5-1-2014

Development of a Visualization System for Highway Safety Management Using Safety Analyst

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DEVELOPMENT OF A VISUALIZATION SYSTEM FOR HIGHWAY SAFETY MANAGEMENT USING SAFETY ANALYST

By

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Bachelor's Degree in Civil Engineering

Pulchowk Campus, Institute of Engineering

Tribhuvan University, Nepal

2011

A thesis submitted in partial fulfillment of the requirements for the

Master of Science in Engineering - Civil and Environmental Engineering

Department of Civil and Environmental Engineering and Construction

Howard R. Hughes College of Engineering

The Graduate College

University of Nevada, Las Vegas

May 2014

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

THE GRADUATE COLLEGE

We recommend the thesis prepared under our supervision by

Indira Khanal

entitled

Development of a Visualization System for Highway Safety Management Using Safety Analyst

is approved in partial fulfillment of the requirements for the degree of

Master of Science in Engineering -- Civil and Environmental Engineering

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ABSTRACT

Development of a Visualization System for Highway Safety Management Using Safety Analyst

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The AASHTOWare software, Safety Analyst, is a state-of-the-art tool with significant capabilities and advanced analytical methods for comprehensive analysis and management of highway safety. However, currently, this tool provides very limited visualization capabilities. To address this limitation, this study proposes a Visualization System for Safety Analyst that provides graphical displays, including location and color-coded information for each module. In addition, the system generates charts, which have various degrees of resolution and aggregation; tables; and a report summarizing safety performance measures. The system can use Google Maps and/or ESRI ArcGIS to generate the graphical displays. The advantage of using Google Maps is its simplicity; in contrast, the ArcGIS display provides additional modeling and computing capabilities. All the displays are very intuitive, and can be customized based on the user needs. Because the user can see the locations of every specific site, the displays facilitate analysis as well as the decision-making process. The Visualization System interacts with Safety Analyst so that the user can access all tools and data throughout the entire modeling and analysis process. A tutorial and a survey questionnaire were used to evaluate the effectiveness and usability of the Visualization System. The results suggest

that the participants were very satisfied with the overall concept and performance of the Visualization System. In general, they prefer to use Safety Analyst in conjunction to the Visualization System.

ACKNOWLEDGEMENTS

I would like to express my appreciation to my advisor Dr. Alexander Paz for his continuous support, guidance and encouragement. I would like to thank him for his continuous support during my period of study and his precious assistance for writing technical report. Without his support and knowledge this thesis could not have been a success. I would also like to express my thanks to Dr. Mohamed Kaseko, Dr. Hualiang Teng, Dr. Pramen P. Shrestha and Dr. Brendan Morris for their support and for having served on my Thesis Committee.

I am very grateful to Nevada Department of Transportation (NDOT) for funding this research project. I am very thankful to the representatives from NDOT and University of Nevada, Reno (UNR) for attending the Safety Analyst tutorial and providing me the questionnaire response. I would also like to thank all the UNLV students and 93rd Annual Meeting of Transportation Research Board (TRB) participants who provided me the responses for the questionnaire survey.

I am very thankful to Ms. Julie Longo, Technical writer at the College of Engineering who provided her valuable time for editing the journal paper format of this research study.

Additionally, I cannot forget my colleagues and friends including Naveen Veeramisti, Justin Baker, Loic Belmonte for their help and support in completing this research project. Finally, I would like to thank my family members who have always been a source of inspiration for me.

DEDICATION

This thesis is dedicated to my parents, sister, and brother.

Thank you all for your love, support and care.

I love you all.

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CHAPTER 1

INTRODUCTION

1.1 Background

According to the Strategic Highway Safety Plan (SHSP) (NDOT, 2011) developed by the Nevada Department of Transportation's (NDOT), on average, there are more than 30,000 traffic casualties per year in the US. Approximately, 325 of these casualties occur in Nevada highways. In an attempt to analyze and address traffic safety problems, in 2006, NDOT and the Nevada Department of PublicSafety (DPS) along with other partner agencies prepared the first Strategic Highway safety Plan for Nevada. The Nevada SHSP is a statewide comprehensive plan that seeks to reduce motor vehicle crashes by combining the resources across multi disciplines (NDOT, 2011). Later in 2010, Nevada developed a safety campaign, "Zero Fatalities", with the objective of preventing all traffic fatalities. To support the development of SHSP and provide better solutions for the existing and emerging traffic problems, various federal and state agencies have developed state-of-the-art tools such as the Highway safety Manual (HSM) and Safety Analyst. NDOT is invested in adopting the HSM and Safety Analyst to perform various traffic safety related analyses and activities.

The American Association of State Highway and Transportation Officials (AASTHO) is currently distributing the HSM and Safety Analyst. The HSM provides a variety of methodologies for highway safety management. It describes both traditional as well as state-of-the-art safety analysis approaches. A Transportation Research Board special report about traffic safety goals in the United States encourages the use of these tools for traffic safety planning and management (TRB, 2010). These tools provide statistically sound approaches to facilitate the development of comprehensive programs for traffic safety management. These tools use Empirical Bayes to address many limitations associated with traditional methods. Safety Analyst provides software tools to apply the methods in Part B of the HSM for system wide highway safety management (AASHTO, undated). The part B of the HSM and Safety Analyst provides the steps required for highway safety management process. In contrast, Part C of the HSM is proposed for site specific safety analysis (AASHTO, 2010a). It provides predictive methods for estimating expected average crash frequency for a specific site using Safety Performance Functions (SPFs). SPFs provide estimate of predicted average crash frequency under a given traffic volume and geometric condition (AASHTO, 2010a).

1.2 Problem Statement

A limitation of Safety Analyst is the lack of visualization capabilities to support the analysis of results. This is a significant issue considering the spatial nature of traffic safety. Results from the analysis are provided to the user in a tabular form. In a recent version (4.3.1), released on June of 2013, a map viewer capability was added (AASHTO, 2013). However, this viewer does not allow multiple displays. It only displays a single site at a time. In addition, the user needs to be very familiar with the Analytical Tool in Safety Analyst in order to be able to use the map viewer. It requires significant learning and time. Hence, this research project proposed the development of an alternative and effective method to visualize in a graphical and spatial format the results generated by Safety Analyst. In addition, this study tries to evaluate the effectiveness of the proposed method based on users' needs and perceptions.

1.3 Study Objectives

The objective of this study is to develop and evaluate the effectiveness of a visualization system for assessing network safety analysis using Safety Analyst. To accomplish this objective, the following key capabilities are provided by the proposed system:

1. graphical displays, including the location and color-coded information for each module in Safety Analyst;
2. charts, tables, and a report summarizing safety performance measures; and
3. a Google Map and/or ESRI ArcGIS map displaying results .

In addition, a survey of traffic practitioners is conducted to try to evaluate the effectiveness of the proposed system.

1.4 Organization of Thesis

This report is organized in to five chapters: (i) Introduction, (ii) Literature Review, (iii) Safety Analyst, (iv) Visualization System for Safety Analyst, (v) Evaluation of the Visualization System, and (vi) Conclusions and Recommendations.

Chapter 1 provides an overview of the study including background, problem statement and objectives. Chapter 2 reviews literature related to the use of Geographic Information Systems (GIS) for crash data visualization. Chapter 3 provides a relevant overview of Safety Analyst. Chapter 4 discusses the development of the Visualization System for Safety Analyst. This chapter explains the importance of Google and ArcGIS maps. In addition, a description is provided about the limitations of Google Maps compare to ESRI tools and maps. Chapter 5 presents the evaluation of the Visualization System based on users' perceptions. This chapter explains the methodology adopted to evaluate the tool, data collection, analysis and results. Chapter 6 provides the conclusions and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

Roadway safety management involves the identification of crash locations with potential for improvement, diagnosis and selection of countermeasures, economic analyses of the countermeasures, and before and after safety effectiveness evaluation (Alluri & Ogle, 2011; Gan et al., 2012). Predominantly, GIS is an integral component of numerous crash analysis systems. The graphical display features and mapping capabilities provided by GIS have facilitated the analysis and interpretation of results.

2.1 Geographic Information Systems

GIS has been actively used in wide applications related to transportation engineering, hydraulic modeling and earth sciences. The specific nature of the tool has found its application in crash and pedestrian modeling and human factors (Pulugurtha et al., 2006; Troung and Somenahalli, 2011). Predominantly, various geographic information system (GIS) methods are used to analyze and visualize the data in the field of traffic safety. Graettinger et al. (Graettinger et al., 2005) and Roche (Roche, 2000) discussed how to represent different entities of highway components (roads, crashes, traffic volume) using various features such as lines, points, colors and shapes in ArcGIS. Krishnakumar et al. developed a GIS based tools to identify and rank the sites with potential for pedestrian safety improvements. The tool identifies high crash zones based on kernel density maps and ranks them based on a crash score. The entire map is projected with calculated densities in the ESRI Arc Map (Krishnakumar et al., 2005). The ranking of sites are in separate output in a tabular format. The user has to travel back and forth, to the map and table, to find the ranks and corresponding densities.

Likewise, Ohio Department of Transportation (ODOT) (ODOT, 2012) developed GCAT (GIS Crash Analysis Tool) which is capable of performing queries and displaying traffic crashes based on different attributes such as crash date, crash severity level, weather conditions, collision types, etc. The queried crashes can also be exported as a text file which could be further analyzed with the Microsoft Excel and the CAM tool developed by ODOT to represent the data with statistical charts and graphs (Aylo, 2010).

Xiao et al (Xiao et al., 2012) developed a road maintenance management system based on WebGIS using ArcGIS server and client system. ArcSDE client and ArcSDE server in the ArcGIS is used for data storage. The data is stored in the SQL format. The authors have developed a Web-based interface for querying, displaying the road maintenance data through thematic maps. But, the study does not provide clear information about the front-end visualization or creation of thematic maps using ArcGIS. Qin and Wellner developed GIS Highway Safety Review Tools (GIS-HSR tools) to identify high risk locations with data driven methodology using Python scripting which can be embedded with other tools in ArcGIS (Qin and Wellner, 2011). However the results interface of this tool lacks intuitive visualization and hence requires manual interpretation of the results.

University of Minnesota and Claremont Graduate University (SafeRoadMaps, 2012) developed SafeRoadMaps visualization tool that produces heat maps. The heat maps provide crash risk across an entire area which is similar to kernel density maps/hotspots in ArcGIS. The tool infers crash risk across the entire map area, instead of considering geometric boundary of entity or area where crashes occur. This limitation restricts use of the tool to its capabilities.

Similar to SafeRoadsMaps, usRAP tool was developed to visualize roadway safety by American Automobile Association (AAA) foundation for traffic safety (AAA, 2013a). This tool is a GIS based application for analyzing traffic safety which helps to determine the sites with highest and lowest risk of traffic crashes and fatalities. These sites are shown in the map with color codes to represent the risk level. This tool provides four basic types of risk maps: crash rate map, crash density map, crash rate ratio map and crash savings map which uses crash data for a five year period. Figure 1 shows the crash density map generated by usRAP with different color code information. The results from this tool are only based on observed crash frequencies. However, this tool can act as a major information source for DOTs and decision makers in setting the safety improvement priorities.

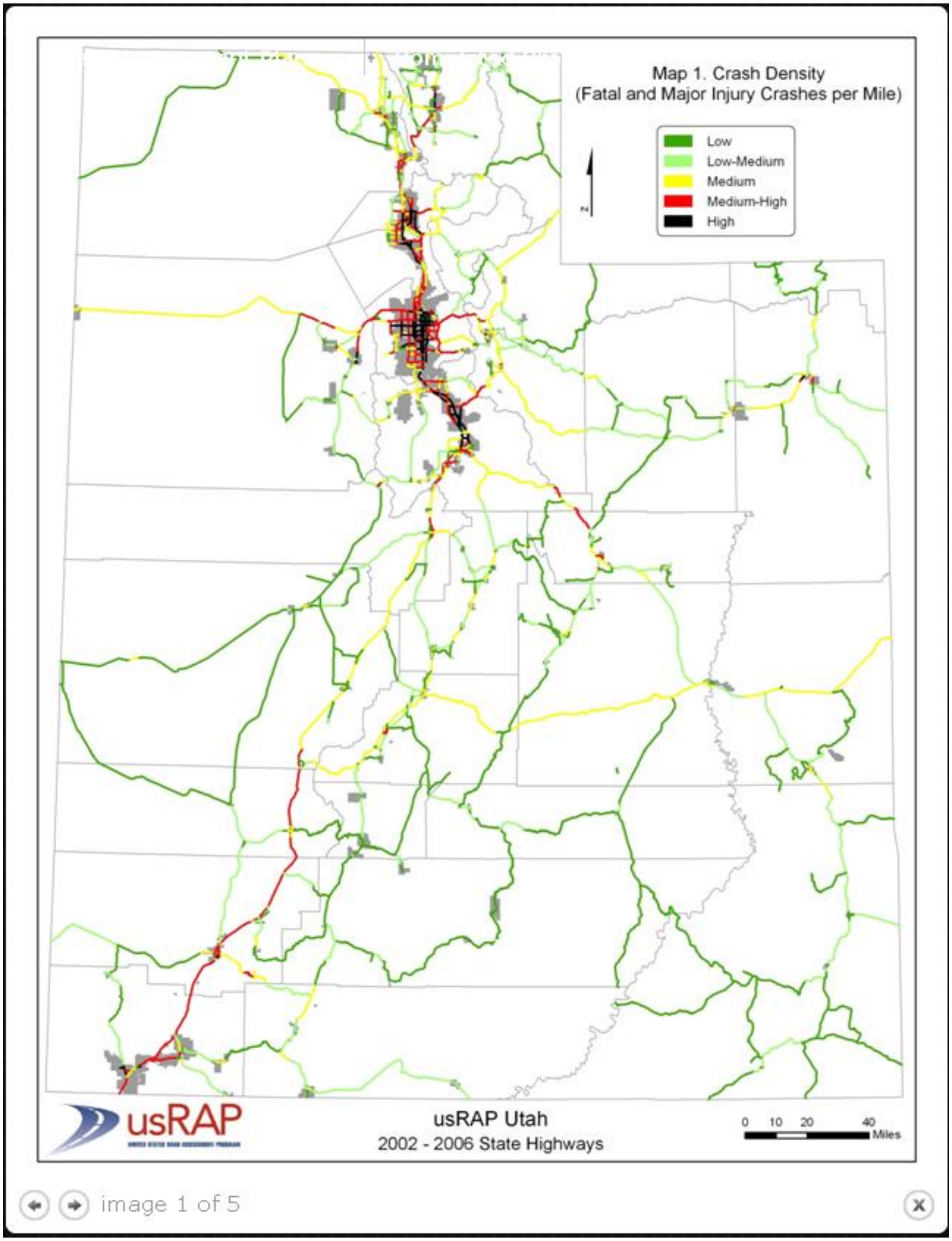


FIGURE 1 Crash Density map generated by usRAP (AAA, 2013b)

