses?
6. Is there a dedicated right-turn lane? Left-turn lane?
  - a) If there is a dedicated right-turn lane, is there right-turn channelization followed by a short or no accelerating/merging lane?
  - b) If there are dedicated lanes, is the storage length of the dedicated lanes sufficient for traffic demand or are there queues of turning vehicles spilling over into through lanes resulting in through drivers being surprised by stopped vehicles ahead?
  - c) If there are dedicated lanes, is there adequate sign and lane delineation placed far enough in advance to warn unfamiliar drivers of the dedicated lane?
7. Is a through lane terminated suddenly at the intersection?
8. Are there any view blockages for vehicles turning right on red which might cause them to stop suddenly?

9. Is the street name sign not readable until 5 seconds or less (at the operating speed) from the stop bar?
10. Is delineation of lanes and stop bars well maintained?
11. Is there a speed limit change near the intersection, leading to wide speed variance?
12. Is pavement coefficient of friction poor, leading to longer than expected stopping distances?
13. Is the intersection adjacent to a bridge (icing during winter months)?
14. Are any of the approaches to the intersection on a downgrade, which leads to longer than normal stopping distances?
15. Is there a horizontal curve at one or more approaches to the intersection limiting the sight distance to the intersection? If yes, is sight distance to signal less than 15 seconds?
16. Were there road closures due to maintenance, weather or other accidents at the time of the accidents?
17. Are there pavement deteriorations, or hazards of another form, resulting in sudden stops or slowdowns?
18. Is there jaywalking within 300 ft of the intersection?

## **Left-Turn Accidents**

### **Contributing Factors**

Left-turn accidents occur due to drivers not seeing or misjudging the speed of oncoming vehicles or conflicting with right turn on red vehicles or crossing pedestrians or bicyclists as they complete their turn.

### **Diagnostic Issues**

1. Is operating speed over 40 mph?
2. Is approaching traffic on a downgrade?
3. Is approaching traffic from a higher speed road?
4. Is the signal visible to the left turning driver throughout the maneuver?

5. Is the signal permissive or protected/permissive? If yes, are there more than two lanes in each direction, not including the left-turn lane? If yes, in peak periods are vehicles only able to turn at the end of the caution phase?
6. Is the clearance interval adequate, given truck volume, size, and intersection width? i.e., Is the clearance interval appropriate for typical truck lengths, for the number of lanes to be crossed when turning left, and the type of exclusive phases—turning and pedestrian phases?
7. Is visibility of approaching traffic poor (less than 10 seconds at operating speed), due to left-turn bay offset or due to view obstructions or due to road curvature?
8. Are there access points very close to the intersection where exiting traffic could use the same through traffic gap as the left turning vehicles?
9. Are pedestrians continuously blocking the left turning movement, leaving left turning vehicles stuck in front of through opposite-direction traffic?
10. Is there poor lane delineation resulting in left turn drivers having difficulty in positioning their vehicles after turning, increasing their clearance time? Is there confusing lane delineation due to work zones created near (downstream) the intersection blocking one or more lanes?
11. Do left turn vehicles conflict with vehicles turning right on red?
12. Is there a bus stop at the intersection creating pedestrian movements that may surprise the left turning driver?

## **Right-Turn Accidents**

### **Contributing Factors**

Right-turn accidents occur due to drivers accepting a gap in front of a vehicle they did not notice or for which they misjudged the speed. When made on a red light, they also occur due to conflicts with pedestrians crossing.

### **Diagnostic Issues**

1. Is through volume such that opportunity for right turn on red is very limited and unsafe?
2. Is this a skewed intersection with the acute angle to the left making search to the left difficult?

3. Is this intersection on a horizontal curve, making search to left difficult?
4. Is there a U-turn movement at the intersection that could conflict with right turn on red?
5. Is the major road right lane equipped with a channelizing island? If yes, could the minor road motorist be misled and pull out inappropriately because of assuming that a major road vehicle is turning right, when it fact it is going through?

## **Right-Angle Accidents**

### **Contributing Factors**

Right angle accidents occur due to drivers running through red lights.

### **Diagnostic Issues**

1. Is this the first signal after many miles without a signal?
2. Is the signal change interval long leading to drivers trying to avoid stopping for a red light?
3. Is the clearance interval adequate for the operating speed?
4. Is the clearance interval adequate given truck volume/size and intersection width?
5. Is the operating speed over 40 mph? If yes, is there long distance detection? High truck volume? Nearby higher speed road?
6. Are there winter related surface issues such as icing leading to drivers being unable to stop in time?
7. Is there a downgrade into the intersection?
8. Is the surface coefficient of friction as required for expected stopping distances?
9. Are there any visibility problems related to the traffic signals?
10. Is there any malfunction of signals?

