Diagnosis of Safety Problems Using Safety Analyst for Efficient and Effective Safety Management

Sheetal Thukral, M.Eng., P.Eng.
Transportation Engineer
CIMA+
3027 Harvester Road, Suite 400
Burlington, ON L7N 3G7
sheetal.thukral@cima.ca

Pedram Izadpanah, Ph.D., P.Eng.
Senior Project Manager, Transportation Engineering
CIMA+
3027 Harvester Road, Suite 400
Burlington, ON L7N 3G7
pedram.izadpanah@cima.ca

Michael Pardo, P.Eng.
Traffic Safety Management Section, Traffic Office
Ministry of Transportation Ontario
2nd Floor South, 301 St. Paul Street
St. Catharines, ON L2R 7R4
Michael.pardo@ontario.ca

Boyka Pachova, M.A.Sc., H.H.Humphrey Fellow
U.S. Department of State Alumna
Senior Project Manager
TIRSS, Central Region Traffic Office
Ministry of Transportation Ontario
1201 Wilson Ave., Bldg. "D", 6th Fl.
Toronto, ON M3M 1J8
Boyka.Pachova@ontario.ca

Susan Nichol, M.A.Sc., P.Eng.
Head, Traffic Safety Management Section, Traffic Office
Ministry of Transportation Ontario
2nd Floor South, 301 St. Paul Street
St. Catharines, ON L2R 7R4
Susan.Nichol@ontario.ca

Alireza Hadayeghi, Ph.D., P.Eng.
Director, Transportation Engineering
CIMA+
3027 Harvester Road, Suite 400
Burlington, ON L7N 3G7
Alireza.hadayeghi@cima.ca

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Abstract

The Safety Analyst software was released by the American Association of State Highway and Transportation Officials (AASHTO) in 2009. The software enables road agencies to automate their safety management programs. The Ministry of Transportation of Ontario (MTO) is undertaking a project to implement Safety Analyst. In this project, all four modules of Safety Analyst are being configured for the Province of Ontario. Diagnosis and Countermeasure Selection Module enables the Ministry to conduct in-service road safety reviews (ISRSR) more efficiently by providing tools to identify collision patterns at a site and guiding traffic analysts during site visits. Identification of collision patterns is an important step to diagnose potential safety problems at a site. The definition of collision pattern is often a challenging concept because it is a function of a number of factors such as the site type, the traffic exposure, and the overall collision experience in the jurisdiction. For collision pattern identification, Safety Analyst provides capabilities to develop collision diagrams, generate collision summaries, and conduct statistical tests (test of proportion and test of frequency). This paper discusses and recommends a methodical approach to objectively identify collision patterns utilizing the Safety Analyst capabilities. Additionally, Safety Analyst is equipped with an "expert" system which guides the analyst towards appropriate office and field investigations. The expert system includes diagnostic scenarios for intersections and road segments. This paper provides a process through which additional diagnostic scenarios were developed for freeway and ramp sections for the Province of Ontario. The process includes identification of major collision patterns based on analysis of historical collisions (for all sites in the Province), engineering parameters as well as human factors principles.

1 Introduction

During the past two decades, road authorities have started to recognize the challenges, associated with a reactive approach to road safety [1]. The Highway Safety Manual (HSM) [2] presents a systematic approach for a road safety management process, as shown in Figure 1. This road safety management process starts with "network screening" in which the main goal is to identify road locations that are likely to benefit the most from safety improvements.

The next step in the road safety management process is the "diagnosis". This step identifies the safety concerns of the locations, identified in the network screening process, by examining the contributing factors of the collisions that have occurred at these locations.

The "countermeasure" and the "economic appraisal" sections constitute the next steps in the road safety management process. They involve the selection of treatments, which are potentially capable of addressing the safety issues, identified in the "diagnosis" step. More than one countermeasure with the potential to mitigate the problem is often identified in the course of this selection process. A subsequent economic appraisal will evaluate all options for all problem locations in order to ensure that the countermeasures are economically viable. In the countermeasure "prioritization of projects" step, the objective is to maximize benefits in terms of collision reductions, subject to budget restrictions.

The "safety effectiveness evaluation" step involves monitoring implemented improvements to assess whether safety improved as anticipated. The information obtained in this step is extremely valuable for prospective studies so that more informed decisions maximizing the effectiveness of each countermeasure can be made.

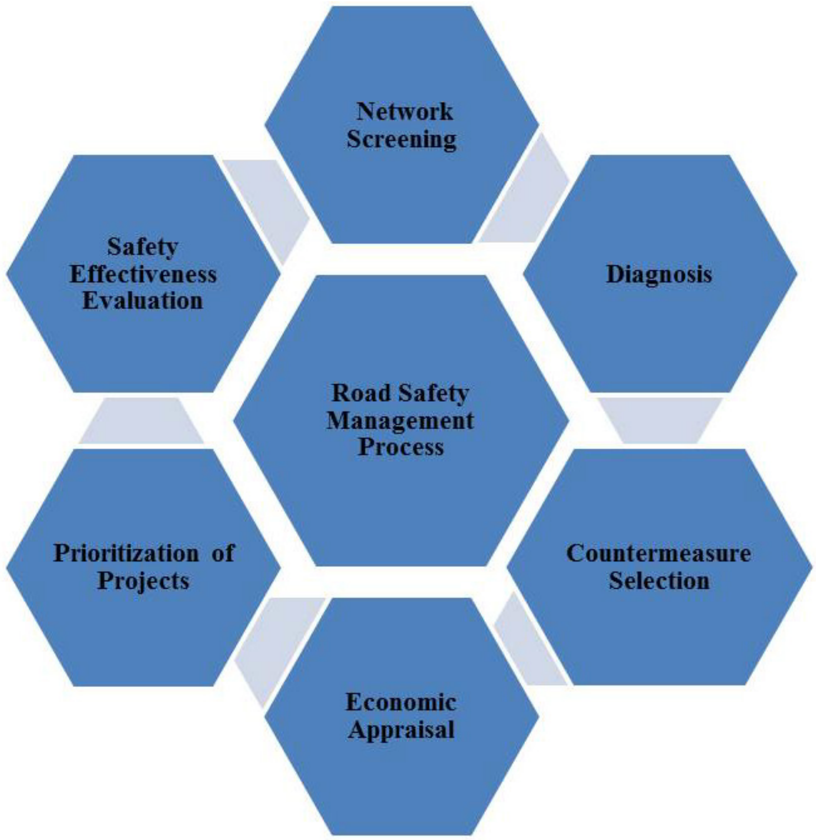

FIGURE 1: ROAD SAFETY MANAGEMENT PROCESS [2]

The road safety management process is a continuous process and demands significant resources from road authorities, and particularly those jurisdictions which constitute large geographic areas (such as the ministries of transportation). The process requires an extensive amount of data, which should be collected annually. Consequently, road authorities are interested in automating the road safety management process as much as possible in order to increase the efficiency of their road safety programs. In response to this increasing need of road authorities, the Safety Analyst software was developed by Federal Highway Administration (FHWA) and released by AASHTO in 2009. Safety Analyst is a software package, which consists of 4 modules, and these modules correspond to the six steps of the road safety management process, as outlined above.

The Ministry of Transportation Ontario (MTO) roadway network includes a wide range of facilities, including mainline road segments, interchanges, ramps, intersections, and ramp terminals. MTO has a road safety program in which locations with potential for safety improvements are identified in each MTO region [3, 4, and 5] and ISRSRs are conducted on these locations.