Critical Analysis Reporting Environment (CARE) was developed by the Center for Advanced Public Safety at the University of Alabama (CAPS, 2009a). Amongst the visualization tools, CARE tool is more advanced than its peers. CARE was developed primarily for crash analysis with both an online and desktop version. However, this tool can be used to analyze any type of data. It provides tool that allows sorting, analyzing and comparing the data using different variables in the data. The tool is equipped with major functions that allow statistical analyses with charts and graphical displays, hotspots generation, collision diagrams for specific locations, report generation for hotspots and spatial displays with the integration of ArcView.

The online version of CARE is known for its visual representation whereas the desktop version known for its statistical analysis ability. Both the versions provide various graphs with the help of querying and filter techniques based on crash attributes. CARE also has a GIS extension that enables spatial analysis. With this capability, CARE provides the sliding window line diagram. This feature provides a window of specified length that moves over a linear route segment which represents a stack of observed crashes those occurred along the route. This methodology is unique to CARE and easier to interpret the observed crashes. However, CARE does not provide any visual representation of results of high crash locations based on safety analysis (CAPS, 2009a). Figure 2 shows the desktop version of CARE while figure 3 shows the online version.

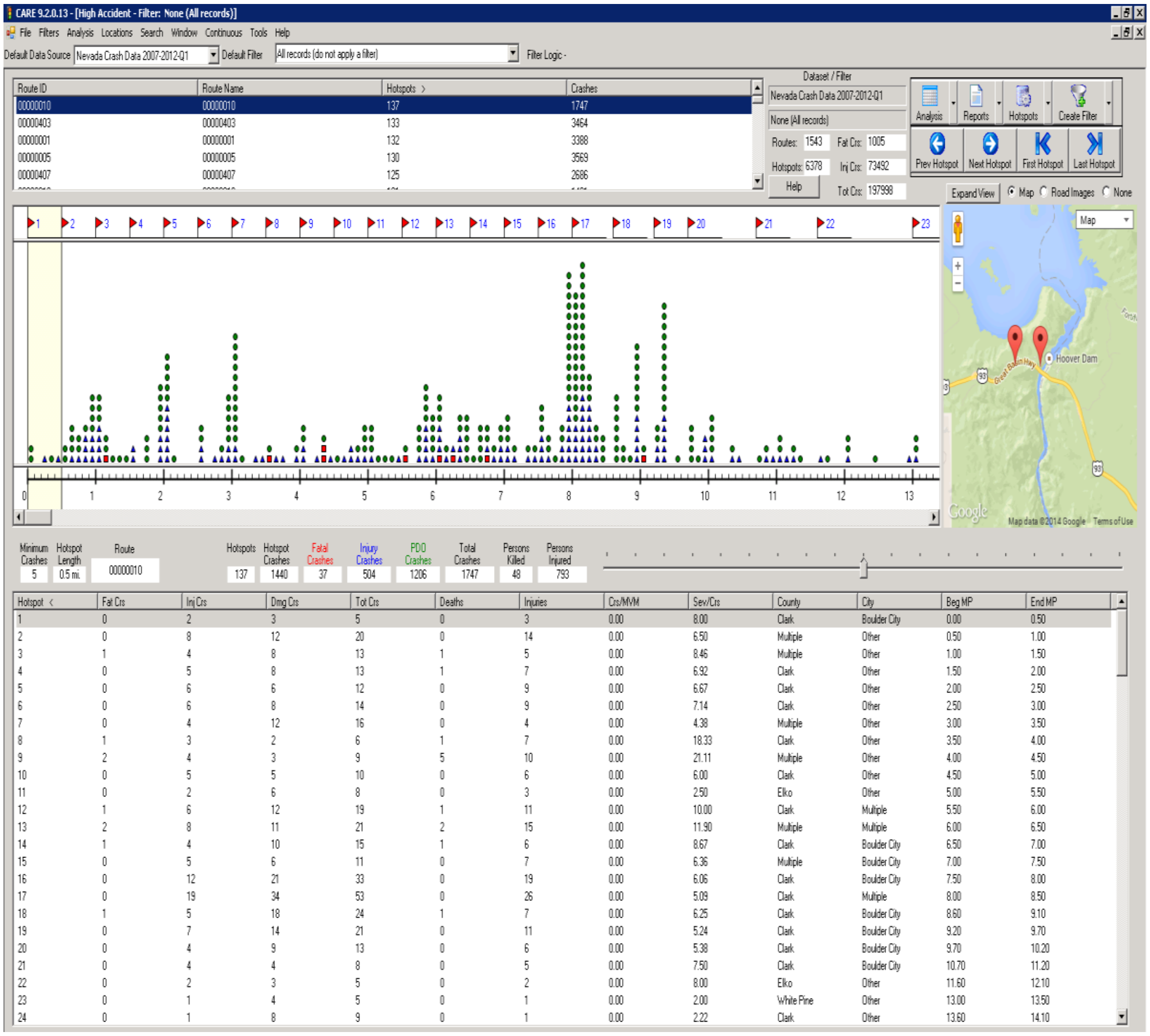


FIGURE 2 Desktop version of CARE interface with sliding window approach

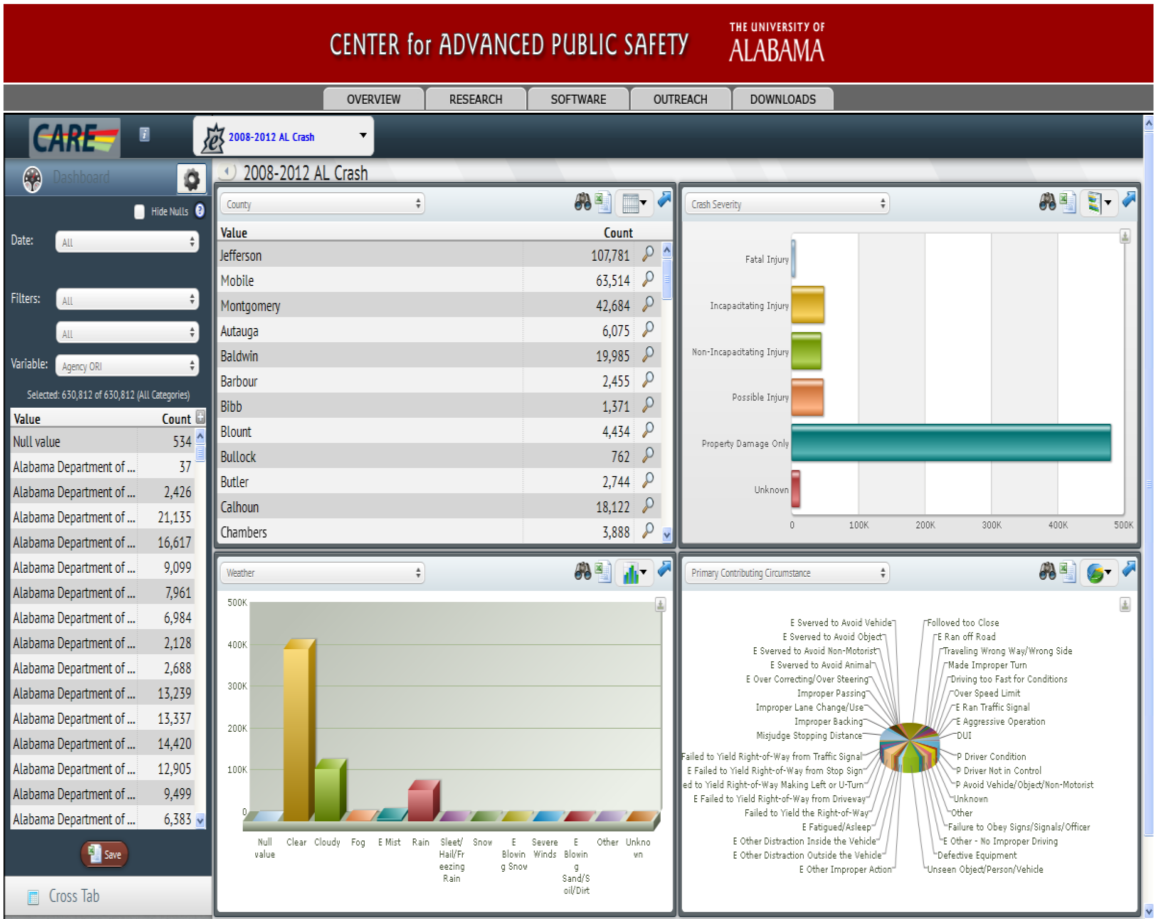


FIGURE 3 Web version of CARE interface (CAPS, 2009b)

Ma et al developed a GIS system that allows user to select site locations and display the Safety Analyst results spatially. The developed GIS system is capable to visualize both the input and output data of Safety Analyst. The tool allows the users to select the sites to analyze in the analytical tool of Safety Analyst which then provides the output of Safety Analyst in the developed GIS interface (Ma et al., 2012). The snapshot of the interface is shown in figure 4. However, the system developed by them only allows user to visualize the results of network screening module solely for the state of Florida.

FIGURE 4 GIS interface for Safety Analyst developed by Ma et.al, 2012

To the best of our understanding, most of the existing analysis tools, including Safety Analyst, do not provide visualization capabilities that facilitates user understanding of the output of all the modules with ease. This study proposed a Visualization System that addresses the current limitations. The following are the benefits of using the proposed system:

1. provides multiple graphical representations of the inputs and outputs for each module in Safety Analyst
2. Google map, non-commercial and ESRI ArcGIS, commercial maps are used to display spatial characteristics of the inputs and outputs
3. several charts and plots display various safety performance measures

2.2 Comparison of Google Maps and ArcGIS

Google Maps and ArcGIS provide different capabilities and associated limitations. Google maps are easily accessible. In contracts, ArcGIS requires an expensive desktop or server application. Additional characteristics for each of these two technologies are provided below.

Usability

Although ArcGIS is expensive, after purchase, there are not additional fees regardless of loads and usage. In contracts, Google Maps API is free for developers; however, after more than 25000 map loads per day for 90 consecutive days, Google starts charging based on each map load and usage. The user has the option to pay for each map loads or to buy a business version of Google Maps API (Google Developers, 2014).

Security

In general, ArcGIS maps are considered more secured than Google maps. Almost every large agency prefers ArcGIS over Google Maps. Google Maps has open access to the data stored in its cloud. Hence, there is always a chance for security threats unless the agencies host locally. In contrast, ArcGIS provides its own isolated network cloud based facilities for data storage (Landmark Geographic Solutions INC., 2012).

Data formats and maintenance

ArcGIS has the ability to work with a variety of data formats including .shp, .dbf, kml, Geodatabases, WFS and RASTERS. In addition, it can export the data into CAD and dbase files. In contrast, Google Maps are limited to KML and KMZ formats. Most of the initial data creation and maintenance works are performed using ESRI tools. Typically the users of such data prefer working within the ESRI environment over

Google Maps. This ultimately requires less data update, data conversion and errors (Landmark Geographic Solutions INC., 2012).

Offline performance

ArcGIS does not require Internet access. Google maps require Internet access. Although Internet is widely available, having the additional option to work offline is an added advantage.

Additional modeling and mapping capability

ArcGIS provides many simple and advance modeling and mapping tools that are not available in Google Maps. Although it is possible to develop those tools in Google Maps, significant programming may be required depending of the complexity of the required tool.

CHAPTER 3

SAFETY ANALYST

3.1 Introduction

As previously mentioned, Safety Analyst provides computer automated state-of-the-art tools to identify and manage system wide safety improvements in a cost effective way. Safety Analyst (ITT Corporation, 2011) consists of altogether four major tools that serve as a complete package of a highway safety management system: the Administration Tool, the Data Management Tool, the Analytical Tool and the Countermeasure Implementation Tool.