## Side-Swipe Accidents

### Contributing Factors

Occur due to drivers changing lanes suddenly or due to drivers trying to avoid rear-ending a driver who has slowed or stopped.

### Diagnostic Issues

Same as for rear-end accidents.

1. Is there a dedicated left- or right-turn lane? If so, is there adequate sign and lane delineation warning unfamiliar drivers of the dedicated lane, especially in peak periods?
2. Do left turn vehicles conflict with the vehicles turning right on red?
3. Is there parallel parking near the intersection resulting in side swipes when drivers pull into traffic without looking?
4. Are there large trucks with turning radii greater than provided at the intersections, thus encroaching onto adjacent lanes?

## Loss of Control Accidents

### Contributing Factors

- Speed too high for turning movement
- Attempt to avoid other vehicle or road user (see most relevant other accident type)
- Attempt to avoid animal (see section on animal accidents)
- Late realization of desired road path

### Diagnostic Issues

1. Do many accidents involve avoidance of animals?
2. Can crossing road name be identified at least 5 seconds from the intersection at operating speeds? Is the intersection pavement surface visible from 10 seconds away at operating speed?
3. Is this a Y intersection where a reconstructed road curves but the former road was a tangent?

4. Is there dirt or gravel on the pavement? Is there a pavement edge drop greater than 2 inches? Are there side slopes greater than 2:1?
5. Is the intersection positioned after a vertical/horizontal alignment that forces drivers to drop their speeds unexpectedly?

## **Pedestrian Accidents**

### **Contributing Factors**

- Lack of visual search by pedestrian (believes in right of way, inattentive, impaired)
- Noncompliance with signal
- Noncompliance with marked crosswalk
- Lack of visual search by motorist (overloaded, inattentive, impaired, view blockage)
- Pedestrian emerges at unexpected time or place
- Poor visibility

### **Diagnostic Issues**

1. Is the intersection width greater than 50 ft?
2. Are pedestrian signal heads present?
3. Does the signal allow pedestrians to cross the intersection at a speed of 3.3 ft/sec? If no, is there a refuge median?
4. Are there view blockages for turning drivers?
5. Are most of the accidents occurring at night? If yes, is there streetlighting? Is it well maintained?
6. Does a transit vehicle stop near or at the intersection? If yes, does it stop on the far side? On the near side?
7. Are pedestrian crossings conspicuous and not hidden by stopped buses (at near side)?
8. Do many of the accidents involve children?
9. Do many of the accidents involve older people?

10. Are pedestrians jaywalking within 300 ft of the intersection?

## **Bicycle Accidents**

### **Contributing Factors**

- Lack of reflective devices
- Lack of visual search by bicyclist
- Failure to dismount while crossing
- Noncompliance with signal
- Noncompliance with marked crosswalk
- Lack of visual search by motorist (overloaded, inattentive, impaired, view blockage)
- Bicyclist emerges at unexpected time or place
- Poor visibility

### **Diagnostic Issues**

1. Is there a nearby bike route?
2. Are there view blockages for turning drivers?
3. Are most of the accidents occurring at night?
4. Is the left turn movement for motor vehicles complicated by an unusual intersection layout or median?

## **Appendix B**

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# **Example of Diagnosis and Countermeasures: Signalized Intersections**

## Rear-End Accidents

### Diagnostic Question

Is the signal isolated? If yes, is operating speed over 40 mph? Is there long distance detection?

Two yes answers (isolated intersection and speed over 40 mph) followed by a no answer (no long distance detection) leads to:

#### *Diagnosis*

The higher the speed at which an intersection is approached, the longer is the dilemma zone. Longer dilemma zones are more likely to result in conflicts between lead drivers who decide to stop and following drivers who have decided to go through on the appearance of the caution. The use of long distance detection, whereby induction loops in the road are used to delay the signal change until there is a gap in traffic, will greatly reduce this type of accident.

***Countermeasure for consideration:*** long distance detection

Three yes answers (isolated intersection, speeds over 40 mph, long distance detection) leads to:

#### *Diagnosis*

The programming of the long distance detection device may no longer be appropriate.

