JOINT TRANSPORTATION
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INDIANA DEPARTMENT OF TRANSPORTATION
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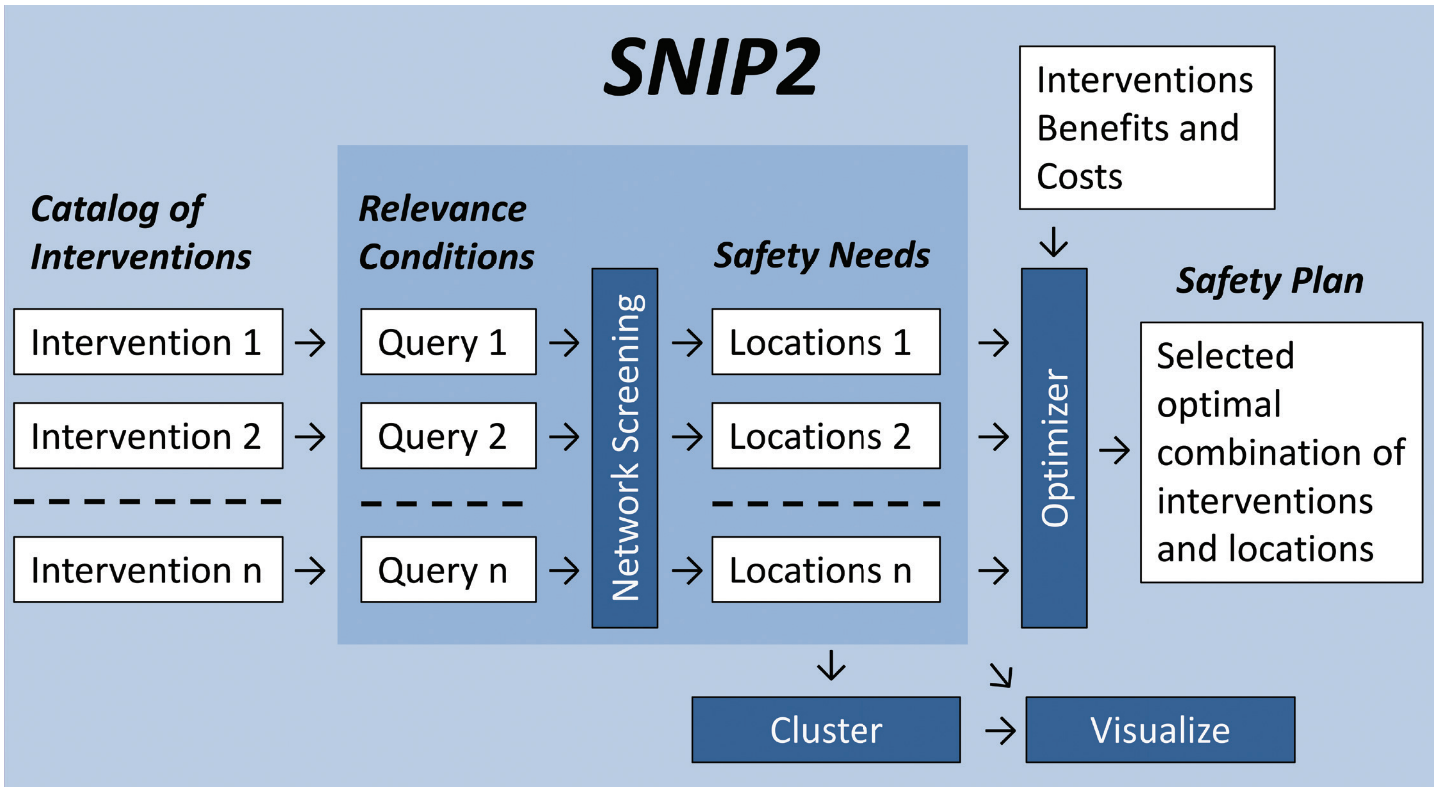
A Systematic Approach to Identifying Traffic Safety Needs and Intervention Programs for Indiana

Volume I—Research Report



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JOINT TRANSPORTATION RESEARCH PROGRAM

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16. Abstract

This report presents the results of JTRP Project “A Systematic Approach of Identifying Safety Intervention Programs for Indiana (SNIP2),” which aimed to develop SNIP2 to support identification of roads that have excessive crashes of the types defined by the user. In addition, this tool is capable of selecting the best combination of high-crash roads and relevant safety interventions that maximizes the safety benefits and keeps the total cost within the budget and other user-defined constraints.

Unlike other studies considering the implementation time of safety projects, the optimization objective of SNIP2 is to identify an optimal combination of countermeasures renewable within a long time horizon. This simplification is accomplished by representing the projects through their annualized costs and benefits. It allows consideration of many projects for large road networks and it makes the SNIP2 suitable for identification of safety focus areas in strategic safety plans. The SNIP optimizer – a heuristic approximation of a large-size mixed integer knapsack problem based on a greedy search was extensively tested and evaluated. It was found producing optimal or near-optimal solutions in a sufficiently short time. Another research result is a comprehensive catalog of countermeasures for Indiana – a list of countermeasure names, road and crash conditions for the countermeasure relevance, corresponding crash modification factors, and countermeasure costs.

The SNIP2 is computer software developed with close collaboration with the INDOT future users. It includes an updated crash and state road database. A user’s manual describes on the necessary details of the software and various aspects of its use. Two example studies are also included in the manual to illustrate its use and to better presents the SNIP2 features.

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EXECUTIVE SUMMARY

A SYSTEMATIC APPROACH TO IDENTIFYING TRAFFIC SAFETY NEEDS AND INTERVENTION PROGRAMS FOR INDIANA: VOLUME I—RESEARCH REPORT

Introduction

A systemic approach to identifying road locations that exhibit safety problems was provided by the Safety Needs Identification Program (SNIP) developed by the Purdue University Center for Road Safety (CRS) in 2011. That project aimed to prove the concept of a road network screening method by developing a working prototype tool. This report presents the results of a new JTRP project aimed to develop a next version—SNIP2. As does its predecessor, SNIP2 supports identification of roads that have excessive crashes of the types defined by the user. In addition, this tool is capable of selecting the best combination of high-crash roads and relevant safety interventions that maximizes the safety benefits and keeps the total cost within the budget and other user-defined constraints. SNIP2 can also estimate the cost and the safety effect of a given safety plan.

Findings

- The conceptual framework of the safety screening tool was developed in order to cope with the complexity of the data management and safety screening operations. There are two major components: (1) Data Renewal Process (DRP) and the user-end interface with a computational engine, and (2) a crash and roadway database.
- Unlike other studies considering the implementation time of safety projects, the optimization objective of SNIP2 is to identify an optimal combination of countermeasures renewable within a long time horizon. This simplification is accomplished by representing the projects through their annualized costs and benefits. It allows consideration of many projects in large road networks and it makes the SNIP2 suitable for identification of safety focus areas within a realistic strategic safety plan.
- The optimizer—a new component of SNIP2—applies a greedy search to a heuristic approximation of a large-size mixed integer knapsack problem. The algorithm was extensively tested and evaluated using randomized solutions. The developed algorithm was found producing optimal or near-optimal solutions sufficient for the considered application domain. The algorithm is sufficiently flexible to easily incorporate needed constraints. The time-efficiency meets the user's specifications.
- One of the research results is a comprehensive catalog of countermeasures for Indiana—a list of countermeasure names, road and crash conditions for the countermeasure relevance, corresponding crash modification factors, and countermeasure costs. The developed catalog can be edited and then utilized for developing an Indiana strategic safety plan and for other purposes.
- The SNIP2 runs in the MS Windows XP/Vista/7/8 environment. It requires the MS. NET Framework 4.0, MS SQL Server, and Google Earth or ArcGIS Explorer.

Implementation

The SNIP2 is computer software developed with close collaboration of INDOT future users. It includes an updated crash and state road database. A user manual describes the necessary details of the software and various aspects of its use. Two example studies are also included in the manual to illustrate its use and to better presents the SNIP2 features.

The SNIP2 is a complex tool that requires a careful implementation plan. Its implementation to INDOT's practice includes three phases:

1. Intensive SNIP2 testing by a selected small group of INDOT users (several weeks).
2. One-day workshop organized by INDOT to demonstrate the software through hands-on practice and to identify potential SNIP users.
3. Organization-wide SNIP2 implementation with continuing feedback to the Center of Road Safety.

The Center for Road Safety is involved in all three phases of the SNIP2 implementation by providing requested help, collecting the users' feedback, and implementing the recommendations.

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1. INTRODUCTION

In July 2012, Moving Ahead for Progress in the Twenty-first Century (MAP-21) authorized funding for federal-aid highway projects, highway safety programs, transit programs, and other projects. MAP-21 builds upon and updates a host of highway, transit, bicycle, and pedestrian programs and guidelines that were first established in 1991. Among its provisions, MAP-21 continues the funding of the Highway Safety Improvement Program (HSIP) and sets a streamlined agenda for the purpose of accelerating our nation's efforts in reducing highway fatalities and serious injuries on public roads. The 2010 revision of the Indiana Strategic Highway Safety Plan (SHSP) states that *"…the Indiana Strategic Highway Safety Plan identifies critical highway safety problems and opportunities for saving lives, reducing suffering and economic losses resulting from traffic crashes. It also serves to coordinate the traffic safety activities of state agencies, municipal entities and private highway safety organizations."* The importance of an integrated approach to traffic safety, data analyses, application of the latest research, and best practices from across the U.S. are emphasized as a means of generating a sound basis and tools for safety management decisions. The strategies in the SHSP emphasis areas were identified in the Indiana SHSP and state agencies (the Indiana Department of Transportation (INDOT), the Indiana Criminal Justice Institute, and the Indiana State Police) continue their efforts to improve road safety in Indiana.

A systemic approach to identifying road locations that exhibit safety problems consistent with the SHSP safety emphasis areas was provided by the Safety Needs Identification Program (SNIP) developed by the Purdue University Center for Road Safety (CRS) in 2011 within Joint Transportation Research Program (JTRP) Project No. SPR-3315. That project aimed to prove the concept of a road network screening method by developing a working prototype tool. This report presents the results of JTRP Project No. SPR-3616, "A Systematic Approach of Identifying Safety Intervention Programs for Indiana (SNIP2)," which aimed to develop a next version of SNIP—SNIP2—that could be fully implemented. As does its predecessor, SNIP2 supports identification of INDOT-administered roads that have excessive crashes of the types defined by the user. In addition, this tool needs to be capable of selecting the best combination of high-crash roads and relevant safety interventions that maximizes the safety benefits and keeps the total cost within the budget and other user-defined constraints. For that purpose, SNIP2 encompasses the concepts developed and tested in SNIP as well as a new module that facilitates selection of the most cost-effective combination of road locations and safety countermeasures. The Indiana local roads are not included in the current tools because data available for these roads at the system level are currently insufficient.

This report presents the SPR-3616 research effort and its outcome pertaining to the new elements of SNIP2. More details regarding SNIP can be found in the past report on SNIP (Tarko et al., 2011). The second volume of this report, "SNIP2 User Manual," explains how to use the tool.

2. SNIP CONCEPTS

SNIP2 includes two major components:

1. The Data Renewal Process (DRP) that prepares the updated SNIP2 database (Figure 2.1).
2. The SNIP2 tool including the user's interface and the up-to-date database (Figure 2.2).

The DRP is performed on a regular basis, most typically once a year, by a dedicated team in charge of maintaining the SNIP2 in an up-to-date version.

The SNIP2 tool is a computer application that supports the following four operations (see Figure 2.2):

1. Identification of high-crash road elements (segments, intersection, and ramps) that exhibit excessive numbers or proportions of crashes of a type defined by a user,
2. Clustering the identified high-crash road elements into larger sections that exhibit similar safety needs.
3. Visualization of the individual road elements and road clusters on digital maps, and
4. Selection of the most cost-effective combination of road elements and safety countermeasures according to the user-defined budget and other constraints.

2.1 Data Renewal Process

The Data Renewal Process (DRP) includes updating the existing data by reaching to sources for new data, reformatting them to meet the standards of the CRS database (called also master database), integrating these data into tables that meet the master database specifications, and replacing the existing data. These new formatted and integrated data are then post-processed to prepare them for use by the network safety screening tool. The data maintenance is facilitated by a suite of procedures developed by the CRS or available in ArcGIS. The data updating may be performed annually or when a major change of data at any of the data sources occurs to reflect these changes to the screening process.

The DRP facilitates the updating of the GIS and non-GIS data in a convenient and short time. The data management procedures include ArcGIS geo-processing and VBA-implemented and Model Builder codes that are not packaged as a single module, but rather which are used separately as needed to maintain the flexibility of the data management process. The DRP acquires data from the sources, reformats and pre-processes it, and links it together. This procedure is presented in Tarko et al. (2011).

2.2 Road Network Screening

The Road Network Screening module facilitates screening of road elements to identify high-crash locations. A

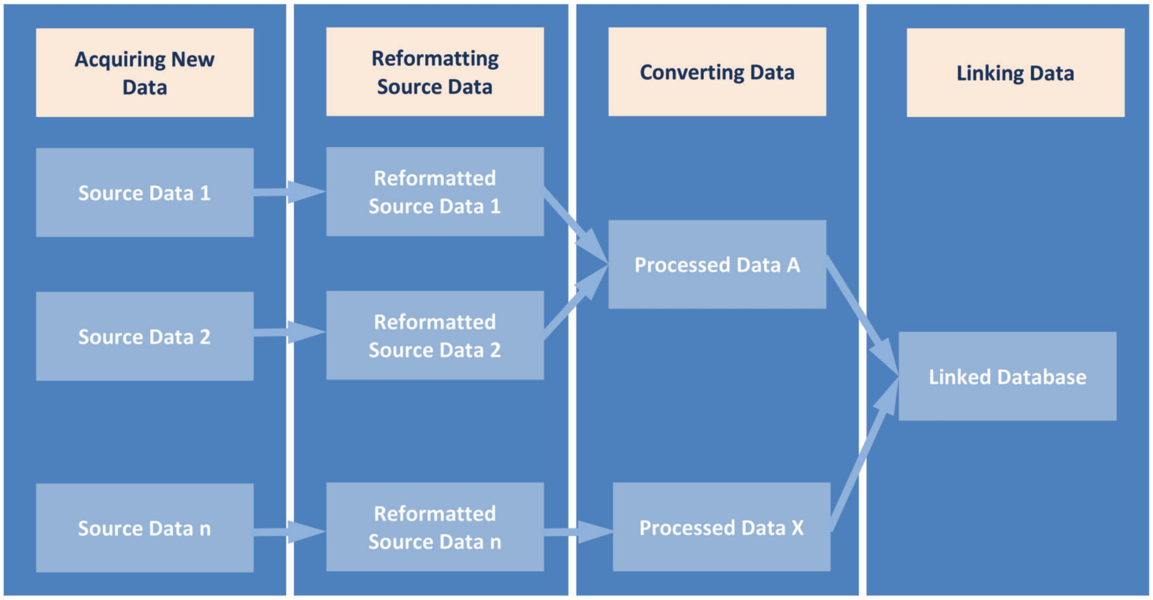


Figure 2.1 SNIP Data Renewal Process.

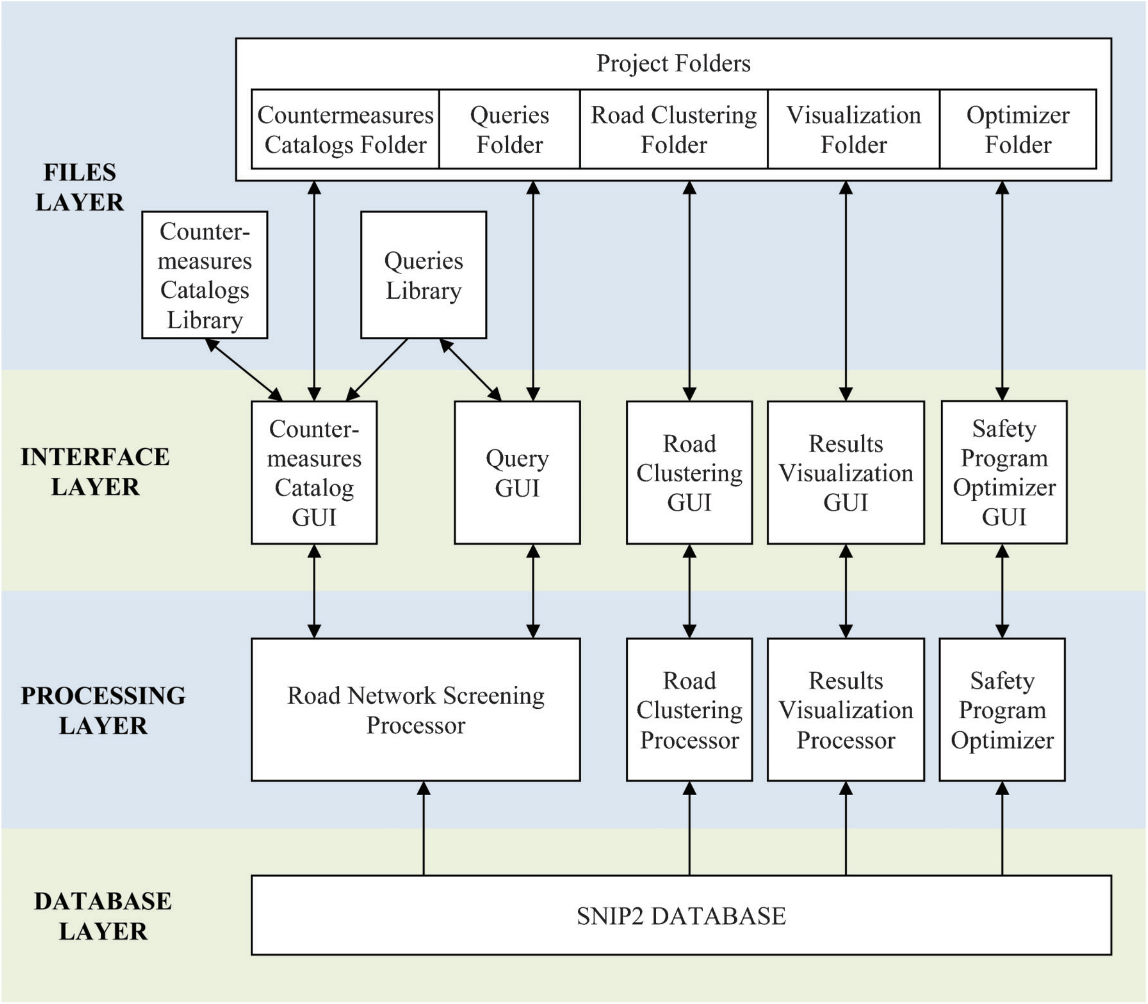


Figure 2.2 SNIP2 architecture.

road location is a road intersection, an interchange roadway segment, a road segment or a ramp. A *road intersection* is a portion of the roads within the intersection impact zone. The intersection center is defined as a point, and the 250-foot segments adjacent to the intersection point define the intersection impact zone. A *road interchange* is a portion of the roads within the interchange impact zone. The interchange impact zone consists of freeway and non-freeway segments. For freeway segments the interchange zone extents 1500 ft beyond the farthest merging or diverging point. The non-freeway segments extend 250 ft beyond the farthest merging or diverging point. A *road segment* is a road stretch between the intersection/interchange impact zones. Long road segments are divided into smaller parts to allow more specific location with safety needs (such as curves). Rural segments longer than 0.5 mile are divided into sub-segments whose lengths are as close to 0.5 mile as possible. Urban road segments longer than 0.25 mile are divided into sub-segments whose lengths are as close to 0.25 mile as possible. A *ramp* is the part of interchange that permits traffic from one highway to pass through the junction without directly crossing the other traffic stream.

The Road Network Screening module facilitates building Queries and Countermeasures Catalogs and performs screening tasks that identify crashes and road elements that meet the query criteria. For example, the user may need a list of rural road segments with narrow shoulders that are experiencing a considerable number of severe single-vehicle crashes in order to identify locations where widening shoulders might be justified. The Queries and Catalogs built by the user are saved in a Project Folder for later project continuation. The user also has an option of saving the Queries and Catalogs to Libraries to be used in other future projects. The Road Network Screening Processor executes the screening task by accessing the SNIP2 Database and searching for crashes and roads according to a query currently in use; and the results of the screening task are saved in the Project Queries Folder. These results can be then accessed by other SNIP2 processors (clustering, visualization, and optimizer). The screening method has been modified and is described in Appendix A.

2.3 Road Clustering

Road segments and intersections that exhibit an excessive number of crashes may be concentrated along longer road sections. The clustering module builds a cluster starting with the road element which has the strongest evidence of high-crash situation. The algorithm allows adding a road element if to the current cluster if: (1) the element is adjacent to the currently built cluster, (2) it has sufficiently high confidence that it experiences too many crashes. When no additional element can be added to the cluster, the clustering tool stops building the current cluster and searches for a next road element suitable to build a new cluster. The clustering ends when no suitable road elements can be found. The user can restrict the clusters building only along the same routes to follow the common practice in scoping road studies.

Clustering road elements can reveal large scale safety issues that otherwise might be overlooked if the screening analysis is focused on individual spots. For example, clustering segments with excessive numbers of rear-end crashes may reveal a spill-over safety effect that originated at a signalized intersection with a capacity shortage or where traffic signals are poorly coordinated. Similarly, clustering smaller geographic units, such as townships, with a particular safety problem (e.g., speeding) can help identify larger areas where police enforcement or campaigning might be beneficial.

Clustering state road segments and intersections along state routes can help INDOT identify parts of corridors that require certain road improvements from a safety standpoint. These clusters might be found useful in scoping such projects. This procedure is presented in more detail in Tarko et al. (2011) and also shown in Appendix B.

2.4 Results Visualization

The road network screening module saves the results of a query in a tabular format convenient for clustering and for additional processing as needed. The final results may also be displayed on GIS maps to visualize the spatial distribution of the identified roads. Such visualization is beneficial in presenting the results to decision-makers and to identify spatial pattern not detectable otherwise. Since the identified road components are geo-coded with the respective latitude and longitude, they can be visualized with the display features offered by Google Earth and ArcGIS. This procedure is presented in more detail in Tarko et al. (2011) and also shown in Appendix C.

2.5 Safety Program Optimizer

The user has an option of developing a list of road elements and relevant safety countermeasures for these roads that maximize the safety benefit within a preselected budget level. The primary input to the optimization is a user-defined or selected Countermeasures Catalog. The catalog includes all the specific countermeasures to be considered. The catalog also includes for each countermeasure the following inputs: queries that yield the relevant road segments, Crash Modification Factors (CMFs) to evaluate the safety benefit of the countermeasure applied to a relevant road element, and unit costs needed to estimate the countermeasure's implementation cost. The estimated benefits and costs are annualized. The optimizer selects the pairs of countermeasures that correspond to the road elements to maximize the overall benefit within the assumed budget. The results are saved in the Optimizer Folder as a list of road elements with applied countermeasures and corresponding economic benefits and costs together with summarized economic indicators.

The Road Network Screening, Road Clustering, and Results Visualization modules are described with more details in Tarko et al. (2011). The companion volume provided together with this report, the User Manual, describes the details of a new Graphical User Interface developed for SNIP2 which provides more convenience and flexibility in building and performing queries. The Manual also describes the Data Renewal Process.

The remainder of this report focuses on the new component of the SNIP—the Optimizer—and its needed inputs: the CMFs and the unit costs of the safety countermeasures.

3. DATA MANAGEMENT

3.1 Data Sources

The **road network** representation is a "spatial backbone" of SNIP. The data consist of polylines that represent road segments. Intersections were added through processing the initial network shape file and the associated segment data.

The **Indiana road inventory** provides geometric data, including the number and width of lanes, the type and width of shoulders, the type and width of medians, the Annual Average Daily Traffic (AADT) and other pieces of information.

Ramp data are present in the Indiana road inventory. The ramp data found in the Indiana road inventory have been used due to its better quality and particularly due to its higher level of completeness.

Bridge data are extracted from the National Bridge Inventory (NBI) online database (http://www.fhwa.dot.gov/bridge/nbi/ascii.cfm). This dataset is in a tabular format and includes the coordinates for the bridge center points.

County, township, and city/town boundary shape files are available at the Indiana Map website (http://www.indianamap.org). The Indiana Map is a collaborative effort of the Indiana Geographic Information Office (GIO), the Indiana Geographic Information Council (IGIC), the Indiana Department of Transportation (INDOT), the Indiana Geological Survey (IGS), the University Information Technology Services (UITS) of Indiana University, and other federal, state, and local partners. However, these databases require additional information from other sources. Land-use, demographics, and employment data are integrated by spatially joining the Traffic Analysis Zone (TAZ) level information, which is available from the Modeling and Forecasting Section of INDOT, with the township and county information. This type of integration from smaller to larger aggregation levels help in the integration of the necessary exposure variables for crash screening. For example, the number of registered vehicles was an exposure condition to conduct crash rates based on safety screening. Since this information was available in the TAZ data, it was aggregated to a higher geographic unit, city, or township by spatial join. A list of all the important basic data collected for building the master record sets is shown in Table 3.1.

Crash data from Indiana State Police provides detailed crash information including locations, vehicles involved, drivers, injured people, weather and road conditions, and contributing circumstances.

All the sources with GIS coordinates should have a unique coordinate system to maintain the consistency of the spatial relations. In this case, the Universal Transverse Mercator (UTM) North American Datum (NAD) 1983 zone 16 was the coordination system for

TABLE 3.1
Data sources for safety screening tool

Component Dataset	Contents	Source	Derivative Database
Road network	Roadway network	INDOT	Intersection points layer
Indiana road inventory	Geometric information such as lanes, median, shoulder; pavement data such as roughness or rutting and AADT (adjusted/total counts)	INDOT	Ramp layer
Traffic counts	Traffic counts (not adjusted)	MPOs or local transportation agencies (collected as part of other CRS projects)	
Bridge data	Bridge geometry information; condition indices; construction and maintenance data such as year of construction, maintenance date, etc.	National Bridge Inventory (NBI) online source (http://www.fhwa.dot.gov/bridge/nbi/ascii.cfm)	Bridge GIS layer
INDOT traffic controllers maintenance layer	Traffic controllers location and type	INDOT	n/a
Land-use and demographic data in traffic analysis zones (TAZ)	Employment by types, industry profile, demographic profile, and population (from 2000 census)	Modeling and Forecasting Section, INDOT	Aggregated information into city, townships, and county levels
County, township and city boundary layer	Name, geographic extent, and IDs	Indiana maps (http://www.indianamap.org/)	
Crash data (2003–2012)	Collision, unit, operator information, etc.	Indiana State Police	n/a

the network layer and hence all other shape files. Any shape files in different coordinate systems were converted to this particular datum.

3.2 Data Preprocessing

3.2.1 Adjusting AADT

AADT values in the Indiana road inventory database are provided for the years when traffic was measured. AADT values for other years were estimated by interpolation between the AADTs for earlier and later years. If the AADT was known only for the earlier year or only for the later year, then the annual traffic growth factors recommended by INDOT were used.

Some roads had 24-hour traffic counts with the date of traffic measurement. These counts were converted to the AADT by applying proper conversion factors that accounted for weekly and monthly traffic variability on various types of roads (values recommended by INDOT).

3.2.2 Preprocessing of the Road Network Layer

As discussed earlier, the Indiana road inventory layer does not contain information about intersections so it was necessary to create intersections by processing the road network shape file and the bridge data. Also, it was important to consider generic classifications that are already utilized by INDOT.

Long road segments are divided into smaller pieces to allow more specific location of the segments with safety needs. Rural segments longer than 0.5 mile are divided into sub-segments whose lengths are as close to 0.5 mile as possible. Urban road segments longer than 0.25 mile are divided into sub-segments whose lengths are as close to 0.25 mile as possible.

Preprocessing the network involves certain operations on the shape file to make it ready for data integration. Therefore, only roads with a value of 1 on the system variable were selected, but all segments were used to create the intersection layer. Table 3.2 shows the basic roadway segments and intersection types.

3.2.3 Creating Intersections

Since information about intersections is not available, it was necessary to create a process that identifies intersections. The steps to create the intersections layer are explained in Table 3.3. A total of 1,075 and 23,441 state-state and state-local intersections were created, respectively.

3.3 Preparing the Road Network

3.3.1 Splitting Segments

Splitting long segments into short pieces of uniform length is needed for more precise identification of locations with safety issues. Before the splitting process was performed, the network needed to be "un-split" by using the GIS geo-processing tool that avoids combining segments of different names and different types. This step ensured reasonable homogeneity of the combined segments and avoided segment identification problems. Then, the combined segments, most of which start and end at intersections, were split into shorter element segments using the rules in Figure 3.1. The *round* operation is the standard rounding rule applied to zero decimal digits after rounding.

3.3.2 Linking Geographic Areas

Each network element (segment or intersection) is linked to several types of geographic areas such as county, township, or city/town, based on its inclusion inside the geographic area. All elements were connected to a specific township or county, and only those elements within the geographic jurisdiction boundaries of a city/town were connected to the corresponding city/town.

TABLE 3.2
Basic segment and intersection types

Segment Type	Segment Code	Intersection Type	Intersection Code
Rural two-lane	1	Rural state intersection	1
Rural multilane	2	Rural state-local intersection	2
Rural interstate	3	Urban state intersection	3
Urban multilane	4	Urban state-local intersection	4
Urban two-lane	5		
Urban freeway	6		
Urban one-way	7		
Rural interchange freeway	8		
Rural interchange non-freeway	9		
Urban interchange freeway	10		
Urban interchange non-freeway	11		
Ramp, loop, other	13		

TABLE 3.3
Creating intersection process

Process	Input	Tools	Output
Split polylines	INDOT inventory layer	Data management tools features feature to line	Road layer split at any intersecting point
Create end points	Road layer split at any intersecting point	Data management tools features feature vertices to points	End point layer
Detect duplicate segments	End point layer	Excel find all segments with the same start and end point coordinates	List of segments to be removed
Remove duplicated segments	Road layer split at any intersecting point list of segments to be removed	Link select	Single segment layer split at any intersecting point
Create possible intersection layer	End point layer	Remove duplicated points	Possible intersection layer
Remove bridges	Possible intersection layer bridges layer	Overlay	Possible intersection layer
Remove merges on freeways	Possible intersection layer INDOT inventory layer	Overlay	Intersection layer
Assign intersection attributes	Intersection layer INDOT inventory layer	Overlay summary statistics frequency	Intersection layer
Traffic control	Intersection layer INDOT traffic controllers maintenance layer	Overlay	Intersection layer

3.3.3 Updating Intersection Layer

After integrating the network with the geographic areas, many attributes related to roadway geometry and traffic counts, such as median, shoulder, or AADT information, also were brought in as attributes of the segments. Therefore, it was necessary to update or bring new information to the intersection layer. Intersection link information was obtained by using the ArcGIS geo-processing tool "generate near table." A very small buffer radius was used (e.g., < 1 ft) for the geo-processing tool so that only the adjoining segments were considered to form the near table. After running this operation, each intersection ID was referenced to the adjoining segment IDs. Once the near table was generated, each intersection could be associated with the adjoining segments to receive the required information. Major and minor road AADTs were determined based on averaging the link AADT values for a particular roadway. Also, information about medians, shoulders, etc. was integrated with the intersection. Finally, the signalization information was obtained from the INDOT traffic controllers maintenance layer The following attributes were updated or added as part of this operation: link names, link IDs, major road AADT, minor road AADT, control type (signalized or not), number of legs.