- The ***Administration Tool*** provides capabilities to set up Safety analyst software and to manage access to the use of the software. It can be used to create user defined attributes or to modify federally provided default data to include in the analysis such as the default SPFs present in the Safety Analyst can be replaced with the agency specific SPFs. In addition, this tool also provides the facility to edit the diagnosis questions and countermeasures.
- The ***Data Management Tool*** provides the capabilities to create and maintain Safety Analyst database. It is used to import the data by mapping a user developed database to Safety Analyst. After database-to-database mapping, post process and calibration can be performed in the same tool.
- The ***Analytical Tool*** is composed of four modules, which are responsible for traffic safety analysis and management programs (ITT Corporation, 2011):
    1. A *Network Screening Module* that reviews transportation network by employing empirical Bayes (EB) methodology to identify and rank the sites that have the

potential for safety improvements. The EB methodology addresses regression-to-the-mean bias in the observed data. It calculates estimated crash frequency based on observed and predicted crash frequency.

2. A *Diagnosis and Countermeasure Selection Module* that diagnoses sites with the accident patterns. It also generates collision diagrams for sites with observed crash characteristics. The countermeasure selection tool selects the list of countermeasures based on the diagnosis as well as a set of built-in questions answered by the users.
3. An *Economic Appraisal and Priority Ranking Module* that appraises such economic measures as the benefit-cost ratio and the net present value for multiple, selected alternative countermeasures. Priority ranking tool ranks these countermeasures based on economic appraisal for the implementation.
4. A *Countermeasure Evaluation Tool* that performs the 'before' and 'after' evaluation of the effectiveness of the implemented safety countermeasures.

- The ***Implemented Countermeasure Tool*** provides the capabilities to create a database comprised of the date, location and the type and nature of countermeasures employed in the highway system.

In summary safety analyst is a suite of tools that includes all the methods of roadway safety management process along with the integration of statistically proven EB technique for determining traffic safety.

With these tools and modules in mind, Figure 5 illustrates the conceptual framework for the proposed Visualization System.

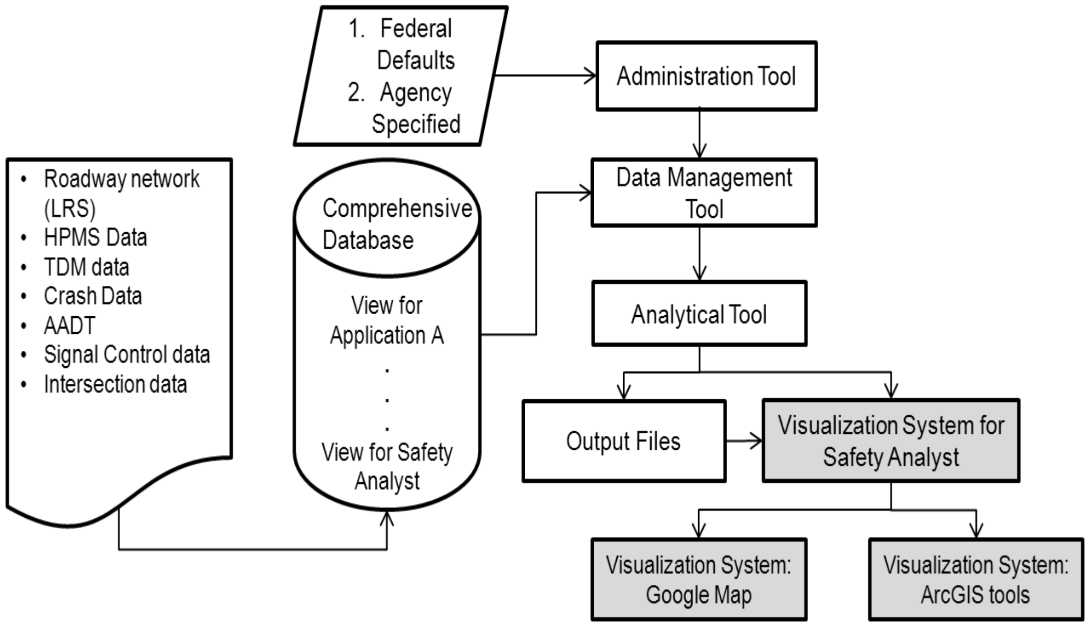


FIGURE 5: Conceptual framework for the proposed visualization system for Safety Analyst

3.2 Input Data

For input, Safety Analyst requires characteristics data for crashes, traffic and roadways, and/or ramps, and/or intersections. Each crash location has to be mapped to the location of a roadway segment, a ramp, or an intersection. Safety Analyst requires mapping to be based on one of four location reference systems: the Route/County/Milepost, the Route/Milepost, the Section/County/Distance, or the Section/Distance (ITT Corporation, 2011). As mentioned earlier, Safety Analyst has two methods to import data, file import and database-to-database mapping. The file-import method supports extensive markup language (xml) and comma separated value (csv) file formats. The database-to-database mapping method requires a database in a relational database management system. In addition, the database has to exist in a format supported by Safety Analyst.

A comprehensive database was created with the data from various sources, such as the roadway network; the highway performance management system (HPMS); the Travel Demand Model (TDM); and data for crashes, signal controls, intersections and annual average daily traffic (AADT). ArcGIS as well as data management tools developed by the University of Nevada, Las Vegas (UNLV) were used in the process to check consistency, integrate, extract, load, and transform the data. A comprehensive database was created storing all the crash, geographic, ramp, intersection, and roadway and traffic data in a raw format. The database developed required a particular formatting as Safety Analyst accepts its own compatible data format. Therefore, a View Tool was created to map the developed database in a database view consistent with the requirements of Safety Analyst.

Using Safety Analyst's Data Management Tool, the View database was mapped to the Safety Analyst database, using database-to-database mapping, in the data import. Then, post-processing was completed to develop site subtypes; calibration was performed as well in order to calibrate coefficients of the default Safety performance functions. The network screening module in the Analytical Tool was used to identify and rank sites with the potential for safety improvements. Using the module for diagnosis and countermeasure selection, top-ranked sites were diagnosed, and several countermeasures were selected. Using the module for economic analysis and priority ranking, selected countermeasures were analyzed and ranked based on economic measures.

3.3 Location Referencing System

As mentioned earlier the Safety Analyst supports four different types of location reference system for different facilities. It requires the location of segment, ramps or intersections in any of the following four systems (ITT Corporation, 2011).

i. Route/Milepost: In this system, a milepost value is assigned along the route of a particular facility. For example, the location of a roadway segment is provided with name or route number and its numeric begin and end milepost value.

ii. Route/County/Milepost: In this system, a milepost value is assigned to a route in a county. For example, the location of a roadway segment is provided with route name or route number, county name or county code and its numeric begin and end milepost values.

iii. Route/Section/Distance: In this system a segment length is assigned to a route instead of the milepost values. For example, the location of a roadway segment is provided with route name or number, section ID or code and the distance of the segment.

iv. Section/Distance: In this system, a route name or number is not provided. Section Id or code and the numeric distance of the segment are assigned to a particular route.

All the roadway inventory data for the Safety Analyst needs to be generated using one of the above mentioned any one of the four location reference system. Safety Analyst identifies the facility type and assigns the crash locations based on these location reference systems. In addition, the crash data also must possess either a milepost location or a distance value to exactly locate on any type of facility. For this study, Route/County/Milepost location reference system was used. The milepost values for each crash data can be computed using the Linear Referencing System of Arc map. The Linear Referencing System is the standard method of spatially referencing any feature by determining its relative location along a measured linear feature (ArcGIS Resource Center, 2010). This system is very important for both the visualization tool i.e. Google map and ArcGIS map, as it correctly locates the spatial location of potential sites of improvement in the maps.

3.4 Output Files

Safety Analyst provides an output in tabular format. The output from the network-screening module in the Analytical Tool is available in csv, portable document format (pdf), rich text format (rtf), and hypertext markup language (html) (ITT Corporation, 2011). Figure 6 shows the network screening results in html format and figure 7 shows the csv format.

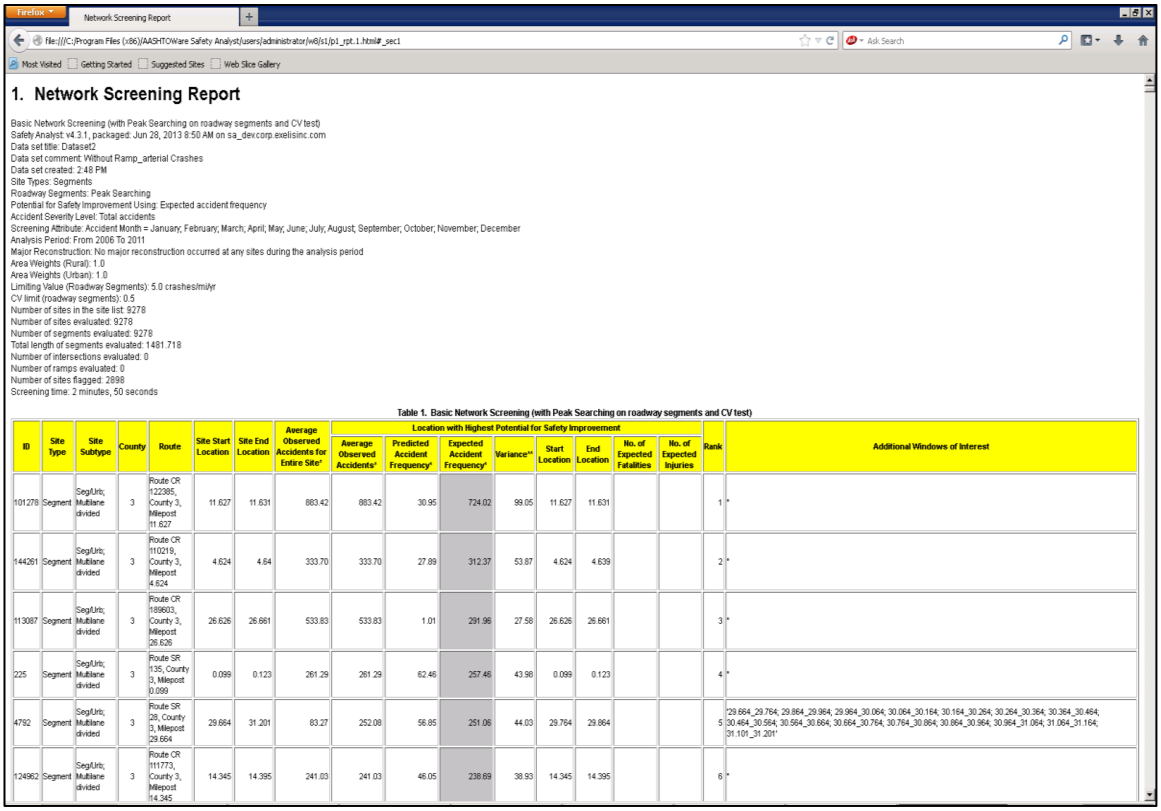


FIGURE 6 Network screening results in html format

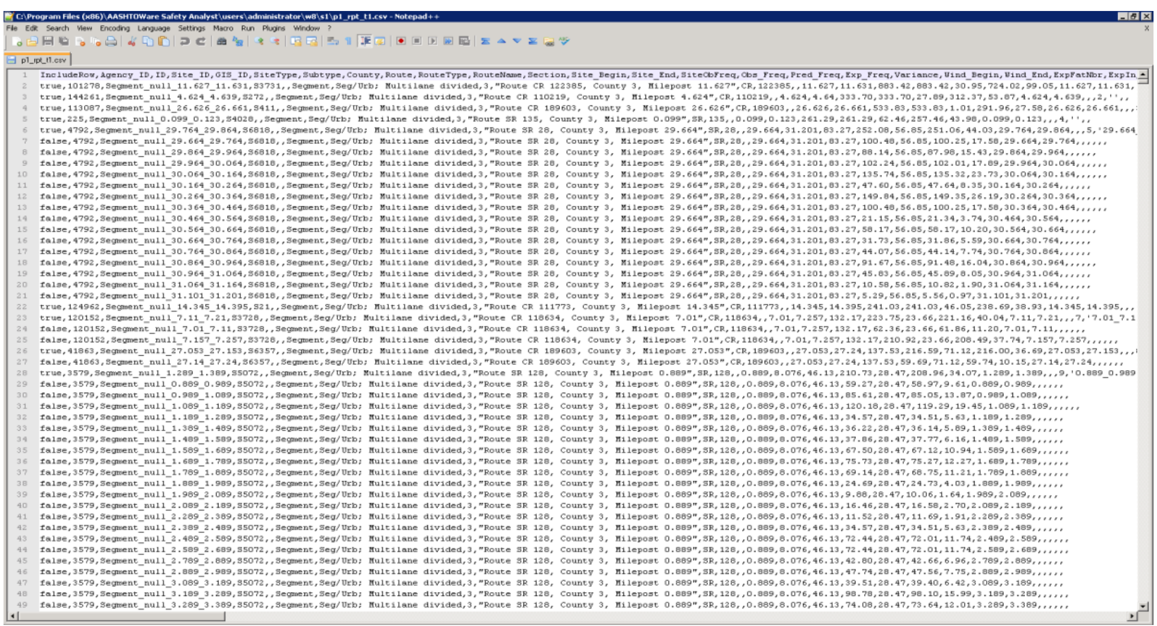


FIGURE 7 Network screening results in csv format

The csv file is used at the back end to process the results, and the pdf and rtf files are used at the front end for generating editable reports. The other three modules provide output in html, pdf, and rtf file formats. Table1 shows the output for the five top-ranked sites from the network screening module of the Analytical Tool.