An ISRSR of a road utilizes its collision history to identify safety issues. The collision data are analysed to identify safety concerns by identifying contributing collision patterns. Then, site visits are conducted to note any issues at the locations that can be co-related to the identified collision patterns. This process results in suggestion of countermeasures to mitigate the identified issues.

MTO has initiated a project to configure Safety Analyst to take advantage of the automation, provided by the software. In this initiative, all four analytical modules in Safety Analyst, (Network Screening, Diagnosis and Countermeasure Selection, Economic Appraisal and Priority Ranking, and Countermeasure Evaluation) are configured for roads under provincial jurisdiction.

The Diagnosis and Countermeasure Selection Module of Safety Analyst provides the capabilities to diagnose the nature of safety performance at a specific site by identifying collision patterns and to select potential countermeasures. This process also guides the analyst to look at the specific deficiencies during the site visit component of the ISRSR process. The module provides three tools to identify collision patterns including: collision summary statistics, collision diagrams, and statistical tests. The diagnosis and countermeasure selection process utilizes an "expert" system, which in turn relies on various diagnostic scenarios that can be developed for any site type within a roadway network. The Safety Analyst software inherently contains diagnostic scenarios for roadway segments and intersections, but it does not have diagnostic scenarios for ramps and freeways. However, Safety Analyst is flexible software that allows jurisdictions to develop new diagnostic scenarios or customize the existing scenarios to their conditions. During configuration of the Diagnosis and Countermeasure Selection Module for MTO, diagnostic scenarios for freeways and ramps were developed.

The main objective of this paper is to discuss and provide a methodical approach to objectively identify collision patterns utilizing the Safety Analyst capabilities. The paper also discusses the process through which diagnostic scenarios for freeways and ramps were developed for MTO.

The organization of the paper is as follows: Section 2 provides a brief introduction to the Safety Analyst software and its capabilities. Section 3 explains the analytical capabilities of Diagnosis and Countermeasure Selection Module in more detail. Section 4 provides the process through which diagnostic scenarios for freeways and ramps were developed for the Province of Ontario. Section 5 provides an approach to identify the contributing collision patterns of a problem location. Section 6 provides a detailed description of the diagnostic scenarios of Safety Analyst. Section 7 provides a detailed methodology used for development of diagnostic scenarios for freeways and ramps for the Province of Ontario. Section 8 concludes the paper with an overall summary and some closing remarks.

2 Safety Analyst Software

Safety Analyst is comprised of four tools and four modules as shown in Figure 2.

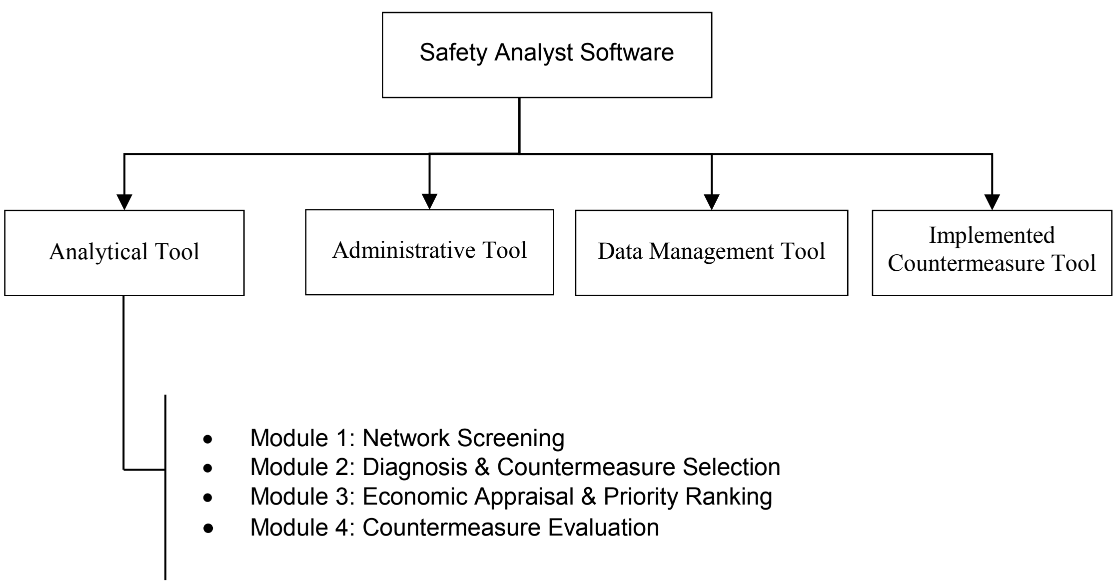

FIGURE 2: SAFETY ANALYST TOOL

2.1 Analytical Tool

The Analytical Tool provides capabilities to assist in conducting all of the steps in the road safety management process. The Analytical Tool further contains four modules as shown in Figure 2, which correspond to the six steps of the road safety management process as outlined Figure 1.

Module 1 of Safety Analyst is the Network Screening Module. The main purpose of this module is to conduct Network Screening for the road authority's entire road network (or a subset of the network) to identify locations with potential for safety improvements that could benefit from further safety investigation. The network screening analysis utilizes site specific characteristics (i.e., site geometrics, traffic volume, and a collision history) and safety performance to prioritize sites based on their expected reduction in collision frequency. This module corresponds to the first step of the road safety management process and allows the user to conduct network screening by multiple methods; the major one of these is the "Basic Network Screening Method", which uses the Empirical Bayes (EB) method to rank sites.

Module 2 of Safety Analyst is the Diagnosis and Countermeasure Selection Module. The locations identified having potential for safety improvement from Module 1 can be investigated by utilizing this module. This module assists the analyst in the diagnosis of safety concerns at a location and identification of a set of countermeasures to mitigate safety concerns. The Diagnosis and Countermeasure Selection Module corresponds to second and third steps of the road safety management process. This module is the main focus of this paper and will be explained in more detail in Section 3.

Module 3 of Safety Analyst is the Economic Appraisal and Priority Ranking Module. This module is used to conduct an economic appraisal for one or a combination of countermeasures for a site to identify whether a countermeasure is cost-effective. Also, this module is able to develop a ranked list of alternative countermeasures based on a range of priority ranking measures. These measures include safety benefits in terms of collisions reduced and/or economic terms. Safety Analyst is capable of solving an optimization problem to identify the best countermeasures which are able to maximize benefits subject to the budget constraints. This module corresponds to fourth and fifth steps of the road safety management process.

Module 4 of Safety Analyst is the Countermeasure Evaluation Module. This module provides an opportunity for road authorities to evaluate the safety effectiveness of implemented countermeasures by conducting observational before-and-after studies.

2.2 Administrative Tool

The Administrative Tool is used by a software administrator to setup the software for the road authority and to manage access to the software. This tool is used to define agency-specific values for each of the modules within the Analytical Tool. For example, road authorities are able to use this tool to enter their own Safety Performance Functions (SPFs), collision modification factors (CMFs), or diagnostic scenarios. Safety Analyst is an AASHTOware product. As a result, default values have been developed based on US standards. For example, the collision table in Safety Analyst is based on the Model Minimum Uniform Crash Criteria (MMUCC) [6]. As a result, the collision report forms (i.e., fields and field names in the report forms) of Canadian jurisdictions are most likely different from the MMUCC. The Administrative Tool can be used to add components of a road authority's collision table to Safety Analyst as required.