3.3.4 Crash Assignment

Crashes were assigned to roads by considering the crash attributes and the proximity to particular segments and intersections. The proximity-based method included: (1) finding nearby road elements to the crash location based on the coordinates from the police report; (2) matching the characteristics between the road network and the police reports; and (3) road element selection. The crash assignment method is discussed below.

Convert crash records to a shape file. The latitude and longitude values of crash locations found in the electronic crash records were imported to ArcGIS. Using the ArcGIS geo-processing tool called "Display XY data," all crashes having valid coordinates were displayed on an ArcGIS map. The point display file was then exported to a shape file. The new shape file was then projected against the segment and intersection shape file. After this operation, crash shape files for each year (2003 to 2012) containing the collision information were generated.

Nearby road elements. The road network GIS layers, along with all the crashes, were plotted in GIS. A proximity tool, "Near Table" in ArcGIS, is used to identify crashes that are within 250 feet of each intersection. At the most, four elements of each type were identified as potential candidate elements for each crash and moved to the matching process.

Matching score. Four types of elements are considered: road segments, intersections, interchanges, and ramps. For each element type, different verification criterion is applied to score the matching between police reports and element characteristics.

- *Ramps*: The following matches are required for verification purposes:
  - Road names using soundex1 procedure
  - Jurisdiction
- *Interchanges*: The following matches are required for verification purposes:
  - Road names using soundex1 procedure
  - Jurisdiction
  - Functional classification
- *Intersections*: The following matches are required for verification purposes:

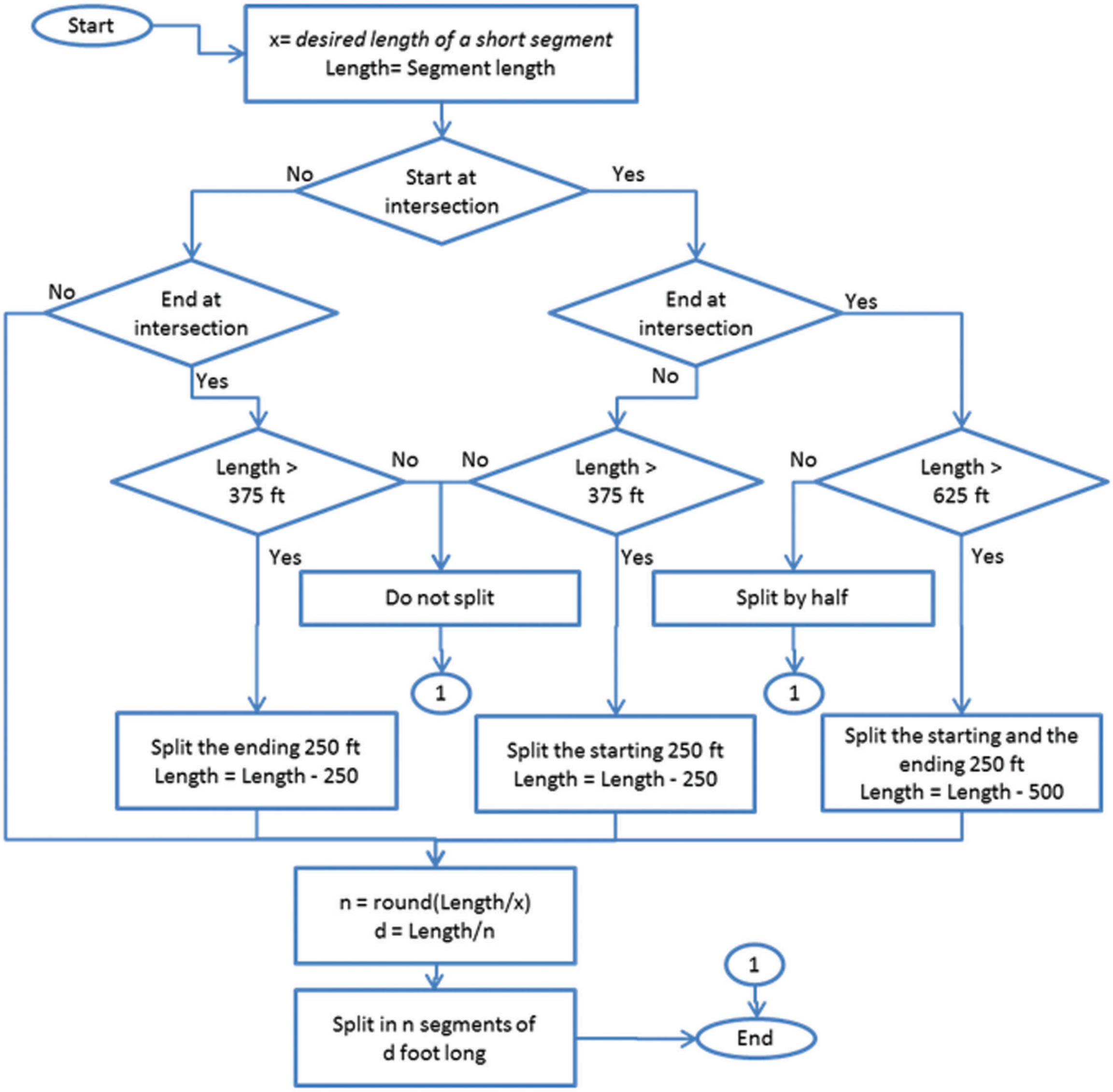


Figure 3.1 Segment splitting rules.

  - Road names using soundex1 procedure for all road names
  - Jurisdiction

- *Segments*: The following matches are required for verification purposes:

  - Road names using 1-*soundex* procedure (1-*soundex* converts an alphanumeric string to a four-character code that is based on how the string sounds when spoken)
  - Jurisdiction
  - Functional classification

Road element selection. Once all potential candidates are scored, each road element type is sorted by its best score and distance. If the police report indicates a ramp, the best scored ramp is selected. If the police report indicates any type of intersection, the best scored intersection is selected. All unassigned crashes are then assigned to segments, interchanges, or ramps based on the minimum distance. All crashes assigned to an intersection leg are moved to the adjacent segment. If there is no adjacent segment, then the crash is assigned to the intersection.

Additional comments are given below to better understand the crash-road assignment method.

The most important criterion is the coordinates recorded in the crash data.

Road names are available from the crash data as well as in the GIS layers. If the road name could be matched between these two data sources, it could provide very good confidence (1,000 points). The names are matched using the *Soundex* procedure to avoid misspelling problems.

County ID and township ID are also used to verify the assignment. However, for some roads or intersections (e.g., all county line roads), they are at the border and the ID might not match. Also, for the township ID, police officers may not have a very good idea about township; thus, this variable only provides limited information (100 for county ID and 10 for township ID).

TABLE 3.5
Crash assignment summary for state road system

Year	Segments	Intersections	Ramps	Total
2003	27775	17929	3617	49321
2004	27752	18243	3811	49806
2005	27278	16067	3006	46351
2006	24871	13816	2311	40998
2007	29110	15394	2172	46676
2008	32825	16219	3549	52593
2009	29309	14970	2826	47105
2010	24159	18926	2378	45463
2011	25575	19548	3683	48806
2012	24927	20722	3983	49632

Finally, the road's functional class is used for assignment. Although it is likely for police officers to mix some categories (e.g., Arterial versus Collector), the functional class could still provide very useful information; for instance, if a crash is recorded between a freeway and a parallel local street, the functional class could tell the difference even without the identification of road names. The matching criteria used are shown in Table 3.4.

The detailed descriptive statistics of crashes assigned to different roadway elements are shown is Table 3.5.

It is important to mention that local crashes are not taken into account in the above data and the corresponding percentage of assigned crashes is near 70%.

3.4 Preparing Final Dataset for Interface

In the last phase of the data preparation, a SAS script merges the crash data to their respective assignments to the different types of infrastructure elements. Further processing of the crash data expands the number of variables available for screening. Finally, the crash and element variables are renamed to conform to the screening component requirements. The resulting crash, segment, and intersection tables are then transferred to the SQL server SNIP2 database and are ready to be accessed by the SNIP2 screening component. The relational database structure of the master record datasets is shown in Figure 3.2.

TABLE 3.4
Road classification criteria

Road Classification in Road Network		Road Classification in Crash Dataset				
		Interstate	US Route	State Road	County Road	Local/City Road
Rural System	Interstate	100	50			
	Principal arterial	50	100	100		
	Minor arterial		100	100		
	Major collector		50	100	100	100
	Minor collector			50	100	100
	Local				100	100
Urban System	Interstate	100				
	Other Freeway/expressway	100	50			
	Principal arterial		100	100	50	
	Minor arterial		100	100	100	100
	Collector				100	100
	Local				100	100

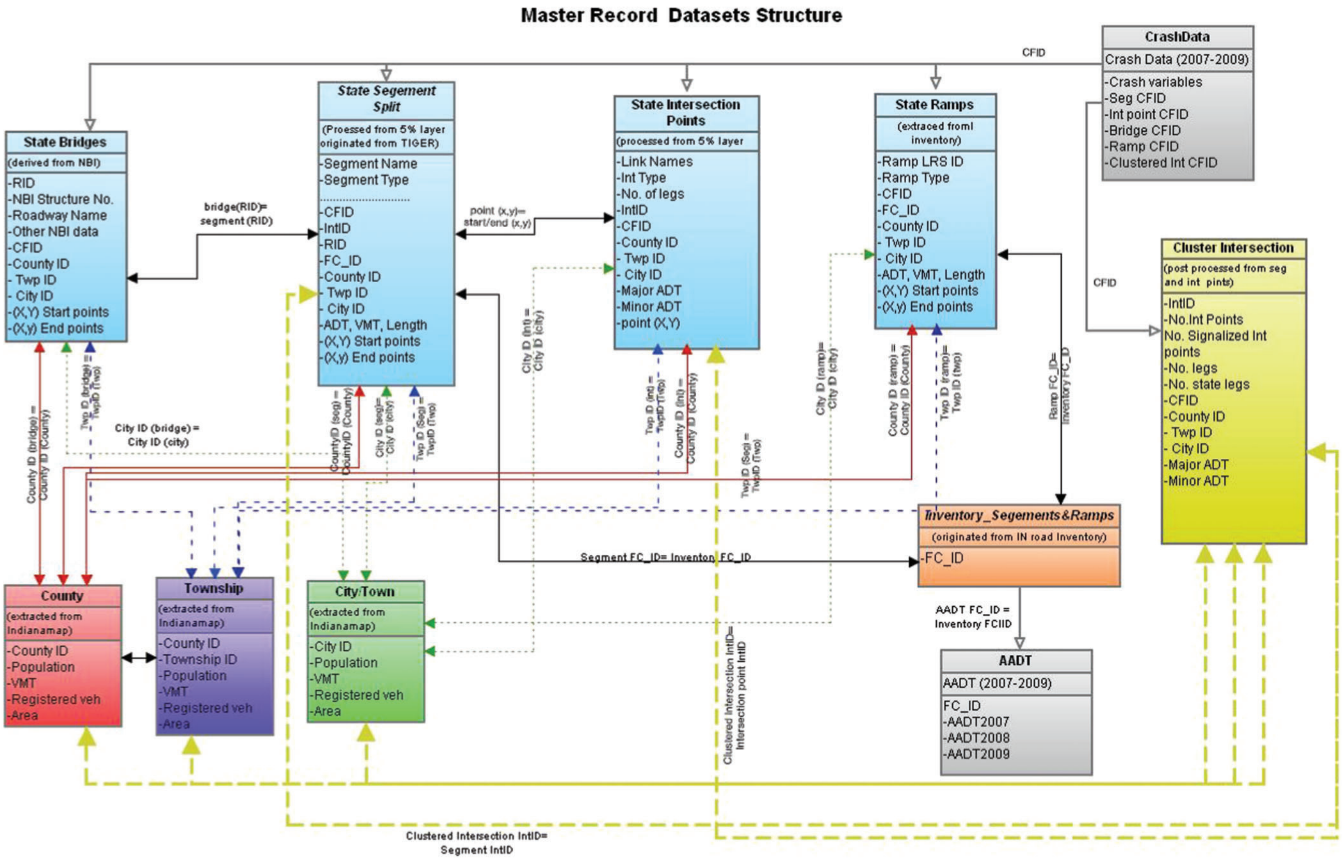


Figure 3.2 Dataset structure for the screening tool.

4. INPUTS TO THE OPTIMIZATION MODULE

4.1 Crash Modification Factors

The commonly-used and practical method of quantifying the safety benefit is the Crash Reduction Factor (CRF), which represents the expected number of crashes saved as a result of the improvement. Typically, CRFs are available for different severity levels and sometimes for certain types of crashes (target crashes). Recently, so-called Crash Modification Factors (CMF) have been introduced and they are used interchangeably with the CRFs. The relation between the two factors is: CMF= 1-CRF/100 where CRF is expressed in percentages while the CMF is a proportion and it has no units. The primary source of CMFs (or CRFs) is the Crash Modification Factors Clearinghouse website supported by the Federal Highway Administration.

4.1.1 Literature Review

NCHRP 500 series reports provide guidance for the implementation of the AASHTO Strategic Highway Safety Plan. This is a series in which relevant information is assembled into single concise volumes, each pertaining to specific types of highway crashes (e.g., run-off-road) or contributing factors (e.g., aggressive driving). Other research studies are summarized below.

Mauga and Kaseko (2010) developed statistical models that related access management (AM) features with traffic safety in midblock sections of street segments. The objective of the study was to evaluate and quantify the impact of the AM features on traffic safety in the midblock sections. A cross-sectional regression model was used to determine that segments with raised medians had lower crash rates by 23% compared to segments with Two-Way Left-Turn Lanes (TWLTLs) in urban area for all crash severities and 21%, 21%, and 33% for KA, BC, and O respectively.

Elvik and Vaa (2004) suggested installing a queue warning changeable countermeasure to reduce rear-end crashes. Meta-analysis was used in the study, and the author showed that this intervention could reduce KA and BC crashes by 21% in both urban and rural areas, but could increase O crashes by 16% for both areas. Tarko et al. (2007) proposed to reduce the degree of horizontal curvature; after performing a regression model, four different equations yielded the CRFs for KA, BC, and O for rural areas.

The addition of lighting at intersections was studied by Donnell et al. (2010), which produced a framework to estimate the safety effects of fixed lighting at a variety of intersection types and locations. A sample framework was demonstrated using Minnesota intersection data; and the results indicated a much lower overall safety benefit from lighting than the previous published studies; the CRF was approximately 8% in both urban and rural areas, which was consistent with the estimates included in the Highway Safety Manual research.

In terms of intersection geometry, Harwood et al. (2003) presented the results of research that performed a well-designed before-after evaluation of the safety effects of providing left- and right-turn lanes for at-grade intersections. The types of improvement projects evaluated included installation of added left-turn lanes, added right-turn lanes, and extension of the length of existing left- or right-turn lanes. An observational before-after evaluation of these projects was performed using several alternative evaluation approaches. The research concluded that the Empirical Bayes method provided the most accurate and reliable results and showed the CRFs for different severities in urban and rural areas.

Lu, Dissanayake, Zhou, and Yang (2001) evaluated the safety and operational impacts of two alternative left-turn treatments from driveways/side streets. The two treatments were direct left-turns and right-turns followed by U-turns. Safety analyses of the alternatives were conducted using two major approaches: traffic crash data analysis and conflict analysis. The results showed that replacing direct left-turns with indirect left-turns could decrease all crashes for KA and BC by 43%, 20% for O, and 28% for all types of crashes in urban and rural areas. Further, this replacement specifically could reduce rear-end crashes by 13% and angle crashes by 35%. Schoon et al. (1994) proposed the countermeasure of converting intersections to roundabouts. The before-and-after method was applied in the study, and they found it reduced 65% of the crashes for KA and BC in urban and rural areas and 42% of the O crashes in both areas. Monsere et al. (2006) indicated that applying CRFs for sight distance improvement reduced approximately 11% of crashes in rural areas.

Fitzpatrick and Park (2010) evaluated the safety effectiveness of the high-intensity activated crosswalk (HAWK) device; before-after evaluations compared crash predictions for the after period (which assumed the treatment had not been applied) to the observed crash frequency for the after period (with the treatment installed) using an empirical Bayes (EB) method. The results showed that there was a 29% reduction in total crashes, a 69% reduction in pedestrian crashes, and a 15% reduction in severe crashes. Gan et al. (2005) concluded that constructing pedestrian bridges or tunnels can reduce pedestrian-related crashes by 86% in urban areas; and installing sidewalk could result in a 74% reduction in pedestrian-related crashes in urban areas.

Park and Saccomanno (2005) evaluated the relationship between countermeasures and collision occurrence at railroad at-grade crossings by using a sequential analytic strategy that combined the tree-based data stratification method with the generalized linear regression technique. They concluded that there was an 87% reduction in crashes in urban and rural areas; and implementing a grade-separated crossing could avoid 100% of crashes. The Illinois Department of Transportation initiated the Highway Safety Improvement Program (HSIP) in 2006, and they found that eliminating grade railroad crossings completely eliminated crashes in both urban and rural areas.

Elvik and Vaa (2004) introduced the intervention of installing guardrails to prevent run-off road crashes. Their meta-analysis indicated a 43% reduction in KA crashes in urban and rural areas and a 17% reduction in BC crashes in both areas for all type of crashes; in terms of run-off-road crashes, KA and BC were reduced by 44% and 47%, respectively, in both urban and rural areas. According to a cable median barrier report created by the Minnesota Department of Transportation (2010), cable median barriers can reduce fatal crashes by 90 percent. Adding a flattening crest of curve, according to Hovey and Chowdhury (2005), can reduce crashes by 51% and 20% for KA and BC, respectively, in urban and rural areas.

Persaud et al. (2003) studied adding centerline rumble strips and concluded they could reduce approximately 15% and 14% of BC and all types of crashes, respectively, in rural areas. When shoulder rumble strips were added, there were 13% and 18% crash reductions related to BC and all types of crashes, respectively, in both urban and rural areas. Traffic calming and speed limit countermeasures are applicable to Indiana; and according to Elvik and Vaa (2004), Park, Park, and Lomax (2010), and Parker (1997), in urban areas, a 16% crash reduction for KA, 24% for BC, 10% for O, and 18% for all types of crashes were possible.

Widening shoulders is applicable in Indiana; and according to Tarko et al. (2007), different equations can be applied to calculate CRFs for shoulder widening. Elvik and Vaa (2004) and Montella (2009) reported that installing a combination of chevron signs, curve warning signs/advisory speed signs, and sequential flashing beacons could reduce KA, BC, and all types of crashes by 24%, 51%, and 34% respectively, in both urban and rural areas.

Retiming signal change intervals to ITE standards can be applied in Indiana; and according to Retting et al. (2002), there was a 12% crash reduction for BC and 8% for all type crashes in both urban and rural areas. However, there appeared to be an increase in rear-end crashes. Increasing the visibility of signals could also reduce crashes according to Srinivasan et al. (2008), Sayed et al. (2005), and Sayed et al. (2007), where an 8% reduction for all types of crashes in urban areas was reported and a 3% reduction in rural areas. Changing from permissive or permissive/protected to protected-only phasing could reduce all types of crashes by 1% and left-turn crashes by 99% in urban area according to Harkey et al. (2008). In NCHRP Report 500, installing new flashers could reduce all types of crashes by 30% in both urban and rural areas. The Illinois Department of Transportation, in their Safety 1-06 Highway Safety Improvement Program, reported that new signal installations could reduce all types of crashes by 30%, right-angle crashes by 67%, and rear-end crashes by 38% in both urban and rural areas. According to Tan (2010), re-striping four-lane undivided to two-lane with bicycle lanes could reduce all type of crashes by 29% in both urban and rural areas.

4.1.2 Proposed Countermeasures and Crash Modification Factors

After reviewing the past literature including NCHRP reports, JTRP reports, and the CMF clearinghouse website, a first draft catalog of safety countermeasures was completed and sent to the INDOT SAC members for review. The SAC members provided feedback by deleting some safety countermeasures which were not applicable to Indiana and adding some additional safety countermeasures which should be considered in Indiana. Also, they provided the capital cost for each safety countermeasure if implemented in Indiana. The catalog of safety countermeasures was finalized according to the comments and recommendations from SAC members, and the conditions of each safety countermeasure were defined.

The first draft of the safety countermeasures was based mainly on information from the CMF Clearinghouse website. There are many safety countermeasures listed at the CMF website and the criteria for selecting those that are appropriate for Indiana are:

1. Only those countermeasures that had a 3-star quality rating or above were selected. The star rating indicates the quality or confidence in the results of the study producing the CRF. The star rating is based on a scale (1 to 5), where 1 indicates the lowest or worst rating, and 5 indicates the highest or best rating. The CMF Clearinghouse review process rates the CMF according to five categories—study design, sample size, standard error, potential bias, and data source—and judges the CMF according to its performance in each category. It assigns a star rating based on the cumulative performance in the five categories. Only those countermeasures that were applicable in Indiana were selected. Different states have different conditions; and only the countermeasures that are applicable in Indiana were selected based on the judgment of INDOT experts.
2. The questionnaire to INDOT experts was distributed and is shown in Appendix B. This survey was the vehicle for INDOT experts to provide comments on the countermeasures list, such as deleting or adding some safety countermeasures where appropriate.
3. Based on the feedback, the final list of safety countermeasures was developed, which included 30 safety countermeasures grouped in 14 categories as shown in Table 4.1.

Once the final safety countermeasures list applicable for Indiana was developed, the CRFs for each countermeasure were calculated using the following procedure:

1. Based on the CMF Clearinghouse website, countermeasures below 3-star quality were deleted.
2. Then weighted average CRF was calculated based on its star quality.

4.2 Cost of Safety Countermeasures

Another important input to the SNIP2 Optimizer is the capital cost figures for all safety interventions, and more accurately, the unit costs per item or mile. Lamptey and Labi (2004), the Highway Economic Requirements System Technical Report (FHWA, 2000), the NCHRP Synreport 191, and Lamptey et al. (2011) provided some useful information in order to quantify the costs of safety interventions for this report; and the INDOT SAC members provided some of the missing cost information for Indiana specifically.

When searching for the unit cost of each countermeasure, there were some available resources in past resources in Indiana (Lamptey & Labi, 2004). Also, in the Indiana contracts database, the unit cost of reducing horizontal curvature is \$2,500,000/mile. In the FHWA's Highway Economic Requirements System Technical Report (FHWA, 2000), the unit cost of installing guardrail is \$225,000/mile on urban interstate and urban two-lane roads, \$185,000/mile on rural interstate, rural multi-lane, and rural two-lane. In NCHRP SynReport 191, the unit cost of adding centerline rumble strips is around \$1,500/mile in rural multi-lane and rural two-lane (Lamptey & Labi, 2004). Also, the unit cost of adding shoulder rumble strips on both sides is \$6,000/mile in rural interstate and rural multi-lane. According to Lamptey et al. (2011), the unit cost of widening a 2-ft. shoulder is \$123,000/mile. For other safety countermeasures, there was inadequate information to provide the unit costs. Therefore, a Safety Countermeasures/Programs Survey (Appendix B) was sent out to INDOT SAC members.

Taking into account that the unit cost could vary significantly by location, for each countermeasure, different cost were assigned by road element type as shown in Table 4.2. The shaded spaces indicate that the safety countermeasures are not applicable in those particular conditions; a blank space indicates that there was no available information for those costs at this time.

4.3 Conditions of Safety Countermeasures

Although there are many safety countermeasures, the countermeasure that will be applied will be determined from the types of crashes that occur at the location, and thus the conditions for each safety countermeasure needed to be defined.

Table 4.3 shows the detailed conditions of each safety countermeasure.

TABLE 4.1
Crash reduction factors for safety countermeasures

Category	Countermeasures	Crash Type	Urban KA	Urban BC	Urban O	Urban All	Rural KA	Rural BC	Rural O	Rural All	Reference
Access management	Replace TWLTL with raised median	All	21	21	33	23					Mauga and Kaseko (2010)
Advanced technology and ITS	Install queue warning changeable signs	Rear end	16	16	−16		16	16	−16		Elvik and Vaa (2004)
Alignment	Reduce horizontal curvature by X degree	All					E	E	E	E	Tarko et al. (2007)
Highway lighting	Add lighting at intersections	Night-time				8				8	Donnell et al. (2010)
Intersection geometry	Add left-turn lanes to major road approaches at intersections	All	37	37		45	58	58			Harwood et al. (2003)
	Add right-turn lanes to major road approaches at intersections	All	9	9		16	9	9		16	Harwood et al. (2003)
	Replace direct left-turns with indirect left-turns	All	43	43	20	28	43	43	20	28	Xu, L. (2001)
		Rear end				13				13	
		Angle				35				35	
	Convert intersection to roundabout	All	65	65	42		65	65	42		Schoon and Van (1994)
	Sight distance improvements	All								11	Christopher et al. (2006)
Pedestrians	Install pedestrian hybrid beacon (HAWK) at intersection	All	15	15		29					Fitzpatrick and Park (2010)
		p				69					Fitzpatrick and Park (2010)
	Construct pedestrians bridge or tunnel	p				86					Gan et al. (2005)
	Install sidewalk	P				74					Gan et al. (2005)
At-grade railroad crossing	Install gates at crossings with signs	All				87				87	Park and Saccomanno (2005)
	Build a grade-separated crossing	All				100				100	Park and Saccomanno (2005)
	Eliminate railroad crossing	All				100				100	HSIP (2006)
Roadside	Install guardrail	All	43	17			43	17			Elvik and Vaa (2004)
		Run off road	44	47			44	47			Elvik and Vaa (2004)
	Install cable median barrier	All	90				90				MnDOT (2010)
	Flatten crest of curve	All	51			20	51			20	Hovey and Chowdhury (2005)
Roadway delineation	Add centerline rumble strips	All						15		14	Persaud et al. (2003)
	Add shoulder rumble strips	Run off road		13		18		13		18	Griffith (1999)
Speed management	Traffic calming and speed limits	All	16	24	10	18				9	Elvik and Vaa (2004); Park and Lomax (2010); Park (1997)

TABLE 4.1

(Continued)

			Urban				Rural				
Category	**Countermeasures**	**Crash Type**	**KA**	**BC**	**O**	**All**	**KA**	**BC**	**O**	**All**	**Reference**
Shoulder treatment	Widen inside shoulder width	All			E				E	E	Tarko et al. (2007)
	Widen outside shoulder width	All					E	E	E	E	Tarko et al. (2007)
Signs	Install a combination of chevron signs, curve warning signs/advisory speed signs, and sequential flashing beacons	All	24	24	51	34	24	24	51	34	Elvik and Vaa (2004); Montella (2009)
Intersection traffic control	Retiming signal change intervals to ITE standards	All		12		8		12		8	Retting et al (2002)
		Rear end		−8		−12		−8		−12	
		Angle		−6		4		−6		4	
		Vehicle/bicycle, p		37		39		37		39	
	Increase visibility of signals	All				8				3	Srinivasan et al. (2008); Sayed and Pump (2005); Sayed and Pump (2007)
	Change from permissive or permissive/ protected to protected-only phasing	All				1					Harkey et al (2008)
		Left-turn				99					
	New flasher installation	All				30				30	NCHRP 500
	New signal installation	All				23				23	HSIP (2006)
		Right angle				67				67	
		Rear end				38				38	
Road diet	Re-stripe four-lane undivided to two-lane with bicycle lanes	All				29				29	Tan (2010)

E= equation; HAWK= high intensity activated crosswalk; P= pedestrians.