TABLE 1 Format for Safety Analyst Results from Network Screening

ID	Site Type	Site Subtype	County	Route	Site Start Location	Site End Location	Average Observed Accidents for Entire Site*	Location with Highest Potential for Safety Improvement								Rank
								Average Observed Accidents*	Predicted Accident Frequency*	Expected Accident Frequency*	Variance **	Start Location	End Location	No. of Expected Fatalities	No. of Expected Injuries	
41046	Segment	Seg/Urb; One-way arterial	3	Route I 1, County 3, Milepost 39.56902	39.569	40.223	233.77	946.1	16.3	864.97	169.76	40.12275	40.22275			1
6557	Segment	Seg/Urb; One-way arterial	3	Route I 1, County 3, Milepost 43.93078	43.9308	44.364	81.07	221.79	12.23	197.66	38.41	44.2642	44.3642			2
7015	Segment	Seg/Urb; One-way arterial	3	Route I 1, County 3, Milepost 35.11215	35.1122	35.768	96.9	203.73	15.67	186.08	37.75	35.61215	35.71215			3
6612	Segment	Seg/Urb; One-way arterial	3	Route I 1, County 3, Milepost 36.72353	36.7235	36.979	67.78	198.62	15.43	181.41	36.28	36.87908	36.97908			4
6607	Segment	Seg/Urb; One-way arterial	3	Route I 1, County 3, Milepost 37.59608	37.5961	38.062	226.08	193.82	16.68	178.35	35.85	37.89607	37.99607			5

CHAPTER 4

VISUALIZATION SYSTEM FOR SAFETY ANALYST

In general, the data used in traffic safety has a spatial context. In 2011, the Federal Highway Administration (FHWA) released a peer-exchange summary report on the applications of GIS for highway safety (FHWA, 2011). This report summarized GIS capabilities and the spatial nature of data availability at various State DOTs. This report expressed a concern about the lack of visualization capabilities for safety programs among safety engineering professionals.

Assimilating the spatial capabilities of outputs for data and state-of-the-art tools, the proposed Visualization System for Safety Analyst includes two tools with alternative displays: Google Map and ArcGIS; both have multiple complimentary menus of the results, including spatial maps, tables, bar charts, and editable reports. The proposed system interacts with Safety Analyst to assist the user in every step of the analysis.

4.1 Google Maps Display Tool for Visualization

The Visualization System with a Google Map display was designed with multiple GIS functions – such as zoom in, zoom out, pan, and select sites – that allow the user to interact with the graphical display. Python, Java, JavaScript, HTML and CSS applications, at the back end, read, parse, extract, and process output files from Safety Analyst. Input data for locations, combined with the output data, is projected on the Google Map display. In this process, the coordinate system for the input location (NAD_1983_UTM_Zone_11N) is automatically converted to Google Map's projection system (GCS_WGS_1984). This tool provides support for all the four modules of the

Analytical Tool in Safety Analyst. The user can use this tool as a desktop or web-based application.

The network-screening module has two different methods to analyze the sites, (i) a conventional network-screening method and (ii) a method that provides a percentage report by site type. In turn, each method has several network-screening algorithms. The first method has six different algorithms and the second method has three different algorithms. Figure 8, 9 and 10 illustrates how the desktop application enables a user to choose the output file for a specific analysis method.

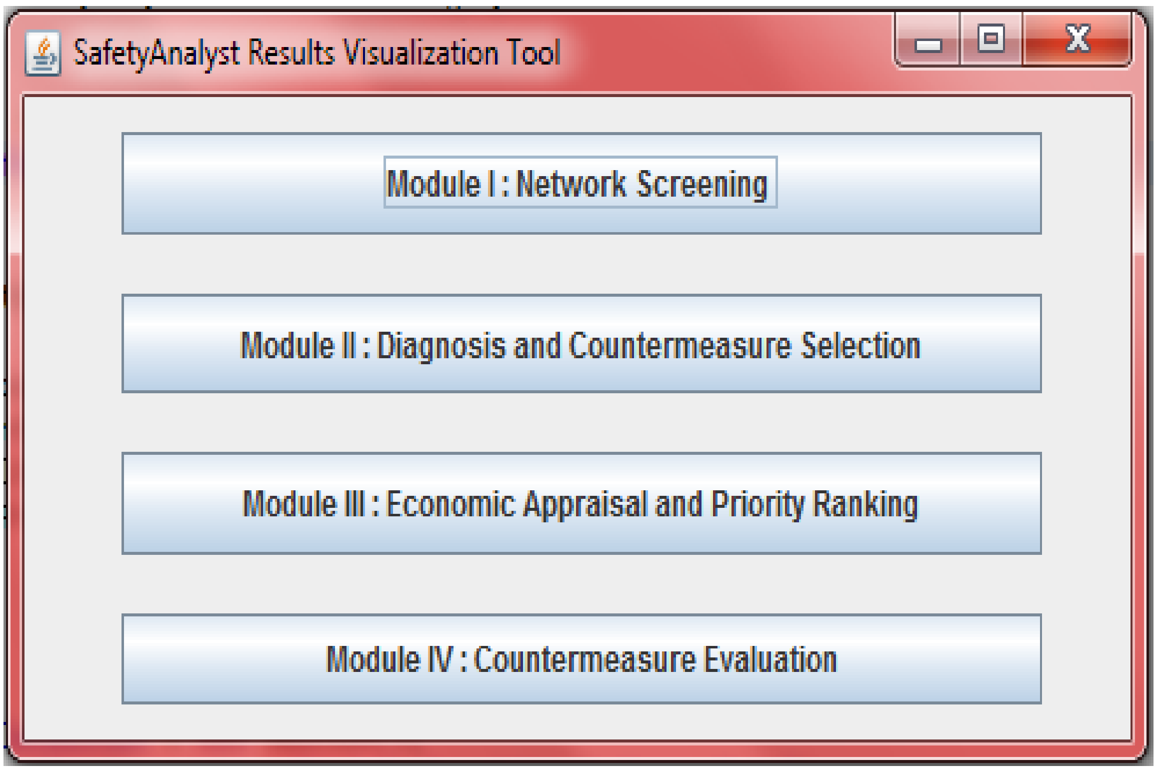


FIGURE 8 Selection of a Module using the Standalone Desktop Application

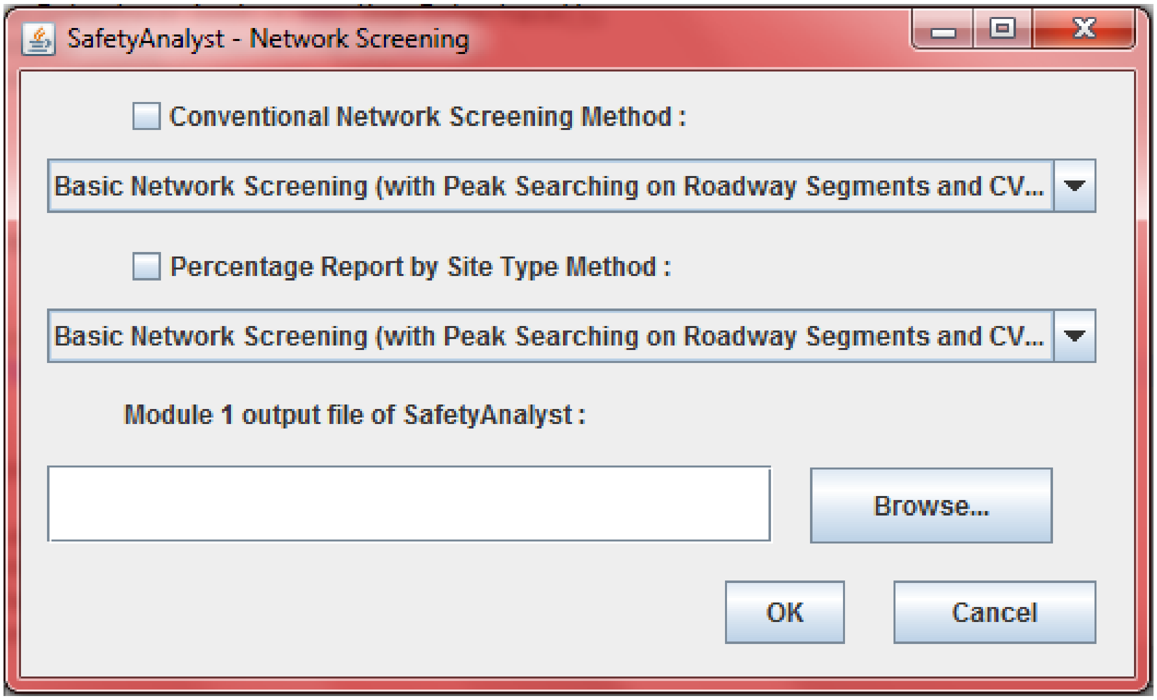


FIGURE 9 Selection of Network Screening Method using the Standalone Desktop Application

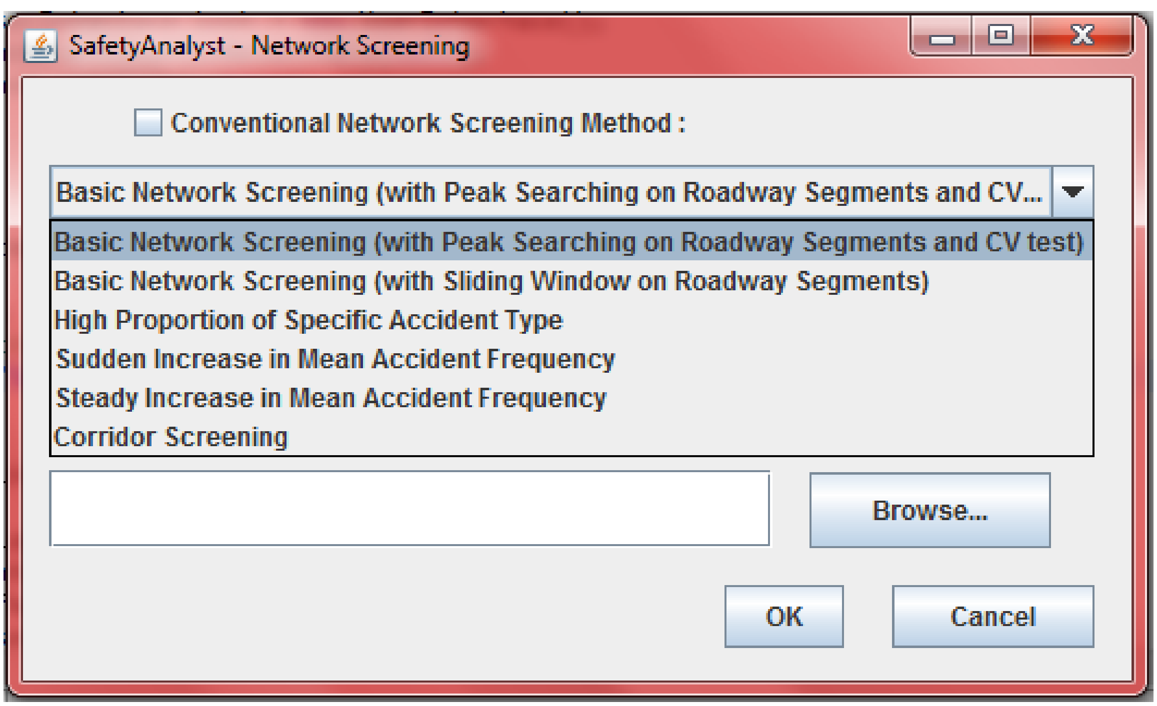


FIGURE 10 Selection of algorithm using the Standalone Desktop Application for Safety Analyst

The web-based application displays a comprehensive interface over the internet with the deployment of Safety Analyst results. Figure 11 shows the web interface of the Safety Analyst visualization, using a Google Maps display. A dropdown box is provided for each network screening method in order to select the type of algorithm output.