2.3 Data Management Tool

The required input data for Safety Analyst are categorized into three groups: (1) infrastructure inventory data; (2) historical traffic volume data; and (3) historical collision data. The Data

Management Tool provides capabilities for road authorities to create and maintain the Safety Analyst databases containing these data.

2.4 Implemented Countermeasure Selection Tool

The Implemented Countermeasure Tool provides capabilities to road authorities to assign the implemented countermeasures to the sites in Safety Analyst by creating and maintaining a special-purpose database that documents the date, location, and nature of physical improvements to the highway network [7]. Once the implemented countermeasures are assigned to sites, users can evaluate safety impacts of their implemented countermeasures using a before-and-after analysis.

3 Diagnosis and Countermeasure Selection Module

The Diagnosis and Countermeasure Selection module combines the second and third steps in the road safety management process shown in Figure 1. This module assists traffic analysts in diagnosing safety concerns at a location based on the collision patterns exhibited at that location, and presents a list of countermeasures to choose from to mitigate the identified safety concerns.

The first step in the diagnosis of safety concerns at a location using this module is the identification of collision patterns. Once the collision patterns for a particular location are identified, the safety concerns of that location can be diagnosed. Output from the diagnosis process is the identification of specific collision patterns and a list of safety concerns that may potentially be mitigated by countermeasures.

4 Tools for Identification of Collision Patterns

As a part of the Analytical Tool, Safety Analyst provides a number of tools to assist the analyst to identify the collision patterns of interest for diagnosis of safety concerns at a location. Prior to diagnosis and countermeasure selection module, the basic network screening in Network Screening Module of Safety Analyst can identify sites with higher-than-expected collision frequencies, for different collision patterns, based on the excess collision frequency method. The excess collision frequency is the expected collision frequency that is in excess of what is considered long term average for that type of site. In conjunction with the network screening outputs, Safety Analyst is equipped with the following three collision pattern identification tools within the Diagnosis and Countermeasure Selection Module [7].

- Collision summary statistics,
- Collision diagrams, and
- Statistical tests on collision frequencies and/or proportions.

The collision summary statistics provides an awareness of predominant collision types that have occurred on a site. These collision tests are then tested statistically to identify over-represented attributes. The collision diagrams pinpoint the locations of specific collision clusters within a site, which can guide the analysts to identify deficiencies if any at the problem locations during the site visit.

The following sections provides a detailed description of the above three tools.

4.1 Collision Summary Statistics

The analyst has the ability to create the collision summary report for a given site, based on the observed number of collisions. The common attributes in the collision summary report are presented in Table 1.

TABLE 1: COMMON ATTRIBUTES IN THE COLLISION SUMMARY REPORT

Collision Summary Attributes	
	Number of vehicles involved
Collision month	Pedestrian indicator
Collision severity level	Relationship to junction (intersection)
Collision time of day	Roadway surface condition
Alcohol/drug involvement	Run-off road indicator
Bicycle indicator	School bus indicator
Collision type Contributing circumstances, environment	Tow-away indicator
Contributing circumstances, road	Vehicle configuration
Day of week	Vehicle maneuver/action
Driver age	Vehicle turning movement
Driveway indicator	Weather condition
First harmful event	Work zone related
	Initial direction of travel
	Light condition

The analyst can specify three separate ways to display the collision data for each attribute: tables, pie charts, and bar charts. In tabular format, the number of collisions is provided by year and totals. The observed percentages are provided for each site. On pie charts, the total collision frequencies are illustrated along with the observed proportions. Finally, on the bar chart, the collision frequencies are provided by year and the collision attribute (e.g. the manner of collision). Table 2, Figure 3, and Figure 4 present sample collision summary reports for "collision type and manner of collision" attribute.

TABLE 2: SAMPLE COLLISION TYPE AND MANNER (TABLE FORMAT)

Description	2004	2005	2006	2007	2008	Total	Observed Percent
Collision with animal	0	0	1	2	0	3	3
Collision with fixed object	0	1	3	0	11	15	16
Other single-vehicle collision	0	1	4	6	11	22	24
Rear-end	5	7	10	5	14	41	45
Sideswipe, same direction	2	1	5	2	1	11	12
Total Collisions	7	10	23	15	37	92	100

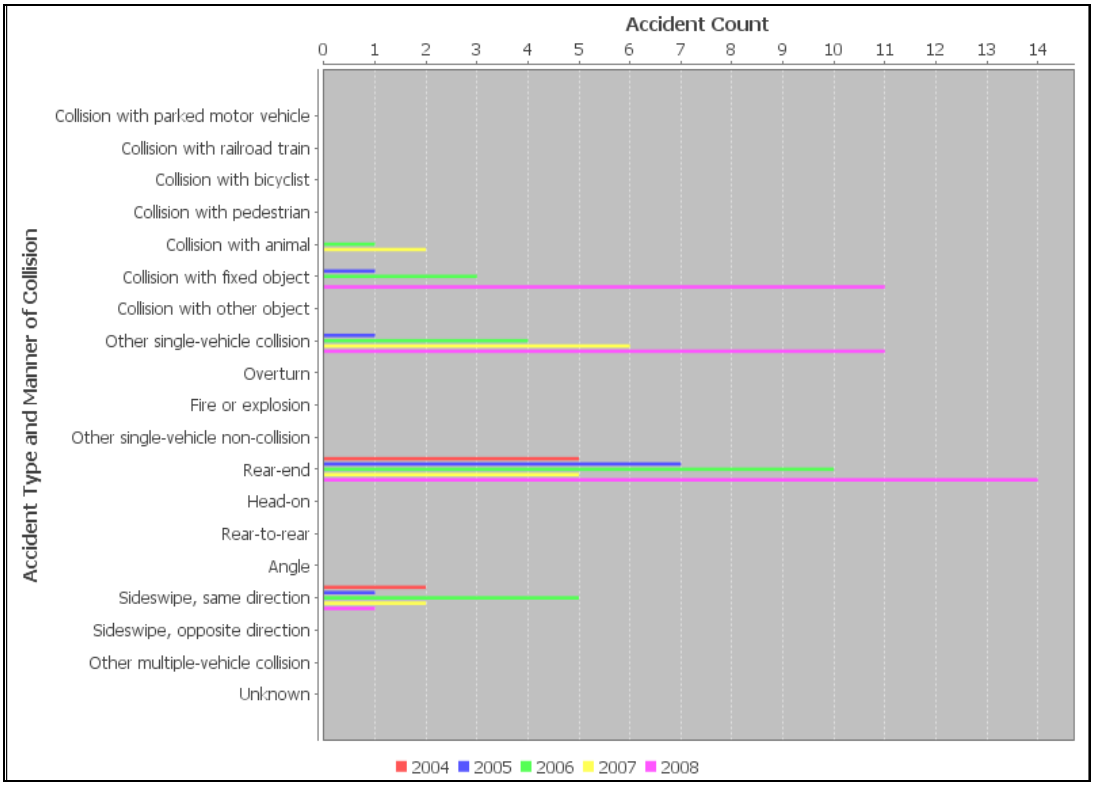

FIGURE 3: SAMPLE COLLISION TYPE AND MANNER OF COLLISION (BAR CHART)