TABLE 4.2
Cost of safety countermeasures

		Cost in $1000s						
Category	**Countermeasure**	**UI**	**Urban Multi-Lane**	**Urban Two-Lane**	**RI**	**Rural Multi-Lane**	**Rural Two-Lane**	**Unit**
Access management	Replace TWLTL with raised median							Mile
Advanced technology	Install queue warning changeable signs	1,200	1,200					System
Alignment	Reduce horizontal curvature		2,500	2,500		2,500	2,500	Mile
Highway lighting	Add lighting at intersection	500	250	125	500	250	150	Intersection
Intersection geometry	Add left-turn lanes to major road approaches at intersections		200	150		200	150	Intersection
	Add right-turn lanes to major road approaches at intersections		200	150		200	150	Intersection
	Replace direct left-turns with indirect left-turns		250			250		Intersection
	Convert intersection to roundabout		2,000	1,500		1,500	1,000	Intersection
	Sight distance improvements		2000			2000		Mile
Pedestrians	Install pedestrian hybrid beacon at intersection		150	150				Intersection
	Construct pedestrians bridge or tunnel	250	250		250	250		Structure
	Install sidewalk		120	120		120	120	Mile
At-grade railroad crossing	Install gates at crossings with signs		300	300		300	300	Crossing
	Build a grade-separated crossing		5,000	5,000		5,000	5,000	Crossing
	Eliminate railroad crossings		50	50		50	50	Crossing
Roadside	Install guardrail	225		225	185	185	185	Mile
	Install cable median barrier	100	100		100	100		Mile
	Flatten crest of curve		1,400	1,400		1,400	1,400	Mile
Roadway delineation	Add centerline rumble strips					1.5	1.5	Mile
	Add shoulder rumble strips (cost for both sides)				6	6	3	Mile
Speed management	Set and post speed limits	1	1	0.5	1	1	0.5	Mile
Shoulder signs	Widen shoulder					123	123	2 ft/Mile
	Install chevrons, warning/ advisory signs, and/or beacons					50	35	Curve
Intersection traffic control	Retiming signal change intervals to ITE standards							Intersection
	Increase visibility of signals		10	10		10	10	Intersection
	Replace left-turn phase(s) with protected-only							Intersection
	new flasher installation		30	20		30	20	Intersection
	new signal installation		150	125		150	125	Intersection
Road diet	Re-stripe four-lane undivided to two-lane with bicycle lanes		75			75		Intersection

TABLE 4.3
Conditions of safety countermeasures

Category	Countermeasures	Conditions
Access management	Replace TWLTL with raised median	Urban: TWLTL, segments, no median, four lane, sideswipe crashes, left-turn crashes
Advanced technology and ITS	Install queue warning changeable signs	Urban/rural: High accidents history, rear-end crashes
Alignment	Reduce horizontal curvature by X degree	Rural: Run off road crashes, head-on crashes; Indiana standards
Highway lighting	Add lighting at intersections	Urban/rural: At intersection, no lighting, night crashes
Intersection geometry	Add left-turn lanes to major road approaches at intersections	Urban/rural: At intersection, rear-end crashes
	Add right-turn lanes to major road approaches at intersections	Urban/rural: At intersection, rear-end crashes
	Replace direct left-turns with indirect left-turns	Urban/rural: At intersection, rear-end crashes, left-turn crashes
	Convert intersection to roundabout	Urban/rural: At intersection, excessive number of non-pedestrian crashes
	Sight distance improvements	Rural: At intersection, all crashes.
Pedestrians	Install pedestrian hybrid beacon at intersection	Urban: At intersection, pedestrian-related crashes
	Construct pedestrians bridge or tunnel	Urban: Pedestrian-related crashes
	Install sidewalk	Urban: Pedestrian-related crashes
At-grade railroad crossing	Install gates at crossings with signs	Urban/rural: Segments, rear-end crashes, train-related crashes
	Build a grade-separated crossing	Urban/rural: Segments, railroad
	Eliminate rail road crossing	Urban/rural: Segments, railroad
Roadside	Install guardrail	Urban/rural: Segments, have a median, head-on crashes, run-off road crashes
	Install cable median protection interstates	Urban/rural: Segments, head-on crashes, run-off road crashes.
	Flatten crest of curve	Urban/rural: Segments, head-on crashes, run-off road crashes.
Roadway delineation	Add centerline rumble strips	Rural: Segments, Head-on crashes (be careful with passing zones)
	Add shoulder rumble strips	Urban/rural: Segments, single vehicle crashes.
Speed management	Traffic calming and speed limits	Urban/rural: Speed-related crashes.
Shoulder treatment	Widen inside shoulder width	Urban/rural: Segments, run-off road crashes, head on crashes, Indiana standards
	Widen outside shoulder width	Rural: Segments, run-off road crashes, Indiana standards
Horizontal curve	Install a combination of chevron signs, curve warning signs/advisory speed signs, and sequential flashing beacons	Urban/rural: Head on crashes, run off road crashes
Intersection traffic control	Retiming signal change intervals to ITE standards	Urban/rural: At intersection, right-angle crashes, rear end crashes, pedestrians crashes, time intervals out of standards
	Increase visibility of signals	Urban/rural: At intersection, rear-end crashes
	Change from permissive or permissive/protected to protected-only phasing	Urban: At intersection, left-turn crashes (the result is too high, but 5 stars)
	New flasher installation	Urban/rural: Rear-end crashes, right angle crashes
	New signal installation	Urban: At intersection, unsignalized, rear-end crashes, right angle crashes
Road diet	Re-stripe four-lane undivided to two-lane with bicycle lanes	Urban/rural: Segments, four lanes

5. OPTIMIZATION

The next step is optimization of the budget by applying the correct safety countermeasures to address specific safety issues. Pal and Sinha (1998) proposed an integer programming method to optimize safety improvement programs by minimizing the number of crashes while accounting for the budget constraints, the major cost components, and the effectiveness of safety interventions in addition to carrying over the unspent funds and safety impacts into future years. The Kentucky Transportation Center (2003) identified and prioritized high- crash locations in need of safety improvements and developed software to produce a generalized estimation of the benefits and costs based on CRFs and the present worth of annual benefits. The objective function in this report is non-linear and some of the constraints are still non-linear, which makes this type of programming unfeasible. Hemmecke et al. (2009) found that in the past few years, researchers from the field of integer programming had increasingly used nonlinear mixed-integer programs. Nevertheless, this is generally considered a very young field, and most of the problems and methods are not well understood or stable as in the case of linear mixed-integer programs.

In the area of heuristic methods, Hrvoje and Jadranka (2003) applied a genetic algorithm to solve a cost minimization problem and concluded that when the population is a small value (such as n=10, 15), the branch and bound approach is a better method to obtain the optimal solution; but if the population is much larger, the genetic algorithm is preferable.

5.1 Problem Definition

Based on the available data, which includes the road information, the crash information, and the catalog of safety countermeasures, a mixed non-linear programming was established.

The objective is to maximize the safety benefit.

$$Max \quad \sum_{i\in\{I\}}\sum_{h\in\{H\}}\sum_{j\in\{J\}} D_{ih}CCRF_{jh}CC_h \times R_{ij}X_{ij} \tag{5.1}$$

s.t.:

Total budget constraint:

$$\sum_{i\in\{I\}}\sum_{j\in\{J\}} C_{ij}R_{ij}X_{ij} \leq TB \tag{5.2}$$

Countermeasure budget constraint:

$$\sum_{i\in\{I\}} C_{ij}R_{ij}X_{ij} \geq B_j \tag{5.3}$$

Regional budget constraint:

$$L_K \leq \sum_{i\in\{I_k\}}\sum_{j\in\{J\}} C_{ij}R_{ij}X_{ij} \leq U_K \tag{5.4}$$

Mutually exclusive constraint:

$$\sum_{j\in\{J_m\}} X_{ij}R_{ij} \leq 1 \tag{5.5}$$

Where:
D_{ih}= crash frequency at location i at level of severity h,
$CCRF_{jh}$= combined crash reduction factor for countermeasure j at severity h,
CC_h= crash cost for h severity (KA, BC, or PDO),
R_{ij}= relevant countermeasure j at location i,
C_{ij}= cost at location i for project j,
TB= total budget,
B_j = minimum budget for projects of type j,
U_k= upper bound budget for regional k,
L_k= lower bound budget for regional k,
I_k = location I belongs to regional k,
J_m= mutually exclusive countermeasures matrix, and
X_{ij}= binary variable.

The formulation shown in Equations 5.1 through 5.5 is consistent with mixed non-linear programming. If several countermeasures were implemented together to enhance the safety benefit at some locations, it is supposed to use combined crash reduction factors, and the equivalent is as follows (Lacy, 2001):

$$\begin{aligned} CCRF_{jh} = 1 - [(1-CRF_{1h}) * (1-CRF_{2h}) \\ *\ldots*(1-CRF_{jh})] = 1 - \prod_{j=1}^{j}(1-CRF_{jh}) \end{aligned} \tag{5.6}$$

Equations 5.2 through 5.6 constitute a general formation that includes most of the practical situations but may change depending on the different circumstances at a given site.

5.2 Algorithm

The above formulations of the optimization problem were approximately solved by using the greedy heuristic search (Wilt et al., 2010).

The optimization algorithm defines the principles of the heuristic method. The first step of the algorithm is to select the hazardous crash locations and then to create a list of potential safety countermeasures. Some countermeasures can be applied together, but some of them are mutually exclusive; therefore, the list is presented in a 0-1 matrix. Next, the benefit for each countermeasure is calculated as shown in Appendix E. Then, the benefit/cost ratio is calculated for the safety countermeasures, and the highest B/C ratio is selected.

If a safety countermeasure satisfies all the constraints, then it will be implemented; however, if it violates some constraint, then it is deleted from the list. The algorithm continues running until no further countermeasures can be selected. The algorithm flowchart in Figure 5.1 shows the steps of the optimization algorithm (Romero, 2013).

Using the developed tool, the safety countermeasures for the crash location can be identified. In accordance with the assigned constraints for different conditions, the optimizer estimates the expected total cost and the total benefit and calculates the benefit/cost ratio. In

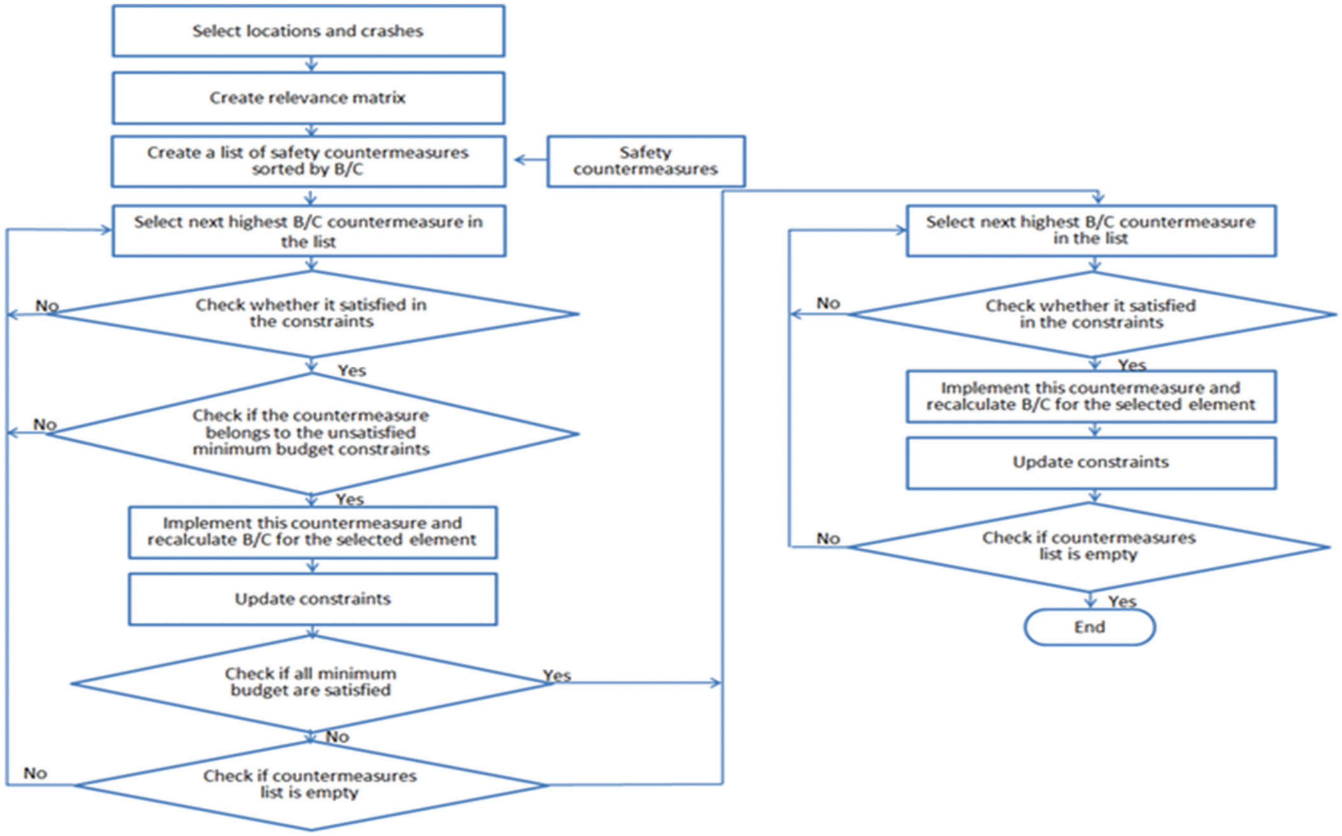


Figure 5.1 Heuristic algorithm flowchart.

order to pictorially explain the process, a figure also appears in the interface. The optimal results are saved as a.csv file.

5.3 Testing and Evaluation

The performance of the heuristic method based on a greedy search was evaluated using a subset of countermeasures and road elements.

- State-administered segments and intersections of Tippecanoe County were considered.
- Implementation of four countermeasures: install new signal; convert intersection to roundabout; widen outside shoulder width; and add shoulder rumble strips.

To test the optimization algorithm, a small sample data set was used to compare the algorithm results with an optimal solution calculated using MS Excel in order to identify the reasons for any differences in the two solutions.

The test was carried out by using different test scenarios for the sample data (e.g., dataset, constraints such as low budget, mutually exclusive countermeasures, etc.).

After all the tests were concluded, evaluation of the optimization method was performed.

- Use the Tippecanoe County dataset.
- Define several evaluation scenarios that have different budgets and constraints.
- Run the optimization algorithm to obtain the optimal solution for each evaluation scenario.
- Randomly select many different points in the feasible region and calculate the respective objective function values.
- Compare the feasible solutions to the optimal solutions.

5.3.1 Background Information

In Tippecanoe County, there are 416 intersections and 700 segments on state-administered road, all of which have an assigned unique ID in the ArcGIS maps. For each particular location, there is detailed information about the conditions at the location (e.g., whether these intersections are signalized or not, the shoulder width of the segments, etc.). Crash data for 2009 through 2011 in Tippecanoe County also were obtained from the Center for Road Safety. Each specific crash has a unique assigned ID number, and the type of crash, the weather at the time of the accident, and other conditions are available. Only state-administered roads are studied in this report.

Using the original dataset, crashes that occurred at each segment and intersection in Tippecanoe County, from 2009 through 2011, were matched. In order to decrease the crashes and enhance safety, safety countermeasures were suggested for implementation. To test the heuristic method, four countermeasures from the CRFs list were selected: (1) new traffic signal installation, (2) conversion of an intersection to a roundabout, (3) widening of the outside shoulder width, and (4) adding shoulder rumble strips. Different safety countermeasures are appropriate for different conditions; therefore, the conditions for applicability of these four countermeasures needed to be clearly defined.

1. New signal installation:
    - State intersection
    - Unsignalized
    - Urban
    - Right-angle crashes from two different approaches and excessive crashes (five or more) in any last three years
2. Convert intersection to roundabout:
    - State intersection
    - Excessive number of non-pedestrian crashes
    - Peak hourly volume entering the intersection $\leq$1500 veh/h

$$V_{PH} = \frac{0.1 \sum_{i=1}^{4} AADT_i}{2} \leq 1500 veh/h$$

3. Add shoulder rumble strips:
    - State segments
    - Rural
    - Excessive number of single vehicle crashes
4. Widen outside shoulder width:
    - State segments
    - Rural
    - Excessive number of run-off road crashes
    - Shoulder design standards in Indiana (Indiana Design Manual, 2013) (Table 5.1 and Table 5.2)

5.3.2 Testing the Algorithm and Implementation of the Heuristic Method

In order to test the optimization algorithm, a small sample data set was selected from the dataset to form four case studies for testing various scenarios.

Case 1: Create an optimization problem with a single countermeasure. The countermeasure consisted of adding shoulder rumble strips, and 10 segments were randomly selected from the *add shoulder rumble strips.csv* file. Five different scenarios were defined in order to test both the sequence of selection and the maximum budget constraints.

1: If the total budget is set at $19,923, which is exactly equal to the total cost, then all the segments in Table 5.3 can be selected. The input data are presented in Figure 5.2. In the output, all the segments were selected, as shown in Table 5.4.

Self-check: The cost for all the segments in Table 5.4 is $19,923; therefore, since the total budget was also $19,923, all the segments could be selected. Further, the total benefit was $58,652, and the B/C ratio was $58,652/$19,923=2.944. The results were the same as the solution that the test algorithm generated.

2: If the total budget is set at more than $19,923, such as $25,000, then all the segments can be selected. The resulting interface is as shown in Figure 5.3.

Self-check: The total cost, total benefit, and total B/C ratio were the same as Scenario 1 with $19,923, $58,652, and 2.944 respectively. The test algorithm solution was also the same.

3: If the total budget constraint is less than $19,923, such as $10,000, then only the segments which have relatively high B/C ratios will be selected. The resulting interface is as shown in Figure 5.4.

The output shows that six out of 10 segments were selected as shown in Table 5.5.

4: The total budget constraint is set at $30,000, but the maximum regional budget is $10,000 in Crawfordsville. The resulting interface is as shown in Figure 5.5.

The output shows that six out of 10 segments were selected as shown in Table 5.6.

Self-check: The selected segments were the same as Scenario 3 because all the segments were in Tippecanoe County, which is in the INDOT Crawfordsville District. Thus, under the regional budget constraint, no matter how large the total budget will be, the optimal solution is always the same.

5: If the total budget constraint is set at $13,000, then only the segments which have relatively high B/C ratios will be selected. The resulting interface is shown in Figure 5.6.

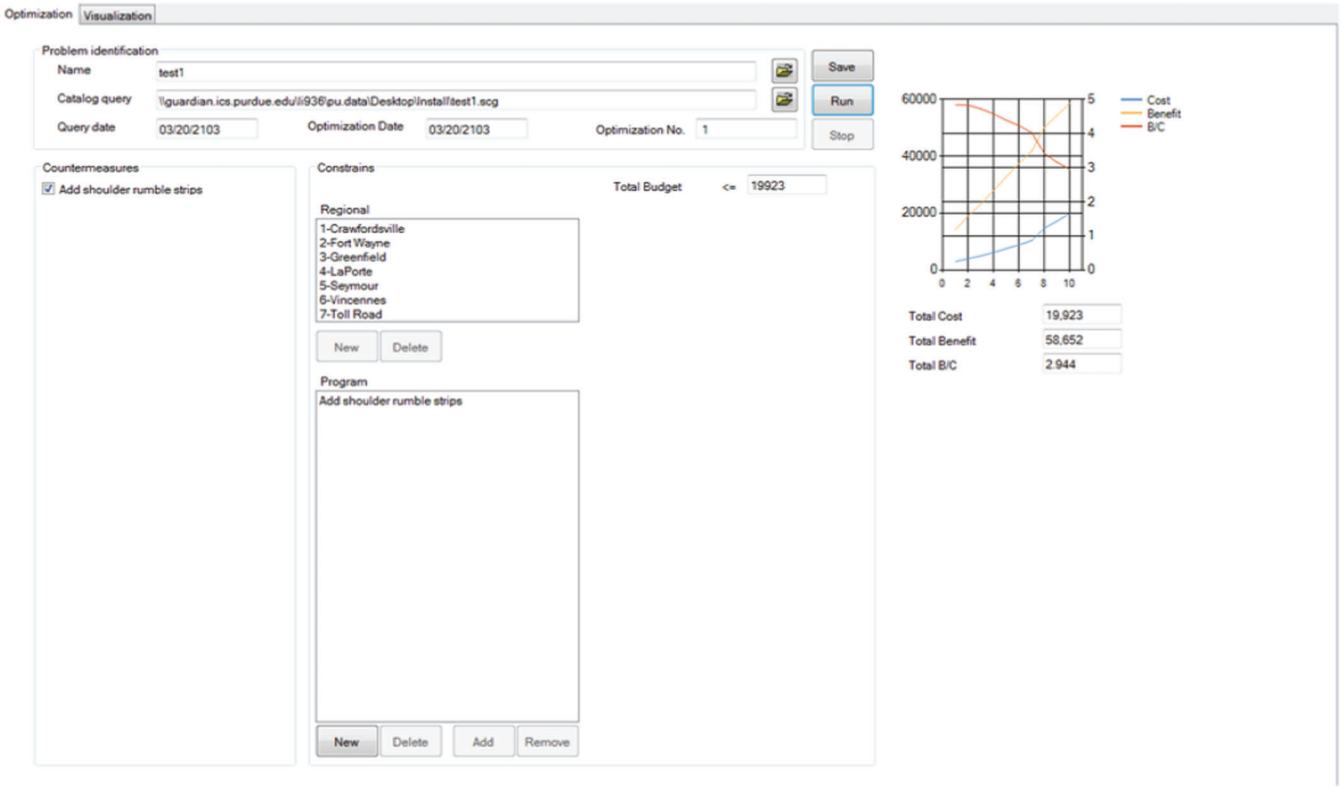
The output shows that eight out of the 10 segments were selected as shown in Table 5.7.

TABLE 5.1
Shoulder width design standards for rural arterial

Design Element	Rural Arterial—2 Lanes			Rural Arterial—4 or More Lanes
AADT	<400	400≤AADT<1500	1500≤AADT<2000	Not specified
Shoulder width	2 ft	4 ft	6 ft	10 ft

TABLE 5.2
Shoulder width design standards for rural collector

Design Element	Rural Collector, State Route			
AADT	<400	400≤AADT<1500	1500≤AADT<2000	>2000
Shoulder width	2 ft	4 ft	6 ft	8 ft



Problem identification

Name: test1

Catalog query: \\guardian.ics.purdue.edu\li936\pu.data\Desktop\Install\test1.scg

Query date: 03/20/2103

Optimization Date: 03/20/2103

Optimization No.: 1

Countermeasures

☑ Add shoulder rumble strips

Constrains

Total Budget <= 19923

Regional

1-Crawfordsville
2-Fort Wayne
3-Greenfield
4-LaPorte
5-Seymour
6-Vincennes
7-Toll Road

Program

Add shoulder rumble strips

Total Cost: 19,923

Total Benefit: 58,652

Total B/C: 2.944

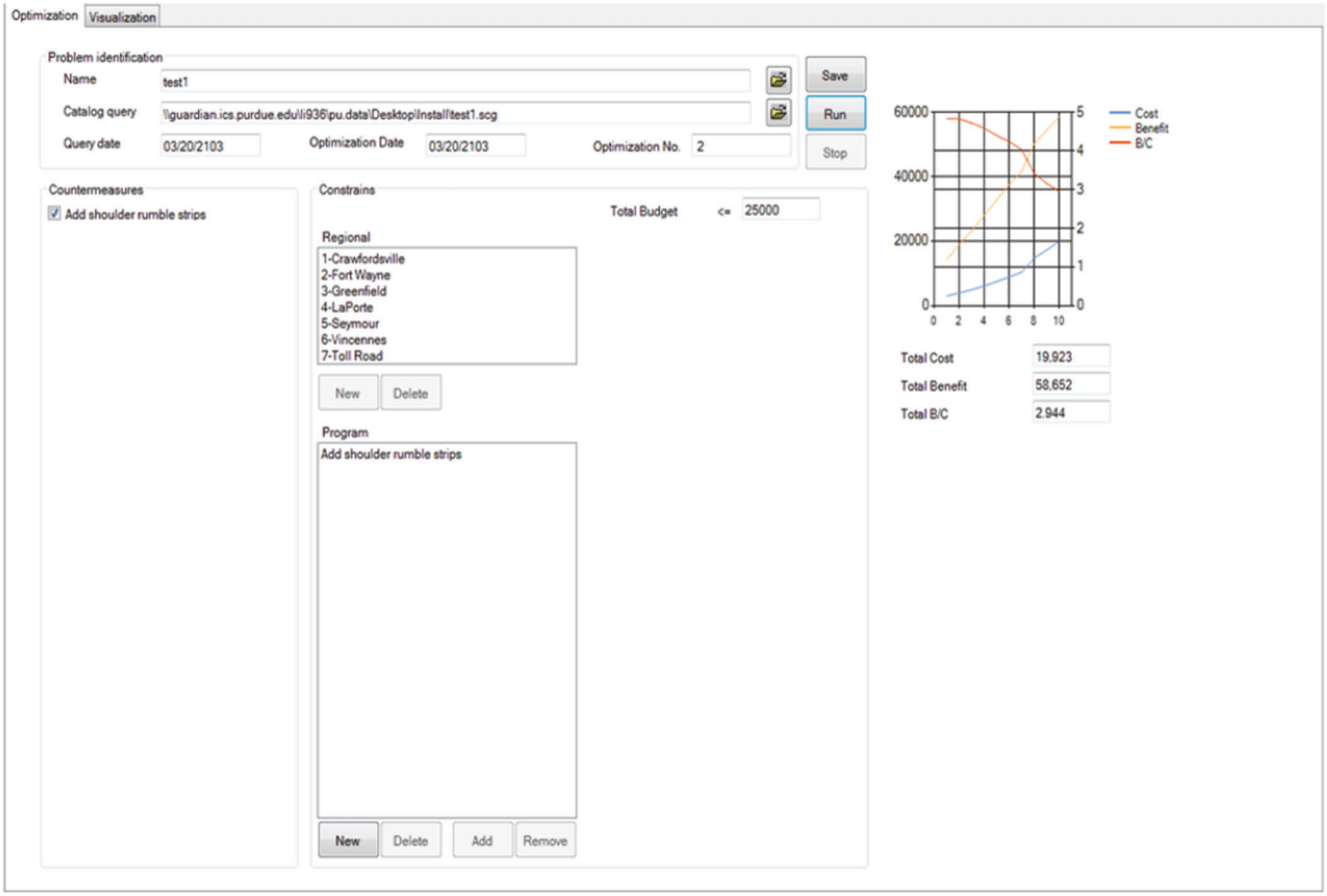
Figure 5.2 Test algorithm interface of Scenario 1 in Case 1.

TABLE 5.3
Test Case 1 sample dataset

CFID Segment	Total Cost	Total Benefit	B/C
218618	4350	8463	1.95
225795	1398	4752	3.4
235280	987	4752	4.81
237139	990	4231	4.27
238149	2526	4231	1.68
238248	1512	4231	2.8
239995	2946	14257	4.84
247281	1188	4752	4
417817	2682	4231	1.58
420356	1344	4752	3.54

TABLE 5.4
Output of selected segments for Scenario 1 in Case 1

CFID Segment	Total Cost	Total Benefit	B/C
239995	2946	14257	4.84
235280	987	4752	4.81
237139	990	4231	4.27
247281	1188	4752	4
420356	1344	4752	3.54
225795	1398	4752	3.4
238248	1512	4231	2.8
218618	4350	8463	1.95
238149	2526	4231	1.68
417817	2682	4231	1.58



Problem identification

Name: test1

Catalog query: \\guardian.ics.purdue.edu\li936\pu.data\Desktop\Install\test1.scg

Query date: 03/20/2103

Optimization Date: 03/20/2103

Optimization No.: 2

Countermeasures

☑ Add shoulder rumble strips

Constrains

Total Budget <= 25000

Regional

1-Crawfordsville
2-Fort Wayne
3-Greenfield
4-LaPorte
5-Seymour
6-Vincennes
7-Toll Road

Program

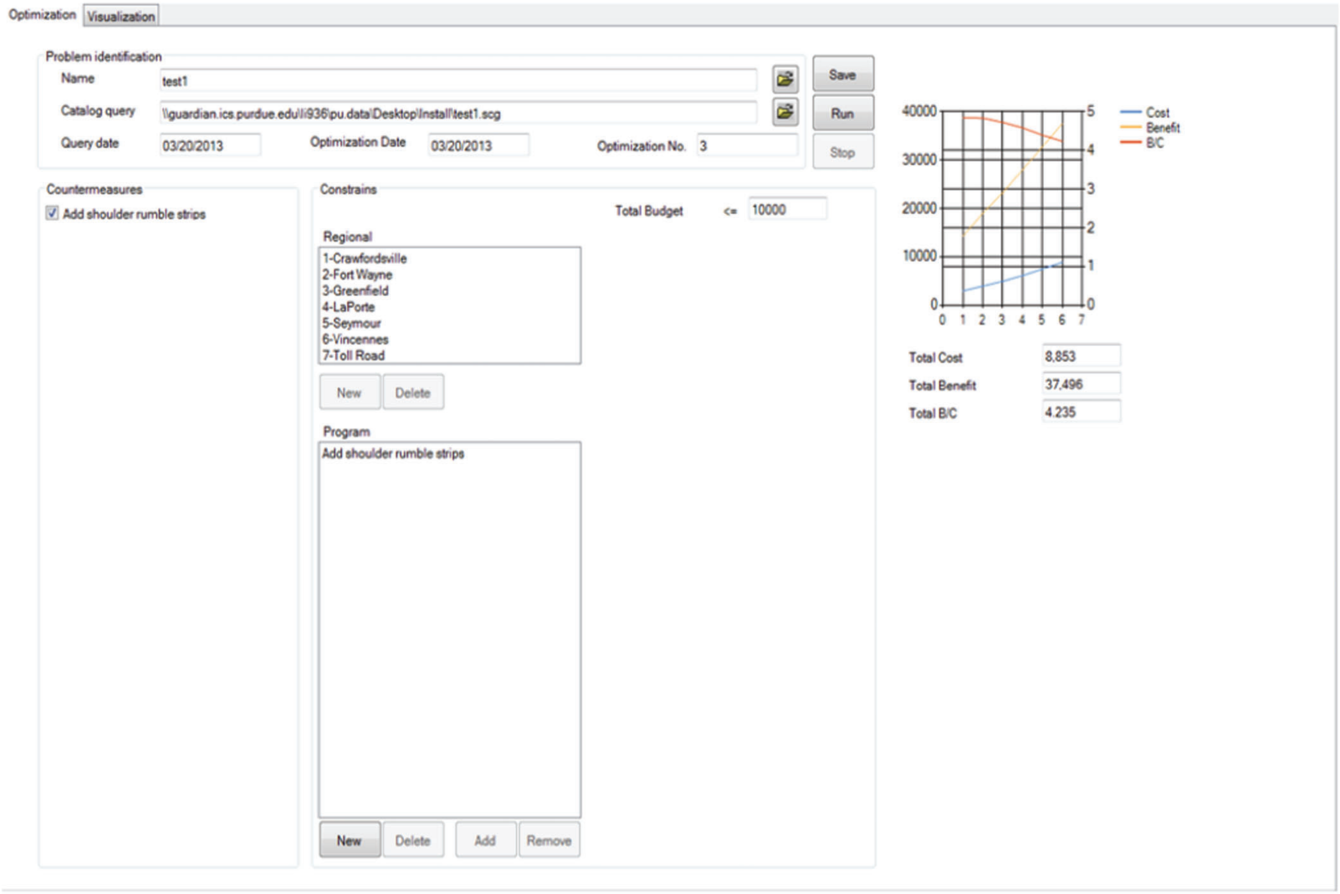
Add shoulder rumble strips

Total Cost: 19,923

Total Benefit: 58,652

Total B/C: 2.944

Figure 5.3 Test algorithm interface of Scenario 2 in Case 1.