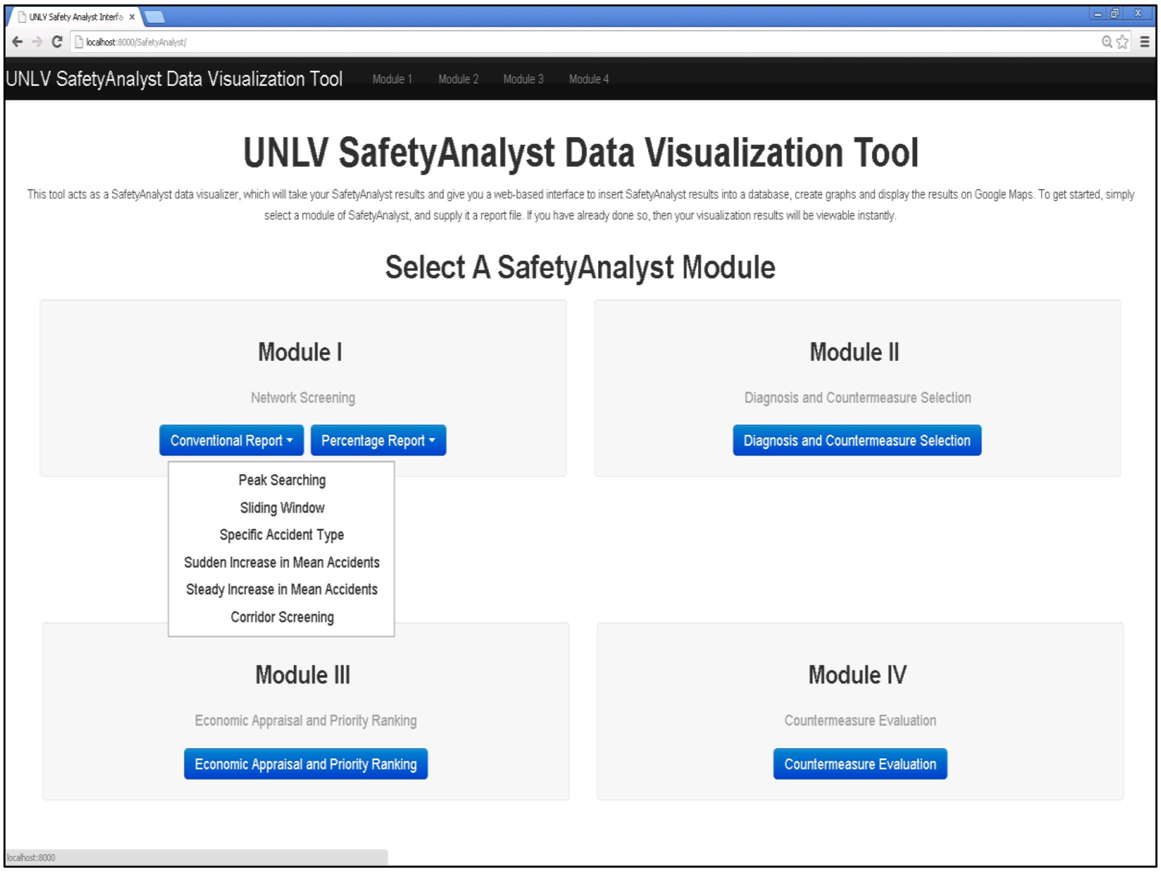


FIGURE 11 Web interface of output visualization for Safety Analyst, using Google Map

For network screening results, three complementary visualization options are provided by the web based application. Three tabs provide these options:

(i) The first tab enables the user to choose the ranking of the sites and generates, for the desired ranks, Figure 12 which provides a side by side display of spatial and tabular output. The Google Map is provided with a function to select the ranked sites with balloon icons. The icons have different colors to distinguish roadway segments, ramps, and intersections as shown in figure 13 (a), (b) and (c). The roadway segment and ramp sites are displayed as a line shape, using ‘begin’ and ‘end’ mileposts of the segment. The user can zoom in or select the specific site by clicking the balloon icons. Once the site is selected in Google Maps, the corresponding row of the site is highlighted in an adjacent table section.

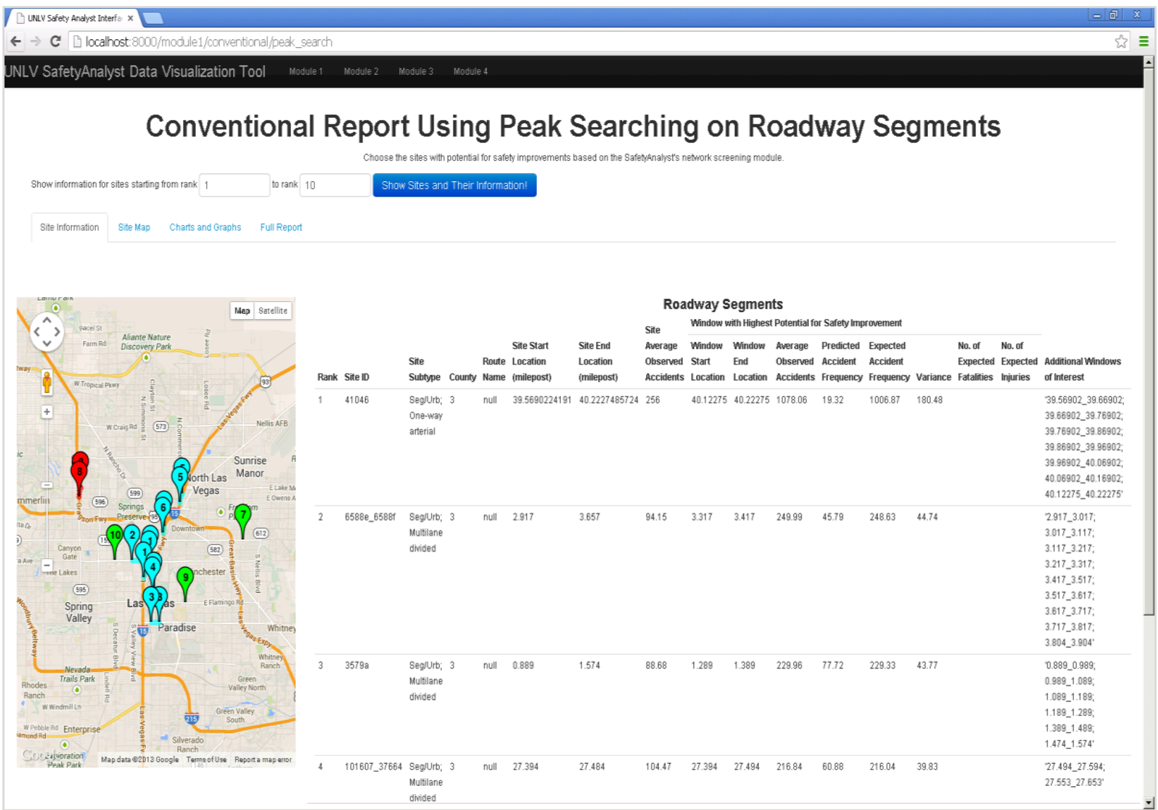
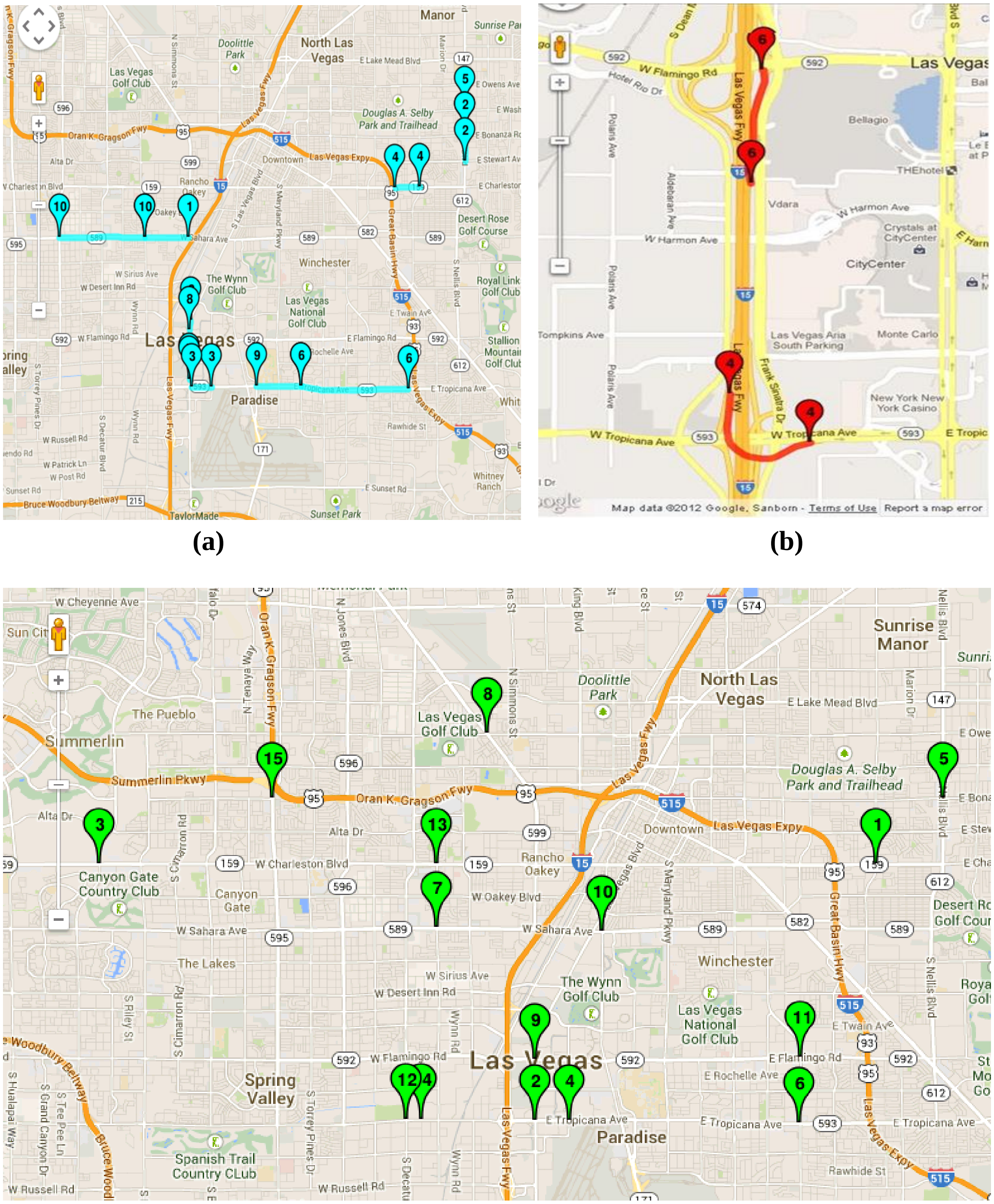


FIGURE 12 Visualization of network screening results in spatial and tabular format



(a) (b)

(c)

FIGURE 13 Visualization for (a) Roadway Segments, (b) Ramps and (c) Intersections

(ii) The second tab generates bar charts for various safety performance measures, such as observed, predicted, and expected crash frequencies (Figure 14). In addition, the user can select the type of graphs as either a stacked bar chart or a simple bar chart.

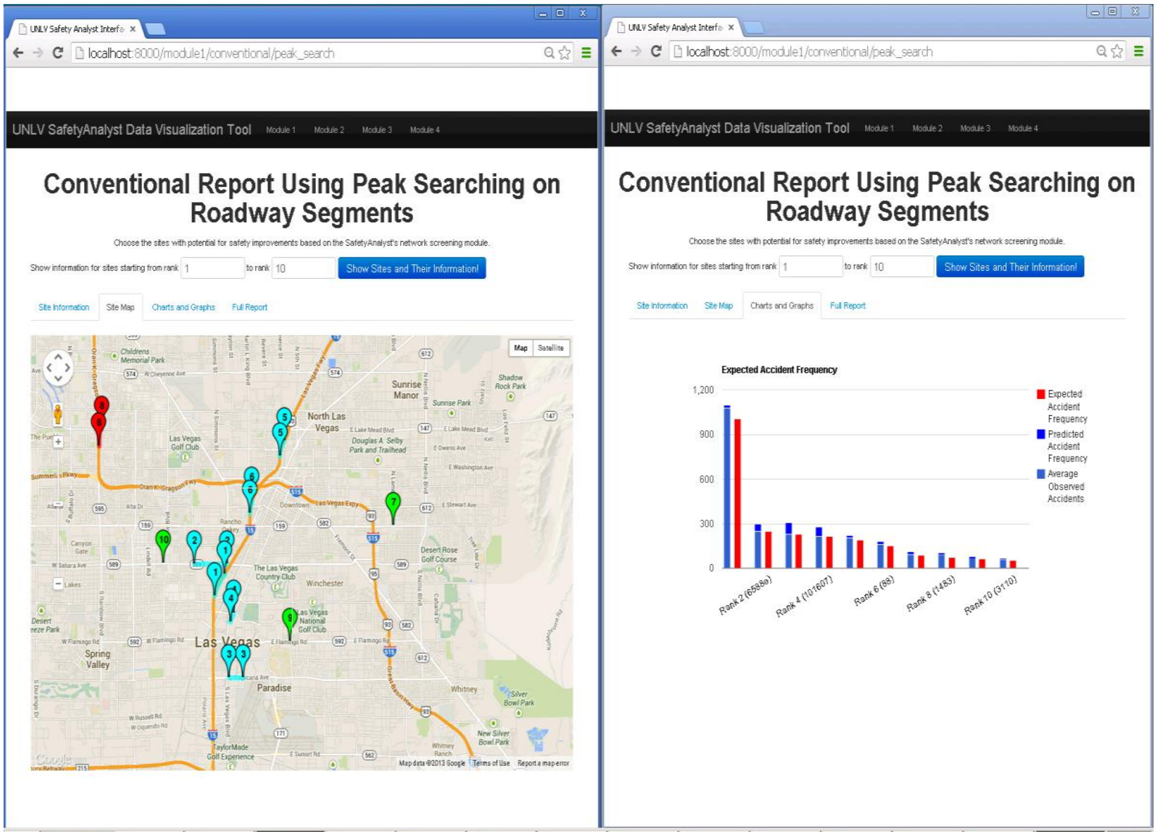


FIGURE 14 Visualization of network screening results in spatial and bar chart format

(iii)The third tab generates a Safety Analyst report with all results. The user has an option to edit this report with the inclusion of spatial site locations and bar charts (Figure 15).

