DEVELOPMENT OF A GIS-BASED TRAFFIC SAFETY ANALYSIS SYSTEM

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Development of a GIS-based Traffic Safety Analysis System

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ABSTRACT

Traffic safety analyses have historically been used by transportation professionals as a means to evaluate safety of an area. This paper summarizes the methodology to develop a traffic safety analysis system – one that integrates crash data and roadway related information in a Geographic Information System (GIS) environment. The system includes customized user interfaces to support queries and capabilities to export results. This system supports both macro level and micro level analyses. The system further offers capabilities to query crash data based on attributes from the database. The system also contains a module to identify high crash locations based on methods identified from the published literature. The methods range from those based on simple crash frequency to more complex methods which incorporate different weights for crashed based on the crash outcomes. The system can be used to evaluate the effectiveness of a safety program by performing ‘before and after’ studies. An application of the system is illustrated using data from the Las Vegas metropolitan area in the state of Nevada.

INTRODUCTION

Over the past decade, traffic crashes have resulted in over 42,000 fatalities annually in the United States (1). Analyses of relevant data are essential to develop strategies to improve road safety. However, data required for such analyses often come from multiple sources, in varied formats, with various levels of accuracy and reliability. Computerized tools and systems offer great potential to combine such data and to perform the required analyses. Due to the spatial nature of disparate datasets needed for transportation safety analysis, the GIS platform would be a good option to integrate them. Kumaresan provides additional information on the advantages of using GIS for development of such a system (2). Further, the GIS platform offers a natural environment for development of a safety analysis system using the consolidated database due to its data integration and mapping capabilities. The advantage of viewing data in spatial format, hence enabling the user for spatial analyses, is perhaps a very important benefit of using GIS.

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LITERATURE REVIEW

Analysis of Crash Data

Several efforts have been initiated throughout the United States to create crash reporting systems which allow agencies to access these data. The Fatality Analysis Reporting System (FARS) developed by the National Highway Traffic Safety Administration (NHTSA) (3) is one such system that aims to provide a measure of overall highway safety and thereby to evaluate the effectiveness of highway safety programs. Parrish et al. (2003) explains the Critical Analysis Reporting Environment (CARE), developed by the University of Alabama (4). The aim of CARE was to analyze automobile crashes to aid in developing strategies to reduce crashes. Similarly, University of North Carolina’s Highway Safety Research Center (HSRC) has developed a crash data query website that contains data from 2001-2006 available for public usage Alabama (5). Iowa Department of Transportation uses Crash Mapping Analysis Tool (CMAT) to provide access to crash data and additional features like crash stacking, inclusion of speed and volume information (6). Kim et al. describes the Crash Outcome Data Evaluation System (CODES) system used in Hawaii, New Hampshire, Maryland and South Carolina (7). CODES involves the linkage and analysis of police crash data, emergency medical services transport data, hospital data, and insurance claims. Many state agencies like Nevada Department of Transportation (8), Washington State Department of Transportation (9) and Department of Transportation of Arlington (10) have developed systems to aid in traffic safety analysis and management.

Advantages of Using GIS to Develop Crash Analysis Tool

Motor vehicle crash data for metropolitan regions are typically collected and maintained by several agencies such as federal, state, local agencies and law enforcement agencies. Therefore, there likely are significant differences in their formats and in different data structures. In order to integrate crash data with other relevant information like roadway data, GIS provides an environment to facilitate data integration, analysis (11) and display of results. The use of GIS also extends the level of analyses to perform spatial analyses and grid-cell modeling (12). More detailed commentary on the rationale for this approach is included in a report that forms the basis of this paper (13).