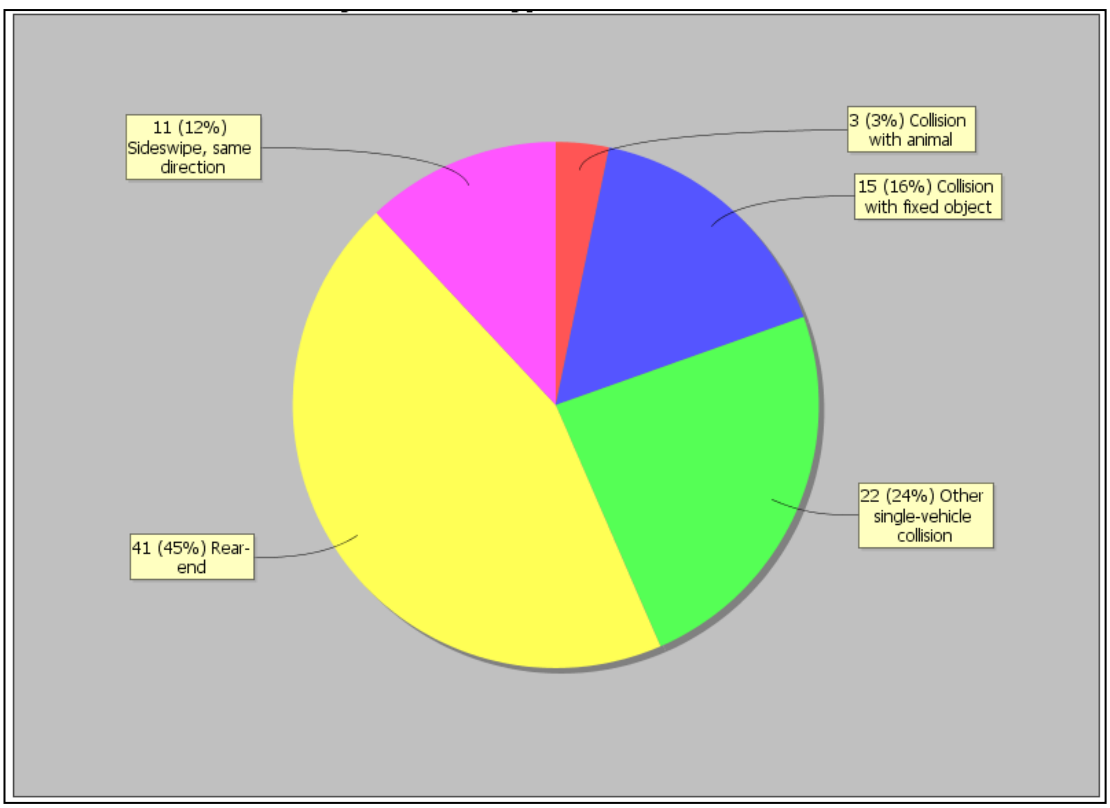

FIGURE 4: SAMPLE COLLISION TYPE AND MANNER OF COLLISION (PIE CHART)

In addition, each report provides a table with “Collision Case Identifier” for each collision associated with the attribute selected, which is hyperlinked to the details of the collision. Table 3 illustrates the table showing collision case identifier for each collision. The attributes of each collision can be quickly accessed with a click of the mouse.

TABLE 3: SAMPLE COLLISION TYPE AND MANNER OF COLLISION (COLLISION CASE IDENTIFIER)

Description	Accident Case Identifier
Collision with parked motor vehicle	70131680
Collision with railroad train	
Collision with bicyclist	
Collision with pedestrian	40610278, 61032119
Collision with animal	
Collision with fixed object	80832566, 50891871, 41011604
Collision with other object	
Other single-vehicle collision	41091260, 50190946, 80780496, 81080266, 60770759, 80630855, 80512777, 80761361, 41181994

The collision summary tools can assist the analyst in obtaining a better understanding of the types of collisions that have occurred at the site under investigation. Collision types that are predominantly occurring should be tested by the statistical tests available in this module to identify whether any of these collision attributes are over-represented.

4.2 Collision Diagrams

Safety Analyst provides the capability to create a collision diagram, as a visual representation of the collision history with schematic arrows and symbols, for roadway segments, intersections, and ramps. Collision diagrams show the spatial relationship between collisions and the subject site and can potentially assist analysts to identify any collision patterns on the site. Although the collision diagram viewer is based on collision type and manner of collision, other collision attributes (i.e. presented in Table 1) can be added as annotations to the collision diagram. Given the frequency of collisions shown in the example in Table 2, it appears that the rear-end collision is a collision pattern of interest for further analysis.

4.3 Statistical Tests

In conjunction with collision summary reports and collision diagrams, Safety Analyst is equipped with statistical procedures for identifying the collision patterns of interest. The statistical tests are based on tests for collision frequencies and collision proportions, to identify the large count of collisions of a given collision type, and large proportion of those collisions compared to proportions for similar sites, respectively. The following sections provide the details of the available statistical tests.

Test of Collision Frequencies

Test of collision frequency is based on comparing the average observed collision frequency and the average Empirical Bayes (EB)-adjusted collision frequency[1] (expected collision frequency) to a limiting value, as specified by the user, for each of the individual collision types. The average

[1] This term is used in the Safety Analyst reports produced by the Diagnosis and Countermeasure Selection Module

observed collision frequency is based on the observed collisions, the number of years in the analysis period, and the length of the segment/ramp being analyzed. The average EB-adjusted collision frequency is based on the expected collision frequency for the entire analysis period. For roadway segments and ramps, the units for this measure are collision per kilometre per year (acc/km/yr)[2], and for intersections, the units are collisions per year (acc/yr). It may be noted that this test is conducted as part of the basic network screening.

Test of Collision Proportions

Test of collision proportions is based upon the proportions of observed collision attributes at a given site compared to the proportion of the collision attributes at similar locations (with the same site subtype). If the proportion of the collision attribute is statistically larger than the similar sites, the collision attribute at the subject sites is over-represented and deserves investigation.

The rationale behind the proportional test is that the collision frequency tests only reveal a portion of the issue. For example, a site with high collision frequencies and high travel exposure level (i.e. AADT) may not be selected for further investigation since high collision frequency is expected for a site with such characteristics. It may also be the opposite case, where a specific collision attribute at a site with relatively few collisions would be selected for conducting the diagnosis analysis because the collision attribute can be over-represented.

5 Methodology for Identifying Collision Patterns at a Location

The first step in identification of collision patterns is a review of the collision summary results to have a better understanding of collision attributes of the site. The collision summary statistics tool as detailed in Section 4.1 displays collision attributes in tables, pie charts, and bar charts. A collision diagram provides a visual tool for identification of collision patterns spatially occurring. It will assist analysts to visually identify any collision clusters at a particular location.

The next step is to perform statistical tests to identify the over-representation of the candidate collision patterns. Test of collision frequency is based on comparing the observed and expected collisions with a user-defined limiting value. This test is conducted as part of the basic network screening. Therefore, it is recommended that this test not be used as the results of basic network screening will identify whether a site has higher than expected collision frequency. Any user-defined limiting value will be an arbitrary cut-off value. If the test is used, the limiting value of zero should be used.

Test of collision proportions can potentially identify collision patterns by comparing the observed collisions at the site to the proportion of collisions at similar sites. A confidence interval of 90% is recommended to be used for the test of collision proportion. As a summary, Figure 5 presents the collision pattern identification process that is recommended to be used by analysts.

[2] Although Safety Analyst shows acc/mile/year, the Safety Analyst version configured for Ontario is based on the Metric System.