***Countermeasure for consideration:*** Review programming of long distance detection device.

***Countermeasure contra-indications:*** If AADTs are greater than x at most times of the day, the signal will “max-out” and be unable to provide a gap for approaching traffic.

A no answer to either of the first two questions will end the diagnosis for this set of questions.

### Diagnostic Question

Considering both approaches, is the intersection one of a sequence of signalized intersections? If yes, are the signals uncoordinated with each other so that traffic stops and starts frequently?

Yes answers to both these questions lead to:

### ***Diagnosis***

Accidents mainly happen when the signal changes and traffic must stop and start. The greater the coordination between consecutive signals, the more smoothly traffic flows, the less stopping and starting there is, and the fewer intersection accidents will occur.

***Countermeasure for consideration:*** signal coordination

***Countermeasure contra-indications:*** If signals are greater than x miles apart, signal coordination will be ineffective.

### **Diagnostic Question**

Is the minor road signal activated and changing too frequently?

### ***Diagnosis***

Accidents mainly happen when the signal changes and traffic must stop and start. The frequent changes resulting in short green phases that will not permit the dissipation of the queues at the approaches to the intersection at the end of one or more cycles, will result in short advances, numerous stops along the same leg of the intersection, creating frustrations, and greater risk taking by drivers.

***Countermeasure for consideration:*** modification of signal timings to provide priority and phase min/max times in accordance to the current demand, minimizing stops and coordinating with main road signalization.

## Appendix C

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# Preliminary List of Countermeasures to be Addressed by *SafetyAnalyst*

## Site-Specific Countermeasures

- Intersection: Unsignalized or Signalized
  - Improve sight distance
  - Improve delineation of stop bar and center and lane lines
  - Provide lateral rumble strips
  - Improve road name signing
  - Provide turn lane
  - Provide longer turn lane
  - Channelize turn lane
  - Install lane assignment signs to provide guidance through intersection
  - Widen shoulder
  - Close access points
  - Add signals
  - Provide flashing beacons on advance warning signs
  - Improve delineation
  - Remove/restrict movements at access points
  - Improve lighting
  - Install in-pavement crosswalk lighting
  - Install a roundabout
  - Install median acceleration lanes
  - Reduce speed limit on approaches
  - Increase enforcement
  - Restrict parking near corners
  
- Intersection: Signalized Only
  - Improve visibility of signal heads
  - Provide back-up plates for signals
  - Improve sight distance to traffic signal
  - Provide strobe lights on traffic signals
  - Provide a protected left-turn phase
  - Provide actuated signals
  - Install dilemma detection system
  - Prohibit right turn on red
  - Modify signal timing
  - Provide signal coordination
  - Implement long distance detection
  - Provide “Signal Ahead” warning sign
  - Add pedestrian signals
  - Install pedestrian-actuated signals
  - Add countdown to pedestrian signals
  - Install cameras to detect red-light running
  - Upgrade the signal controller to allow different phasing or actuation
  
- Corridor
  - Improve roadway delineation

- Add guardrail
  - Flatten side slopes
  - Realign roadway
  - Remove roadside hazards
  - Close access points
  - Improve access points
  - Add lanes
  - Widen lanes
  - Widen shoulder
  - Pave shoulder
  - Widen clear zone
  - Provide two-way left-turn lane
  - Provide passing lanes
  - Add pedestrian crossing
  - Add pedestrian refuge island
  - Add shoulder edge rumble strips
  - Add centerline raised pavement markers
  - Add centerline rumble strips
  - Add edgeline raised pavement markers
  - Improve lighting
  - Remove/restrict movements at access points
  - Provide bicycle lanes
  - Implement school speed zone
  - Improve pavement friction
  - Restrict parking near driveways
  - Install proper advance warning signs
- Railroad-Highway Grade Crossings
    - Improve sight distance
    - Provide gates
    - Provide flashing lights
    - Modify speed limit
    - Improve lighting
    - Provide grade separation
    - Provide flashing beacons on advance warning signs
    - Install train-actuated signals
    - Improve crossing surface

## Condition-Specific Countermeasures

- Wet/Slippery Pavement
  - Provide anti-skid pavement treatment
  - Modify grade/superelevation
- Darkness
  - Provide or improve lighting
  - Improve roadway delineation
  - Provide chevron markers on curves
- Older Drivers
  - Provide protected left-turn phase
  - Provide intersection channelization
  - Improve delineation
  - Install lane assignment signs to provide guidance through intersections
  - Modify access points
- Younger Drivers
  - Modify access points