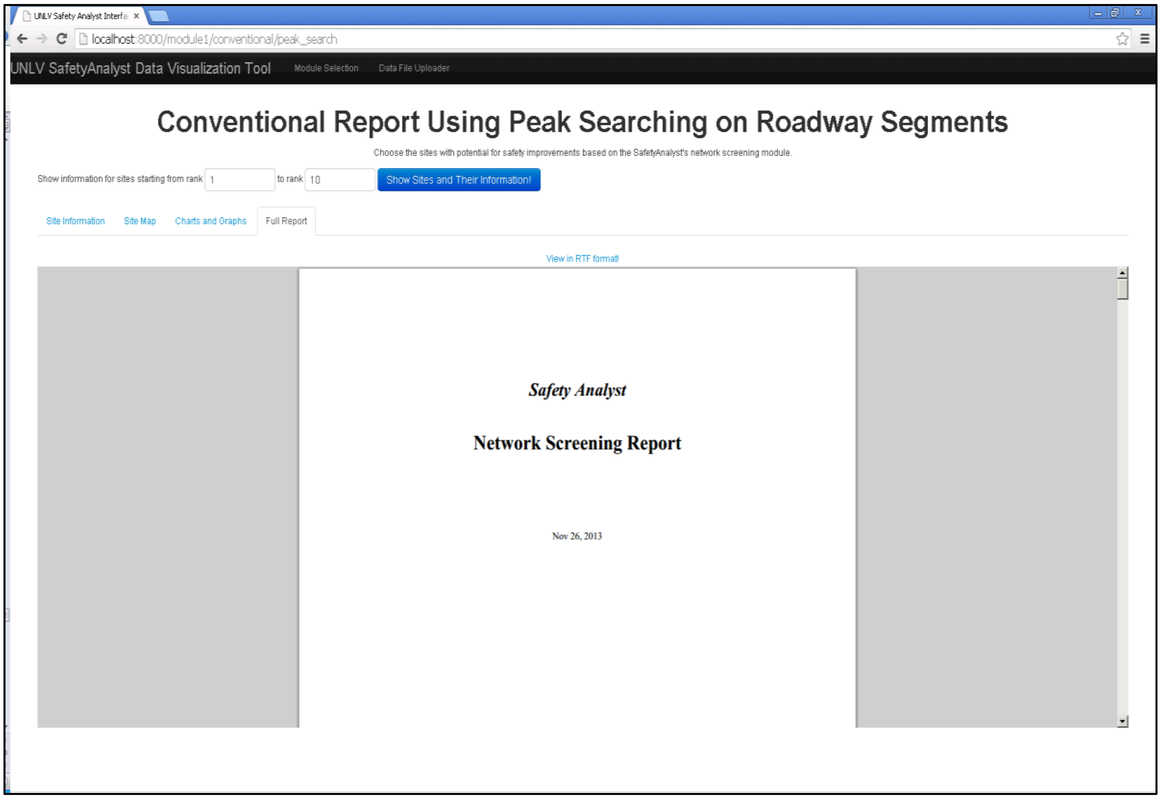


FIGURE 15 Visualization of network screening results in spatial and report format

The second module, Diagnosis and Countermeasure Selection, does not require visualization support, necessarily, because the interpretation of its output is straightforward. However, the proposed visualization tool provides an interface with the accident summary report, and collision diagram generated by Safety Analyst, along with the corresponding site map (Figure 16). This module can be expanded to include a condition diagram (AASHTO, 2010b).

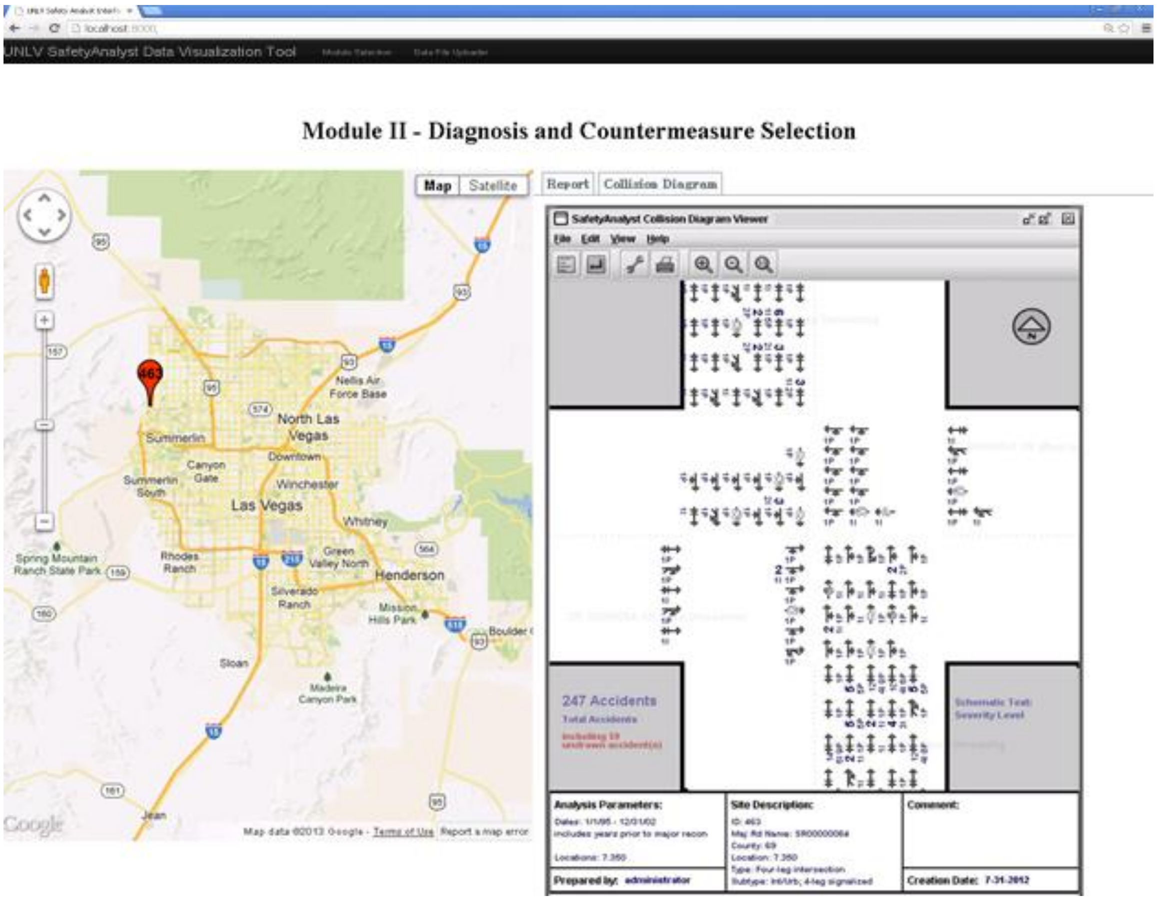
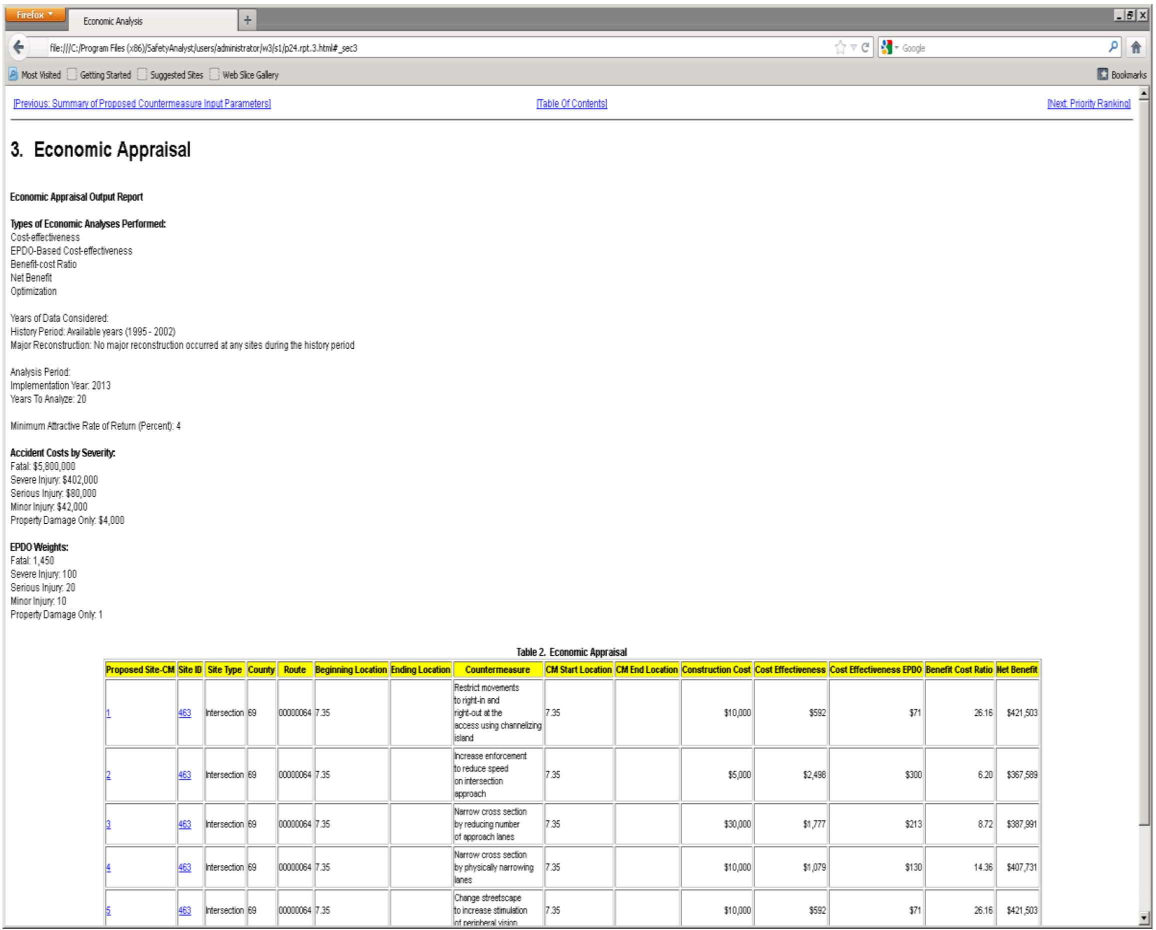


FIGURE 16 Visualization of Diagnosis and Countermeasure Selection, as provided by the proposed Visualization System

Figure 17 shows how the results from the third module are provided to the user by Safety Analyst, and Figure 18 illustrates the results as provided by the Google Map display tool. Measures for economic appraisal include the countermeasure cost per accident reduced, the benefit-cost ratio and/or the net present value (ITT Corporation, 2011). The user has the option to use default values or the state-specific value for various attributes used in the calculation of the economic appraisal methods. Priority ranking is provided for alternative countermeasures of a specific site or for countermeasures of multiple sites, based on the economic appraisal. It is easy and beneficial to compare the results for alternative countermeasures of single and multiple sites in a graphical format.

The application provides the location of multiple selected sites on a Google Map, a table with all the relevant information for each site, and bar charts for the desired variables.



[Previous: Summary of Proposed Countermeasure Input Parameters] [Table Of Contents] [Next: Priority Ranking]

3. Economic Appraisal

Economic Appraisal Output Report

Types of Economic Analyses Performed:
Cost-effectiveness
EPDO-Based Cost-effectiveness
Benefit-cost Ratio
Net Benefit
Optimization

Years of Data Considered:
History Period: Available years (1995 - 2002)
Major Reconstruction: No major reconstruction occurred at any sites during the history period

Analysis Period:
Implementation Year: 2013
Years To Analyze: 20

Minimum Attractive Rate of Return (Percent): 4

Accident Costs by Severity:
Fatal: $5,800,000
Severe Injury: $402,000
Serious Injury: $80,000
Minor Injury: $42,000
Property Damage Only: $4,000

EPDO Weights:
Fatal: 1,450
Severe Injury: 100
Serious Injury: 20
Minor Injury: 10
Property Damage Only: 1

Table 2. Economic Appraisal

Proposed Site-CM	Site ID	Site Type	County	Route	Beginning Location	Ending Location	Countermeasure	CM Start Location	CM End Location	Construction Cost	Cost Effectiveness	Cost Effectiveness EPDO	Benefit Cost Ratio	Net Benefit
1	463	Intersection	69	00000064	7.35		Restrict movements to right-in and right-out at the access using channelizing island	7.35		$10,000	$592	$71	26.16	$421,503
2	463	Intersection	69	00000064	7.35		Increase enforcement to reduce speed on intersection approach	7.35		$5,000	$2,498	$300	6.20	$367,589
3	463	Intersection	69	00000064	7.35		Narrow cross section by reducing number of approach lanes	7.35		$30,000	$1,777	$213	8.72	$387,991
4	463	Intersection	69	00000064	7.35		Narrow cross section by physically narrowing lanes	7.35		$10,000	$1,079	$130	14.36	$407,731
5	463	Intersection	69	00000064	7.35		Change streetscape to increase stimulation of peripheral vision	7.35		$10,000	$592	$71	26.16	$421,503