Problem identification

Name: test1

Catalog query: \\guardian.ics.purdue.edu\li936\pu.data\Desktop\Install\test1.scg

Query date: 03/20/2013

Optimization Date: 03/20/2013

Optimization No.: 3

Countermeasures

☑ Add shoulder rumble strips

Constrains

Total Budget <= 10000

Regional

1-Crawfordsville
2-Fort Wayne
3-Greenfield
4-LaPorte
5-Seymour
6-Vincennes
7-Toll Road

Program

Add shoulder rumble strips

Total Cost: 8,853

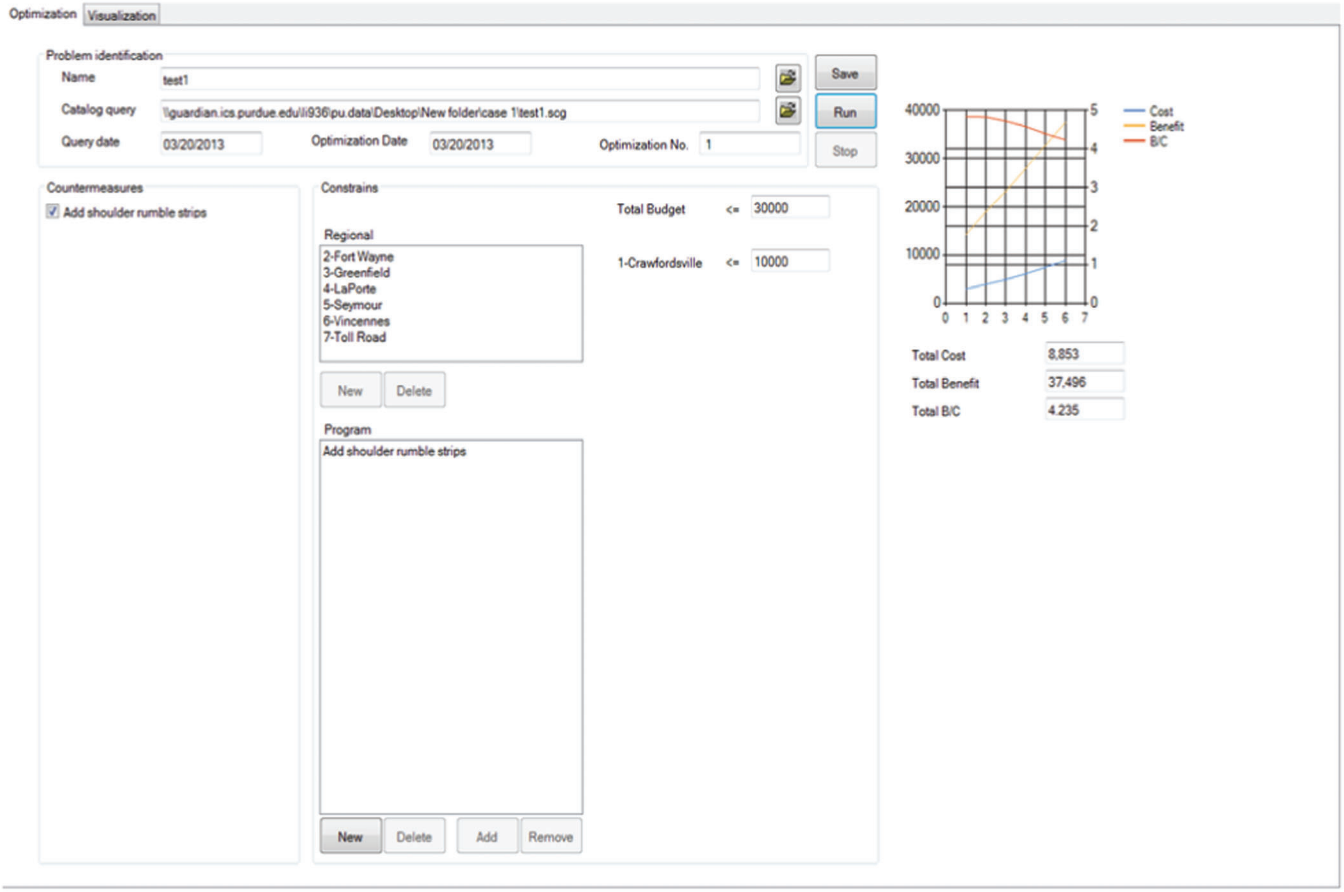
Total Benefit: 37,496

Total B/C: 4.235

Figure 5.4 Test algorithm interface of Scenario 3 in Case 1.

TABLE 5.5
Output of selected segments for Scenario 3 in Case 1

CFID Segment	Total Cost	Total Benefit	B/C
239995	2946	14257	4.84
235280	987	4752	4.81
237139	990	4231	4.27
247281	1188	4752	4
420356	1344	4752	3.54
225795	1398	4752	3.4



Problem identification

Name: test1

Catalog query: \\guardian.ics.purdue.edu\li936\pu.data\Desktop\New folder\case 1\test1.scg

Query date: 03/20/2013

Optimization Date: 03/20/2013

Optimization No.: 1

Countermeasures

☑ Add shoulder rumble strips

Constrains

Total Budget <= 30000

1-Crawfordsville <= 10000

Regional

2-Fort Wayne
3-Greenfield
4-LaPorte
5-Seymour
6-Vincennes
7-Toll Road

Program

Add shoulder rumble strips

Total Cost: 8,853

Total Benefit: 37,496

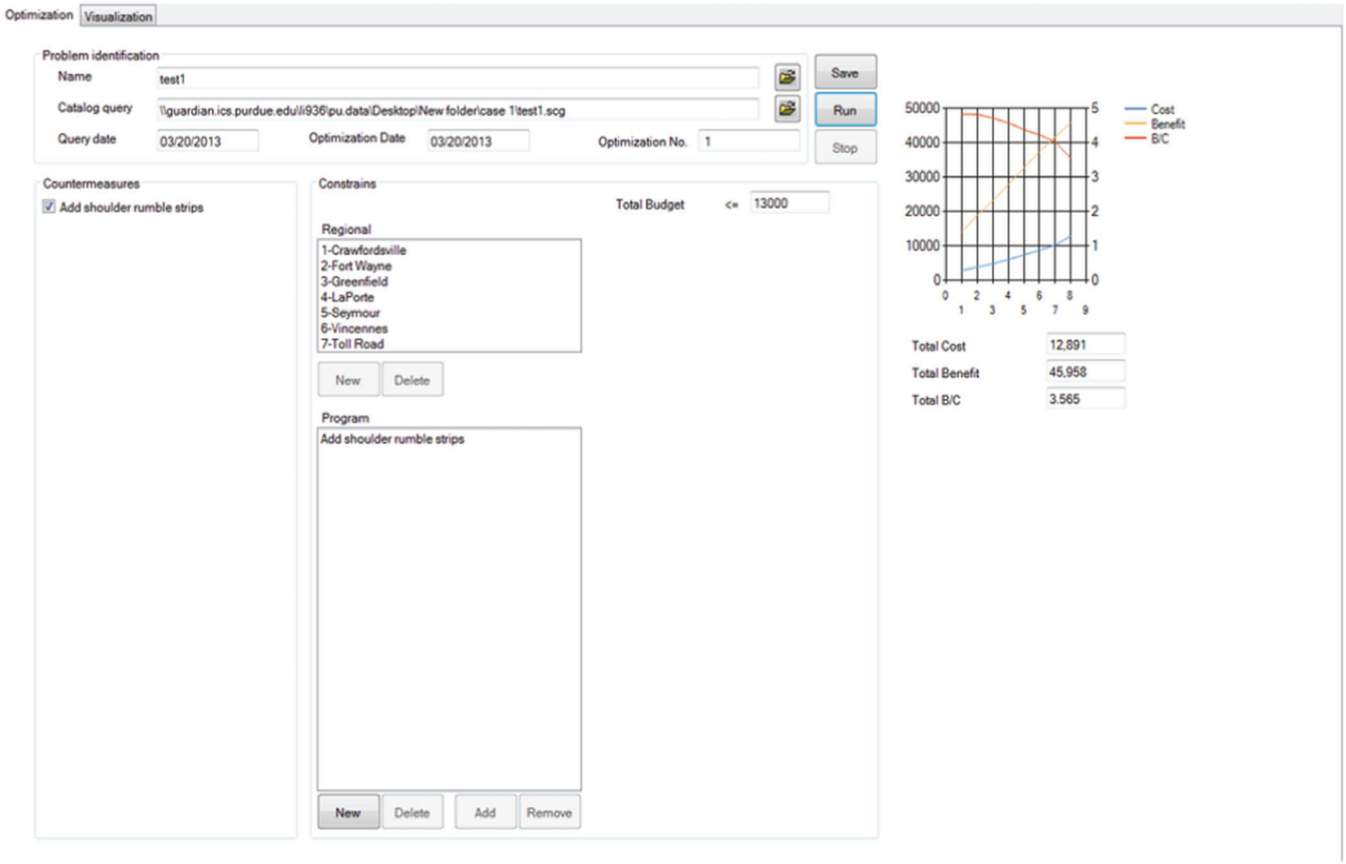
Total B/C: 4.235

Figure 5.5 Test algorithm interface of Scenario 4 in Case 1.

TABLE 5.6

Output of selected segments for Scenario 4 in Case 1

CFID Segment	Total Cost	Total Benefit	B/C
239995	2946	14257	4.84
235280	987	4752	4.81
237139	990	4231	4.27
247281	1188	4752	4
420356	1344	4752	3.54
225795	1398	4752	3.4



Problem identification

Name: test1

Catalog query: \\guardian.ics.purdue.edu\li936\pu.data\Desktop\New folder\case 1\test1.scg

Query date: 03/20/2013

Optimization Date: 03/20/2013

Optimization No.: 1

Countermeasures

☑ Add shoulder rumble strips

Constrains

Total Budget <= 13000

Regional

1-Crawfordsville
2-Fort Wayne
3-Greenfield
4-LaPorte
5-Seymour
6-Vincennes
7-Toll Road

Program

Add shoulder rumble strips

Total Cost: 12,891

Total Benefit: 45,958

Total B/C: 3.565

Figure 5.6 Test algorithm interface of Scenario 5 in Case 1.

Self-check: Even though CFID 218618 had a higher B/C ratio than CFID 238149, it was not selected because the total cost of the first seven higher B/C ratio segments was $10,365 and the total budget was $13,000. Therefore, the remaining budget was $2,635, which was less than the CFID 218618 segment cost of $4,350. Therefore, the next qualified candidate, CFID 238149, with a cost of $2,526, was selected.

Case 2: Create another optimization problem with two mutually exclusive countermeasures. The safety countermeasures consisted of a new signal installation and the conversion of an intersection to a roundabout. Six intersections were randomly selected from the *new signal installation.csv* file and four intersections were selected in the *convert intersection to roundabout.csv* file as shown in Table 5.8 and Table 5.9; and two different scenarios were defined in order to test both the sequence of selection, the mutual exclusivity, and the maximum budget constraints.

TABLE 5.7
Output of selected segment for Scenario 5 in Case 1

CFID Segment	Total Cost	Total Benefit	B/C
239995	2946	14257	4.84
235280	987	4752	4.81
237139	990	4231	4.27
247281	1188	4752	4
420356	1344	4752	3.54
225795	1398	4752	3.4
238248	1512	4231	2.8
238149	2526	4231	1.68

1: The total budget constraint was set at $7,000,000, which was larger than the total cost if all the intersections were selected. The resulting interface was as shown in Figure 5.7.

The output shows that nine out of the 10 intersections were selected as shown in Table 5.10.

Self-check: The total cost of implementing the safety countermeasures in all the intersections was $6,750,000, but the optimal solution had a cost of $5,250,000 even though the total budget constraint was larger than $6,750,000, which was due to the fact that an intersection was selected in both datasets—CFID 6544 as shown in

TABLE 5.8
Test Case 2 subset sample dataset from *convert intersection to roundabout.csv*

CFID Intersection	Total Cost	Total Benefit	B/C
6544	1500000	256418	0.17
6579	1500000	284464	0.19
6800	1500000	216353	0.14
7145	1500000	284464	0.19

TABLE 5.9
Test Case 2 subset sample dataset from *new signal installation.csv*

CFID Intersection	Total Cost	Total Benefit	B/C
6303	125000	30717	0.25
6311	125000	19400	0.16
6544	125000	22633	0.18
6701	125000	19400	0.16
6727	125000	19400	0.16
6883	125000	29100	0.23

Table 5.8 and Table 5.9. Since the B/C ratio in the *new signal installation* table was 0.18, which was larger than the B/C ratio of 0.17 in the *convert intersection into roundabout* table, it could not be selected twice because of the mutual exclusivity constraint regardless of the size of the total budget.

2: If the total budget constraint was set at $5,000,000, then only the intersections which have the relatively high B/C ratios will be selected. The resulting interface was as shown in Figure 5.8.

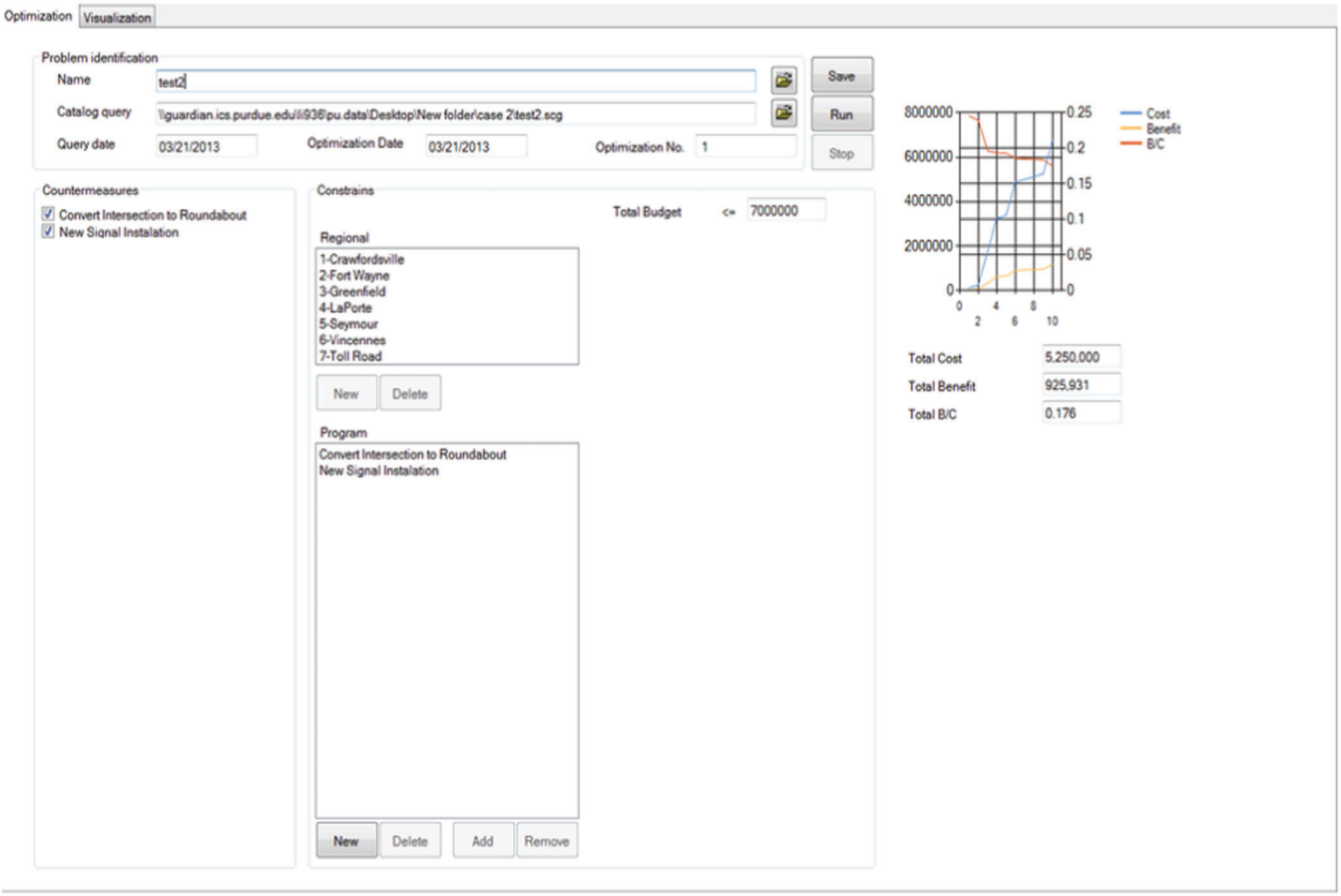
The output shows that eight out of the 10 intersections were selected as shown in Table 5.11.

Self-check: At this point, the total budget was lower than the previous Scenario 1. For the repeated CFID 6544 intersection, the B/C ratio in Table 5.9 is higher than the value in Table 5.8. Thus, the CFID 6544 intersection in Table 5.12 was selected and the CFID 6544 intersection in Table 5.8 could not be selected because of the mutual exclusivity constraint.

Case 3: Use the same sample dataset as in Case 2, but add more minimum countermeasure constraints, such as that the cost to convert an intersection to a roundabout must be at least $3,500,000. In this case, the interface was as shown in Figure 5.9.

The output shows that seven out of the 10 intersections were selected as shown in Table 5.12.

Self-check: Three out of the four intersections that met the minimum program constraint in the *convert intersection to roundabout* table were selected. CFID 6544 intersection in the table was selected because, after selecting two candidates in the convert intersection to roundabout table, the total cost was $3,000,000. Since the minimum program budget was $3,500,000, the third candidate, CFID 6544, was selected. Meanwhile, CFID intersection 6544 in the *new signal installation* table could not be selected because of the mutual exclusivity constraint. Four other intersections with relatively higher B/C ratio candidates in the *new signal installation* table were also selected in order to make use of the entire budget.



Name: test2

Catalog query: \\guardian.ics.purdue.edu\li936\pu.data\Desktop\New folder\case 2\test2.scg

Query date: 03/21/2013

Optimization Date: 03/21/2013

Optimization No.: 1

☑ Convert Intersection to Roundabout
☑ New Signal Instalation

Total Budget <= 7000000

1-Crawfordsville
2-Fort Wayne
3-Greenfield
4-LaPorte
5-Seymour
6-Vincennes
7-Toll Road

Convert Intersection to Roundabout
New Signal Instalation

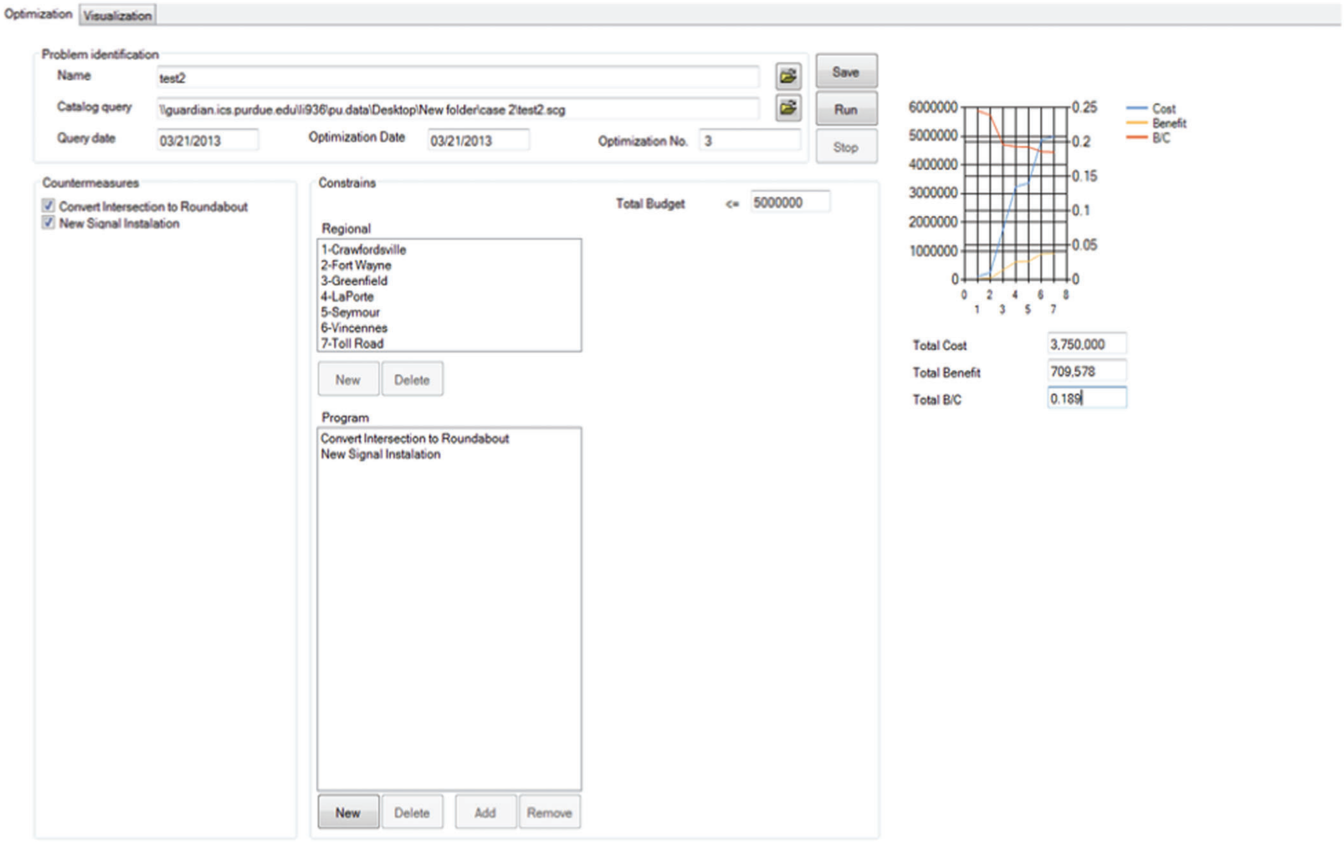
Total Cost: 5,250,000
Total Benefit: 925,931
Total B/C: 0.176

Figure 5.7 Test algorithm interface of Scenario 1 in Case 2.

TABLE 5.10
Output of selected intersections for Scenario 1 in Case 2

CFID intersection	Applied Countermeasures C	Applied Countermeasures D	Total Cost	Total Benefit	B/C
6303	1	0	125000	30717	0.25
6883	1	0	125000	29100	0.23
6579	0	1	1500000	284464	0.19
7145	0	1	1500000	284464	0.19
6544	1	0	125000	22633	0.18
6311	1	0	125000	19400	0.16
6727	1	0	125000	19400	0.16
6701	1	0	125000	19400	0.16
6800	0	1	1500000	216353	0.14

C= new signal installation; D= convert intersection to roundabout; 1= applied; 0= not applied.



Name: test2
Catalog query: \\guardian.ics.purdue.edu\li936\pu.data\Desktop\New folder\case 2\test2.scg
Query date: 03/21/2013
Optimization Date: 03/21/2013
Optimization No. 3

☑ Convert Intersection to Roundabout
☑ New Signal Instalation

Total Budget <= 5000000

1-Crawfordsville
2-Fort Wayne
3-Greenfield
4-LaPorte
5-Seymour
6-Vincennes
7-Toll Road

Convert Intersection to Roundabout
New Signal Instalation

Total Cost: 3,750,000
Total Benefit: 709,578
Total B/C: 0.189

Figure 5.8 Test algorithm interface of Scenario 2 in Case 2.

TABLE 5.11
Output of selected intersections for Scenario 2 in Case 2

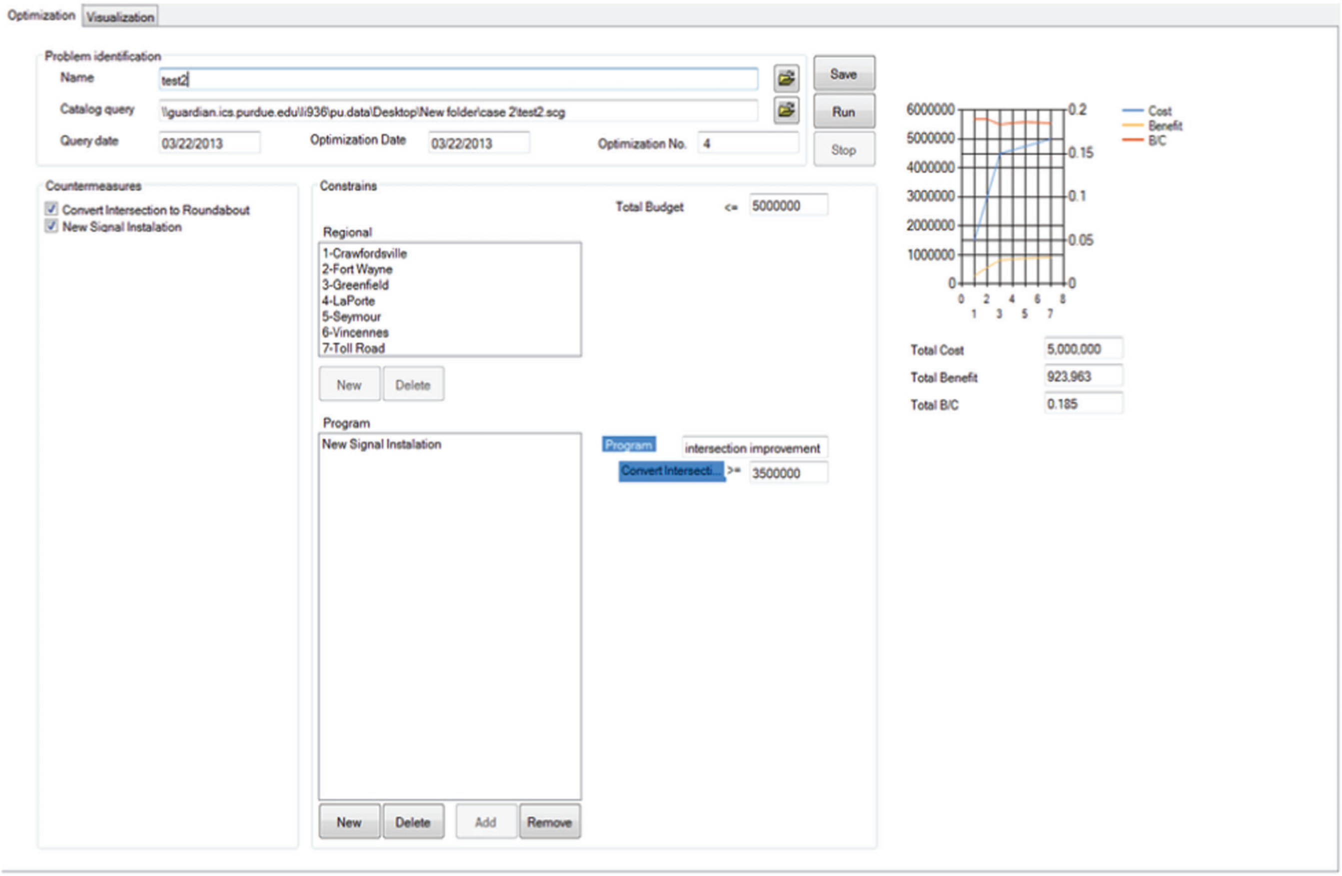
CFID Intersection	Applied Countermeasures C	Applied Countermeasures D	Total Cost	Total Benefit	B/C
6303	1	0	125000	30717	0.25
6883	1	0	125000	29100	0.23
6579	0	1	1500000	284464	0.19
7145	0	1	1500000	284464	0.19
6544	1	0	125000	22633	0.18
6311	1	0	125000	19400	0.16
6701	1	0	125000	19400	0.16
6727	1	0	125000	19400	0.16

C= new signal installation; D= convert intersection to roundabout; 1= applied; 0= not applied.

TABLE 5.12
Output of selected intersections in Case 3

CFID Intersection	Applied Countermeasures C	Applied Countermeasures D	Total Cost	Total Benefit	B/C
6579	0	1	1500000	284464	0.19
7145	0	1	1500000	284464	0.19
6544	0	1	1500000	256418	0.17
6303	1	0	125000	30717	0.25
6883	1	0	125000	29100	0.23
6311	1	0	125000	19400	0.16
6727	1	0	125000	19400	0.16

C= new signal installation; D= convert intersection to roundabout; 1= applied; 0= not applied.



Problem identification
Name test2
Catalog query \\guardian.ics.purdue.edu\li936\pu.data\Desktop\New folder\case 2\test2.scg
Query date 03/22/2013
Optimization Date 03/22/2013
Optimization No. 4

Countermeasures
☑ Convert Intersection to Roundabout
☑ New Signal Instalation

Constrains
Total Budget <= 5000000

Regional
1-Crawfordsville
2-Fort Wayne
3-Greenfield
4-LaPorte
5-Seymour
6-Vincennes
7-Toll Road

Program
New Signal Instalation

Program intersection improvement
Convert Intersecti... >= 3500000

Total Cost 5,000,000
Total Benefit 923,963
Total B/C 0.185

Figure 5.9 Test algorithm interface of Case 3.

TABLE 5.13
Test Case 4 subset sample dataset from *add shoulder rumble strips.csv*

CFID Segment	Total Cost	Total Benefit	B/C
225795	1398	4752	3.4
238248	1512	4231	2.8
238149	2526	4231	1.68
218618	4350	8463	1.95
417817	2682	4231	1.58

Case 4: Create another optimization problem with two countermeasures. The countermeasures consisted of adding shoulder rumble strips and widening the outside shoulder width. Five segments were randomly selected in the *add shoulder rumble strips.csv* file and five segments were selected in the *widen outside shoulder width.csv* file. Since these two safety countermeasures could be carried out in the same location at the same time, they are not mutually exclusive. The sample dataset is shown in Table 5.13 and Table 5.14.

There were two identical segments named CFID-225795. When the total budget constraint was set at $1,540,000, the interface is as shown in Figure 5.10.

In the output, all 10 segments were selected as shown in Table 5.15.

Self-check: All 10 segments, including the two identical segments, were selected because the minimum total costs of the safety countermeasures implemented in the 10 segments were $1,539,307, which is less than the budget, and two safety countermeasures are not mutually exclusive; thus, all the segments were selected and the total benefit and total B/C ratio were $175,195 and 0.114 respectively.

5.3.3 Evaluation of Heuristic Optimization Algorithm

The testing yielded reasonable results. Therefore, evaluation of the heuristic method was initiated. The purpose of the evaluation was to assess how closely the heuristic solution was to the optimal solution. Since the optimal solution was not known and obtaining it would be time-consuming, a random generation of feasible solutions was applied in the evaluation. A sufficient number of random solutions had to be generated to evaluate the heuristic solution. This evaluation was carried out with another computer tool that generates random solutions, checks their feasibility, calculates the objective function for feasible solutions, and computes the statistics of the solutions evaluated so far.

The number of generated feasible solutions had to be sufficiently large to claim that the results reasonably well reflected the quality of the heuristic solution. The evaluation generated positive results if the random search for a feasible solution was not better than the heuristic one, or a better solution was found in a random search that was only marginally superior to the heuristic method solution.

The specifications of the computer generating this search are as follows:

TABLE 5.14
Test Case 4 subset sample dataset from *widen outside shoulder width.csv*

CFID Segment	Total Cost	Total Benefit	B/C
244054	275255	27646	0.1
245175	341392	33175	0.097
420804	323045	33175	0.103
225795	286518	22117	0.077
247866	300628	33175	0.11

- Dell computer, Windows XP.
- Intel Core (TM) 2 Duo CPU 3.00 GHZ
- 3.25GB of RAM

Two different scenarios were defined to evaluate the heuristic algorithm. The entire original dataset is contained in Appendix C.