OBJECTIVE

The literature review suggested that although some studies are conducted in analyzing crash data using GIS, these features have to be tailored to fit agencies’ analyses requirement. Implementing a bigger system is both time consuming and expensive. On the other hand, most of the existing tools did not address micro analyses in detail. From a safety engineers’ and planners’ perspective, it is extremely important to have a safety analysis system capable of performing detailed micro level analyses for evaluating effectiveness of their safety programs. The objective of this paper is to demonstrate the development of a safety analysis system using crash data and roadway data. The aim of this paper is to explain the concepts of both macro and micro analyses for a region using the existing crash data and street centerline data. Examples from the Las Vegas Metropolitan area are used to illustrate the capabilities of the system developed.

METHODOLOGY AND SYSTEM DEVELOPMENT

Data Assimilation

The initial step in the development of an analysis system is to identify the data required to support the desired analyses and the format in which they are available. Data assimilated
included crash data for the time period 2002 to 2006 from the Nevada Department of Transportation and roadway network (street centerline) information from the Clark County GIS Management Office (GISMO) (14). The crash database contains several crash characteristics including vehicle related, roadway related, crash related and person related details (15). One of the issues related to data assimilation in this research was the compatibility of both the data sets after incorporating them in a GIS environment.

System Architecture and Design
The system is intended to support performing safety analyses in terms of querying crash data and ranking of high crash locations. The analyses can be broadly classified into micro and macro levels of examination. Macro level analyses involve analyses on a larger spatial scale such as a city, while micro analyses focus at a smaller spatial extent such as an intersection or roadway segment. As for output, the system was required to support representation of the results in a form that would be acceptable for most users. Furthermore, the software and hardware requirements were to be easily available to the users.

METHODOLOGY AND SYSTEM DEVELOPMENT

System Development
The safety analysis system was developed for the crash data as a whole and another section was dedicated solely to bicycle and pedestrian crashes for analyzing and evaluating improvements to those particular categories of road users. The development of the entire safety analysis system can be described in three parts: 1) macro-analyses; 2) micro-analyses – intersection and street segment; and 3) the high crash ranking analysis system for various locations. Figures 1a, 1b, and 1c describe the tool structure of the above-mentioned sections.

Macro-Analyses
The system provided the user with options to query for crash data on a macro (area-wide) level or on micro (location-specific) level. After deciding on the type of query the system listed the options that could be included in querying the crash data pertaining to the specific location. Most of the attributes listed in the crash database such as severity, crash type, day of week, time of day etc. could be included in developing a query. A basic search option is provided to the user to perform a quick search of the crash data for any criterion that the database supported on a macro or area wide level. The user entry in this section is restricted to three entries. This option facilitates the user to work with a combination of 3 criteria of crash characteristics. A sample of this application is shown in the case study section.

Micro-Analyses
Crash analyses in micro-level can be performed for locations – either intersections or street segments. As Figure 1b indicates, analyses based on intersection or segment would allow the user to further make use of multiple combinations of queries to arrive at specific results. The following section describes both these options in detail.

(a) Crashes at an Intersection - The main objective of the intersection level analysis option is to analyze safety aspects at an intersection location. The data entry section involved the entry of the names of the cross streets and the buffer distance to be considered around the intersection from which crash data is to be extracted. The flow of the logic is represented in figure 2.

(b) Crashes on a Street Segment - The third option for crash analysis is based on identifying street segments. This option permits evaluation of long segment of a street comprised of several smaller sections or just one section. The data entry for the street segment analyses
FIGURE 1 Tool structure.

a Macro - Analysis Tool Structure.

Data – crash, roadway

Macro (area-wide) analyses

Query using 3 criteria – crash characteristics

b Micro-Analyses Tool Structure – intersection and street segment.

Data – Crash, Roadway

Crashes at an intersection

Crashes on a street segment

Multiple Queries

Severity

Crash type

Time period

Day of week

Time of day

Roadway factors

Vehicle Details

Weather

c High Crash Ranking Tool Structure.

Data – crash, roadway

Crash frequency for areas

Assign ranks

Frequency

Weights
required the choice of the names of the main street as well as the cross streets between which the main street segment was to be located. The coding tasks were performed based on the figure 3.

c) **Multiple Query Criteria** - Based on the selected intersection or street segment, the system provides the user an interface to build a query based on various user defined criteria using data fields from the crash database. The user options to select the criteria for the multiple query analysis are placed on four tabs in four broad categories as follows: date & time, crash characteristics, vehicle characteristics, and road characteristics.

