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Development of a safety analysis and an intersection infrastructure system

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DEVELOPMENT OF A SAFETY ANALYSIS AND AN INTERSECTION INFRASTRUCTURE SYSTEM

by

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ABSTRACT

Development of a Safety Analysis and an Intersection Infrastructure System

by

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GIS and GPS technologies have found immense applications in the field of transportation engineering. Different features related to transportation safety are inventoried using these technologies. The databases so created serve as main source for safety analyses, decision making and reporting. Many different analyses tools are available to assist engineers, planners and policy makers in the process of improving transportation safety. GIS-based analyses tools provide tabular and graphic display, thereby expediting the analyses process and improving the spatial understanding. The advantages of such tools increase if they can be provided on the World Wide Web. One such software system that offers online analyses tool is the ArcIMS.
This research is aimed at developing a GIS-based tool to inventory signalized intersection attributes. In addition, an internet based analyses system that utilizes the signalized intersection database and the crash database is developed. The tools provide number of choices to perform user-defined queries to generate specific results. The system is developed using Visual Basic .Net programming language. The applications developed here are demonstrated with the data available for the Las Vegas metropolitan area.
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CHAPTER 1

INTRODUCTION

Transportation studies involve collection, maintenance, and analyses of data in order to design for the present needs and to provide improvements for future needs. Facilitating efficient analyses with large amounts of data requires proper database development and their management. One such application of data management lies in the field of traffic safety. In particular, intersection crashes contribute to about 50% of the total crashes (Hakkert and Mahalel 1978, 69-79). Crashes involving fatalities are of particular concern. Traffic safety engineers are continuously developing techniques to reduce the number of crashes and/or their severity. Such efforts require analyses of crash data. These data come in different formats and data sets, vary considerably over the time and space dimensions. Thus, it is imperative to effectively manage such disparate datasets.

1.1 Database

Safety analysis requires detailed knowledge of all those factors that determine the dangerousness of the infrastructure. To obtain good results, the analysis related to transportation safety should include complete and
reliable information related to accidents, infrastructure features and traffic conditions. The information in the database becomes fundamental for such analysis. The architecture of the database must be planned appropriately in addition to need for adding the geo-references (Augeri, Cafiso, and LaCava 2003, 547-554).

A database is a collection of records stored in a defined sequence in order to support queries, analyses and to provide results based on the used needs. Data related to the transportation system managed by public agencies are typically under the purview of a number of departments. A central database structure would help such departments to capture their respective data, incorporate the same with other datasets, and perform various analyses. This helps expedite various data dependent activities. A common database that is routinely updated also provides for up-to-date data made available to all users. This improves the accuracy and timeliness of analyses based on such data.

The development of a database requires collection of appropriate data. For databases related to transportation systems, location is one of the important features that needs to be considered. The use of advanced data collection techniques including Global Positioning System (GPS) and Geographic Information System (GIS) are of great value in the development of such databases. The GPS allows the user to digitally (i.e., in an electronic format) record the location based on a spatial reference system. On the other hand,
the GIS software allows easy viewing of these locations. These techniques help reduce the time required for data collection and also help reduce the effort for data integration and management.

1.2 Techniques used in transportation related database development

The Georgia Department of Transportation (GDOT) is one among a number of state DOTs who maintain inventory of public roads within the state. The inventory serves as a complete source of information for estimation of official mileage, condition, status, type, and use of all public roads in Georgia (Tsai, Wu, and Wang 2004, 542-547). The database provides as the main source for reporting, analysis, and decision. The traditional method of data collection was to use the pen and paper. The use of new technologies such as GPS/GIS would significantly improve the process of data collection. The researchers believe that the new system would significantly improve the productivity and the data quality for field operation and expedite the analyzing and reporting processes.

GPS technology is based on a satellite navigation system designed by the U.S. Department of Defense. The satellites provide coded signals which are decoded by the GPS receiver to compute the current location and time. GPS receivers are designed to provide three-dimensional locations including latitude, longitude and altitude, in addition to time (http://en.wikipedia.org/wiki/Global_Positioning_System). The nominal GPS
operational constellation consists of 24 satellites, of which at least four are required to compute location and time. Combing the GPS technology with a system that can display geographic information such as the GIS could lead to better addressing the needs of transportation analyses based on spatial data.

GIS can be defined as the technology that allows maps to be programmed using simple code and then stored in a computer, allowing for future modification whenever necessary. GIS includes two sets of databases: the spatial data, which includes the location of features, and the attribute data that include additional information about the features. According to Environmental Systems Research Institute, "GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps." (www.gis.com/whatisgis/index.html)

1.3 Database usage

Transportation analysis deals with databases related with a variety of aspects. For example, crash analysis requires details about high crash locations, number of crashes, casual factors, etc. Safety engineers require details about crashes to make appropriate developments to improve safety. Similarly, roadway analysis requires knowledge about the different physical features related to it. These physical features such as traffic signals, supports, streetlights require installation, maintenance and replacement
(Morse 1997). A database that includes the details of related attributes becomes necessary for such analyses.