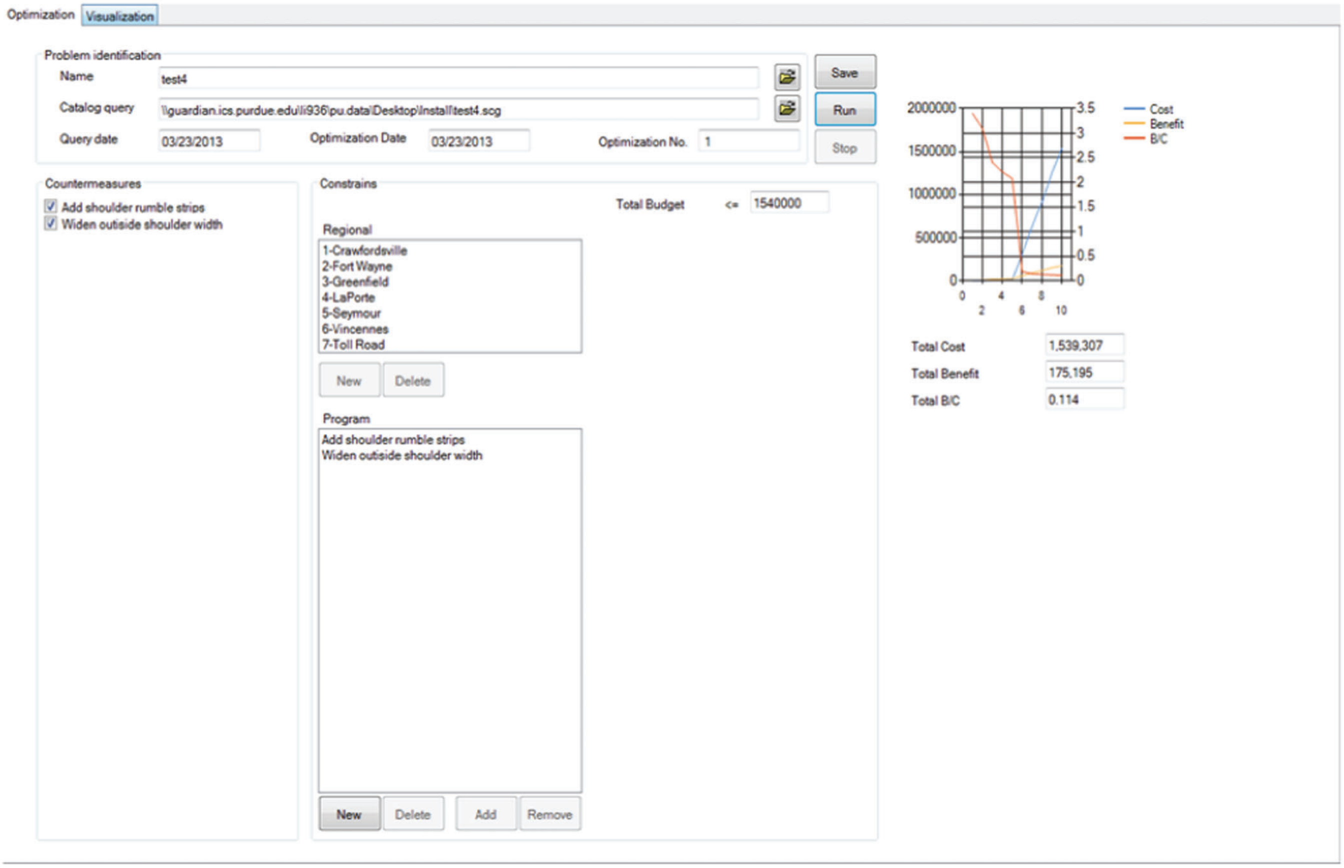
Scenario 1: Create an optimization problem with four countermeasures which include the following: adding shoulder rumble strips, widening the outside shoulder width, installing a new traffic signal, and converting an intersection to a roundabout. All the elements in these four files (Appendix C) were selected as the candidates. The total budget constraint is set at $450,000 and the minimum program constraint is that the total cost of widening the outside shoulder width must be at least $50,000. The interface is shown in Figure 5.11.

In the interface, researchers can select different countermeasures. A "$\surd$" means this countermeasure is selected and appears in the program column. There are six INDOT regions: Crawfordsville, Fort Wayne, Greenfield, LaPorte, Seymour, and Vincennes. Also, add the toll road in the region column. Researchers can select different budget constraints, regional constraints, and program constraints. The optimization column shows the current results. The horizontal axis represents the number of selected elements, the left-vertical axis represents money in dollars, and the right-vertical axis denotes the benefit/cost ratio.

After running 50 hours and 7 minutes, the results show that the random run best solution was slightly better than the heuristic method solution. The comparison information is shown in Table 5.16.

According to Table 5.16, the difference between the total safety benefit of the random and heuristic solutions is approximately 1%. The outputs of the selected elements are shown in Table 5.17.

Figure 5.12 shows that there were 28 identical location-countermeasure pairs; but there were 10 differences. One countermeasure for CFID 6303, CFID 6333, CFID 6547, CFID 6883, and CFID 7309 was in the heuristic solution, but there was no countermeasure in the random solution. One countermeasure for CFID 6800 was in the random solution, but there was no countermeasure in the heuristic solution. Two countermeasures for CFID 244054 and CFID 245175 were in the heuristic solution, while there was only one countermeasure in the random solution.



Problem identification

Name: test4

Catalog query: \\guardian.ics.purdue.edu\li936\pu.data\Desktop\Install\test4.scg

Query date: 03/23/2013

Optimization Date: 03/23/2013

Optimization No.: 1

Countermeasures

☑ Add shoulder rumble strips
☑ Widen outside shoulder width

Constrains

Total Budget <= 1540000

Regional

1-Crawfordsville
2-Fort Wayne
3-Greenfield
4-LaPorte
5-Seymour
6-Vincennes
7-Toll Road

Program

Add shoulder rumble strips
Widen outside shoulder width

Total Cost: 1,539,307

Total Benefit: 175,195

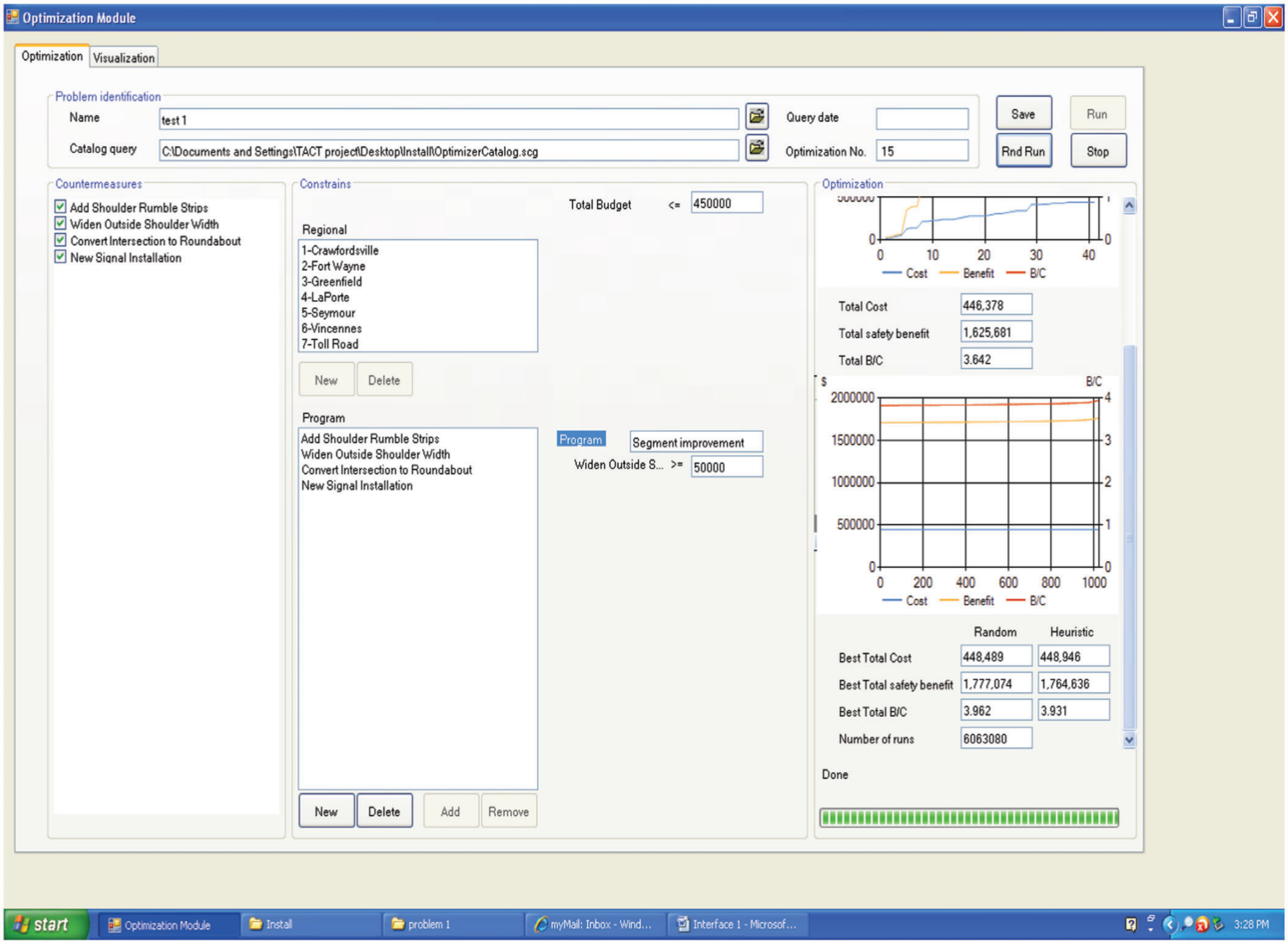
Total B/C: 0.114

Figure 5.10 Test algorithm interface of Case 4.

TABLE 5.15
Output of selected segments in Case 4

	Applied Countermeasures				
CFID Segment	**A**	**B**	**Total Cost**	**Total Benefit**	**B/C**
225795	1	0	1398	4752	3.40
238248	1	0	1512	4231	2.80
218618	1	0	4350	8463	1.95
238149	1	0	2526	4231	1.68
417817	1	0	2682	4231	1.58
247866	0	1	300628	33175	0.11
420804	0	1	323045	33175	0.10
244054	0	1	275255	27646	0.10
245175	0	1	341392	33175	0.10
225795	0	1	286518	21121	0.07

A= add shoulder rumble strips; B= widen outside shoulder width; 1= applied; 0= not applied.



Problem identification

Name: test 1

Catalog query: C:\Documents and Settings\TACT project\Desktop\Install\OptimizerCatalog.scg

Query date:

Optimization No. 15

Countermeasures

☑ Add Shoulder Rumble Strips
☑ Widen Outside Shoulder Width
☑ Convert Intersection to Roundabout
☑ New Signal Installation

Constrains

Total Budget <= 450000

Regional
1-Crawfordsville
2-Fort Wayne
3-Greenfield
4-LaPorte
5-Seymour
6-Vincennes
7-Toll Road

Program
Add Shoulder Rumble Strips
Widen Outside Shoulder Width
Convert Intersection to Roundabout
New Signal Installation

Program: Segment improvement
Widen Outside S... >= 50000

Optimization

Total Cost: 446,378
Total safety benefit: 1,625,681
Total B/C: 3.642

	Random	Heuristic
Best Total Cost	448,489	448,946
Best Total safety benefit	1,777,074	1,764,636
Best Total B/C	3.962	3.931
Number of runs	6063080	

Done

Figure 5.11 Evaluation interface of Scenario 1.

Two countermeasures for CFID 226032 and CFID 417817 were in the random solution, and only one countermeasure in the heuristic solution.

Figure 5.13 compares the safety countermeasures selected in the heuristic method solution to the random run best solution. It showed that there were 21, 5, 12, and 3 elements selected to implement add shoulder rumble strips (A), widen outside shoulder width (B), new signal installation (C), and convert intersection to roundabout (D) in the heuristic solution compared to 21, 5, 7, and 4 for the four countermeasures respectively in the random solution.

TABLE 5.16
Comparison of random and heuristic method solutions in Scenario 1

	Heuristic	Random
Budget spent	448,946	448,489
Total safety benefit	1,764,636	1,777,074
Total B/C	3.931	3.962
Number of runs	1	6,063,080
Execution time(s)	0.03	180,420

The random solution was superior to the heuristic method solution because it had more safety benefits.

Scenario 2: Create another optimization problem with four countermeasures which include the following: add shoulder rumble strips, widening the outside shoulder width, installing a new traffic signal, and converting an intersection to a roundabout. All the elements in these four files are selected as the candidates. The total budget constraint is set at $450,000, and the interface appears in Figure 5.14.

After 49 hours and 37 minutes, the results show that the heuristic method solution is slightly better than the random best solution. The comparison information is shown in Table 5.18.

According to Table 5.18, the difference in the total safety benefits between the random run best solution and the heuristic solution is approximately 1%. The outputs of selected elements are shown in Table 5.19.

Figure 5.15 shows that there were 32 identical location-countermeasure pairs. But, there were five differences. One countermeasure for CFID 6303, CFID 6333 was in the heuristic solution, but there was no countermeasure in the random solution. One counter-

TABLE 5.17
Output of selected elements in Scenario 1

Heuristic Method Solution								Current Random Run Best Solution							
	Applied Countermeasures								Applied Countermeasures						
CFID Element	A	B	C	D	Annual Cost	Annual Benefit	B/C	CFID Element	A	B	C	D	Annual Cost	Annual Benefit	B/C
6275	0	0	1	0	12500	58200	4.66	6275	0	0	1	0	12500	58200	4.66
6288	0	0	1	0	12500	63050	5.04	6288	0	0	1	0	12500	63050	5.04
6300	0	0	1	0	12500	121250	9.70	6300	0	0	1	0	12500	121250	9.70
6303	0	0	1	0	12500	30717	2.46								
6333	0	0	1	0	12500	37183	2.97								
6547	0	0	1	0	12500	30717	2.46								
6579	0	0	0	1	75000	284464	3.79	6579	0	0	0	1	75000	284464	3.79
6587	0	0	1	0	12500	53350	4.27	6587	0	0	1	0	12500	53350	4.27
6719	0	0	0	1	75000	256418	3.42	6719	0	0	0	1	75000	256418	3.42
								6800	0	0	0	1	75000	216353	2.88
6883	0	0	1	0	12500	29100	2.33								
7069	0	0	1	0	12500	80834	6.47	7069	0	0	1	0	12500	80834	6.47
7145	0	0	0	1	75000	284464	3.79	7145	0	0	0	1	75000	284464	3.79
7218	0	0	1	0	12500	85684	6.85	7218	0	0	1	0	12500	85684	6.85
7272	0	0	1	0	12500	54967	4.40	7272	0	0	1	0	12500	54967	4.40
7309	0	0	1	0	12500	32333	2.59								
218618	1	0	0	0	621	8463	13.63	218618	1	0	0	0	621	8463	13.63
225795	1	0	0	0	200	4752	23.76	225795	1	0	0	0	200	4752	23.76
226032	1	0	0	0	118	4752	40.27	226032	1	1	0	0	7006	8469	1.21
232251	1	0	0	0	85	4231	49.78	232251	1	0	0	0	85	4231	49.78
234444	1	0	0	0	33	4752	144.0	234444	1	0	0	0	33	4752	144.0
235280	1	0	0	0	141	4752	33.70	235280	1	0	0	0	141	4752	33.70
236583	1	0	0	0	81	4231	52.23	236583	1	0	0	0	81	4231	52.23
237139	1	0	0	0	141	4231	30.01	237139	1	0	0	0	141	4231	30.01
238122	1	0	0	0	68	4231	62.22	238122	1	0	0	0	68	4231	62.22
238149	1	0	0	0	361	4231	11.72	238149	1	0	0	0	361	4231	11.72
238248	1	1	0	0	7956	12305	1.55	238248	1	1	0	0	7956	12305	1.55
239231	1	0	0	0	159	4752	29.89	239231	1	0	0	0	159	4752	29.89
239995	1	0	0	0	421	14257	33.86	239995	1	0	0	0	421	14257	33.86
241963	1	0	0	0	76	4752	62.53	241963	1	0	0	0	76	4752	62.53
244054	1	1	0	0	13955	39479	2.83	244054	1	0	0	0	192	14257	74.26
245175	1	1	0	0	17308	45008	2.60	245175	1	0	0	0	238	14257	59.90
245360	1	0	0	0	69	4752	68.87	245360	1	0	0	0	69	4752	68.87
247281	1	0	0	0	170	4752	27.95	247281	1	0	0	0	170	4752	27.95
247866	0	1	0	0	15031	33175	2.21	247866	0	1	0	0	15031	33175	2.21
417817	1	0	0	0	383	4231	11.05	417817	1	1	0	0	11371	11570	1.02
420356	1	0	0	0	192	4752	24.75	420356	1	0	0	0	192	4752	24.75
420804	1	1	0	0	16377	41063	2.51	420804	1	1	0	0	16377	41063	2.51

A= add shoulder rumble strips; B= widen outside shoulder width; C= new signal installation; D= convert intersection to roundabout; 1= applied countermeasures; 0= not applied countermeasures.

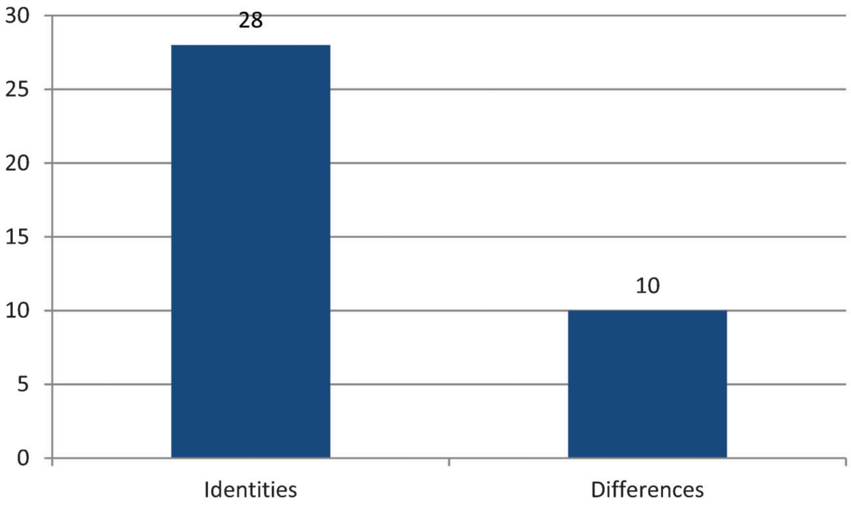


Figure 5.12 Count identities and differences elements in Scenario 1.

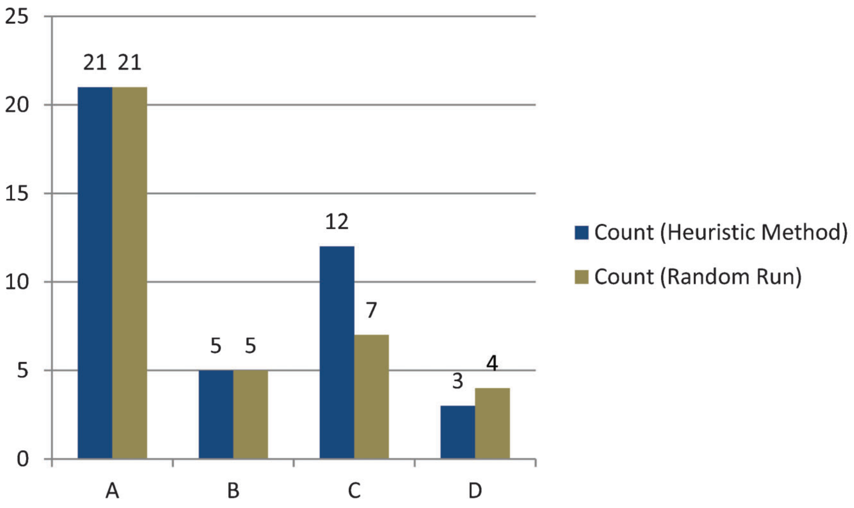
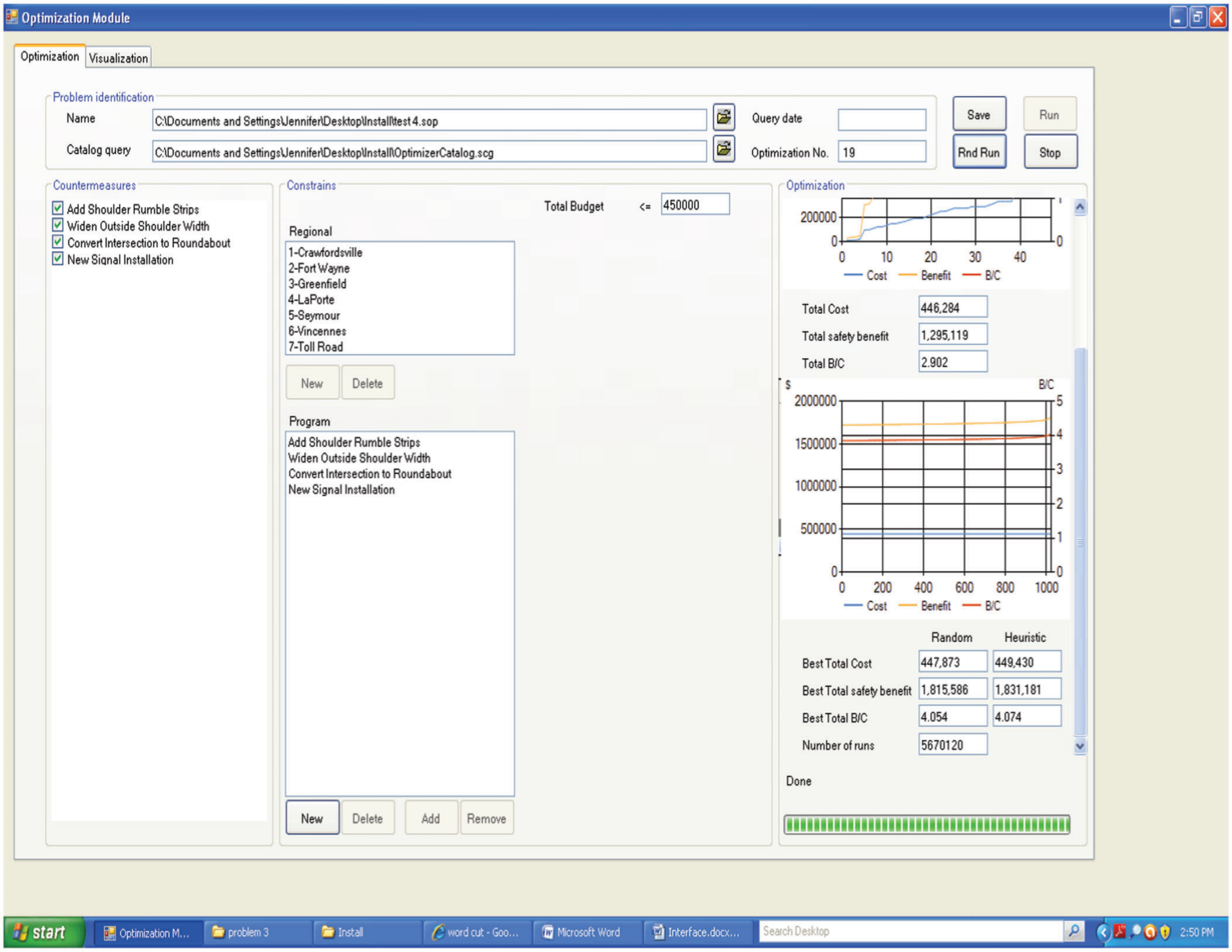


Figure 5.13 Number of selected four different safety countermeasures in Scenario 1.



Name: C:\Documents and Settings\Jennifer\Desktop\Install\test4.sop

Catalog query: C:\Documents and Settings\Jennifer\Desktop\Install\OptimizerCatalog.scg

Query date:

Optimization No. 19

☑ Add Shoulder Rumble Strips
☑ Widen Outside Shoulder Width
☑ Convert Intersection to Roundabout
☑ New Signal Installation

Total Budget <= 450000

Regional
1-Crawfordsville
2-Fort Wayne
3-Greenfield
4-LaPorte
5-Seymour
6-Vincennes
7-Toll Road

Program
Add Shoulder Rumble Strips
Widen Outside Shoulder Width
Convert Intersection to Roundabout
New Signal Installation

Total Cost 446,284
Total safety benefit 1,295,119
Total B/C 2.902

	Random	Heuristic
Best Total Cost	447,873	449,430
Best Total safety benefit	1,815,586	1,831,181
Best Total B/C	4.054	4.074
Number of runs	5670120	

Done

Figure 5.14 Evaluation interface of Scenario 2.

TABLE 5.18
Comparison of random and heuristic solutions in Scenario 2

	Heuristic	Random
Budget spent	449,430	447,873
Total safety benefit	1,831,181	1,815,586
Total B/C	4.074	4.054
Number of runs	1	5,670,120
Execution time(s)	0.03	178,620

TABLE 5.19
Output of selected elements in Scenario 2

Heuristic Method Solution								Current Random Run Best Solution							
	Applied Countermeasures								Applied Countermeasures						
CFID Element	A	B	C	D	Annual Cost	Annual Benefit	B/C	CFID Element	A	B	C	D	Annual Cost	Annual Benefit	B/C
6275	0	0	1	0	12500	58200	4.66	6275	0	0	1	0	12500	58200	4.66
6288	0	0	1	0	12500	63050	5.04	6288	0	0	1	0	12500	63050	5.04
6300	0	0	1	0	12500	121250	9.70	6300	0	0	1	0	12500	121250	9.70
6303	0	0	1	0	12500	30717	2.46								
6333	0	0	1	0	12500	37183	2.97								
6547	0	0	1	0	12500	30717	2.46	6547	0	0	1	0	12500	30717	2.46
6579	0	0	0	1	75000	284464	3.79	6579	0	0	0	1	75000	284464	3.79
6587	0	0	1	0	12500	53350	4.27	6587	0	0	1	0	12500	53350	4.27
6719	0	0	0	1	75000	256418	3.42	6719	0	0	0	1	75000	256418	3.42
6800	0	0	0	1	75000	216353	2.88	6800	0	0	0	1	75000	216353	2.88
7069	0	0	1	0	12500	80834	6.47	7069	0	0	1	0	12500	80834	6.47
7145	0	0	0	1	75000	284464	3.79	7145	0	0	0	1	75000	284464	3.79
7218	0	0	1	0	12500	85684	6.85	7218	0	0	1	0	12500	85684	6.85
7272	0	0	1	0	12500	54967	4.40	7272	0	0	1	0	12500	54967	4.40
7309	0	0	1	0	12500	32333	2.59	7309	0	0	1	0	12500	32333	2.59
218618	1	0	0	0	621	8463	13.63	218618	1	0	0	0	621	8463	13.63
225795	1	0	0	0	200	4752	23.76	225795	1	0	0	0	200	4752	23.76
226032	1	0	0	0	118	4752	40.27	226032	1	0	0	0	118	4752	40.27
232251	1	0	0	0	85	4231	49.78	232251	1	0	0	0	85	4231	49.78
234444	1	0	0	0	33	4752	144	234444	1	0	0	0	33	4752	144
235280	1	0	0	0	141	4752	33.70	235280	1	0	0	0	141	4752	33.70
236583	1	0	0	0	81	4231	52.23	236583	1	0	0	0	81	4231	52.23
237139	1	0	0	0	141	4231	30.01	237139	1	0	0	0	141	4231	30.01
238122	1	0	0	0	68	4231	62.22	238122	1	0	0	0	68	4231	62.22
238149	1	0	0	0	361	4231	11.72	238149	1	0	0	0	361	4231	11.72
238248	1	1	0	0	7956	12305	1.55	238248	1	0	0	0	216	4231	19.59
239231	1	0	0	0	159	4752	29.89	239231	1	0	0	0	159	4752	29.89
239995	1	0	0	0	421	14257	33.86	239995	1	0	0	0	421	14257	33.86
241963	1	0	0	0	76	4752	62.53	241963	1	0	0	0	76	4752	62.53
244054	1	0	0	0	192	14257	74.26	244054	1	0	0	0	192	14257	74.26
245175	1	0	0	0	238	14257	59.90	245175	1	0	0	0	238	14257	59.90
245360	1	0	0	0	69	4752	68.87	245360	1	0	0	0	69	4752	68.87
247281	1	0	0	0	170	4752	27.95	247281	1	0	0	0	170	4752	27.95
								247866	0	1	0	0	15031	33175	2.21
417817	1	0	0	0	383	4231	11.05	417817	1	0	0	0	383	4231	11.05
420356	1	0	0	0	192	4752	24.75	420356	1	0	0	0	192	4752	24.75
420804	1	0	0	0	225	9504	42.24	420804	1	1	0	0	16377	36708	2.24

A= add shoulder rumble strips; B= widen outside shoulder width; C= new signal installation; D= convert intersection to roundabout; 1= applied countermeasures; 0= not applied countermeasures.

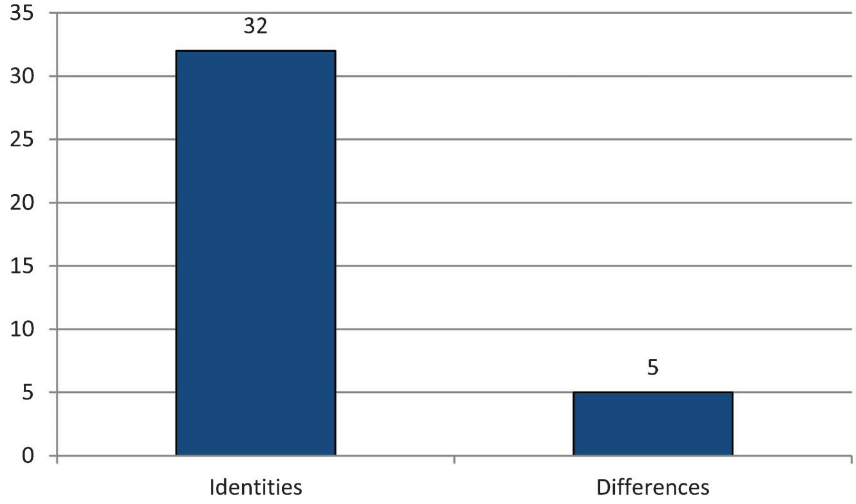


Figure 5.15 Count identities and differences elements in Scenario 2.

measure for CFID 247866 was in the random solution, but there was no countermeasure in the heuristic solution. Two countermeasures for CFID 238248 were in heuristic solution, only single countermeasure in random solution. Two countermeasures for CFID 420804 were in random solution, only single countermeasure in heuristic solution.

Figure 5.16 compares how many safety countermeasures were selected in the heuristic method solution with the random best solution. It shows that there were 21, 1, 11, and 4 elements selected to implement add shoulder rumble strips (A), widen outside shoulder width (B), new signal installation (C) and convert intersection to roundabout (D) in the heuristic solution while there were 21, 2, 9, and 4 for the four countermeasures respectively in the random solution.

In Scenario 2, currently, the heuristic method solution is better than the random solution, which means it generated positive results and more time would be needed to obtain a better random solution than the heuristic method solution under these constraints.

Scenario 3: Create another optimization problem with four countermeasures that include the following: adding shoulder rumble strips, widening the outside shoulder width, installing a new traffic signal, and converting an intersection to a roundabout. All the elements in these four files are selected as the candidates. If the total budget constraint is set at $500,000, the minimum program constraint is that the total cost of converting an intersection to a roundabout must be at least $150,000. The interface is shown in Figure 5.17.