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**FIGURE 2** Flow chart for selecting crashes for intersection level analysis.
High Crash Ranking

The system facilitates the identification of high crash locations based on total crashes and weighted ranking (16). The methodology followed for identification of high crash ranking was (a) simple crash frequency procedure – assigning ranks based on total number of crashes in that
particular location and (b) weighted ranking procedure – assigning ranks based on weights specified for different levels of severity – fatal, injury or PDO.

CASE STUDY: LAS VEGAS METROPOLITAN AREA

The various analyses tools listed in the methodology section are illustrated using examples from the Las Vegas metropolitan area in the case study section. ESRI’s ArcGIS software version 9.2 (17) was used to develop the safety analysis system. This was because of several advantages it possesses in spatial display and data integration. Besides the technical capabilities it offered, this was also the software used by agencies in Las Vegas Metropolitan area. Its in-built VBA application was the programming environment used to develop the various analysis tools and operations. Microsoft Excel was also used for displaying the analysis results in tabular format. Another type of output possible using the ArcGIS software was to display the results graphically on the map window.

Macro Analyses

This section describes the use of the tool in performing macro-level analyses. In order to illustrate this option, the following sample query statement (broken down into three parts) is shown:

- First Criterion: Crash type – Head-on, and
- Second Criterion: Severity – Injury, and
- Third Criterion: Year – 2004

The first step for a user to perform this sample query was to click on the ‘First Criterion’ combo-box (Figure 4, Label a). From the list, ‘Crash Type’ criterion had to be chosen. After choosing ‘Crash Type’ as the data field to be queried on, the user had to click on the ‘Load unique values’ button as shown in Figure 4, Label b. This would load all unique values in the criterion to Figure 4, Label c. The next step was for the user to choose ‘Head on’ from the list.
Thus, the first criterion is to set to crash type to “head on.” Next, the connection between the first and second statement was to be mentioned (Figure 4, Label d). The operators available for use are: ‘And’ and ‘Or’, and they would be displayed on clicking the down arrow button next to the box. For this example, the use of the ‘And’ operator was required.

The same procedure of selection of criteria had to be followed for criteria two and three also. The final appearance of the screen after data entry is shown in Figure 4. The results for this query are shown in Figure 5 (zoomed in for clarity).

![Figure 5 Results of the query: Angle crashes that caused injuries in 2005.](image)

**Micro Analyses**

This section describes the performance of location-specific analyses in terms of whether it was an intersection or a roadway segment. The tool for this option has been demonstrated using suitable examples from the Las Vegas area.

**a) Crashes at an Intersection**

In the first step, the user had to choose the names of the intersecting streets. Clicking the button shown in Figure 6, Label a resulted in the streets names of Las Vegas area from the Street Centerline database being loaded on to the combo-box labeled ‘Choose the First Street.’ For example, for the Rainbow-Sahara intersection, the user selected ‘Rainbow’ for the 1st street and ‘Sahara’ for the 2nd street or vice versa. The next step was to enter the buffer distance into the textbox titled ‘Input the Buffer Distance’ (Figure 6, Label b) and specify the unit (Figure 6, Label c.) For illustration purposes, the buffer distance was chosen as 250 and the unit for this distance was chosen as ‘feet.’