Using the different crash databases available and techniques developed, safety engineers perform crash analyses in order to develop countermeasures to improve safety. However, deployment of the counter measures is dependent on the available funds. For example, a crash database and an analyses system could be used to help safety engineers identify high crash locations also called as black-spots or high-risk locations. These high-risk locations are mostly identified based on crash frequency, severity and density over a certain time period (Sayed and Abdelwahab 1997, 107-113). Numerous high-risk identification methods have been designed by researchers. Some of these methods are designed to identify the causal factors also. Once the high-risk locations are identified, it is necessary to understand crash behavior, design countermeasures and implement them in order to improve safety. Safety improvements aim to reduce the number of crashes and/or their severity.

Researchers have developed numerous models to identify crash-prone locations or black spots. In order to provide for better data management and to facilitate multi department collaborative efforts, sometimes crash data are made available on the web. These websites provides information about general trend for crashes, type of crash, severity, weather condition, and the
ability to build query to serve more specific interests. Some of these websites also provide mapping with the help of GIS.

Although most of the high-risk locations identified have high crash frequencies or densities, it is necessary to further analyze the identified locations in order to rank them depending on measures of risk. Since the funding available is usually limited, it is necessary to prioritize the locations to be treated and the treatment options based on risks, costs and benefits. This involves statistical analyses of the identified high-risk locations.

1.4 Problem statement

The Clark County Department of Public Works (CCDPW), Las Vegas maintain crash records which are scanned into image format and stored in a central system named KoVis. KoVis is document management software that is used to organize documents in image format. Each crash record obtained from the Las Vegas Department of Motor Vehicles consist details spread over 8-9 pages. These documents can be retrieved by the traffic management staff using the KoVis system, based on five factors: location of crash (street names) date and crash severity (fatal, injury and property damage only). The retrieved documents are then downloaded and analyzed. Identification of crashes based on other factors such as type of crash, day of the week, was not possible using the KoVis system. Thus, an alternate method to identify crashes based of various attributes is developed in this research.
A database consisting of a signalized intersection details will provide for proper intersection infrastructure management such as regular maintenance, material calculation, etc. A signalized intersection database of newly re/configured signalized intersections was not maintained by the Clark County, Las Vegas. For the purpose, a data collection tool using the GIS/GPS techniques would provide added advantage. In addition to the intersection database development, an analyses tool to retrieve records based on various intersection attributes becomes necessary.

1.5 Study objectives

The first part of this research focuses on developing a crash data analysis tool that can be used over the intranet/internet. The crash data analysis system includes key details about the crash such as location, type and severity, day of week, information about the vehicles and persons involved etc. The system is designed to provide information about collisions with an option to generate specific queries as needed by the user.

In the second part of this research work, an effort is made to develop a spatially referenced intersection infrastructure database with a focus on signalized intersections. Intersection description includes a number of factors such as the intersection ID, the location of intersection, the number of lanes, lane width, the number of signal heads and their type. Hence, it is necessary to prioritize the different fields that have to be included in the database.
Further, an analysis tool is developed to perform queries on the intersection database.

This research includes designing and developing a crash analysis system using crash data obtained from the Las Vegas Metropolitan Police Department. This database consists of seven tables which will be described in detail later in this document. The crash data are geo-coded using Crossroads Software. The crash analysis system developed herein is designed using Visual Basic codes to provide with a number of dropdown user choices. Thus, in addition to the accident number, the user is allowed to build queries to generate results of several specific queries. The database includes details of crashes from October 2003 to May 2006.

Further, a database of signalized intersection for a section of the Las Vegas Metropolitan area is developed. The database contains details about the intersection including location of the intersection, number of intersection legs, road width at intersection, signal master arm length, number of signal heads, and their type, control box location in addition to photos of the intersection traffic signals from different directions. A signalized intersection analysis tool is developed to assist users to analyze intersection attributes. Lastly, the crash data analysis tool and the intersection analysis tool are integrated.
CHAPTER 2

LITERATURE REVIEW

Identification of black spots is one of the steps to plan for safety improvements. However, the reason(s)/cause(s) for having increased number of crashes at a particular location needs to be identified to deploy appropriate countermeasure(s). If this reason(s)/cause(s) identified is/are correctable, safety engineers can plan accordingly to improve safety. A number of methods have been developed for the identification of crash prone (high crash) locations. Recently, online crash data analysis websites have become available to provide for easier accessibility. These websites provide the user the ability to analyze general crash trends and generate results to specific queries.

Some of the online crash analysis websites use geographic information system (GIS) to provide for spatial analysis in addition to tabular or graphical results. Thus, the user can not only generate specific results but also spatially view them with the help of mapping software. The results thus obtained can be used for further study in order to improve safety. However, number of crash occurrences is not the only criterion to identify high crash locations. Other factors such as traffic volume, type of crashes, weather
conditions also have to be analyzed. Some of the crashes might be due to changes at the locations which need to be analyzed before further study. In order to identify high crash locations that are significant, researchers also need to perform statistical analyses. This chapter describes some of the research performed in the field of crash data analysis and online crash websites.