After 92 hours and 7 minutes, the results show that the random best solution is slightly better than the heuristic method solution. The comparison information is shown in Table 5.20.

According to Table 5.20, the difference between the total safety benefits of the random best solution and the

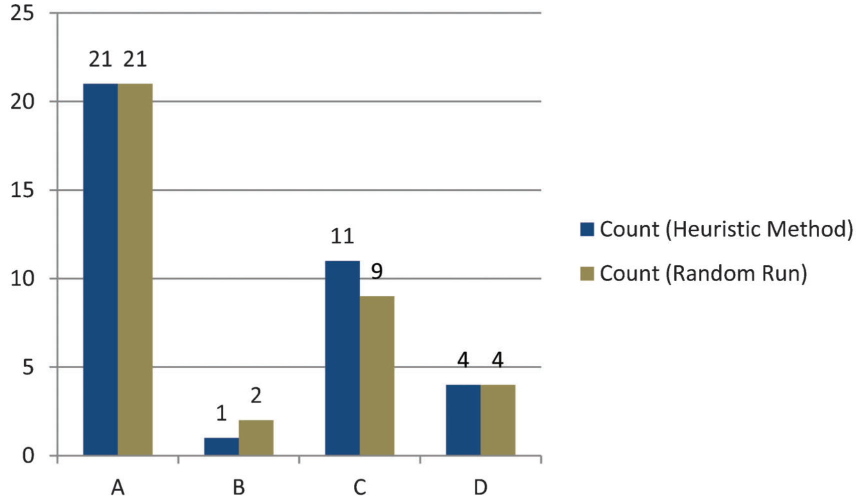
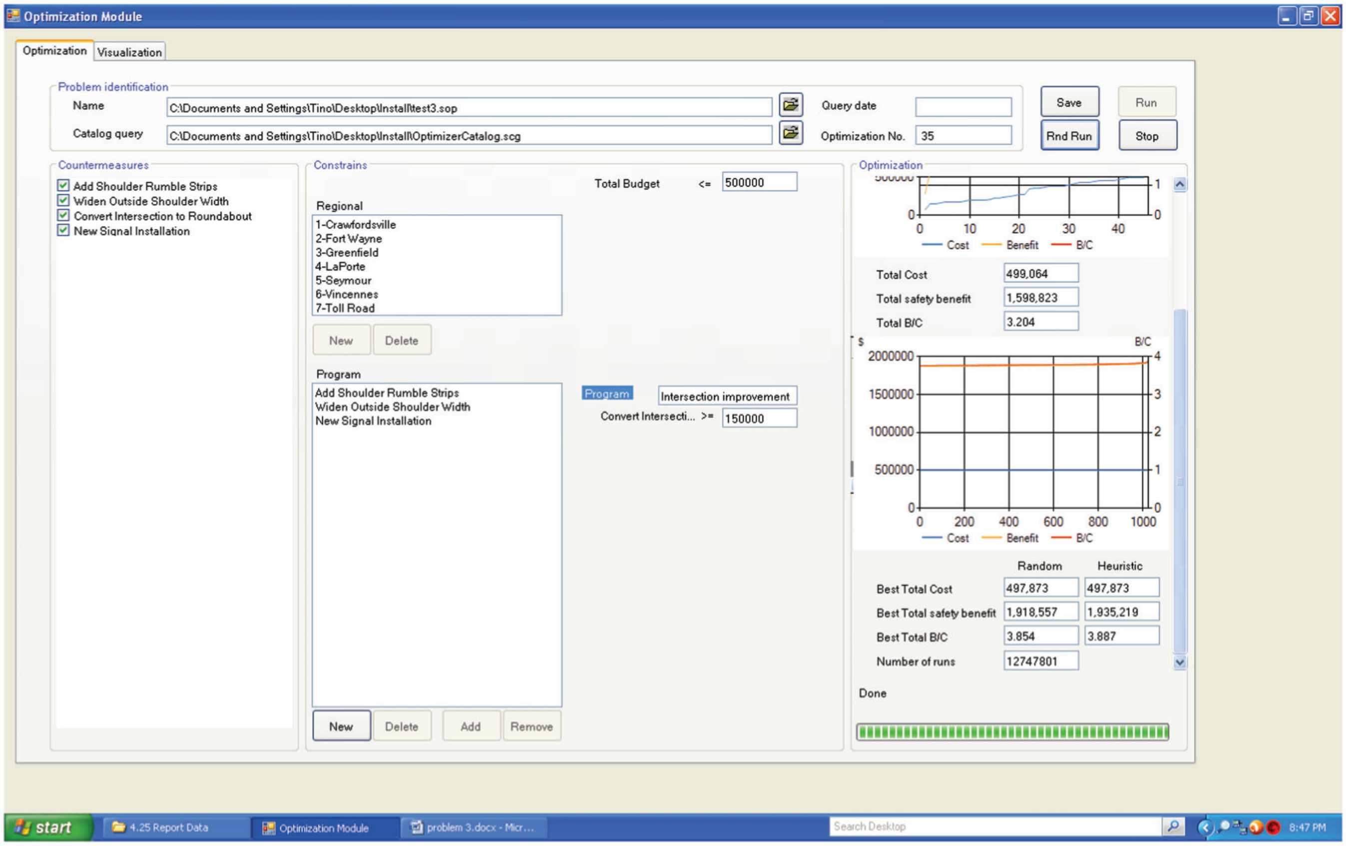


Figure 5.16 Number of selected four different safety countermeasures in Scenario 2.



Name C:\Documents and Settings\Tino\Desktop\Install\test3.sop

Catalog query C:\Documents and Settings\Tino\Desktop\Install\OptimizerCatalog.scg

Query date

Optimization No. 35

☑ Add Shoulder Rumble Strips
☑ Widen Outside Shoulder Width
☑ Convert Intersection to Roundabout
☑ New Signal Installation

Total Budget <= 500000

Regional
1-Crawfordsville
2-Fort Wayne
3-Greenfield
4-LaPorte
5-Seymour
6-Vincennes
7-Toll Road

Program
Add Shoulder Rumble Strips
Widen Outside Shoulder Width
New Signal Installation

Program: Intersection improvement

Convert Intersecti... >= 150000

Total Cost	499,064
Total safety benefit	1,598,823
Total B/C	3.204

	Random	Heuristic
Best Total Cost	497,873	497,873
Best Total safety benefit	1,918,557	1,935,219
Best Total B/C	3.854	3.887
Number of runs	12747801	

Done

Figure 5.17 Evaluation interface of Scenario 3.

heuristic solution is approximately 1%. The outputs of selected elements are shown in Table 5.21.

Figure 5.18 shows that there were 35 identical location-countermeasure pairs. But, there were four differences. One countermeasure for CFID 6303, CFID 6883 was in the heuristic solution, and there was no countermeasure in the random solution. One countermeasure for CFID 6701 and CFID 6727 was in the random solution, and there was no countermeasure in the heuristic solution.

Figure 5.19 shows how many safety countermeasures were selected in the heuristic method solution compared to the random best solution. It shows that there were 22, 1, 13, and 4 elements selected to implement add shoulder rumble strips (A), widen outside shoulder width (B), new signal installation (C) and convert intersection to roundabout (D) in both solutions.

TABLE 5.20
Comparison of random and heuristic solutions in Scenario 3

	Heuristic	Random
Budget spent	497,873	497,873
Total safety benefit	1,935,219	1,918,557
Total B/C	3.887	3.854
Number of runs	1	12,747,801
Execution time(s)	0.03	331,620

The random solution was superior to the heuristic method solution because the random solution had more safety benefits.

Scenario 4: Create another optimization problem with four countermeasures which include the following: adding shoulder rumble strips, widening the outside shoulder width, installing a new traffic signal, and converting an intersection to a roundabout. All the elements in these four files are selected as the candidates. If the total budget constraint is set at $400,000, the minimum program constraint is that the total cost of widening outside shoulder must be at least $45,000. The interface is shown in Figure 5.20.

After 25 hours and 16 minutes, the results show that the random best solution is slightly better than the heuristic method solution. The comparison information is shown in Table 5.22.

According to Table 5.22, the difference between the total safety benefits of the random best solution and the heuristic solution is approximately 1%. The outputs of selected elements are shown in Table 5.23.

Figure 5.21 shows that there were 33 identical location-countermeasure pairs, but there were two differences. One countermeasure for CFID 247866 was in the heuristic solution, and there was no countermeasure in the random solution. One countermeasure for CFID 6547 was in the random solution,

TABLE 5.21
Output of selected elements in Scenario 3

	Heuristic Method Solution							Current Random Run Best Solution							
CFID	Applied Countermeasures								Applied Countermeasures						
Element	A	B	C	D	Annual Cost	Annual Benefit	B/C	CFID Element	A	B	C	D	Annual Cost	Annual Benefit	B/C
6275	0	0	1	0	12500	58200	4.66	6275	0	0	1	0	12500	58200	4.66
6288	0	0	1	0	12500	63050	5.04	6288	0	0	1	0	12500	63050	5.04
6300	0	0	1	0	12500	121250	9.70	6300	0	0	1	0	12500	121250	9.70
6303	0	0	1	0	12500	30717	2.46								
6333	0	0	1	0	12500	37183	2.97	6333	0	0	1	0	12500	37183	2.97
6544	0	0	1	0	12500	22633	1.81	6544	0	0	1	0	12500	22633	1.81
6547	0	0	1	0	12500	30717	2.46	6547	0	0	1	0	12500	30717	2.46
6579	0	0	0	1	75000	284464	3.79	6579	0	0	0	1	75000	284464	3.79
6587	0	0	1	0	12500	53350	4.27	6587	0	0	1	0	12500	53350	4.27
								6701	0	0	1	0	12500	19400	1.55
6719	0	0	0	1	75000	256418	3.42	6719	0	0	0	1	75000	256418	3.42
								6727	0	0	1	0	12500	19400	1.55
6800	0	0	0	1	75000	216353	2.88	6800	0	0	0	1	75000	216353	2.88
6883	0	0	1	0	12500	29100	2.33								
7069	0	0	1	0	12500	80834	6.47	7069	0	0	1	0	12500	80834	6.47
7145	0	0	0	1	75000	284464	3.79	7145	0	0	0	1	75000	284464	3.79
7218	0	0	1	0	12500	85684	6.85	7218	0	0	1	0	12500	85684	6.85
7272	0	0	1	0	12500	54967	4.40	7272	0	0	1	0	12500	54967	4.40
7309	0	0	1	0	12500	32333	2.59	7309	0	0	1	0	12500	32333	2.59
218618	1	0	0	0	621	8463	13.63	218618	1	0	0	0	621	8463	13.63
225795	1	0	0	0	200	4752	23.76	225795	1	0	0	0	200	4752	23.76
226032	1	0	0	0	118	4752	40.27	226032	1	0	0	0	118	4752	40.27
232251	1	0	0	0	85	4231	49.78	232251	1	0	0	0	85	4231	49.78
234444	1	0	0	0	33	4752	144.0	234444	1	0	0	0	33	4752	144.0
235280	1	0	0	0	141	4752	33.70	235280	1	0	0	0	141	4752	33.70
236583	1	0	0	0	81	4231	52.23	236583	1	0	0	0	81	4231	52.23
237139	1	0	0	0	141	4231	30.01	237139	1	0	0	0	141	4231	30.01
238122	1	0	0	0	68	4231	62.22	238122	1	0	0	0	68	4231	62.22
238149	1	0	0	0	361	4231	11.72	238149	1	0	0	0	361	4231	11.72
238248	1	0	0	0	216	4231	19.59	238248	1	0	0	0	216	4231	19.59
239231	1	0	0	0	159	4752	29.89	239231	1	0	0	0	159	4752	29.89
239995	1	0	0	0	421	14257	33.86	239995	1	0	0	0	421	14257	33.86
241963	1	0	0	0	76	4752	62.53	241963	1	0	0	0	76	4752	62.53
244054	1	0	0	0	192	14257	74.26	244054	1	0	0	0	192	14257	74.26
245175	1	0	0	0	238	14257	59.90	245175	1	0	0	0	238	14257	59.90
245360	1	0	0	0	69	4752	68.87	245360	1	0	0	0	69	4752	68.87
247281	1	0	0	0	170	4752	27.95	247281	1	0	0	0	170	4752	27.95
247866	1	0	0	0	15031	33175	2.21	247866	1	0	0	0	15031	33175	2.21
417817	1	0	0	0	383	4231	11.05	417817	1	0	0	0	383	4231	11.05
420356	1	0	0	0	192	4752	24.75	420356	1	0	0	0	192	4752	24.75
420804	1	1	0	0	16377	36708	2.24	420804	1	1	0	0	16377	36708	2.24

A= add shoulder rumble strips; B= widen outside shoulder width; C= new signal installation; D= convert intersection to roundabout; 1= applied countermeasures; 0= not applied countermeasures.

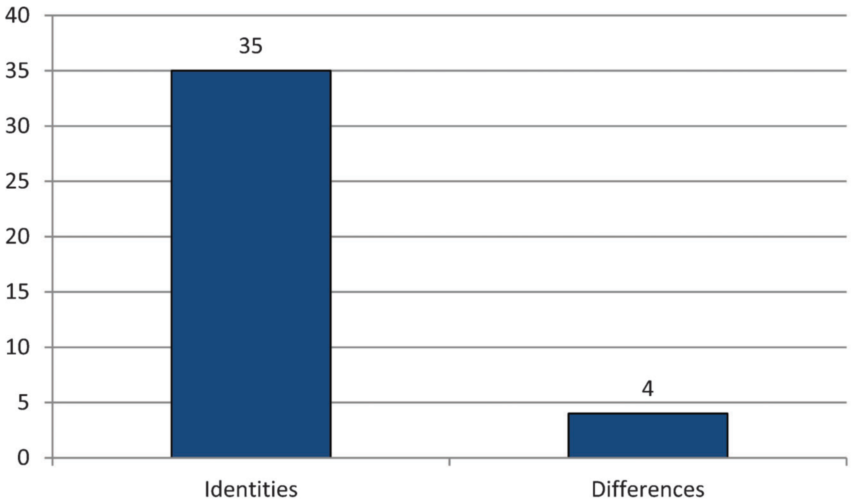


Figure 5.18 Count identities and differences elements in Scenario 3.

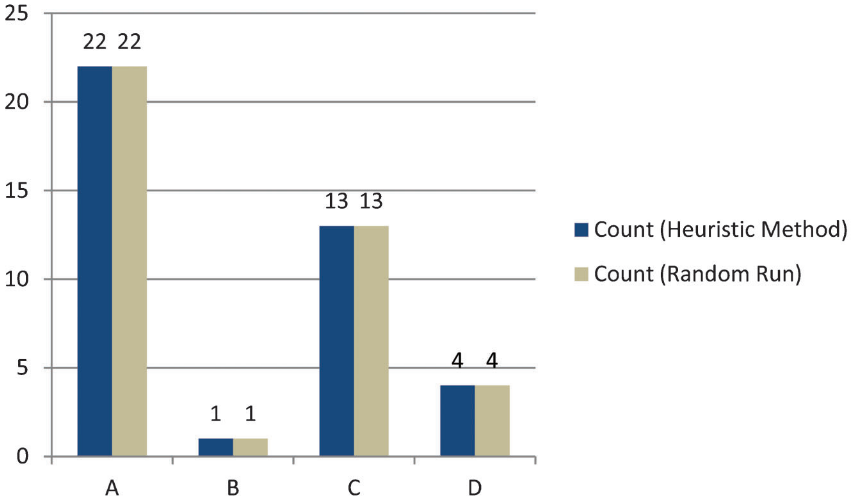
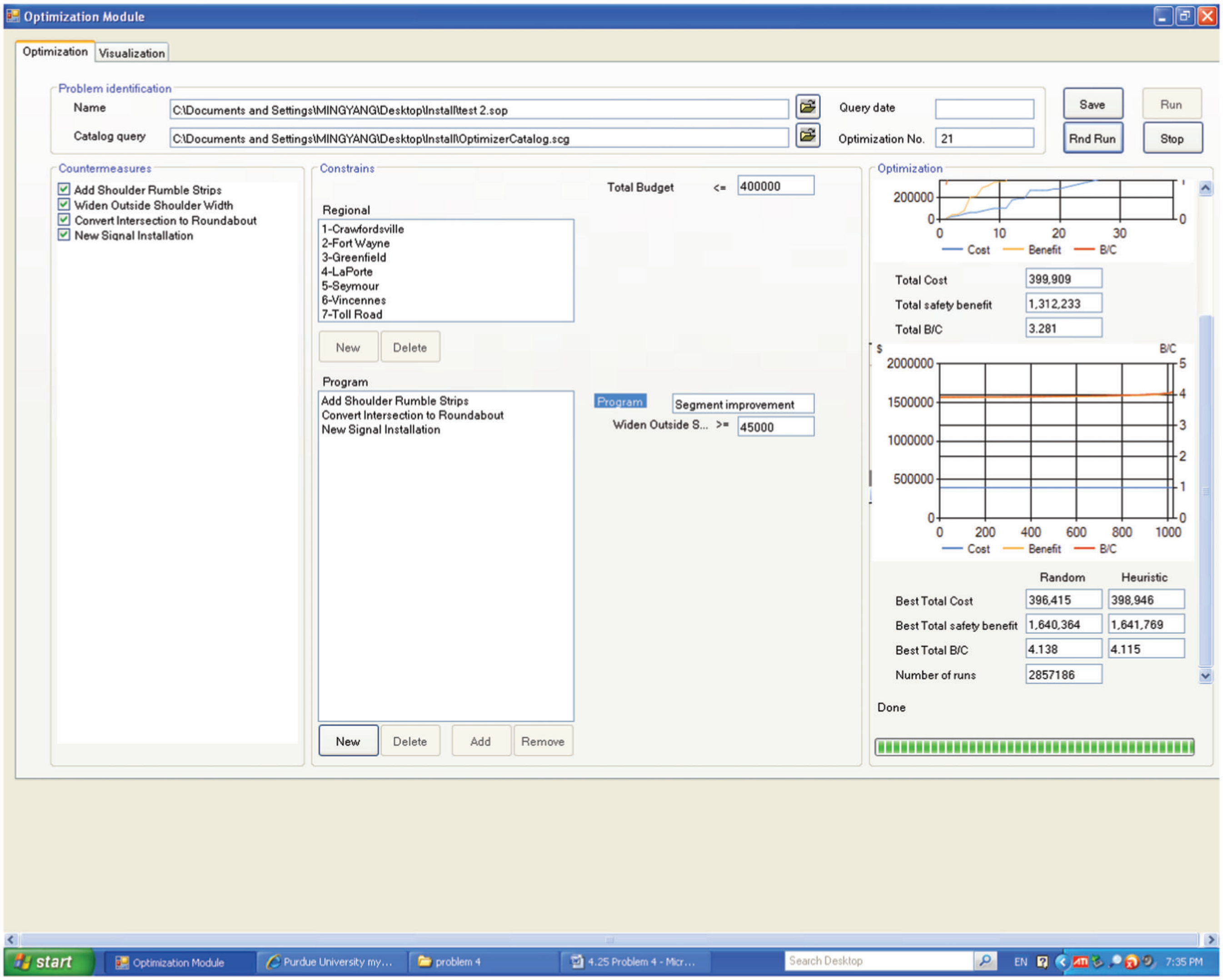


Figure 5.19 Number of selected four different safety countermeasures in Scenario 3.



Problem identification

Name: C:\Documents and Settings\MINGYANG\Desktop\Install\test 2.sop

Catalog query: C:\Documents and Settings\MINGYANG\Desktop\Install\OptimizerCatalog.scg

Query date:

Optimization No.: 21

Countermeasures

☑ Add Shoulder Rumble Strips
☑ Widen Outside Shoulder Width
☑ Convert Intersection to Roundabout
☑ New Signal Installation

Constrains

Total Budget <= 400000

Regional

1-Crawfordsville
2-Fort Wayne
3-Greenfield
4-LaPorte
5-Seymour
6-Vincennes
7-Toll Road

Program

Add Shoulder Rumble Strips
Convert Intersection to Roundabout
New Signal Installation

Program: Segment improvement

Widen Outside S... >= 45000

Optimization

Total Cost	399,909
Total safety benefit	1,312,233
Total B/C	3.281

	Random	Heuristic
Best Total Cost	396,415	398,946
Best Total safety benefit	1,640,364	1,641,769
Best Total B/C	4.138	4.115
Number of runs	2857186	

Done

Figure 5.20 Evaluation interface of Scenario 4.

TABLE 5.22
Comparison of random and heuristic solutions in Scenario 3

	Heuristic	Random
Budget spent	398,946	396,415
Total safety benefit	1,641,769	1,640,364
Total B/C	4.115	4.138
Number of runs	1	2,857,186
Execution time(s)	0.03	96,960

TABLE 5.23
Output of selected elements in Scenario 4

Heuristic Method Solution								Current Random Run Best Solution							
	Applied Countermeasures								Applied Countermeasures						
CFID Element	A	B	C	D	Annual Cost	Annual Benefit	B/C	CFID Element	A	B	C	D	Annual Cost	Annual Benefit	B/C
6275	0	0	1	0	12500	58200	4.66	6275	0	0	1	0	12500	58200	4.66
6288	0	0	1	0	12500	63050	5.04	6288	0	0	1	0	12500	63050	5.04
6300	0	0	1	0	12500	121250	9.70	6300	0	0	1	0	12500	121250	9.70
6333	0	0	1	0	12500	37183	2.97	6333	0	0	1	0	12500	37183	2.97
								6547	0	0	1	0	12500	30717	2.46
6579	0	0	0	1	75000	284464	3.79	6579	0	0	0	1	75000	284464	3.79
6587	0	0	1	0	12500	53350	4.27	6587	0	0	1	0	12500	53350	4.27
6719	0	0	0	1	75000	256418	3.42	6719	0	0	0	1	75000	256418	3.42
7069	0	0	1	0	12500	80834	6.47	7069	0	0	1	0	12500	80834	6.47
7145	0	0	0	1	75000	284464	3.79	7145	0	0	0	1	75000	284464	3.79
7218	0	0	1	0	12500	85684	6.85	7218	0	0	1	0	12500	85684	6.85
7272	0	0	1	0	12500	54967	4.40	7272	0	0	1	0	12500	54967	4.40
218618	1	0	0	0	621	8463	13.63	218618	1	0	0	0	621	8463	13.63
225795	1	0	0	0	200	4752	23.76	225795	1	0	0	0	200	4752	23.76
226032	1	0	0	0	118	4752	40.27	226032	1	0	0	0	118	4752	40.27
232251	1	0	0	0	85	4231	49.78	232251	1	0	0	0	85	4231	49.78
234444	1	0	0	0	33	4752	144.0	234444	1	0	0	0	33	4752	144.0
235280	1	0	0	0	141	4752	33.70	235280	1	0	0	0	141	4752	33.70
236583	1	0	0	0	81	4231	52.23	236583	1	0	0	0	81	4231	52.23
237139	1	0	0	0	141	4231	30.01	237139	1	0	0	0	141	4231	30.01
238122	1	0	0	0	68	4231	62.22	238122	1	0	0	0	68	4231	62.22
238149	1	0	0	0	361	4231	11.72	238149	1	0	0	0	361	4231	11.72
238248	1	1	0	0	7956	12305	1.55	238248	1	1	0	0	7956	12305	1.55
239231	1	0	0	0	159	4752	29.89	239231	1	0	0	0	159	4752	29.89
239995	1	0	0	0	421	14257	33.86	239995	1	0	0	0	421	14257	33.86
241963	1	0	0	0	76	4752	62.53	241963	1	0	0	0	76	4752	62.53
244054	1	1	0	0	13955	39479	2.83	244054	1	1	0	0	13955	39479	2.83
245175	1	1	0	0	17308	45008	2.60	245175	1	1	0	0	17308	45008	2.60
245360	1	0	0	0	69	4752	68.87	245360	1	0	0	0	69	4752	68.87
247281	1	0	0	0	170	4752	27.95	247281	1	0	0	0	170	4752	27.95
247866	0	1	0	0	15031	33175	2.21								
417817	1	0	0	0	383	4231	11.05	417817	1	0	0	0	383	4231	11.05
420356	1	0	0	0	192	4752	24.75	420356	1	0	0	0	192	4752	24.75
420804	1	1	0	0	16377	41063	2.51	420804	1	1	0	0	16377	41063	2.51

A= add shoulder rumble strips; B= widen outside shoulder width; C= new signal installation; D= convert intersection to roundabout; 1= applied countermeasures; 0= not applied countermeasures.

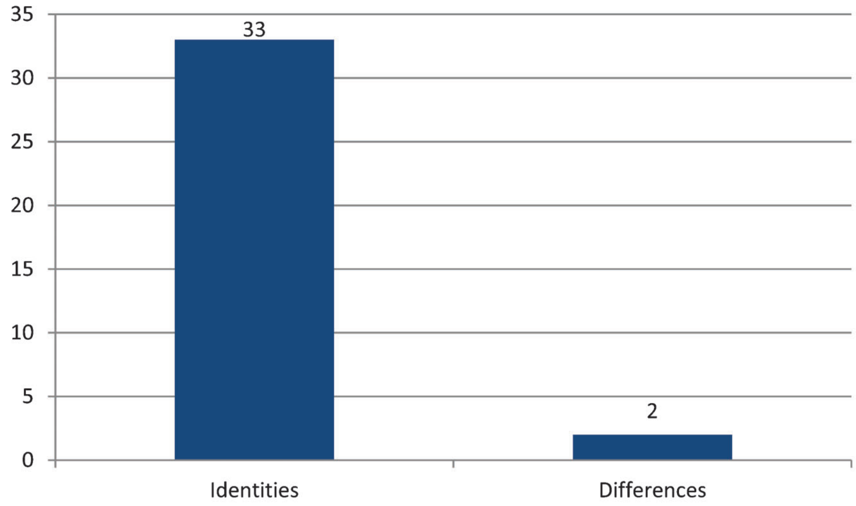


Figure 5.21 Count identities and differences elements in Scenario 4.

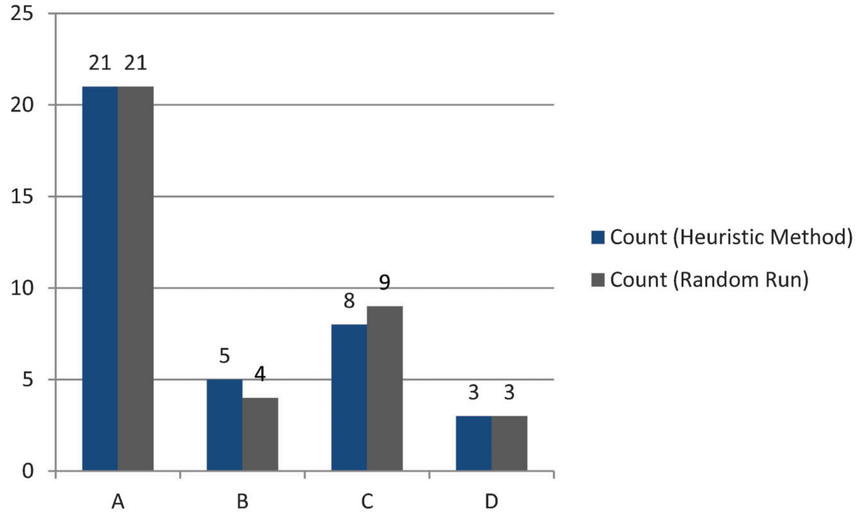


Figure 5.22 Number of selected four different safety countermeasures in Scenario 4.

and there was no countermeasure in the heuristic solution.

Figure 5.21 shows how many safety countermeasures were selected in the heuristic method solution compared to the random best solution. It shows that there were 21, 5, 8, and 3 elements selected to implement add shoulder rumble strips (A), widen outside shoulder width (B), new signal installation (C) and convert intersection to roundabout (D) in the heuristic solution compared to 21, 4, 9, and 3 for the four countermeasures respectively in the random solution.

In Scenario 4, currently, the heuristic method solution is better than the random solution, which means it generated positive results and more time would be needed to obtain a better random solution than for the heuristic method solution under these constraints.

6. SUMMARY

The conceptual framework of the safety screening tool was developed in order to cope with the complexity of the data management and safety screening operations.

As a part of SPR 3315, the safety screening tool was developed to facilitate the overall screening for the state road elements using user-defined crash selection criteria. The user needs to specify the scope, element, and selection criteria for a particular screening. Apart from the crash selection criteria, the network selection criteria can facilitate screening for roadway deficiencies.

The draft user interface is being delivered to INDOT as part of this report. A workshop for training INDOT personnel will be arranged in the near future in order to get INDOT's feedback.

This report provides a relatively complete list of the safety countermeasures currently applicable and suitable in Indiana, which can serve as useful resources when engineers are implementing safety countermeasures to reduce the number of crashes and the severity of crash injuries in Indiana. In addition, crash reduction factors (CRFs) are proposed for each safety countermeasure; and these proposed values can be useful for the process of safety benefit prediction. Also, the unit costs and conditions for the safety countermeasures are explained, which will provide engineers with a good approach to calculating the total costs of safety countermeasures and where to implement the possible improvements.

Testing the proposed algorithm and evaluating the heuristic method demonstrated that the heuristic method developed by Dr. Tarko and Dr. Romero is a sufficient and quick approach to obtain a good solution. The main contribution of this report is to test and evaluate the performance of the heuristic method. This heuristic method applies quite well when the total budget is large, therefore, future work can continue to develop this heuristic method to make it also work quite well when the total budget is not very large.

The presented SNIP2 relies on the quality and completeness of the input data. The limited availability of roadway data and the lack of roadside data jeopardize the effectiveness of roadway safety management. A combined use of available road inventory data, digital imagery, and high-resolution maps may provide a long sought data useful for road management. A project is needed to study the INDOT-administered roads. The developed method could be then adapted to local roads where the need for data is particularly acute.

REFERENCES

Abdelwahab, H. T., & Abdel-Aty, M. A. (2001). Development of artificial neural network models to predict driver injury severity in traffic accident at signalized intersections. *Transportation Research Record*, *1746*(1) 6–13. http://dx.doi.org/10.3141/1746-02

Breyer, J. P. (2000). Tools to identify safety issues for corridor safety-improvement program. *Transportation Research Record*, *1717*(1), 19–27. http://dx.doi.org/10.3141/1717-04

Donnell, E. D., Porter, R. J., & Shankar, V. N. (2010). A framework for estimating the safety effects of roadway lighting at intersections. *TRB 89th Annual Meeting Compendium of Papers CD-ROM*. Washington, DC: Transportation Research Board.

Elvik, R., & Vaa, T. (2004). *Handbook of road safety measures*. Oxford, UK: Elsevier.

Federal Highway Administration (FHWA). (2005). *Highway economic requirements systemState version* (Technical report). Washington, DC: U.S. Department of Transportation. Retrieved from http://www.fhwa.dot.gov/asset/hersst/pubs/tech/TechnicalReport.pdf.