FIGURE 17 Economic appraisal results, as provided by Safety Analyst

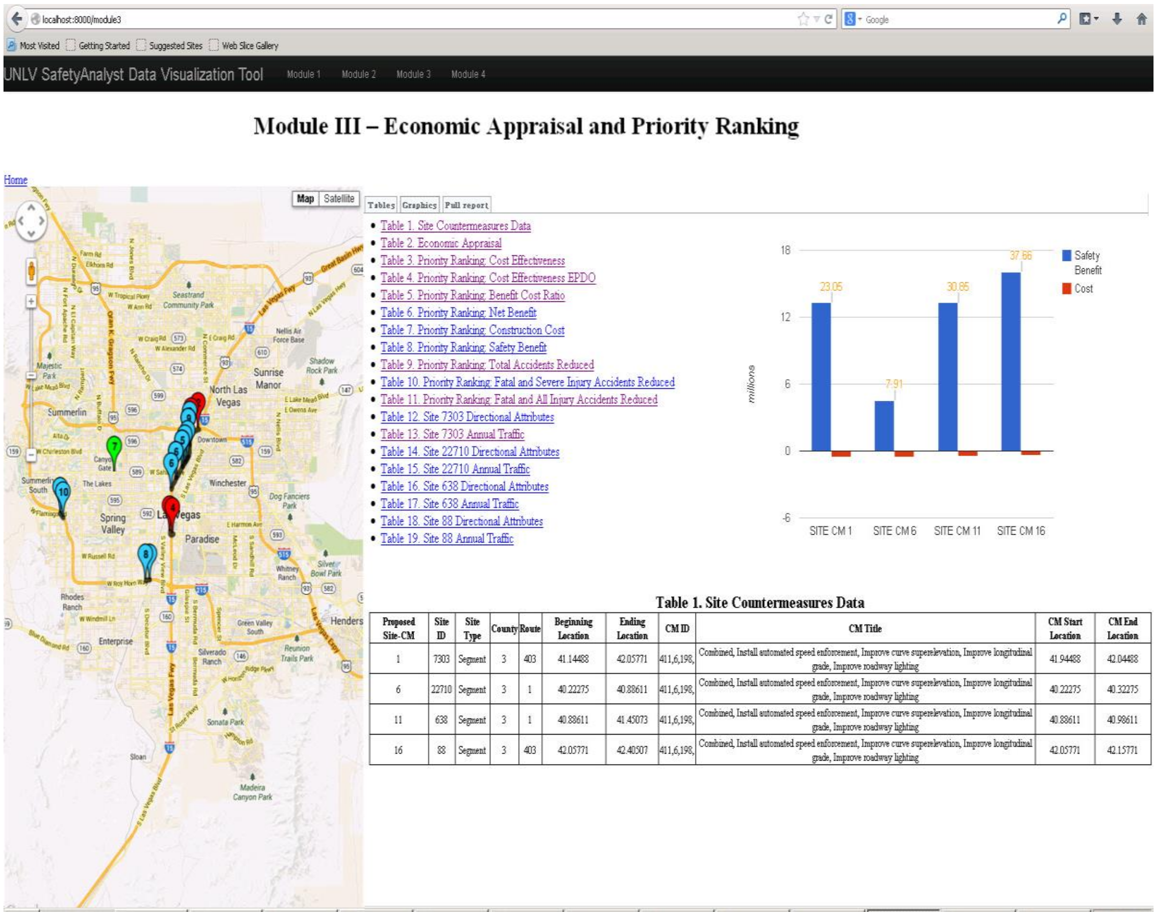


FIGURE 18 Results for economic appraisal and priority ranking, as provided by the proposed Visualization System

The visualization for the fourth module, countermeasure evaluation, was developed to provide the graphs of the 'before' and 'after' evaluations of the implemented countermeasures. The Google Map is used to display the site location in order to advance the improvement of the potential sites after the implementation of countermeasure.

4.2 ESRI ArcGIS Display Tool for Visualization

This tool assimilates various functions of ArcGIS with Safety Analyst outputs to give an application-based spatial visualization. ArcGIS is known for its strong ability to map and visualize data, integrate and share data, provide spatial and statistical analyses of data, and its customization capabilities (ESRI, Undated). Currently, this tool supports only the network-screening module. Visualization with ArcGIS tools provides further modeling and computing capabilities. At the front end, this tool has a map view frame, a data layers frame, a browser window, selection windows, and menu tabs. At the back end are Python scripts that read, parse, extract, and process the output from Safety Analyst. Figure 19 displays the GUI of the visualization.

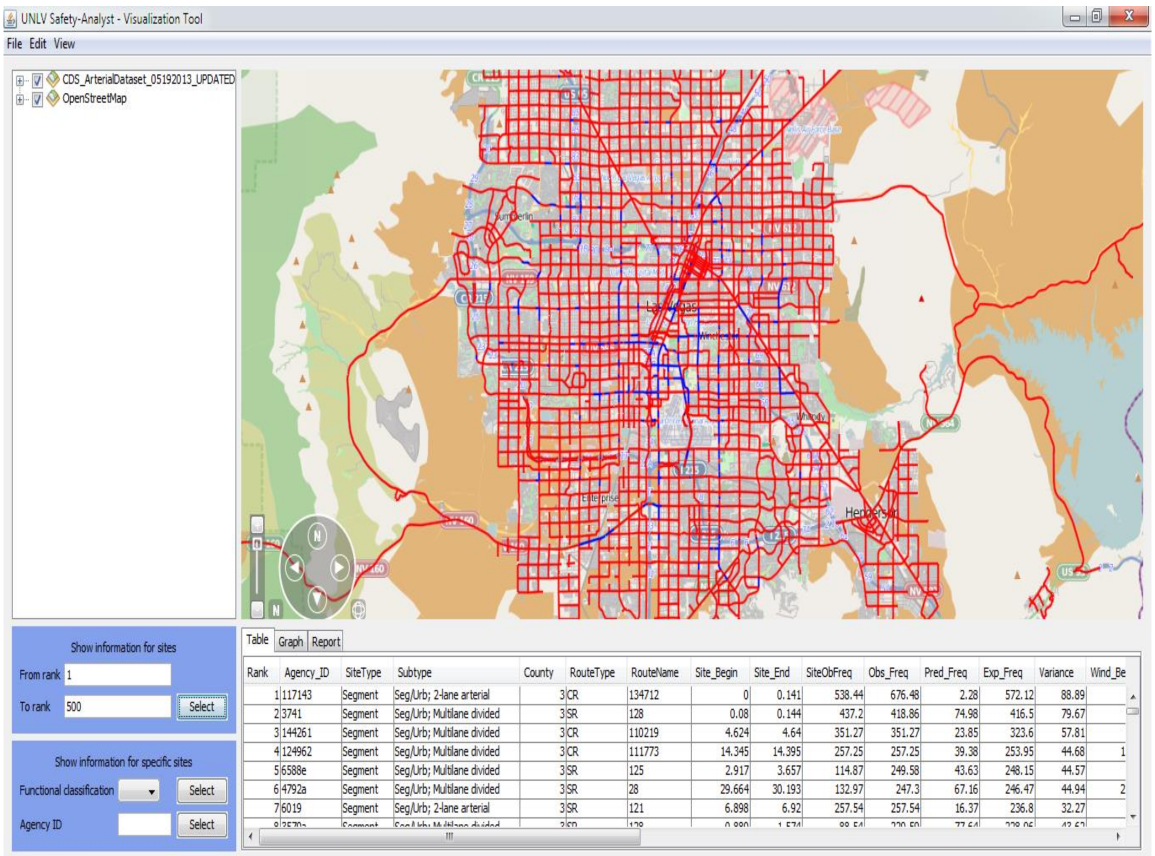


FIGURE 19 Visualization with an ArcGIS portal view

Map Viewer and Data Layer Frame

The Map viewer displays the base maps from the ArcGIS. The map viewer, along with the navigation bar, allows the user to execute basic operations, such as zoom in, zoom out, pan, and full extent. It has operational tools, including selecting and unselecting data elements in the map; and adding base layer maps, such as Open Street maps, Bing maps, or ESRI world imagery maps. The data-layer frame displays the layers being used for the map viewer and analysis. The layers can be turned on or off, based on the needs of the user.

File-browser Function

The browser window enables the user to choose the desired output file. At the back end of the tool, a Python script processes csv output files from Safety Analyst. This script maps the Agency Site ID of the Safety Analyst output file with the agency site ID of the existing source or base layers, i.e., roadway segments, ramps, or intersections. Consequently, this functionality avoids stating the coordinate system to project and overlay with the base layers.

Selection Function

By means of the selection window, sites with the highest potential for safety improvement can be selected based on network screening ranks. With this function, Python scripts at the back end select and highlight the ranked sites on the map. In addition, the user has an option to select ranked sites based on Functional Classification/Site ID or vice versa. For example, the user can enter 'Functional Classification as 1' and then click 'Select', and the map viewer displays all the ranked sites under Functional Class 1. Then, the user can select the sites among the ranked sites based on 'From Rank' and 'To Rank'.

Menu Tabs

Three complimentary displays are embedded in the menu tab beneath the map viewer. Based on the selection of ranks, the Graph tab displays the stacked bar chart, as shown in Figure 20. The stacked bar chart summarizes the performance measures for observed, predicted, and expected crash frequencies provided by Safety Analyst. Figure 21 shows the enlarged version of the bar chart generated by the proposed visualization tool. The table tab shows the Safety Analyst output in the table format, and the report tab generates the report in an editable version.

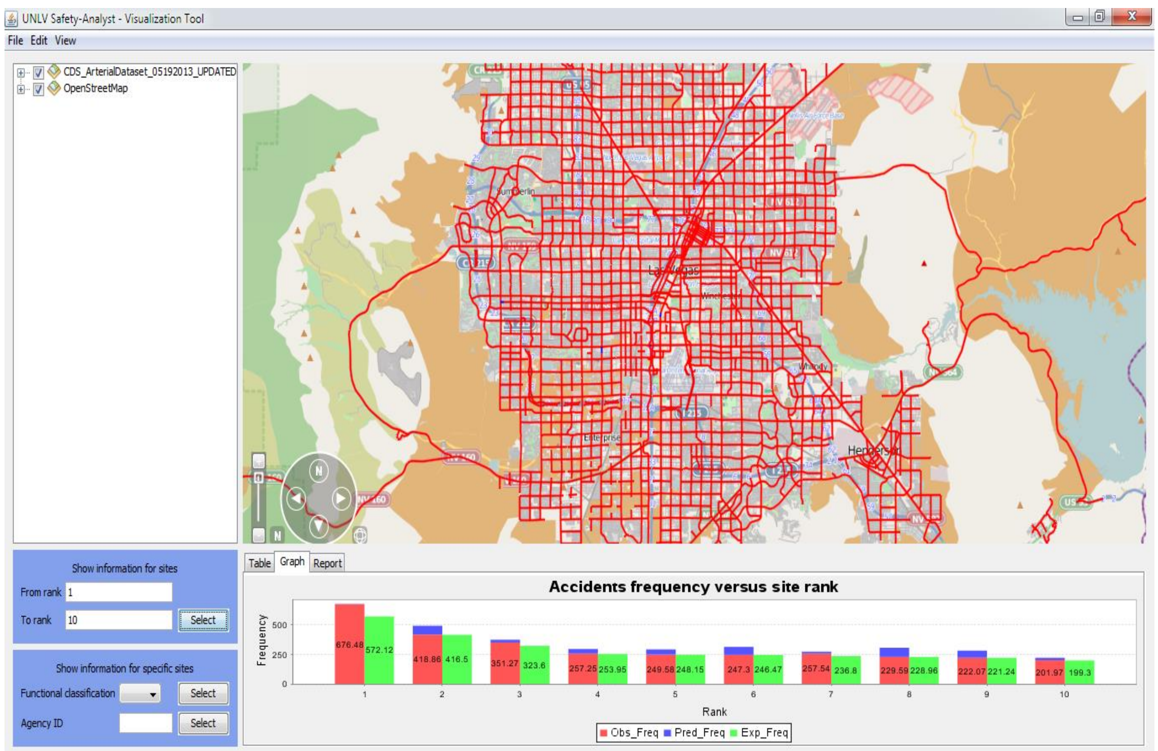


FIGURE 20 Visualization of network screening results in spatial and bar chart format

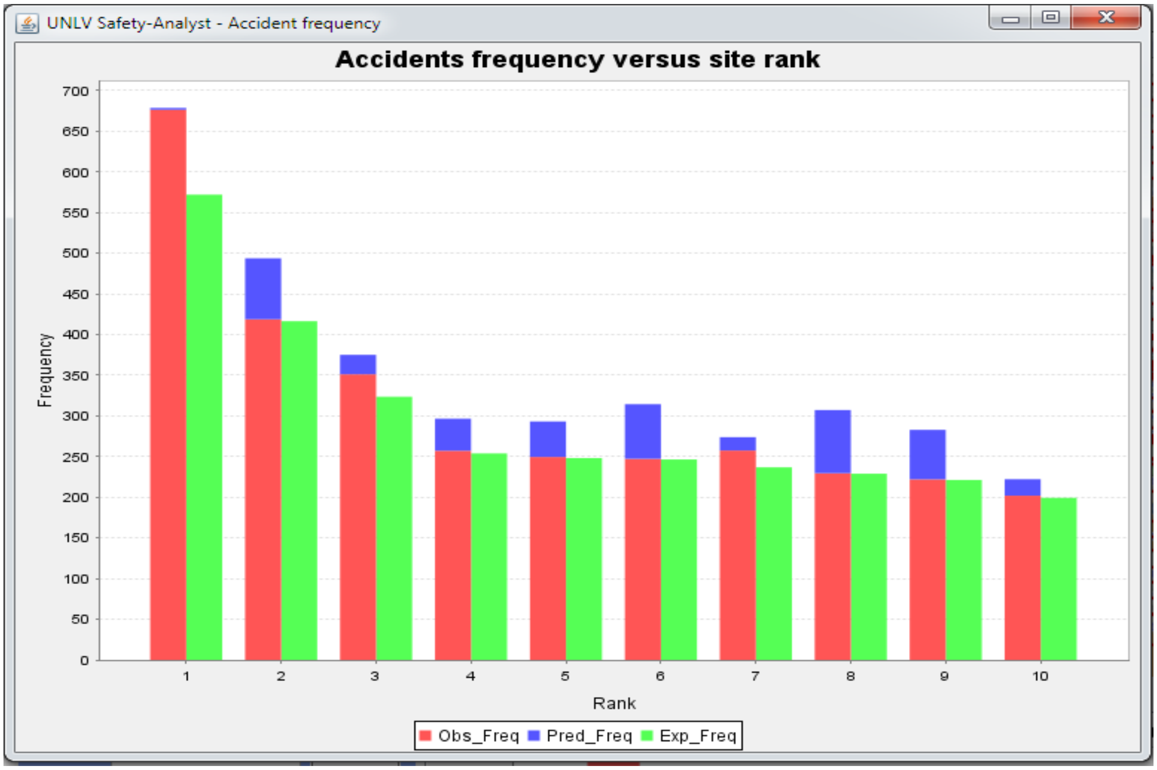


FIGURE 21 Enlarged view of the bar chart generated by the visualization tool

Data Editing Function:

This function allows the user to open and edit the attribute table of the source or base layer file. The user can easily rewrite the attributes and save for future reference. The user can make a copy of the original source layer and perform the editing function to save as a new layer file.