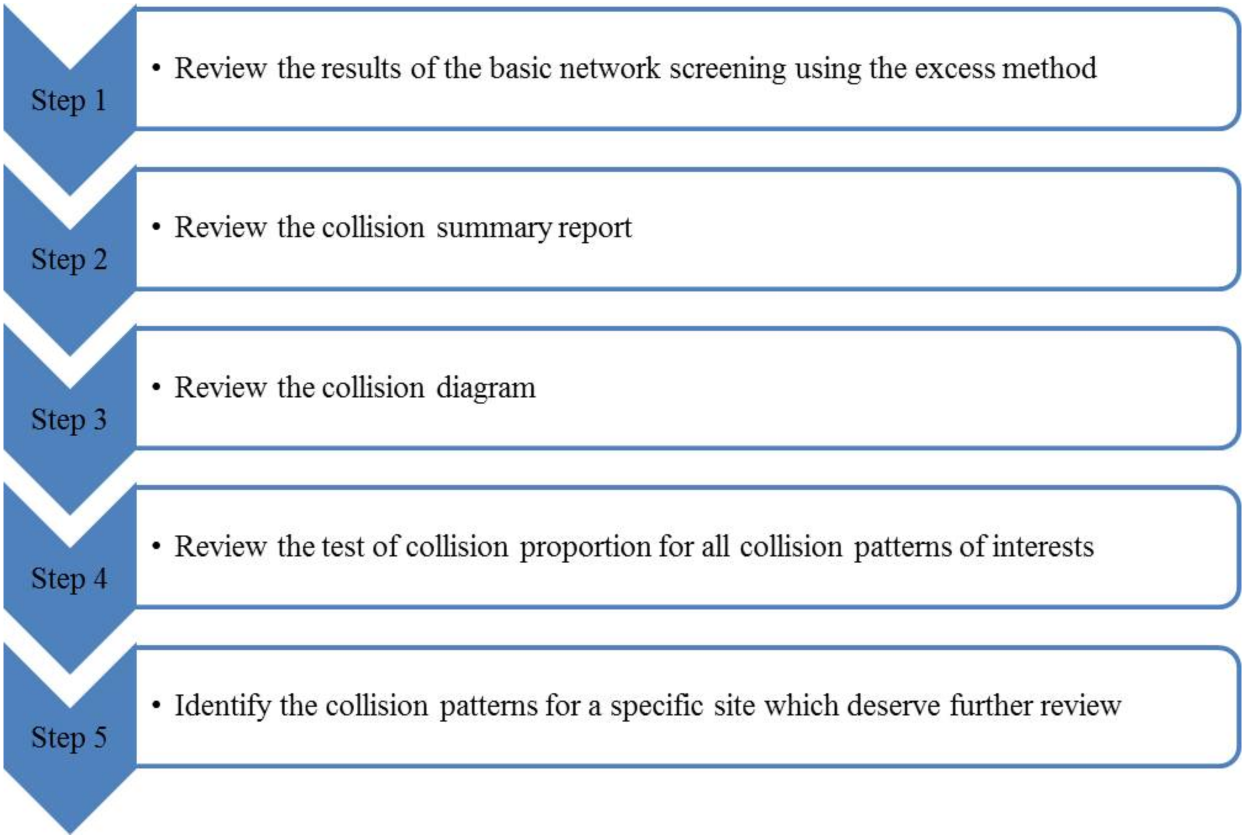

FIGURE 5: COLLISION PATTERN IDENTIFICATION TOOL

6 Diagnostic Scenarios

Safety Analyst is equipped with an “expert” system that guides the analyst towards appropriate office and field investigations. The expert system is used to identify potential countermeasures to address the collision patterns identified during the diagnosis process. This diagnostic process includes both traditional engineering considerations and a human factors component, to help diagnose safety concerns at a site. The output of the expert system is a list of potential countermeasures to address the identified safety problems.

The expert system includes the following components:

- Diagnostic scenarios;
- Diagnostic questions;
- Countermeasures; and
- Procedures.

Figure 6 shows the relationship between various components of the expert system.

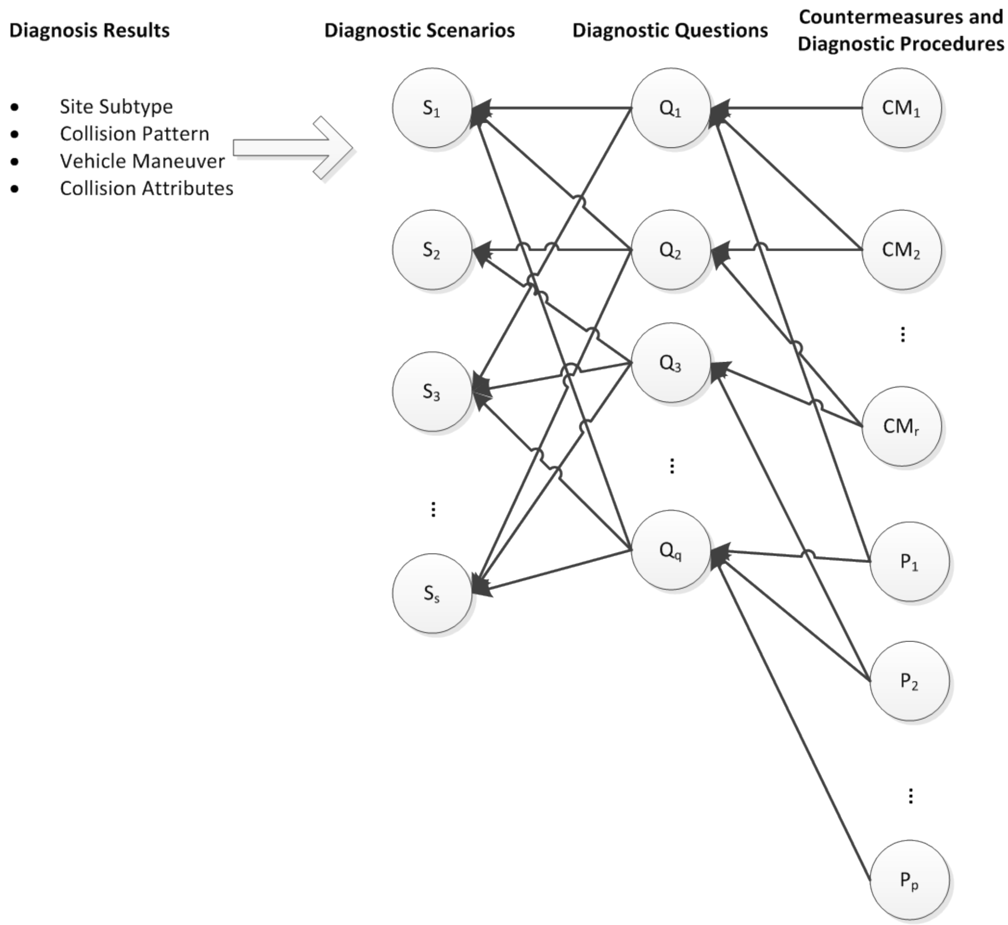

FIGURE 6: RELATIONSHIP BETWEEN VARIOUS ELEMENTS IN THE DIAGNOSTIC EXPERT SYSTEM

The diagnostic scenarios in Safety Analyst were developed for each site subtype, collision pattern, vehicle maneuver, and collision attribute. The diagnostic scenarios include different diagnostic questions with a Yes, No, or Unknown response. Depending upon the response to a given question, the logic of the system leads the analyst through a different series of questions. A diagnostic question is not unique to one particular diagnostic scenario and may appear in different scenarios. The same countermeasures or procedures may be suggested by Safety Analyst in response to a diagnostic question. Procedures often instruct the analyst to gather more information through a field visit or guidelines and manuals. Depending on the answer of the analyst to a diagnostic question, three events may happen:

- The analyst is posed with another diagnostic question;
- A countermeasure is suggested by Safety Analyst; or
- A procedure is suggested by Safety Analyst.