Fitzpatrick, K., & Park, E. S. (2010). *Safety effectiveness of the HAWK pedestrian crossing treatment* (Report No. FHWA-HRT-10-042). Washington, DC: Federal Highway Administration.

Gan, A., Shen, J., & Rodriguez, A. (2005). *Update the Florida crash reduction factors and countermeasures to improve the development of district safety improvement projects*. Miami: Safety Office, State of Florida Department of Transportation; Lehman Center for Transportation Research, Florida International University.

Griffith, M. S. (1999). Safety evaluation of roll-in continuous shoulder rumble strips installed on freeways. *Transportation Research Record*, 1665, 28–34.

Harkey, D. (2008). *Accident modification factors for traffic engineering and ITS improvements* (NCHRP Report 617). Washington, DC: Transportation Research Board.

Harwood, D. W., Bauer, K. M., Potts, I. B., Torbic, D. J., Richard, K. R., Rabbani, E. R., . . . Griffith, M. S. (2003). Safety effectiveness of intersection left- and right-turn lanes. *82nd Transportation Research Board Annual Meeting*. Washington, DC: Transportation Research Board.

Hemmecke, R., Köppe, M., Lee, J. & Weismantel, R. (2009). Nonlinear integer programming. *50 years of integer programming 1958–2008: The early years and state-of-the-art surveys*. Retrieved from http://arxiv.org/pdf/0906.5171.pdf&embedded=true.

Hovey, P. W., & Chowdhury, M. (2005). *Development of crash reduction factors* (Report No. FHWA/OH-2005/12). Columbus, OH: Ohio Department of Transportation.

Illinois Department of Transportation. (2006). *Safety engineering policy memorandum—Safety 1-06*. Springfield, IL: Author.

Indiana Department of Transportation. (2013). *Indiana design manual*. Indianapolis, IN : Author. Available at http://www.in.gov/indot/design_manual/files/IDM_Complete_2013.pdf.

Kentucky Transportation Center. (2003). *Development of procedures for identifying high-crash locations and prioritizing safety improvements* (Research Report KTC-03-15/SPR250-02-1F). Lexington: Kentucky Transportation Center, University of Kentucky.

Lacy, J. K. (2001). *Recommended procedure for combining crash reduction factors*. Chapel Hill, NC: Highway Safety Research Center.

Lamptey, G., & Labi, S. (2004). *Development of analytical and software tools for highway safety management* (MS thesis). West Lafayette, IN: Purdue University.

Lamptey, G., Samdariya, A. J., Labi, S. & Sinha, K. C. (2011). *Indiana's safety management system software package 1 (SMSS)A review*, Paper presented at the 3rd International Conference on Road Safety and Simulation, September 14–16, 2011, Indianapolis, USA. Retrieved from http://onlinepubs.trb.org/onlinepubs/conferences/2011/RSS/1/Lamptey,G.pdf.

Lu, J., Dissanayake, S., Zhou, H. & Yang, X. K. (2001). *Operational evaluation of right turns followed by U-turns as an alternative to direct left turns* (Report submitted to Florida Department of Transportation), Tampa: University of South Florida. Retrieved from http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_TE/FDOT_BC132_v3_rpt.pdf.

Mauga, T., & Kaseko, M. (2010). *Modeling and evaluating the safety impacts of access management (AM) features in the Las Vegas Valley*. Paper presented at the 89th Annual Meeting of the Transportation Research Board, Washington, DC.

MnDOT. (2010) *Cable median barrier report*. Retrieved November 2012 from http://www.dot.state.mn.us/trafficeng/reports/cmbarrier.html

Montella, A. (2009). Safety evaluation of curve delineation improvements, an empirical Bayes observational before-after study. *TRB 88th Annual Meeting Compendium of Papers CD-ROM*. Washington, DC: Transportation Research Board.

Monsere, C., Bertini, R., Breakstone, A., Bonner, C., Bosa, P., de la Houssaye, D., Horowitz, Z., & Hunter-Zaworski, K. (2006). *Oregon Department of Transportation, Traffic Engineering and Operations Section crash reduction factors*. Salem, OR: Oregon Department of Transportation.

National Cooperative Highway Research Program. (2004). *NCHRP 500: Strategy 17.1 E11—Flashing beacons at stop-controlled intersections*. Washington, DC: Transportation Research Board.

Pal, R., & Sinha, K. C. (1998). Optimization approach to highway safety improvement programming. *Transportation Research Record*, 1640, 1–9.

Park, E. S., Park, J., & Lomax, T. J. (2010). A fully Bayesian multivariate approach to before-after safety evaluation. *Accident Analysis & Prevention*, *42*(4), 1118–1127. http://dx.doi.org/10.1016/j.aap.2009.12.026

Parker, M. R., Jr. (1997). *Effects of raising and lowering speed limits on selected roadway sections* (Report No. FHWA-RD-92-084). Washington, DC: Federal Highway Administration.

Park, Y.-J., & Saccomanno, F. F. (2005). Collision frequency analysis using tree-based stratification. *Transportation Research Record*, 1908, 121–129.

Persaud, B. N., Retting, R. A., & Lyon, C. (2003). Crash reduction following installation of centerline rumble strips on rural two-lane roads. *Accident Analysis & Prevention*, *36*(6), 1073–1079. http://dx.doi.org/10.1016/j.aap.2004.03.002.

Podnar, H., & Skorin-Kapov, J. (2003). Genetic algorithm for network cost minimization using threshold based discounting. *Journal of Applied Mathematics and Decision Sciences*, *7*(4), pp. 207–228.

Retting, R. A., Nitzburg, M. S., Farmer, C. M., & Knoblauch, R. L. (2002). Field evaluation of two methods for restricting right turn on red to promote pedestrian safety. *ITE Journal*, *72*(1), 32–36.

Romero, M. (2013). *Research note on heuristic algorithm description* (Unpublished). Center for Road Safety (CRS), West Lafayette , IN: Purdue University.

Sayed, T., Leur, P., & Pump, J. (2005). Safety impact of increased traffic signal backboards conspicuity. *TRB 84th Annual Meeting: Compendium of Papers CD-ROM*, Vol. TRB#05-16. Washington, DC: Transportation Research Board.

Sayed, T., El Esawey, M, & Pump, J. (2007). Evaluating the safety impacts of improving signal visibility at urban signalized intersections. *TRB 86th Annual Meeting: Compendium of Papers CD-ROM*, Vol. TRB#07-135. Washington, DC: Transportation Research Board.

Schoon, C., & van Minnen, J. (1994). The safety of roundabouts in the Netherlands. *Traffic Engineering and Control*, 35, 142–148.

Srinivasan, R., Council, F., Lyon, C., Gross, F., Lefler, N., & Persaud, B. (2008). Evaluation of the safety effectiveness of selected treatments at urban signalized intersections. *TRB 87th Annual Meeting Compendium of Papers CD-ROM*. Washington, DC: Transportation Research Board.

Tan, C. (2010). *Evaluation of lane reduction "road diet" measures on crashes*. Washington, DC: U.S. Department of Transportation, Federal Highway Administration.

Tarko, A. P. (2011). *Research note on optimal long-term regional safety planning* (Unpublished). West Lafayette, IN: Purdue University.

Tarko, A., Iqbal, M. A., Inerowicz, M., Liang, H., Panicker, G., & Ramos, J. (2007). *Safety conscious planning in Indiana: Predicting safety benefits in corridor studies, Volume 1: Research Report* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2006/21). West Lafayette, IN: Purdue University. http://dx.doi.org/10.5703/1288284313366

Tarko, A. P., Inerowicz, A., & Liang, H., Ramos, J. (2007). *Safety conscious planning in Indiana: Predicting safety benefits in corridor studies, Volume 2: PASS and INPASS user manual* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2006/21). West Lafayette, IN: Purdue University. http://dx.doi.org/10.5703/1288284313367

Wilt, C., & Thayer, J., Ruml, W. (2010). *A comparison of greedy search algorithms. Department of Computer Science*. Durham: University of New Hampshire.

Xu, L. (2001). Right turns followed by U-turns vs. direct left turns: A comparison of safety issues. *ITE Journal*, *71*(11), 36–43.

APPENDIX A. SCREENING CONCEPTS

IDENTIFICATION METHOD

The safety identification method includes components designed to fulfill the agency's need to systematically investigate a particular problem. The following items are the core components necessary for a successful identification method:

1. Scope, elements, and selection criteria
2. Safety performance measures
3. Exposures measures
4. Statistical evaluation measures

Scope, Elements, and Selection Criteria

Scope

Scope or domain is the geographic unit in which the user is willing to conduct the screening. In the safety screening tool, three scopes have been defined: state, county, and city/town. The scope can be limited to a particular county/township or multiple counties/townships, but should always be greater than the elements in geographic extent.

Element

Element is the smallest unit of aggregation level that a user wishes to investigate. Elements can be the facility type (e.g., segments, intersection points, intersection, ramps, or bridges) or can be a smaller geographic unit within the scope. Therefore, the scope or domain is the group of elements an agency wishes to investigate.

Selection Criteria

After defining the scopes and elements, it is important to define the selection criteria. The selection criteria basically facilitate obtaining a subset of the elements within the scope. Within the conceptual framework of safety screening, which was discussed in Chapter 2, the "Screen Rule Editor" is used to define the selection criteria, which can be of two types:

1. Crash selection criteria
2. Element selection criteria

Crash Selection Criteria

Crash selection criteria are considered in order to investigate a specific type of crash. For example, an agency might be interested in only fatal or incapacitating injury types of crashes or only nighttime crashes. An example might be obtaining only alcohol-related crash locations for targeted enforcement purposes. The crash selection criteria are mainly dependent on the crash variables and their availability.

Element Selection Criteria

Element selection criteria also have a very specific purpose. Since the Indiana road inventory is embedded in the master record sets, a user might be interested in the crash propensity for a specific design condition (e.g., a particular roadway with a specific median type/width). Combining the crash and element selection criteria can serve as a great tool for choosing candidates for a specific program. Figure A.1 shows the interaction among the scope, element, and selection criteria in the overall safety screening process.

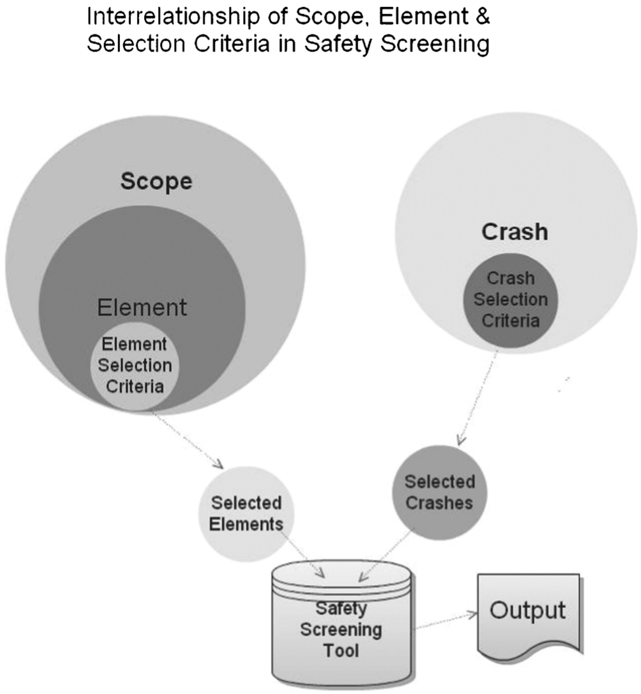


Figure A.1 Scope, element, and selection criteria for safety screening.

Safety Performance Measures

After a user defines the scope, element, and selection criteria, it is important to define the unit of identification. The identification unit is analogous to the ***measures of safety*** which can have three basic types:

- *Crash frequency*: Crash frequency is the crash counts of all crashes or a specific subset of crashes as determined by the user.
- *Crash cost*: Crash cost applies to all crashes or a specific subset of crashes as determined by the user.
- *Crash rate*: Crash frequency/exposure. Exposure can vary based on the type of elements selected.
- *Proportions of crash*: The proportion is the ratio of two different crash counts with the criteria, which is as follows: denominator of crash counts >= numerator of crash counts; for example, the proportion of rear-end crashes to the total number of crashes.

Exposure Measures

Exposures are used to estimate crash rates as the ratio of the crash count and a specific measure of exposure reflecting the analyzed period. They can be AADT, VMT, or road length, depending on the element under investigation (see Table A.1).

TABLE A.1
Exposure measures for different road elements

Element of Investigation	Exposure
County	Population, VMT, registered vehicle, area
City	Population, VMT, registered vehicle, area
Township	Population, VMT, registered vehicle, area
State Segment	Link volume (ADT, VMT), length
State-State Intersection	Total approach volume (ADT, VMT)
State-Local Intersection	State (major) road volume
Ramp	Link volume (ADT, VMT), length
Bridge	Link volume (ADT, VMT), length

STATISTICAL EVALUATION

Notation

Basic variables:
c = number of studied crashes during the analysis period
w = cost of crashes on road element during the analysis period
m = estimate of the expected crashes or cost during the analysis period and for the exposure,
v = variance of the m estimate
Variables needed to calculate w, m, and v:
e = exposure on road element (AADT, length L, VMT during the analysis period)
r = number of reference crashes on road element during the analysis period
u = unit crash cost
N = number of road elements in the group of roads
S = total number of studied crashes in the group of roads during the analysis period
R = total number of reference crashes in the group of roads during the analysis period
E = total exposure in the group of roads during the analysis period
W = total cost of crashes in the group of roads during the analysis period
sub k = indicates severity level k

Two distributions are used to evaluate the statistical significance of the safety problem: Gamma distribution and Negative Binomial Distribution. Gamma distribution has parameters α and β, such that mean is $\alpha\beta$, and variance is $\alpha\beta^2$ and density: $f(\lambda)=\frac{1}{\beta^{\alpha}\Gamma(\alpha)}\lambda^{\alpha-1}\exp(-\lambda/\beta)$. The Negative Binomial distribution can be viewed as a mixture of Poisson distributions with the Poisson parameter λ distributed according to the Gamma. The parameters of Negative Binomial the distributions are inherited from the Gamma. The mean is $\alpha\beta$, and the variance is $(\alpha\beta+\alpha\beta^2)$, and density: $P(c)=\frac{\Gamma(\alpha+c)}{\Gamma(\alpha)c!}\left(\frac{\beta}{1+\beta}\right)^{c}\left(\frac{1}{1+\beta}\right)^{\alpha}$. The MS Excel parameterization of the Gamma distribution is as introduced above while the Negative Binomial distribution uses parameters: $r=\alpha+1$ and $p=1/(1+\beta)$.

Concepts

Let c be the recorded number of crashes of a certain type used to evaluate a road element's safety during the analysis period. An agency wants to know if this number of crashes indicates that there is a safety problem on the considered road element. The safety problem is confirmed if the number of crashes c is significantly higher than the number expected for the exposure e on the considered road element.

There are a number of exposure measures including the traffic volume entering an intersection or the vehicle-miles travelled along a road segment. The number of crashes m expected for the exposure is the product of the average crash rate S/E in the considered group of roads and the exposure e on the studied road element.

The segment length can be used if the traffic volume is missing. This option is reserved for local roads that typically do not have traffic volumes measured. The number of crashes m expected for the exposure is the product of the average crash density in the group of roads and the length of the studied road element.

Checking if the considered crashes constitute too large of a proportion of a wider category of crashes (reference crashes) is another important safety test. For example, all intersection crashes may serve as reference crashes for a proportion of right-angle crashes. The number of crashes m expected in this case is the product of the reference proportion S/R (average proportion of intersection crashes that are right-angle crashes in the group of considered intersections) and the reference crashes r at the studied intersection.

Use of Exposure E (Volume, VMT, L)

The first step is to estimate the crash rate S/E in the considered group of roads, where S is the total number of considered crashes in the group of roads and E is the total exposure in that group. The expected number of crashes m on the considered road element is the product of the exposure e on this road element and the crash rate S/E in the road group: $m=e\cdot S/E$. The variance of this estimate is caused by the varying number of S crashes scaled with e/E. The estimate m is distributed according to the Gamma distribution $G(\alpha=S,\ \beta=e/E)$ with the variance $v=\alpha\beta^2=S(e/E)^2$.

The test if the actual number of crashes c is larger than the number m expected for the exposure e is done through checking if the crash count c is sufficiently far into the right tail of the distribution of crash counts around the uncertain Gamma-distributed mean m. This test calls for using the Gamma-mixture of Poisson distributions thus for using the Negative Binomial distribution $NB(\alpha=S,\ \beta=e/E)$. The crash count c indicates that the current safety on the road element is worse than expected for the exposure if the cumulative distribution NB at c takes high value (for example, higher than 0.95). This value is called **confidence F**—the probabilistic measure which varies between 0 and 1.

Using the Excel notation, the calculation of confidence F is:

$F=\Sigma_{x=0..c}$ NegBinom.Dist(x, $r=\alpha+1$, $1/(1+\beta)$)=Beta.Dist($1/(1+\beta)$, $r=\alpha+1$, c+1, 1),

or more specifically: F=Beta.Dist(1/(1+e/E), S+1, c+1,1)=

Another method of statistical significance is the **index I**—the quality control measure that tells the difference between the estimated safety and the target safety (expected for the exposure) measured with the standard deviation of the difference estimate. A high value of index I, for example, higher than 2, indicates a safety problem.

$$I=\frac{c-m}{\sqrt{v}}.$$

The value I may be questionable and inconsistent with the significance F if the underlying distribution is strongly skewed to the right (Gamma and Negative Binomial distributions tend to be skewed if the expected value is close to zero). It may lead to an I-based ranking that is inconsistent with the F-based ranking. Since agencies may prefer using index I, an equivalent I_e value is proposed that is determined based on the calculated F value. It uses an "equivalent" normal distribution which preserves the original m, c, and F values. The equivalent parameter σ_e needs to be calculated. Given that the standardized cumulative normal distribution can be closely and conveniently approximated with the logistic function:

$$\Phi(c)\cong 1-\frac{1}{1+\exp\left(1.7\cdot\frac{c-m}{\sigma}\right)}$$

the equivalent σ_e that provides the same F value as the Gamma distribution is:

TABLE A.2
Levels of statistical evidence

Statistical Evidence of Safety Problem	Confidence F	Index I_e
None or very weak	<0.80	<0.8
Weak	0.80–0.90	0.8–1.3
Considerable	0.90–0.95	1.3–1.7
Strong	0.95–0.99	1.7–2.7
Very strong	>0.99	>2.7

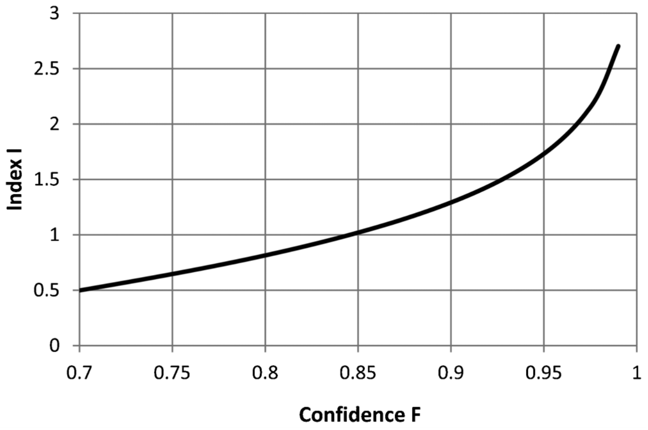


Figure A.2 Relationship between the index of Frequency I and the significance of Level F.

$$F \cong 1 - \frac{1}{1 + \exp\left(1.7 \cdot \frac{c-m}{\sigma_e}\right)}$$

or:

$$\sigma_e = \frac{1.7(c-m)}{\ln\left(\frac{F}{1-F}\right)}$$

The equivalent I_e value can be calculated as follows:

$$I_e = \frac{s-m}{\sigma_e} = \frac{\ln(F) - \ln(1-F)}{1.7}$$

To control the overflow error, small values of F and 1-F should not be used. Instead, an assumed small negative value of ln(F) and ln(1-F), for example −99, should be used. Since the equation for I_e is an approximation (although a close one), I_e should be set at a value 0 of s=m to avoid an obviously counterintuitive result.

The relationship between the index I and the significance F is shown in Figure A.2 and summarized in Table A.2. It can be concluded that an I_e lower than 1.25 indicates no or weak statistical evidence of a safety problem ($F<0.90$), and an I_e between 1.3 and 1.7 indicates considerable evidence (F between 0.90 and 0.95), and an I_e between 1.7 and 2.7 indicates strong evidence (F between 0.95 and 0.99), and an I_e larger than 2.7 indicates very strong evidence.

Proportion of Crashes

The reference proportion is the estimated proportion of studied crashes S in the reference crashes R in the group of roads: S/R. The expected number of crashes at a single road element which corresponds to the reference proportion is calculated as: $m=r \cdot S/R$, where r is the number of reference crashes on the road element and S/R is the proportion of studied crashes in the reference crashes in the group of roads (reference proportion). The variance of the estimate m is caused by variability of all the component crash counts: r, S, and R. These counts are not independent from each other as explained in Figure A.3. To estimate the variance of the m estimate, the crashes in the group of considered roads have been divided into four counts: c, c1, c2, c3, and c4 in a way that these counts vary independently and can be used to calculate the counts r, S, and R: R=c+c1+c2+c3, S=c+c1, and r=c+c2. The derivation of the variance of estimate m; $v= (2crSR+r^2SR+rS^2R-3r^2S^2)/R^3$ is described below.

The variance of m=rs/d is calculated as the variance of $m=(c+c_1)(c+c_2)/(c+c_1+c_2+c_3)$ with four independent sources of Poisson variance: c, c_1, c_2, and c_3. The variance has been derived from the following equation:

$$\operatorname{var} m(c,c_1,c_2,c_3) = \left(\frac{\partial m}{\partial c}\right)^2 \cdot c + \cdots + \left(\frac{\partial m}{\partial c_3}\right)^2 \cdot c_3.$$

The validity of the derived variance and of the assumption of Gamma distribution applied to this criterion has been evaluated using simulation of 10,000 values of the m estimates for two distinct sets of values of c, r, s, and d. The simulated distribution of the m estimates and corresponding Gamma distributions with the parameters calculated in steps 2, 3, and 4 are shown in Figure A.4 (for (c=10, s=210, r=210, d=510, m=45.3, v=18.1) and Figure A.5 for (c=1, s=6, r=3, d=18, m=0.44, v=1.0). The simulation-based evaluation confirms the validity of the method for estimating right-hand distribution tails of m estimates.

Estimation of the significance F is made using equation:
$F = \text{Beta.Dist}(1/(1+\beta), \alpha+1, c, 1)$,
where $\alpha=m^2/v$ and $\beta=v/m$, thus
$F=\text{Beta.Dist}(1/(1+v/m), m^2/v+1, c, 1)$.
The Index I_e is calculated as

$$I_e = \frac{\ln(F) - \ln(1-F)}{1.7}$$

Cost Criterion

Traffic volume, AADT, and segment length are useful in calculating the expected cost of crashes on the studied road element. The expected cost of crashes can be obtained by multiplying the crash cost rate per unit exposure averaged for the studied road network with the exposure values for the studied road element.

The expected cost of crashes on a road segment or at an intersection exceeds the expected cost under the given exposure. An estimate of the expected number of crashes at severity level k is distributed according to Gamma with parameters $\alpha=c_k$ and $\beta=1$. Thus, the mean value is $m_k=c_k$ and the variance is $v_k=c_k$. The scaling property of the Gamma distribution allows assuming that the cost of all crashes of severity k at the location is also distributed

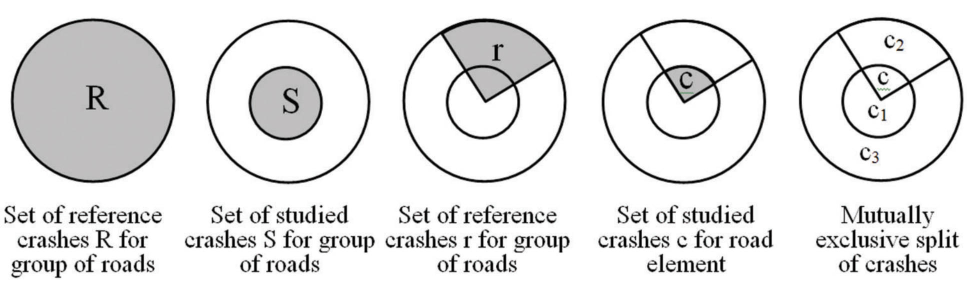


Figure A.3 Dependence between crash counts.

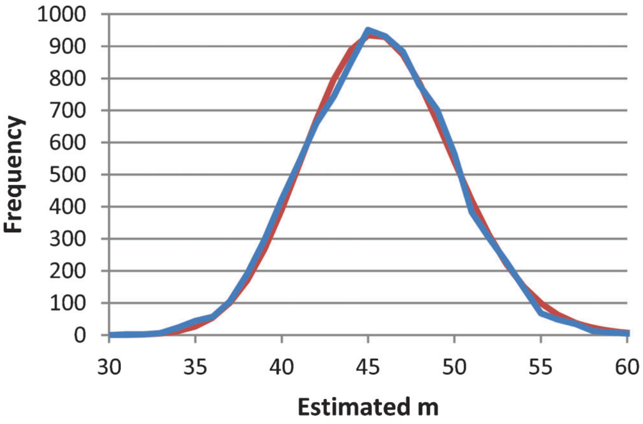


Figure A.4 Case 1: simulated (blue) versus calculated (red) distributions of m estimates.

as Gamma with parameters: $\alpha = c_k$, $\beta = u_k$. The corresponding mean $m_k = c_k u_k$, and variance $v_k = c_k {u_k}^2$. Thus, the cost of all crashes on the road is:

$$w = \sum\nolimits_k c_k u_k$$

and the close approximation of the variance of cost estimate (confirmed with Monte Carlo experiments) is:

$$v_1 = \sum\nolimits_k c_k u_k^2$$

If the cost of crashes on the road expected for the exposure can be calculated as: $m = e \cdot W/E$, where e is the exposure on the considered road element, W is the total cost of crashes in the group of roads, and E is the total exposure in the group of roads. The estimate m has variance $v_2 = \Sigma_j \frac{v_{wj}}{E^2}$ which is the total cost variance and E is the total exposure in the road group. The variance of the difference between the w and m estimates is approximated with the sum of the two component variances v_1 and v_2. The test is this time based on the Gamma distribution:

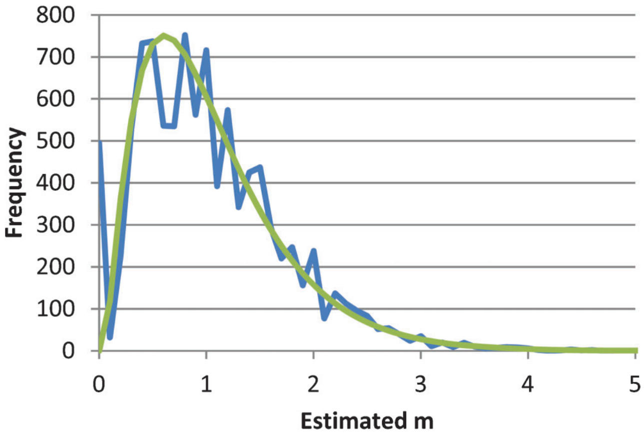


Figure A.5 Case 2: simulated (blue) versus calculated (green) distributions of m estimates.

$$F = 1\text{-Gamma.Dist}\left(W, \alpha = \frac{m^2}{v_1 + v_2}, \beta = \frac{v_1 + v_2}{m}, 1\right)$$

and index I_e is calculated as before:

$$I_e = \frac{\ln(F) - \ln(1 - F)}{1.7}$$

Computations

See Table A.3, "Calculating F and I for the three screening criteria and two versions of SPF."

TABLE A.3
Calculating F and I for the three screening criteria and two versions of SPF

Screening Criterion	Crashes/Cost on Road Element	Crashes/Cost Expected on Road Element m	Variance v	Significance F	Index I	Index I_A
Crash Frequency: simplified SFP	c	$m=e(S/E)$	$v_1=c$ $v_2=S(e/E)^2$ $v=v_1+v_2$	F_{CF}=Beta.Dist($1/(1+v_2/m)$, m^2/v_2, c+1, 1)	$I=(c-m)/v^{1/2}$	$I_{AF}=(\ln(F_{CF})-\ln(1-F_{CF}))/1.7$
Crash Frequency: full SFP	c	$m=SPF(e)$	$v_2=d^2m$	F_{CF}=Beta.Dist($1/(1+v_2/m)$, m^2/v_2, c+1, 1)	$I=(c-m)/v^{1/2}$	$I_{AF}=(\ln(F_{CF})-\ln(1-F_{CF}))/1.7$
Crash Proportion	c	$m=r(S/R)$	$v_1=c$ $v_2=(2crSR+r^2SR+rS^2R-3r^2S^2)/R^3$ $v=v_1+v_2$	F_{CP}=Beta.Dist($1/(1+v_2/m)$, m^2/v_2, c+1, 1)	$I=(c-m)/v^{1/2}$	$I_{AP}=(\ln(F_{CP})-\ln(1-F_{CP}))/1.7$
Crash Cost: simplified SPF	$w=\Sigma c_k u_k$	$m=e(W/E)$	$v_1=\Sigma_k c_k u_k^2$ $v_2=\Sigma_k d_k m_k^2 u_k^2$ $v=v_1+v_2$	F_{CC}=Gamma.Dist(w, m^2/v, v/m, 1)	$I=(w-m)/v^{1/2}$	$I_{AC}=(\ln(F_{CC})-\ln(1-F_{CC}))/1.7$
Crash Cost: full SPF	$w=\Sigma c_k u_k$	$m=\Sigma m_k u_k$	$v_1=\Sigma_k c_k u_k^2$ $v_2=\Sigma_k d_k m_k^2 u_k^2$ $v=v_1+v_2$	F_{CC}=Gamma.Dist(w, m^2/v, v/m, 1)	$I=(w-m)/v^{1/2}$	$I_{AC}=(\ln(F_{CC})-\ln(1-F_{CC}))/1.7$

Notations in alphabetic order: c= number of crashes on road element, c_k= number of studied crashes of severity k, c_{kj}= number of studied crashes of severity k on road element j, d= over-dispersion parameter of SPF, e= exposure on road element (AADT, length L, VMT), E= total exposure in the group of roads, m= estimate of the crashes or cost expected for the exposure, r= number of reference crashes on road element during, R= total number of reference crashes in the group of roads, S= total number of studied crashes in the group of roads, SPF(e)= estimated expected crash count on a segment for the exposure e, u_k= unit cost of crash of k severity, w= cost of crashes on road element, W= total cost of crashes in the group of roads, and v= variance of the m estimate.

APPENDIX B. ROAD CLUSTERING

The screening tool identifies which road elements experience an excessive number of crashes. Clustering these elements into longer road sections may reveal useful spatial regularities that may be useful to INDOT engineers in scoping corridor improvement projects and other safety-oriented programs.