Clicking the ‘Search’ button would prompt the system to check for the existence of the specified intersection location and then performance of the sequence of operations to extract crashes that occurred around the intersection. The output for the sample query that was run with the data entry as given in the previous figure is shown in Figure 7.
b) Crashes on a Street Segment

In order to illustrate the operation extraction of crashes that occurred on a street segment, the segment of Sahara Avenue between Buffalo Drive and Rainbow Boulevard is shown. The data entry for this example and the results are shown in Figure 8.
Multiple Query Criteria

After either of the two above-mentioned tools – location of crashes at an intersection or on a street segment is performed; the multiple query criteria window pops open to enable the user to include a variety of criteria in his/her query statement. For previously run street segment query example, the multiple query window is shown in Figure 9. The various crash characteristics are grouped under the 4 tabs highlighted in Figure 9, Label a: Date/Time, Crash, Vehicle, Road details. Sample results for the query and export options (figure 10) are shown in Figure 11a (shapefile) and 11b (table).
At this point the system allows the user to either export the results as a shapefile (Figure 11a) or as a spreadsheet table (Figure 11b).
In this section, the High Crash Ranking tool is described for a sample run in order to explain the step by step procedure to be followed by the user to get required results with regard to whether it was based on a) total number of crashes or b) weights for severity levels.

For the crash frequency procedure, assuming that the user wanted to rank the locations in Las Vegas area based on the total number of crashes that occurred at each location in the year 2004 for a buffer distance of 200 feet around the intersection, the High Crash Ranking feature shown in Figure 12, Label a had to be used. After clicking the High Crash Location button, the ranking would be performed by the system. The resulting ranks obtained for the year 2004 and buffer size 200 feet are shown in Figure 13a. If the user wishes to make use of the option to include weights while ranking the locations, the feature shown in Figure 12, Label b had to be used. In order illustrate this feature, assuming the user wished to append weights for severity to the previously mentioned query year and buffer distance, fatal being 10, injury being 5 and PDO being 2, clicking the ‘Weighted Ranking’ button triggered the system to calculate the sum of
weights. The results obtained for the specified weights of severity levels having been incorporated in the ranking procedure, are shown highlighted in Figure 13b.

ISSUES AND ERRORS

The Safety Analysis System was developed using ArcGIS 9.2. However, after completion of the project, ESRI released ArcGIS 9.3. When tried to use the tool in the new version, the system showed some compatibility issues. These were resolved and the system was deployed successfully.

CONCLUSIONS AND RECOMMENDATIONS

The main objective of this paper was to summarize the methodology to develop a safety analyses system to perform analyses in both macro and micro level. The paper describes the development of such a system using GIS software. This system could be used to identify safety issues in an area. It could also be used to monitor traffic safety programs and their effectiveness. The safety analysis system thus developed was able to perform crash analysis at a specific location in a detailed manner as well as rank locations based on number of crashes. Some advantages of the safety analysis system are:

- The safety analysis system helps evaluate safety concerns on roadways in an area or at specific locations.
- The High Crash Ranking tool can be used to assign ranks to locations based on the total number of crashes that occurred around it.
- The safety analysis system enables users to integrate various formats of data and to obtain results based on queries and spatial analyses and to display results as maps.
- The safety analysis system can be used to perform before and after studies to determine the effectiveness of a transportation safety program. Also, the user interface helps users who are not familiar with GIS functionalities to make use of the developed analysis tools.

Some of the recommendations of the study are:

- From the crash database, it was found that the records contained numerous misspelled entries. Since the querying of data depended entirely on the individual entries in the
database, addressing all possible spellings of a particular factor could not be achieved entirely. Creation of a reliable crash database would help to improve the accuracy of the results obtained by using the various analysis tools.

- Use of information technology by means of handheld/PDA type devices while recording crash reports would help in minimizing data inconsistencies and misspells in addition to the time saved in manual inclusion of each report into the crash database.
- Incorporation of other traffic-related information such as traffic volumes/mix, traffic control and operational information, roadway-related information in evaluating traffic safety would help in improving the analyses possible. For example, computation of crash rates such as the crashes per million entering vehicles at an intersection would provide a measure for ranking crashes.

![Attributes of 2004 bus/04year](image1)

a Year 2004 and buffer size 200 feet.

![Attributes of 2004 bus/04year](image2)

b Weighted ranking for Severity – 10, 5 and 2.

**FIGURE 13** High Crash Ranking results.
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