All diagnostic scenarios in Safety Analyst have a consistent and common format. Table 4 illustrates the common components of diagnostic scenarios and provides a brief description for each component. These components are used by the Safety Analyst software to match each diagnostic scenario to a site based on site type, site subtype, attribute, collisions pattern, and vehicle maneuver. Statement and Rationale provide information to the user about the logic behind development of the diagnostic scenario.

TABLE 4: COMPONENTS OF A DIAGNOSTIC SCENARIO

Component	Description
Title	A unique title for each diagnostic scenario
Site Type	The site types (e.g. road segments) to which the diagnostic scenario can be applied
Site Subtype(s)	The site subtypes (e.g. 2 lane rural roads) to which the diagnostic scenario can be applied
Attribute	A characteristics of the scenario
Collision Pattern(s)	Collision patterns (e.g. rear-end) to which the diagnostic scenario is applicable
Vehicle Maneuver(s)	Maneuvers of vehicles involved in collisions that are applicable to the diagnostic scenarios (e.g. “2 changing lanes” which means that both vehicles were changing lanes at the same time)
Statement	A brief description of the circumstance of the collision
Rationale	A fundamental principle behind the scenario
Diagnostic Questions	A set of questions to support the evidence of the cause of the collisions

An example of a diagnostic scenario is presented in Table 5. The common elements in all scenarios are shown in boldfaced font.

TABLE 5: SAMPLE DIAGNOSTIC SCENARIO

Scenario: (45) - Speeds Too High

Title: Speeds Too High
Site Type: Intersection
Site Subtype(s):
Int/Urb; 4-leg signalized
Attribute(s):
General
Collision Pattern(s):
Sideswipe, same direction
Vehicle Maneuver(s):
2 changing lanes
1 left-turn, 1 changing lanes
1 left-turn, 1 overtaking/passing
1 right-turn, 1 changing lanes
1 right-turn, 1 overtaking/passing
1 thru, 1 changing lanes
1 thru, 1 overtaking/passing

Statement: Sideswipe crashes 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 avoid other drivers changing lanes. As a result, vehicles come into conflict with vehicles in adjacent lanes that are changing lanes on the intersection approach. Changing lanes is sometimes recorded as overtaking or passing.

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, 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.
Diagnostic Question(s): [see Figure 8]

The diagnostic questions for the above scenario are presented in the form of a flow chart in Figure 7.

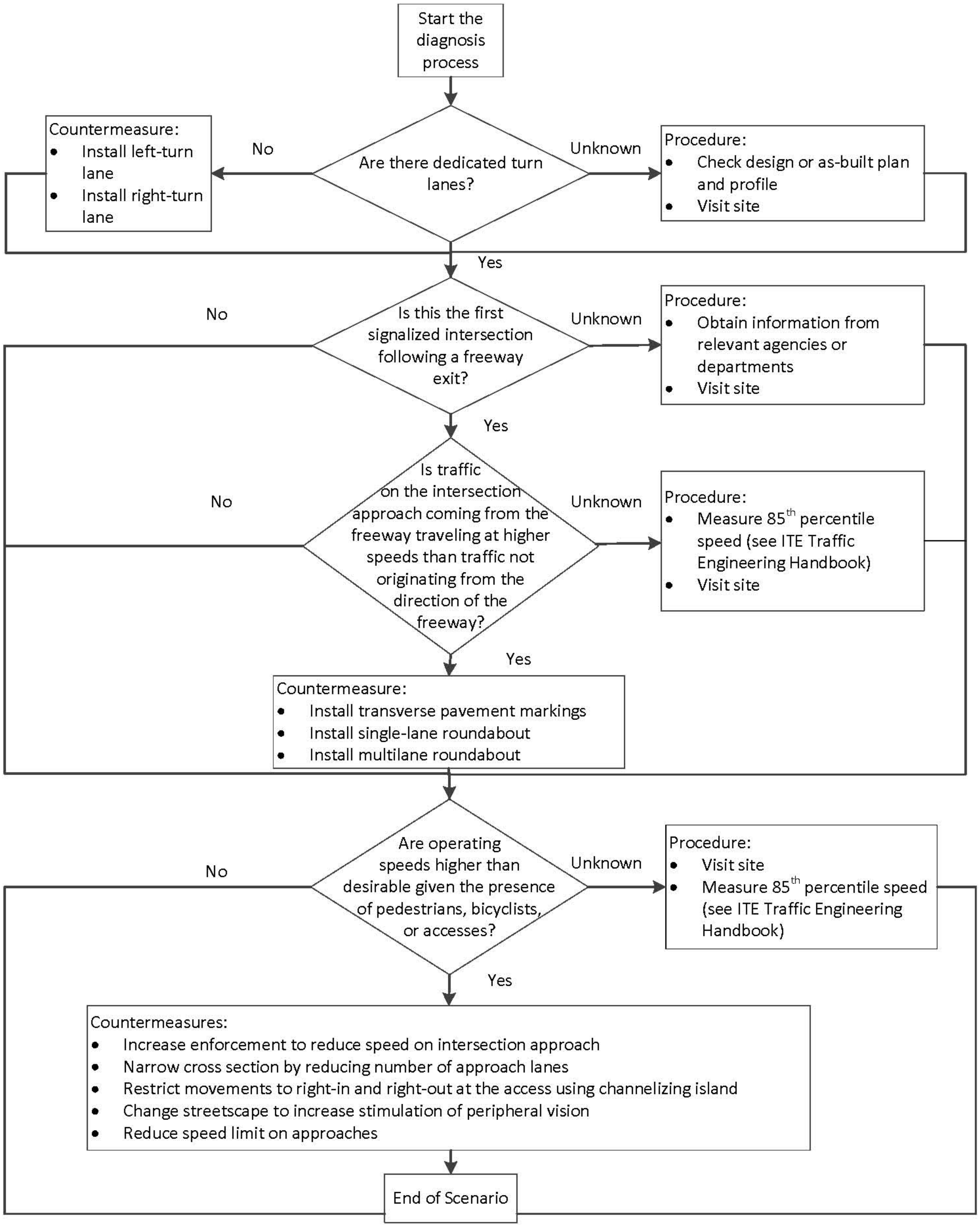

FIGURE 7: DIAGNOSTIC SCENARIO IN A FLOW CHART FORMAT

As can be seen in Figure 8, based on an answer to a diagnostic scenario, the user is prompted by countermeasures, procedures or further diagnostic questions. Depending upon the answers to preceding questions, succeeding questions may be different. Also, depending on answers to questions, arrays of countermeasures are suggested by Safety Analyst. If answers to questions are unknown, the analyst is guided to obtain answers to the questions (e.g. conduct a site visit or measure 85th percentile speed (see ITE Traffic Engineering Handbook)). The expert system provides flexibility of removing some of the recommended countermeasures and/or adding countermeasures that were not recommended during the diagnosis process.