It is important to note that elements with safety needs should be clustered based on the safety performance measures in order to obtain relevant road clusters from the safety management point of view. The following text describes the statistical basis of clustering and the clustering method itself.

STATISTICAL BASIS

There are three basic safety measures that can be used to identify road elements with excessive numbers of certain categories of crashes: crash frequency, crash rate, and crash proportion. Crashes are subject to a strong random fluctuation over time and two safety performance indices, Confidence F and Index I, are proposed to estimate the level of statistical confidence indicated in the detected excessive number of crashes as a systematic issue rather than the effect of random fluctuation.

Significance F is the probability of a safety level equal to or better than the one observed during the period of analysis if the expected safety level in the long run is average for the type of location and under the given exposure. The higher the significance of F is, the stronger the evidence is that the location experiences a real safety problem. The values of $F=0.90$ and higher are typically used.

Index I is the difference between the safety observed during the period of analysis and the safety expected given the location type and exposure divided by the standard deviation of the difference estimate. It is a simplified measure of Significance F. Values of $I=1.5$ and higher provide sufficient evidence that the location experiences a real safety problem.

Significance F is calculated as BetaDist(1/(1+am), 1/a, c), while Index I is calculated as: $(c\text{-}m)/(c+am^2)^{1/2}$, where: a is the over-dispersion parameter, m is the average crash count in a long run, and c is the actual crash count in the period of analysis. Equations for calculating the values of m and a for different safety measures are shown in Table A.3.

CLUSTERING METHOD

One of the important operations of clustering road elements is evaluation of the safety level in the current clusters to ensure that the obtained clusters experience excessive numbers of crashes. A practical method of updating safety evaluations in clusters is aggregation of the safety measures of the individual network elements included in the cluster. The exact method based on Significance F is statistically and computationally troublesome because summing two Gamma variables does not yield a Gamma variable, and the convenient equivalency between Negative Binomial and Beta distribution cannot be used. Therefore, Index I, which is easy to update for clusters, is calculated instead. The following equation is used to calculate Index I for clusters of multiple road elements:

$$I=\frac{\Sigma_i(c-m)_i}{\sqrt{\Sigma_i(c+am^2)_i}}$$

where values of $(c-m)_i$ and $(c+am^2)$ are known for any road element *i*. The clustering algorithm is shown in Figure B.1. It is important to note that the clustering process is controlled by two user-selected threshold values: I_1 and I_2. The recommended ranges are: (1.25–2) for I_1 and (0–1.25) for I_2 with the recommendation that $I_1>I_2$. The user can restrict the clusters' building only along the same routes to follow the common practice in scoping road projects. Other restrictions may be added to the algorithm as needed. A list of clusters and their elements is obtained based on the screening results, the network topology, and the parameters set by the user.

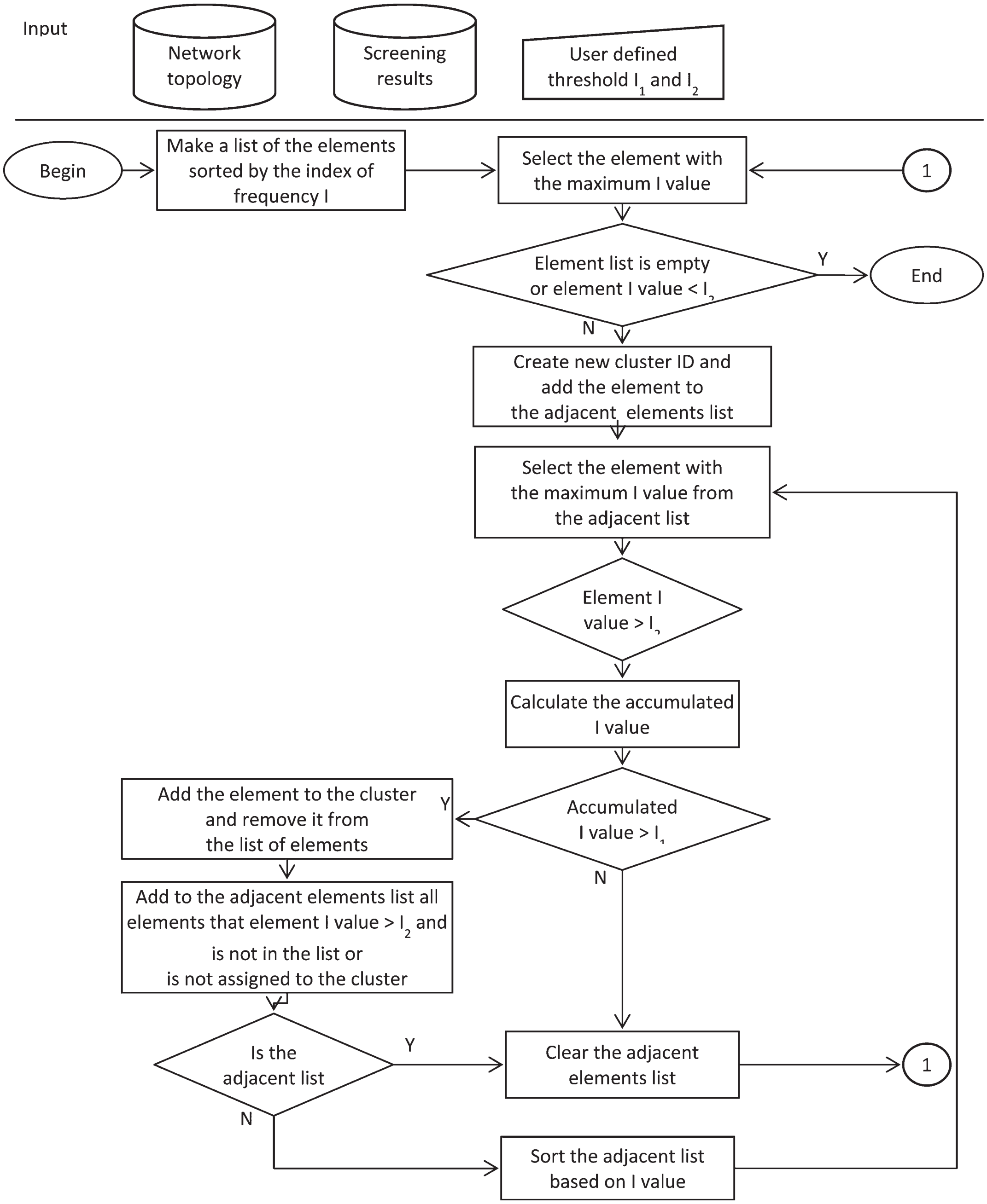


Figure B.1 Clustering algorithm flowchart.

APPENDIX C. RESULTS PRESENTATION

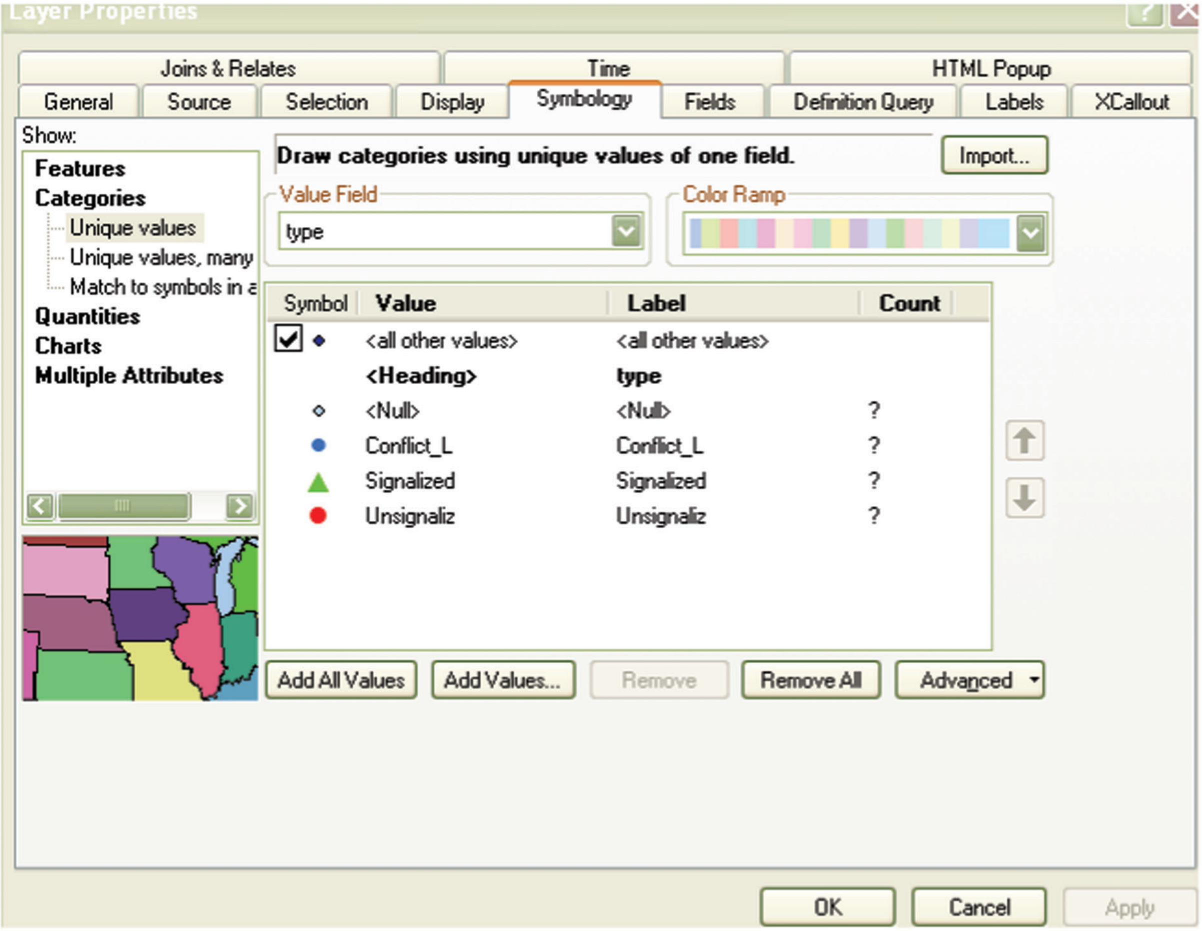
Result presentation is the final step of the screening process. In this phase, the user can visualize the results obtained in the standard screening or clusters/special studies. ArcGIS provides many visualization tools that can accomplish this job. Among the various features available in ArcGIS, the following three visualization tools are widely used:

- Symbology
- Labels
- Selection by attribute

Symbology refers to visualization of a feature (i.e., a single element), categories of elements, quantities, etc., by colors or symbols. Symbology has a special procedure for preparing charts like bar charts or pie charts to be shown as part of the individual element. Figure C.1 shows a sample Symbology selection window.

Labels are useful in displaying a name or a value of a particular attribute on a map; for example, individual roads on a map can be labeled with their names to enhance visualization or to help identify a specific feature on the map. Figure C.2 shows a network layer with and without labels.

Selection by attribute can highlight particular elements of interest on a map. For example, intersections having more than 10 crashes per year can be easily selected and marked. Figure C.3 shows an example of visualization made by "select by attribute tool" in which the highlighted local roads were found to have signalization. The user can easily scan through the map once the features are selected. Details about the results display and visualization are discussed in the User Manual.



Draw categories using unique values of one field.

Value Field: type

Symbol	Value	Label	Count
☑ ◆	<all other values>	<all other values>	
	<Heading>	**type**	
◇	<Null>	<Null>	?
●	Conflict_L	Conflict_L	?
▲	Signalized	Signalized	?
●	Unsignaliz	Unsignaliz	?

Figure C.1 Window in ArcGIS.

Figure C.2 Labeling feature (left: no labeling; right: labeling).

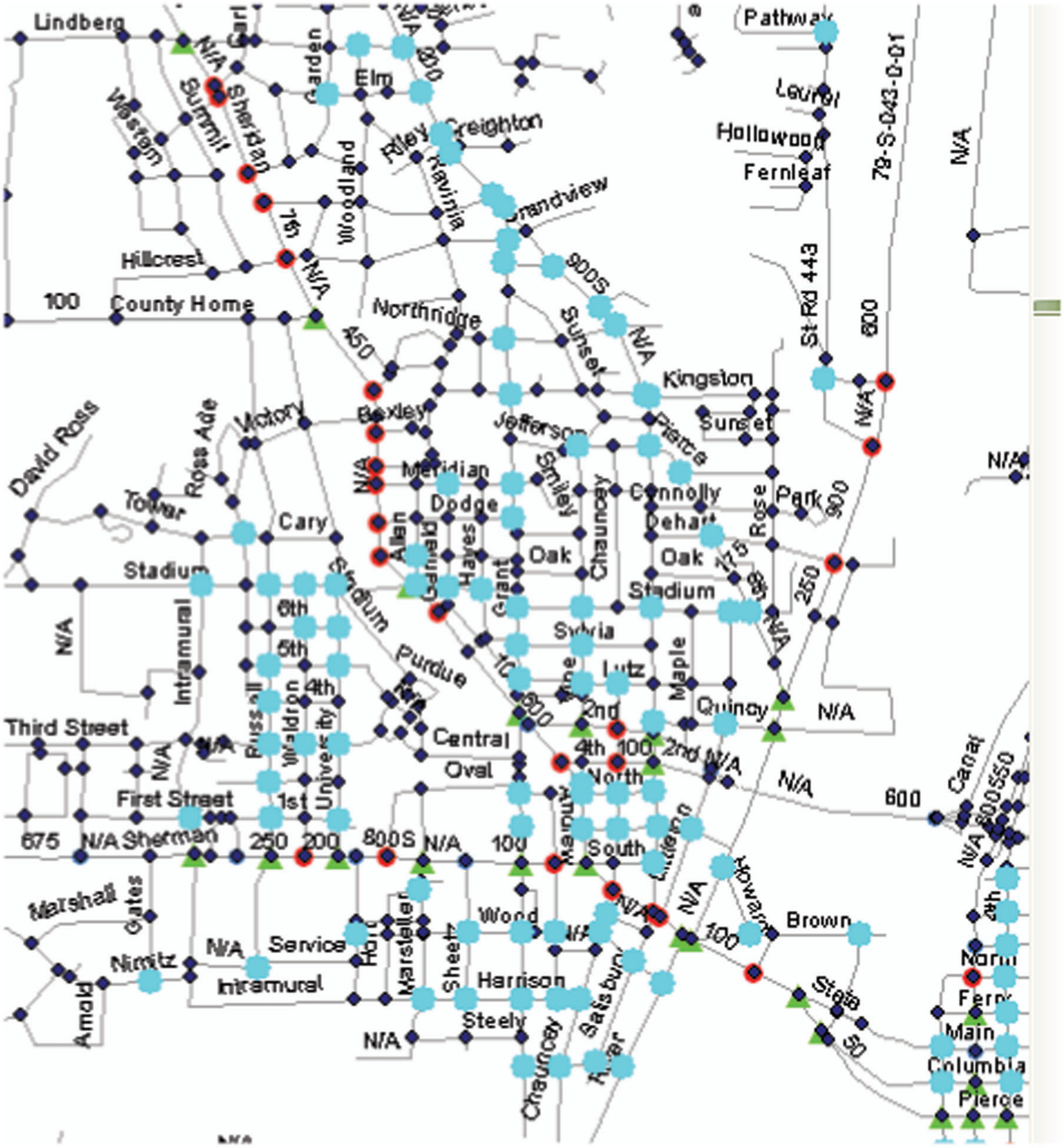


Figure C.3 Selection by attribute.

APPENDIX D. SURVEY FOR INDOT

This appendix presents the questionnaire (Figure D.1) distributed among the SAC members and other INDOT participants to collect information about the typically used countermeasures and corresponding assessed unit costs. The results of this survey are presented in Chapter 4: Inputs to the Optimization Module.

The table below presents example safety countermeasures/programs. Please mark in provided "Use in Indiana" fields those countermeasures that are already used on the INDOT-administered roads (Yes), should be considered for Indiana (Shld), or are not needed for Indiana (No). Add the unit costs of the improvements. Make a guess even if you do not have any specific numbers in mind right away. If any of the provided amounts seem incorrect, write your amounts above them.

Safety countermeasures/programs survey for INDOT

Category	Countermeasure	Use in Indiana			Cost in $1000s						Unit
		Yes	Shld	No	UI	UML	UTL	RI	RML	RTL	
Access management	Install a median					230			189		mi
	Eliminate/close driveways										drvwy
	Replace TWLTL with raised median										mi
Advanced technology	Install queue warning changeable signs										systm
	Implement automated red light running enforcement										intrsc
Alignment	Reduce horizontal curvature					2,500	2,500		2,500	2,500	curve
Highway lighting	Add lighting at intersections										intrsc
Intersection geometry	Add left-turn lanes to major road approaches at intersections										intrsc
	Add right-turn lanes to major road approaches at intersections										intrsc
	Replace direct left-turns with indirect left-turns										intrsc
	Convert intersection to roundabout										intrsc
On-street parking	Prohibit on-street parking										mi
Pedestrians	Install pedestrian hybrid beacon at intersection										intrsc
	Install raised pedestrian crosswalks										crswlk
	Construct pedestrians bridge or tunnel										strctr
	Install sidewalk										mi
At-grade railroad crossing	Upgrade signs to flashing lights										crssng
	Install gates at crossings with signs										crssng
	Build a grade-separated crossing										crssng
Roadside	Install guardrail					225	225		185	185	mi
	Remove or relocate fixed objects outside of clear zone										objct
Roadway delineation	Add centerline rumble strips								1.5		mi
	Add shoulder rumble strips							6	6		mi
Speed management	Set and post speed limits										mi
Shoulder	Widen shoulder width								123	123	mi
Horizontal curve	Install chevrons, warning/advisory signs, and/or beacons										curve
Intersection traffic control	Retiming signal change intervals to ITE standards										intrsc
	Increase visibility of signals										intrsc
	Replace left-turn phase(s) with protected-only										intrsc

*TWLTL-two-way left-turn lane, UI-urban interstate, UML-urban multilane, UTL-urban two-lane, RI-rural interstate, RML-rural multilane, RTL-rural two-lane, mi-mile, drvwy-driveway, systm-system, intrsc-intersection, crswlk-crosswalk, strctr-structure, crssng-crossing, objct-object.

Figure D.1 Safety countermeasures/programs survey for INDOT.

Please identify countermeasures and programs that are used in Indiana or should be considered for Indiana that are not included in the previous table. Use the table provided below. Add the unit costs of the improvements. Make a guess even if you do not have any specific numbers in mind right away.

Additional information survey

Category	Countermeasure	Use in Indiana		Cost in $1000s						Unit
		Yes	Should	UI	UML	UTL	RI	RML	RTL	

Write additional comments:

Figure D.1 Continued.

APPENDIX E. ECONOMIC CALCULATIONS IN SNIP2

Step 1. The required input: safety countermeasures; number of PD, NI, and IF crashes during the period with crash data; average AADT in the period with crash data; unit capital costs in *Y*2 year dollars; service life of the countermeasures; interest rate; inflation rate; and unit costs of PD, NI, and IF crashes in *Y*1 year dollars. The traffic is assumed fixed over years (zero growth rate).

Step 2. Determine the crash reduction factors (*CRF*). In the case of multiple improvements, the CRFs for the individual improvement are combined into one value:

$$CRF = 100 \cdot \left(1 - \Pi_n \left(1 - \frac{CRF_n}{100}\right)\right),$$

where:

$CRF=$ total percent crash reduction factor for multiple improvements,

$CRF_n=$ crash reduction factor for the n$^{\text{th}}$ improvement.

Step 3. Calculate the expected the over-dispersion parameter *D*.

$$M = \frac{\Sigma_j A_j}{N}, \quad V = \frac{\Sigma_j (A_j - M)^2}{N-1}, \quad R = \frac{\Sigma_j A_j}{Y \Sigma_j E_j}, \quad m_j = RY \cdot E_j, \quad V_p = \frac{\Sigma_j (A_j - m_j)^2}{N-1},$$

$$D = \frac{V_p - M}{M^2} \text{ if } D<0 \text{ then assume } D=0,$$

where:

M = average annual frequency of crashes in the group of roads,

A_j = number of PD, NI, or IF crashes on road *j* during period with crash data,

Y = number of years in the period with crash data,

N = number of roads in the group of roads,

V = variance of crashes in the group of roads,

R = average crash rate in the group of roads,

E_j = exposure (average daily VMT, AADT, length L) that represents exposure on road *j*,

m_j = expected number of PD, NI, IF crashes on road *j*,

V_p = average squared residual (A_j-mj) where $m_j = R \cdot Y \cdot E_j$, and

D = over-dispersion parameter.

Step 4. Estimate the crash frequency in the period with crash data. The reported crashes and the expected crashes for the exposure are combined.

$$a = R \cdot E$$

If $D=0$ then $\hat{a}=a$, otherwise $\hat{a} = \left(\frac{1}{D} + A\right) / \left(\frac{1}{D \cdot a} + Y\right)$,

where:

$\hat{a}$ = best estimate of the PD, NI, or FI frequency (crashes/year),

a = PD, NI, or FI frequency (crashes/year) expected at location,

E = exposure measure,

D = over-dispersion parameter,

A = number of *PD, NI*, or *FI* crashes during the period with crash data (crashes in Y years), and

Y = ($LY-FY$+1) number of years in the period with crash data (FY and LY are the first and last years of the period with crash data).

Step 5. Estimate the annual safety benefit, which is the product of the annual frequency *a* of PD, NI, or IF crashes, the CRF, and the crash cost adjusted for inflation.

$$B = a \cdot \frac{CRF}{100} \cdot C_1 \cdot \left(1 + \frac{F}{100}\right)^{PY-Y1},$$

where:

B = annual crash benefit for reducing crashes PD, NI, or FI,

a = PD, NI, IF crash frequency,

CRF = percent crash reduction factor of *k* severity,

C_1 = average cost of PD, NI, or IF crash in year Y1,

F = inflation rate, assumed to be 2% unless otherwise specified, and

PY = present year.

Step 6. Calculate the present worth of the total agency costs, which is the accumulated capital costs of all the improvements. The changes in the maintenance costs and the salvage values are neglected.

$$C = \frac{1}{100} \cdot \left(1 + \frac{F}{100}\right)^{PY-Y2} \cdot \Sigma i \left(C_{2i} \cdot \frac{(1+I/100)^{SL_i-1}}{(1+I/100)^{SL_i}-1}\right),$$

where:

$C=$ annualized countermeasure cost,

$C_{2i}=$ the capital cost of the i^{th} improvement in year *Y*2,

$I=$ interest rate, assume 4% unless specified otherwise, and

$SL_i=$ service life of the i^{th} improvement.

APPENDIX F. INPUT TO THE EVALUATION OF THE OPTIMIZATION METHOD

TABLE F.1
Complete dataset of *add shoulder rumble strip.csv*

CFID Segment	Start_X	Start_Y	End_X	End_Y	CO	D	U	Mile	AADT	LSW	Total Number of Crashes	LN	Average Number of Crashes per Year	Cost	Life Span	Annual Cost	Benefit	B/C
244054	−86.7895	40.50548	−86.7866	40.51146	79	1	0	0.448	12035	2	9	2	3	1344	7	192	14257	74.26
245175	−86.7681	40.52096	−86.7594	40.52554	79	1	0	0.555	12035	2	7	2	3	1665	7	238	14257	59.94
234444	−86.9187	40.43873	−86.9173	40.43884	79	1	2	0.077	13340	0	1	2	1	231	7	33	4752	144
420804	−86.7385	40.53344	−86.7304	40.53793	79	1	0	0.525	9440	2	6	2	2	1575	7	225	9504	42.24
420356	−86.7955	40.5009	−86.7895	40.50548	79	1	0	0.448	12035	2	4	2	1	1344	7	192	4752	24.75
226032	−86.7044	40.3576	−86.6996	40.35596	79	1	0	0.276	5629	3	2	2	1	828	7	118	4752	40.17
239995	−86.8866	40.46856	−86.881	40.48209	79	1	2	0.982	7601	3	7	2	3	2946	7	421	14257	33.88
225795	−87.0424	40.34909	−87.0372	40.35437	79	1	0	0.466	7822	3	3	2	1	1398	7	200	4752	23.79
245360	−86.7568	40.52659	−86.7541	40.52767	79	1	0	0.16	9440	2	1	2	1	480	7	69	4752	69.3
235280	−87.0056	40.44587	−86.9993	40.44589	79	1	0	0.329	2507	2	1	2	1	987	7	141	4752	33.7
241963	−86.8134	40.49234	−86.8104	40.49362	79	1	0	0.178	12035	2	1	2	1	534	7	76	4752	62.29
239231	−86.8356	40.4708	−86.834	40.47585	79	1	2	0.371	14115	2	2	2	1	1113	7	159	4752	29.89
247281	−86.7131	40.54798	−86.7067	40.55109	79	1	0	0.396	9440	2	2	2	1	1188	7	170	4752	28
232251	−86.9104	40.42403	−86.9122	40.42409	79	1	2	0.099	20995	0	1	3	1	594	7	85	4231	49.86
238122	−86.9751	40.4674	−86.9736	40.46739	79	1	2	0.079	13381	0	1	5	1	474	7	68	4231	62.48
238248	−86.9993	40.46829	−86.9946	40.46777	79	1	0	0.252	8888	2	3	5	1	1512	7	216	4231	19.59
236583	−86.9296	40.4549	−86.9281	40.45405	79	1	2	0.095	20146	3	1	5	1	570	7	81	4231	51.96
238149	−86.9472	40.46747	−86.9394	40.46674	79	1	2	0.421	30210	3	3	5	1	2526	7	361	4231	11.72
218618	−86.7191	40.27014	−86.7102	40.26217	79	1	0	0.725	6616	3	5	5	2	4350	7	621	8463	13.62
417817	−86.7832	40.33072	−86.7777	40.32578	79	1	0	0.447	8278	2	3	5	1	2682	7	383	4231	11.04
237139	−86.933	40.45995	−86.9314	40.45787	79	1	2	0.165	30210	3	1	5	1	990	7	141	4231	29.92

CO= county; D= district; U= urban; LN= lane.

TABLE F.2
Complete dataset of *widen outside shoulder width.csv*

CFID Segment	Start_X	Start_Y	End_X	End_Y	CO	D	U	Mile	AADT	LSW	Total Number of Crashes	LN	Average Number of Crashes per Year	Cost	LifeSpan	Annual Cost	Benefit	B/C
244054	−86.7895	40.50548	−86.7866	40.51146	79	1	0	0.45	12035	2	14	2	5	275255	20	13762	27646	2.01
245175	−86.7681	40.52096	−86.7594	40.52554	79	1	0	0.56	12035	2	18	2	6	341392	20	17069	33175	1.94
238248	−86.9993	40.46829	−86.9946	40.46777	79	1	0	0.25	8888	2	4	5	2	154790	20	7739	9846	1.27
420804	−86.7385	40.53344	−86.7304	40.53793	79	1	0	0.53	9440	2	16	2	6	323045	20	16152	33175	2.05
420356	−86.7955	40.5009	−86.7895	40.50548	79	1	0	0.45	12035	2	5	2	2	275255	20	13762	11058	0.8
226032	−86.7044	40.3576	−86.6996	40.35596	79	1	0	0.28	5629	3	2	2	1	137760	20	6888	4525	0.66
218618	−86.7191	40.27014	−86.7102	40.26217	79	1	0	0.72	6616	3	12	5	4	356602	20	17830	16115	0.9
417817	−86.7832	40.33072	−86.7777	40.32578	79	1	0	0.45	8278	2	4	5	2	219756	20	10987	8058	0.73
225795	−87.0424	40.34909	−87.0372	40.35437	79	1	0	0.47	7822	3	10	2	4	286518	20	14325	22117	1.54
247281	−86.7131	40.54798	−86.7067	40.55109	79	1	0	0.4	9440	2	6	2	2	243815	20	12190	11058	0.91
245746	−86.7493	40.52904	−86.7385	40.53344	79	1	0	0.65	9440	2	12	2	4	399750	20	19987	22117	1.11
247866	−86.8693	40.54754	−86.8694	40.55462	79	1	0	0.49	10214	4	16	2	6	300628	20	15031	33175	2.21
416796	−86.828	40.25861	−86.8186	40.25853	79	1	0	0.5	1668	3	2	2	1	184500	20	9225	3472	0.38
244054	−86.7895	40.50548	−86.7866	40.51146	79	1	0	0.45	12035	2	14	2	5	275255	20	13762	27646	2.01

CO= county; D= district; U= urban; LN= lane.

TABLE F.3
Complete dataset of *new signal installation.csv*

CFID Intersection	X_COORD	Y_COORD	County	CITY	Total Number of Crashes	Average Number of Crashes per Year	Cost	Life Span	Annual Cost	Benefit	B/C
6275	−86.9104	40.42796	157	771	36	12	125000	10	12500	58200	4.66
6288	−86.9092	40.42399	157	771	39	13	125000	10	12500	63050	5.04
6300	−86.908	40.42399	157	771	75	25	125000	10	12500	121250	9.7
6303	−86.9077	40.38944	157	807	19	6	125000	10	12500	30717	2.46
6311	−86.9069	40.42667	157	771	12	4	125000	10	12500	19400	1.55
6333	−86.9056	40.42736	157	771	23	8	125000	10	12500	37183	2.97
6544	−86.8943	40.42183	157	807	14	5	125000	10	12500	22633	1.81
6547	−86.8943	40.42001	157	807	19	6	125000	10	12500	30717	2.46
6587	−86.893	40.40994	157	807	33	11	125000	10	12500	53350	4.27
6701	−86.8886	40.41733	157	807	12	4	125000	10	12500	19400	1.55
6727	−86.8858	40.41734	157	807	12	4	125000	10	12500	19400	1.55
6883	−86.871	40.39546	157	807	18	6	125000	10	12500	29100	2.33
7069	−86.8575	40.39552	157	807	50	17	125000	10	12500	80834	6.47
7218	−86.8291	40.41765	157	807	53	18	125000	10	12500	85684	6.85
7272	−86.8166	40.41747	157	807	34	11	125000	10	12500	54967	4.4
7309	−86.8118	40.41753	157	807	20	7	125000	10	12500	32333	2.59

TABLE F.4
Complete dataset of *convert intersection to roundabout.csv*

CFID Intersection	X_COORD	Y_COORD	County	CITY	Total Number of Crashes	Average Number of Crashes per Year	Cost	Life Span	Annual Cost	Benefit	B/C
6579	−86.893	40.41733	157	807	71	24	1500000	20	75000	284464	3.79
6719	−86.8867	40.41735	157	807	64	21	1500000	20	75000	256418	3.42
6800	−86.8772	40.41733	157	807	54	18	1500000	20	75000	216353	2.88
7145	−86.8437	40.38271	157	807	71	24	1500000	20	75000	284464	3.79

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

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