CHAPTER 5

EVALUATION OF THE VISUALIZATION SYSTEM

A survey questionnaire was developed and used to evaluate, to the extent possible, the effectiveness of the propose visualization system. The survey questionnaire is provided in Appendix A. Given various time constraints and limited resources, only the Google Maps version of the proposed visualization system was evaluated. The survey was developed with questions grouped in three major categories:

- Experience with Safety Analyst and the proposed Visualization System
- Usability
- Experience of the respondents on various transportation fields

The first category included questions to capture the users' familiarity with the Analytical Tool in Safety Analyst. In addition, questions were designed to capture the user's experience and associated preference with results provided using and not using the proposed Visualization System. The second category of questions sought to evaluate the overall usability of the Visualization System. The third category of questions was designed to collect relevant information about the technical background of the responders.

5.1 Data Collection

In order to include a representative sample of the population of potential users of the Visualization Tool, the survey was administered only to traffic safety engineers, transportation engineers and transportation engineering students. A hands on tutorial of Safety Analyst and the developed Visualization System was provided to NDOT engineers and planners as well as to members of the safety engineering team of the University of

Nevada, Reno (UNR). Similarly, the tutorial was also provided to transportation engineering students at the University of Nevada, Las Vegas. Finally, a similar tutorial was provided to interested participants of 93rd Transportation Research Board (TRB) Annual Meeting, 2014. Altogether, a total of 38 responses were collected. Table 2 provides the counts of responses.

TABLE 2 Total Number of Responses

Respondents	Count	Percentage
NDOT and UNR	11	29%
UNLV	22	58%
TRB	5	13%
Total Respondents	**38**	**100%**

5.2 Data Coding

Most of the questions were prepared using a 5 point Likert scale starting from Strongly Agree to Strongly Disagree. Codes were assigned to each answer given numerical weight. Table 3 shows the options to the answers as well as the corresponding codes/weights. These codes were used to compute the mean value of responses. Questions with a large mean value are associated with Strongly Agree. In contrast, questions with a small mean value are associated with Strongly Disagree.

TABLE 3 Number Coding For the Type of Answer of the Respondents

Answer Options	**Code**
Strongly Agree	5
Agree	4
Neutral	3
Disagree	2
Strongly Disagree	1

5.3 Distribution of Responses

An important aspect to consider is how much experience influences users' perceptions and preferences.

5.3.1 Experience with Traffic Safety Studies

Table 4 provides the distribution of responses with experience conducting traffic safety studies.

TABLE 4 Total Numbers of Responses with Traffic Safety Experience

Categories	**Total Respondents**
experience group with 1-5 years	53%
experience group with 6-10 years	18%
experience group with 11-15 years	13%
experience group with 16+ years	16%

The large number of sample in group 1-5 is a consequence of having the majority of the respondents being UNLV students.

5.3.2 Experience with Traffic Engineering Studies

Table 5 provides the distribution of responses with experience conducting traffic engineering studies.

TABLE 5 Total Numbers of Responses in with Traffic Engineering Experience

Categories	Total Respondents
experience group with 1-5 years	47%
experience group with 6-10 years	21%
experience group with 11-15 years	18%
experience group with 16+ years	13%

5.3.3 Experience with Traffic Planning Studies

Table 6 provides the distribution of responses with experience conducting transportation planning studies.

TABLE 6 Total Numbers of Respondents with Transportation Planning Experience

Categories	Total Respondents
experience group with 1-5 years	58%
experience group with 6-10 years	11%
experience group with 11-15 years	24%
experience group with 16+ years	8%

5.3.4 Experience with GIS

Table 7 provides the distribution of responses with GIS experience.

TABLE 7 Total Numbers of Responses with GIS Experience

Categories	Total Respondents
experience group with 1-5 years	55%
experience group with 6-10 years	34%
experience group with 11-15 years	11%

5.4. Overall Rating

The first section of the questionnaire contained a total of 10 questions. Most of these questions are related to the capabilities of the Visualization System to help the user navigate through the various modules and tools in Safety Analyst. In addition, it contains questions about the capabilities of the System to present and communicate information to the users. Table 8 shows the average rating for the responses received for the questions about the experience of the users with the Visualization System.

TABLE 8 Overall Rating about the Experience with the Visualization System

Respondents Ratings for the Visualization tool based on:	Mean of Total Sample	Standard Deviation
1. Clearly complements SA location options	4.34	0.53
2. Helps to perform preliminary diagnosis before going to field	4.29	0.65
3. Helps to perform entire diagnosis of the sites without going to the field	2.37	0.85
4. Helps to select effective countermeasure	3.39	0.97
5. Effectively presents information to decision makers	4.08	0.54
6. Assists in step by step procedures for all SA tools resulting prompt decision and actions	4.00	0.77
7. Is only important for network screening tool of SA	3.08	1.00
8. Finds out the errors in the input data and actual site characteristics	3.84	0.75
9. Enables sharing of information regarding sites with potential for safety improvement across various divisions within an agency	4.00	0.77
10. Improves the communication between analyst and the decision makers	4.29	0.52

In general, the results clearly indicate the preference for using the Visualization System in conjunction with Safety Analysis. The answers to the first question indicate that the Visualization System clearly complements the location options provided by Safety Analyst. This question has the highest mean value, 4.34, suggesting that it was extremely evident to most of the respondents that the Visualization System complements Safety Analyst in terms of location. The entire diagnosis of the sites with the visualization tool without going to the field was ranked with smallest mean value, 2.37. This is associated with Disagree on the Likert scale. However, the second question stating that the Visualization System helps to perform preliminary diagnosis without going to the field was ranked with the second highest mean value, 4.29. This suggests that although the preliminary diagnosis can be performed using the Visualization System, a detailed diagnosis of the sites without going to the field is not recommended in any case. This is expected as field investigation is a major part of roadway safety management process. The Visualization System is rated with the second highest mean value, 4.29, in terms of its ability to improve communication between the analyst and the decision makers.

5.5. Overall Rating of the Visualization System in Terms of Usability

Table 9 provides the mean values associated with the usability of the proposed Visualization System.

TABLE 9 Overall Rating about the usability of the Visualization System

Respondents Ratings of the Visualization tool based on:	Mean of Total Sample	Standard Deviation
11. Presentation of results compared to text/table formats as provided by SA	4.16	0.68
12. Helps to learn about SA	3.63	1.13
13. Demands less time and manual interaction	3.76	0.94
14. Conveys clear sense to its intended users	3.92	0.94
15. Very simple to use and visually attractive	3.92	0.94
16. Makes interaction with SA more intuitive	3.76	0.82
17. Appropriate for all users	3.55	0.98

The responders clearly indicate their preference for using the Visualization System over Safety Analyst alone. This is illustrated by the mean value of 4.16 in question 11. Almost all the questions in this category have mean values near to the "Good" rating in the Likert scale. The lowest mean value, 3.55, is associated with question 17. This suggests that it was almost a neutral average response. Hence, we could conclude that the Visualization System is only appropriate for those users who are familiar with the Safety Analyst.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

Conclusions

Safety Analyst provides state-of-the-art analysis tools to prepare a comprehensive program for highway safety management. With the advanced empirical Bayes methodology, Safety Analyst has tremendous data analysis capabilities. Safety Analyst includes a map viewer display with very limited visualization capabilities. The Visualization System proposed in this study facilitates the use of Safety Analyst. It provides displays with location and color-coded information as well as charts and tables summarizing safety performance measures. In addition, Google Maps and/or ESRI ArcGIS can be used to generate the displays. The system transforms tabular results into intuitive displays that support both detailed analysis as well as higher-level decision making. The charts provide various degrees of resolution and aggregation.

A survey questionnaire was used to evaluate the effectives of the Visualization System to complement and enhance the capabilities provided by Safety Analyst. The overall analysis suggested that people support the use of the proposed Visualization System for Safety Analyst. In addition, people find the Visualization System easy to use, especially when people are familiar with Safety Analyst.

Future Work

The proposed Visualization System needs to be further developed to enable capabilities to support all the modules in Safety Analyst using the ArcGIS interface. In addition, concepts used by CARE, such as a sliding window to depict crashes (CAPS, 2009a), can be borrowed to enhance the display features of the Visualization System.

This sliding window will provide observed, predicted, and expected crash frequencies, which are vital safety performance measures that should be considered for the management and analysis of traffic safety.

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APPENDIX A

SURVEY QUESTIONNAIRE

Evaluation of the Safety Analyst Visualization Tool

Section I

1. Safety Analyst provides four options to locate analysis segments: (i) Route and Milepost, (ii) Route, County and Milepost, (iii) Section and Distance, and (iv) Route, Section and Distance.

   Does the visualization tool clearly complement the Safety Analyst location options?

   □ Strongly Agree □ Agree □ Neither Agree nor Disagree □ Disagree □ Strongly Disagree

2. Does the visualization tool help to perform preliminary diagnosis before going to the field?

   □ Strongly Agree □ Agree □ Neither Agree nor Disagree □ Disagree □ Strongly Disagree

3. Do you think the entire diagnosis of the problematic sites can be done with the proposed visualization tool without going to the field to investigate?

   □ Strongly Agree □ Agree □ Neither Agree nor Disagree □ Disagree □ Strongly Disagree

4. Does the proposed visualization tool help to select the effective countermeasures?

   □ Strongly Agree □ Agree □ Neither Agree nor Disagree □ Disagree □ Strongly Disagree

5. How would you rate the effectiveness of the proposed visualization tool to present information to decision makers?

□ Very Effective □ Effective □ Neutral □ Ineffective □ Very Ineffective

6. Does the proposed visualization tool assist during the step by step procedures for all the Safety Analyst tools, thus facilitating prompt action and decisions?

   □ Strongly Agree □ Agree □ Neither Agree nor Disagree □ Disagree □ Strongly Disagree

7. Do you feel that the developed visualization tool is only important for the Network Screening Tool of Safety Analyst?

   □ Strongly Agree □ Agree □ Neither Agree nor Disagree □ Disagree □ Strongly Disagree

8. How useful is the proposed visualization tool in terms of finding out the errors in the input data (e.g. actual site characteristics different to the input data)?

   □ Extremely Useful □ Useful □ No difference □ Useless □ Extremely Useless

9. How do you feel about the statement "The proposed visualization tool enables sharing of information regarding sites with potential for safety improvement across various divisions within an agency"? For example sharing the safety engineering division information with the planning division.

   □ Strongly Agree □ Agree □ Neither Agree nor Disagree □ Disagree □ Strongly Disagree

10. Does the proposed visualization tool help to improve the communication between the analyst and the decision makers?

☐ Strongly Agree ☐ Agree ☐ Neither Agree nor Disagree ☐ Disagree ☐ Strongly Disagree

Section II

11. How do you rate the visualization tool based on the presentation of the results compared to text/table formats as provided by Safety Analyst?

☐ Excellent ☐ Good ☐ Satisfactory ☐ Fair ☐ Poor

12. On a scale from 1 to 5 where 5 is Strongly Agree and 1 is Strongly Disagree, please provide your opinions about the following aspects of the visualization tool:

	1	2	3	4	5
a. The tool helps to learn about Safety Analyst	☐	☐	☐	☐	☐
b. The tool demands less time and manual interaction	☐	☐	☐	☐	☐
c. The tool conveys clear sense to its intended users	☐	☐	☐	☐	☐
d. It is very simple to use and visually attractive	☐	☐	☐	☐	☐
e. The tool makes interaction with Safety Analyst more intuitive	☐	☐	☐	☐	☐
f. The tools is appropriate for all level of users	☐	☐	☐	☐	☐

Section III

13. Please indicate your number of years of experience conducting Traffic Safety studies ____________

14. Please indicate your number of years of experience conducting Traffic Engineering studies __________

15. Please indicate your number of years of experience conducting Transportation Planning studies ______

16. Please indicate your number of years of experience using GIS ______

17. Comments:

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Peer-Reviewed Journal Paper

Paz, A., Khanal, I., Veeramisti, N., Baker, J. and Belmonte, L. Development of a Visualization System for Safety Analyst. *Transportation Research Record: Journal of the Transportation Research Board*, Transportation Research Board of the National Academics, Washington, D.C., 2014.

Thesis Title:

Development of a Visualization System for Highway Safety Management Using

Safety Analyst

Thesis Examination Committee:

Committee Chair, Alexander Paz, Ph.D.

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