It may be noted that diagnostic scenarios for roadways and intersections were initially incorporated into Safety Analyst. The existing scenarios did not include scenarios for freeways and ramps. The scenarios for freeways and ramps were developed for the Province of Ontario during the configuration of Safety Analyst for MTO.

7 Methodology for Development of Diagnostic Scenarios

The following steps were taken to develop diagnostic scenarios for freeways and ramps:

- Review of the collision history associated with freeways and ramps to identify collision patterns;
- Identification of relevant diagnostic scenarios among the available Safety Analyst diagnostic scenarios; and
- Modification of the relevant diagnostic scenarios and development of new diagnostic scenarios.

7.1 Review of Collision History for Freeways and Ramps

Historical collision data were used to determine the predominant collision types for MTO freeways and ramps. Table 6 summarizes the total number of collisions from January 1, 2004 through December 31, 2008.

TABLE 6: SUMMARY OF 5-YEAR COLLISION HISTORY (2004-08)

	Freeways		Ramps	
Collision Type	**# of Collisions**	**Proportion of Total Collisions**	**# of Collisions**	**Proportion of Total Collisions**
Angle	1349	0.45%	69	0.55%
Approach	5283	1.78%	27	0.21%
Rear-end	117228	39.49%	3474	27.55%
Sideswipe	56065	18.89%	1728	13.71%
Single Motor Vehicle (SMV)	111833	37.67%	7157	56.77%
Single Vehicle unattended	1787	0.60%	91	0.72%
Turning Movement	2555	0.86%	11	0.09%
Other	764	0.26%	51	0.40%

As noted in Table 5, the predominant collision impact types associated with freeways are SMV, sideswipe, and rear-end collisions, which constitute almost 96% of all collisions on freeways. SMV, sideswipe, and rear-end collisions constitute almost 98% of all collisions on ramps. As a result, it was decided that the diagnostic scenarios should address these collision patterns.

Historical collision data were further investigated to determine the major collision attributes related to the above collision types. A screening of collision attributes was undertaken to determine frequently occurring collision attributes, e.g. SMV collisions occurring in dark lighting condition and associated with inattentive driver condition and wet and slippery road surface condition attributes.

The collision attributes for the predominant collision impact types for freeways included:

- Less than ideal environmental conditions including rain, snow, freezing rain, and drifting snow;
- Inattentive/impaired driver condition attributes;
- Wet and slippery road surface conditions;
- Speed too fast driver action attributes;
- Dark lighting conditions;
- Lane change event attributes;
- Wild animal event attributes;
- Skidding/sliding event attributes; and
- Ran off road event attributes.

The collision attributes for the predominant collision impact types for ramps included:

- Less than ideal environmental conditions including rain, snow, freezing rain, and drifting snow;
- Wet and slippery road surface conditions;
- Dark lighting conditions;
- Inattentive/impaired driver condition attributes;
- Following too close driver action attributes;
- Speed too fast driver action attributes;
- Lane change event attributes;
- Skidding/sliding event attributes; and
- Ran off road event attributes.

Based on the above results, the diagnostic scenarios have been identified and/or developed to mitigate the identified issues.

7.2 Identification of Relevant Diagnostic Scenarios

The list of diagnostic scenarios that are available in the current version of the Safety Analyst was thoroughly reviewed to identify the scenarios that would best fit the characteristics of the ramps and freeways to address the collision patterns identified in Section 5.1. The identifications were conducted based on five main criteria: (1) driver behaviour; (2) roadside design; (3) road surface condition; (4) traffic operations; and (5) sequence of events.

In terms of driver behaviour, the available scenarios were reviewed to identify which driver behaviours can be contributing factors to the collision patterns identified in the previous section. These scenarios included driver inattention or impairment, and speed too fast. In terms of roadside design, the scenarios which addressed run-off-road events and related deficiencies (e.g.

shoulder conditions) as well as collisions with fixed objects within the clear zone were identified. For road surface conditions, the scenarios involving pavement conditions (e.g. inadequate friction or super elevation), poor drainage conditions, and winter maintenance were identified. In terms of traffic operations, diagnostic scenarios relevant to signage and pavement marking were identified. In terms of sequence of events, diagnostic scenarios relevant to most prominent collision events such as wild animal events, skidding/sliding events, and ran-off road events were identified.

7.3 Modification and Development of Diagnostic Scenarios

7.3.1 Freeways

For freeways, the relevant diagnostic scenarios for multilane divided highway segments in both rural and urban environments were identified as the starting point. However, multilane divided highway segments and freeways have different functional characteristics. A freeway is a divided highway having two or more lanes in each direction with full control of access and egress. Access and egress is achieved by the use of ramps and acceleration/deceleration lanes. A freeway provides uninterrupted flow. Posted speeds at freeways are normally 100 km/h. Multilane divided roadways have four or six lanes, with center medians or a two-way left turn lane (TWLTL). Posted speeds are typically between 60 and 90 km/h. Multilane divided highways are not completely access controlled, resulting in interrupted flow at at-grade intersections and driveways. As a result of these differences in the characteristics of multilane highway segments and freeways, the adopted scenarios were modified to better match the characteristics of freeways.

The modifications to the multilane divided highway segments diagnostic scenarios include:

- Adding new site subtypes by modifying the existing Safety Analyst site subtypes to applicable MTO site subtypes. As an example existing Safety Analyst site subtype "Seg/Rur; Multilane divided" was modified to MTO_Seg/Rur; Fwy (4 ln);
- Removing questions that are not relevant to freeways (e.g. questions regarding accesses);
- Adding or modifying questions specific to freeways (e.g. questions regarding delineators, freeway signage, and lane width);
- Adding or modifying procedures (e.g. conducting weaving analysis and conducting freeway ramp terminal operational analysis); and
- Adding Ontario guidelines for procedures (the existing US guidelines referenced in Safety Analyst were converted to the applicable Ontario and Canadian guidelines and manuals).

In addition to the above modifications, the scenarios have been adjusted in order to provide flexibility, such that a user can select or skip a diagnostic question, based on whether the freeway design is rural or urban.

Four new scenarios to address the operational concerns on freeways were created. Table 7 provides a list of modified multilane divided roadway segment scenarios and the newly developed scenarios for freeways.

TABLE 7 : LIST OF DIAGNOSTIC SCENARIOS IDENTIFIED FOR FREEWAYS

Scenario	Collision pattern	Scenario Attributes
Modified Scenarios		
Road Surface Condition / Superelevation	All single-vehicle	Horizontal curve
Animal Visibility	Collision with animal	General
Road Surface Condition/Drainage	All single-vehicle	Wet weather
Driver Inattention / Impairment	All single-vehicle	General
Roadside Design	All single-vehicle	General
Speeds Too High / Unexpected Curvature / Poor Path Definition	All single-vehicle	Horizontal curve
Roadside Design	All single-vehicle	Horizontal curve
Road Surface Condition/Drainage	Rear-end	Wet weather
Speeds Too High / Unexpected Curvature / Poor Path Definition	Sideswipe	Horizontal curve
Roadside Design	Sideswipe	Horizontal curve
Road Surface Condition / Superelevation	Sideswipe	Horizontal curve
Driver Inattention / Impairment	Sideswipe	General
Road Surface Condition/Drainage	Sideswipe	Wet weather
Newly Developed Scenarios		
Traffic Operations (Interchange)	Sideswipe	General
Traffic Operations (Interchange)	Rear-end	General
Traffic Operations (Transfer Lanes)	Sideswipe	General
Traffic Operations (Transfer Lanes)	Rear-end	General

All the components of the multilane divided highway segment scenarios including the circumstance list, the scenario background summary, diagnostics questions, procedures, and countermeasures were thoroughly reviewed and modified to match the characteristics of freeways and MTO's practices. The questions not relevant to freeways were removed and some new questions were added. New countermeasures were also added to address freeway specific issues based on the collision history of freeways and prevailing engineering practices. The final version of diagnostic scenarios for freeways was then incorporated into the Safety Analyst database.

7.3.2 Ramps

For ramps, the relevant diagnostic scenarios for road segments were identified as the starting point. However, road segments and ramps have different functional characteristics. The principal function of a road segment is to provide mobility to the road users, whereas the principal function of a ramp is to provide access to/from a freeway, generally through short lengths and relatively tight curves. Additionally, ramps and road segments differ in terms of many other characteristics, such as: geometrics, traffic control, traffic operation, traffic volumes and speed, as well as suitable countermeasures. Ramps generally provide one-way traffic operation at a significantly lower speed than the connecting roads. Ramps are connected to freeways by acceleration/deceleration lanes designed for safe merging/diverging into/from the freeway traffic. As a result of these differences in the characteristics of ramps and road segments, the adopted scenarios were modified to better match the characteristics of ramps.

The modifications to the road segment diagnostic scenarios include:

- Adding new site subtypes by modifying the existing Safety Analyst site subtypes to applicable MTO site subtypes. As an example existing Safety Analyst site subtype "Seg/Rur; 2-Lane" was modified to MTO_Ramp/Rur; Flared (off);
- Removing questions that are not relevant to ramps (e.g. questions regarding accesses, utilities, and high volume locations);
- Adding or modifying questions specific to ramps (e.g. questions regarding delineation on the outer edge of ramps, lane designation, posted ramp speeds, shoulder width, and lane width);
- Adding or modifying procedures (e.g. conducting ball bank studies, conducting ramp freeway junction operational analysis); and
- Adding Ontario guidelines for procedures (the existing US guidelines referenced in Safety Analyst were converted to the applicable Ontario and Canadian guidelines and manuals).

A new scenario to address the operational issues on ramps was created. Table 8 provides a list of modified road segment scenarios and the newly developed scenario for ramps.

TABLE 8 : LIST OF DIAGNOSTIC SCENARIOS IDENTIFIED FOR RAMPS

Scenario	Collision pattern	Attributes
Modified Scenarios		
Driver Inattention / Impairment	All single-vehicle	General
Ramp Road Side Design	All single-vehicle	General
Speeds Too High / Unexpected Curvature / Poor Path Definition	All single-vehicle	Horizontal curve
Ramp Road Side Design	All single-vehicle	Horizontal curve
Road Surface Condition / Superelevation	All single-vehicle	Horizontal curve
Road Surface Condition/Drainage	All single-vehicle	Wet weather
Driver Inattention / Impairment	Rear-end	General
Road Surface Condition/Drainage	Rear-end	Wet weather
Driver Inattention / Impairment	Sideswipe	General
Road Surface Condition/Drainage	Sideswipe	Wet weather
Speeds Too High / Unexpected Curvature / Poor Path Definition	Sideswipe	Horizontal curve
Road Surface Condition / Superelevation	Sideswipe	Horizontal curve
Ramp Road Side Design	Sideswipe	General
Ramp Road Side Design	Sideswipe	Horizontal curve
Newly Developed Scenario		
Traffic Congestion (Queuing)	Rear-end	General

All the components of the segment scenarios, including the statement, the scenario background summary, diagnostics questions, procedures, and countermeasures were reviewed and modified to match the characteristics of ramps and MTO's best practices. The questions that were not relevant to ramps were removed and some new questions were added. New countermeasures were also added to address ramp-specific issues based on the collision history for ramps and prevailing engineering practices. The final version of diagnostic scenarios for the "ramp" site type was then incorporated into the Safety Analyst database.

8 Conclusions

Road jurisdictions conduct in-service road safety reviews of the locations with highest potential of safety improvements identified through network screenings of their roadway networks. The outcome of an ISRSR of a location is a series of safety concerns, which may be mitigated through a series of countermeasures. With the arrival of the Safety Analyst software, road authorities have the opportunity to automate significant portions of their road safety management process. Safety Analyst is capable of conducting analyses related to all steps of the road safety management process in an efficient and effective manner.

The Diagnosis and Countermeasure Selection Module of Safety Analyst is equipped with the tools to diagnose safety concerns at a site by identifying the collision patterns and guiding the analyst to look at specific issues as part of a safety review. The module is also capable of recommending a list of countermeasures based on the identified safety concerns. For identification of collision patterns, the module is equipped with three tools including: collision summary statistics, collision diagrams, and statistical tests. For diagnosis and countermeasure selection process, the module is equipped with an "expert" system, which utilizes a series of diagnostic scenarios that lead the analyst to possible outcomes (diagnosis and countermeasures) through a series of diagnostic questions.

The main objective of this paper was to briefly review the tools provided by Safety Analyst to identify collision patterns at a location. The paper also discusses the process through which diagnostic scenarios for freeways and ramps were developed for MTO.

The first step in the process of identification of collision patterns of a location involves a review of the collision summary results by utilizing collision summary statistics tool. The tool has a capability to generate collision statistics reports based on the observed number of collisions of a site in an organized format documenting various possible attributes such as collision type, severity, weather condition, road condition, first harmful event, etc. These reports help in quickly identifying candidate collision patterns of interest (which require further review), and associated major contributing factors. The collision diagrams pinpoint the locations of specific collision clusters within a site, which can guide the analyst to identify issues during the site visit. The candidate collision patterns are then subjected to the statistical testing tool to identify which collision patterns are over-represented.

Diagnostic scenarios were developed for freeways and ramps for MTO. Scenarios for roadways and intersections were already included in Safety Analyst. As a first step in this process, a review of collision history both for freeways and ramps was conducted individually to identify their major collision patterns. Existing scenarios within Safety Analyst were then reviewed to identify the scenarios that would best fit the characteristics and collision patterns of freeways and ramps. These identified scenarios were then modified to match the characteristics and collision patterns of freeways and ramps. Some new scenarios were also developed to address the operational issues on freeways and ramps.

If a road agency intends to develop its own scenarios, it is recommended that the agency should clearly define its site subtypes prior to developing new scenarios. The reason is that sections of a similar site type may have different operational characteristics and, as a result, some scenarios may not apply to those sections.

9 References

1. Hauer, E. (1980). Bias by selection: overestimation of the effectiveness of safety countermeasures caused by the process of selection for treatment. Accident Analysis and Prevention 12.

2. Highway Safety Manual (2010). American Association of State Highway and Transportation Officials (AASHTO), Washington DC.

3. Operational Performance Assessment of Highway and Freeway Sections (2009). Ministry of Transportation Ontario.

4. Operational Performance Assessment of Freeway Interchanges, Ramps, and Ramp Terminals (2006). Ministry of Transportation Ontario.

5. Intersection Operational Performance Assessment Study (2005). Ministry of Transportation Ontario.

6. Model Minimum Uniform Crash Criteria (MMUCC) Guideline (2008). US Department of Transportation, Third Edition.

7. Harwood, D.W., Torbic, D.J., Richard, K.R., and Meyer, M.M. (2010). Safety Analyst: Software Tools for Safety Management of Specific Highway Sites. US Department of Transportation, Federal Highway Administration.