A crash can be described as a rare, random, multifactor event preceded by a situation wherein one or more factors fail to cope with their environment (Kalasova and Stacho 2006, 29-33). The main objectives of crash analysis can be listed as follows:

- Identify of high crash locations
- Analyze crashes and identify countermeasures
- Establish priorities based on funding available
- Implement countermeasures
- Evaluate effect of countermeasures
- Provide data for future planning and enforcement actions

Traffic fatalities are significant in the US and across the world in spite of the advancements in vehicle design, traffic improvements and safety programs. According to the National Center for Statistics and Analysis (NCSA) fatalities per 100 million vehicle miles traveled has been reduced from 1.73 in the year 1994 to 1.47 in 2005 (www-fars.nhtsa.dot.gov).
However, the number of fatalities has increased nationwide as shown in Figure 2.1. These numbers suggest a need to analyze crash data which helps recognize the factors leading to crashes and identify high crash locations. Crash analysis provides means to design safety programs and implement countermeasures in order to reduce occurrence of crashes and/or their severity.

![Figure 2.1 Number of fatal crashes in the US during 1994-2006](image)

2.1 Crash analyses

The increase in number of collisions may be explained based on the fact that increase in traffic volume would results in an increase in the number of collisions, if the crash rate were unchanged. As previously stated, intersection crashes in general constitute about 50 percent of the total
crashes in the US. Thus, an understanding of the relationship between traffic volumes and intersection crashes would provide a basis for improving safety at those intersections. In a study by A.S. Hakkert et al. (1978), exposure was indicated as the number of times vehicles with conflicting paths intended to occupy the same spot at the same time. Other research indicates that the black-spots are those at which the actual numbers of crashes are greater than the expected number. These models can be applied to evaluate the after-effects of traffic regulations such as eliminating left-turning movements or changing two-way street to one-way street (Hakkert and Mahalel 1978, 69-79).

Sayed et al. (1997) showed that crashes must be grouped into one or more combination of the three highway system components comprising of the driver, vehicle, and the road. This system would result in identification of truly hazardous locations since the locations are those at which treatments could improve safety. The modified black spot identification method requires a location to exhibit significant correctable crashes to be identified as a black-spot. The modified system results in an identification of fewer high crash locations since the crashes considered are the ones that could have been avoided through corrections. The ranking of the identified locations differ from the traditional method for the same reason.

Thus, crash analyses become one of the important steps to design appropriate countermeasures in order to improve safety. Many tools have
been developed by researchers to assist in the process of crash analyses. Some of these tools are explained next.

2.2 GIS-based crash analyses tools

Although GIS have found its applications in the field of crash data, its use has been limited. Computerized tools are used in number of states in the US which combines the road inventory data and traffic operations data. The addition of GIS offers spatial referencing capabilities and graphical displays. Researchers at the North Carolina Center for Geographic Information and Analysis have developed a computerized crash referencing and analysis system using GIS. Crash data from eight US states including California, Illinois, Maine, Michigan, Minnesota, North Carolina, Utah and Washington were used in the analysis tool depending on the quality, range of available data and the ability to merge data from various files. The analysis tool provides users with functions needed to edit tabular and spatial crash and roadway data and perform crash analysis. The system is designed with file/report management, crash location editing and data analysis. Management tools allows user to import and export data file. The editing tools helps user to position a crash at the correct location. In addition the system allows user to view crash reports and collision diagrams. The crash analysis tools allow crash analysis based on crash location divided into five programs: At intersections, along roadway segments, clustered around
specific roadway feature, within a defined corridor. Various crash factors can be combined in each program to generate user specific results. The system is currently used by the FHWA in addition to other contractors and researchers to study highway safety issues and evaluate the effectiveness of accident countermeasures.

Spring, G.S. (1992) describes the application of GIS in the traffic control inventories management programs in North Carolina. The author indicates that the previously used system provided poor access to poor quality data. The paper describes the work in progress aimed at examining the use of GIS for the purpose. Small computer technologies and guidelines that may be used during the selection of hardware and software specifically for those systems designed for the city department of transportation are described. According to the author, a more cost effective, safer and more efficient highway systems can more readily provided for the community by providing better access to important traffic facilities data. This can be achieved by improving the quality of the data and by integrating other related data (Spring 1993, 1-6).

GIS based crash data analysis may influence the traffic safety in the field on engineering, enforcement, education and emergency response (Roche 2000, 85-94). GIS provides the ability to perform macroscopic analysis without getting into specific details. It allows microscopic analysis to evaluate crashes at selected regions. The use of GIS in the field of transportation safety has
resulted in reduced time and effort. One important application of GIS is to find high crash locations. One of the drawbacks of identifying locations with high crash frequencies is that the traffic volume is not accounted for. However, this problem can be solved by considering crash rate instead of crash frequency. GIS applications provide the ability to perform various queries on isolated groups of data. Although number of tools provide with the ability to sort data in a tabular form, the importance of GIS lies in the field of spatial display.

Researchers at the Center for Transportation Research and Education, Iowa State University, have developed a GIS-based Accident Location and Analysis System (GIS-ALAS). The system allows users to generate accident statistics, identify crashes based on various factors. The GIS-ALAS system designed to overcome the drawbacks of a previously developed crash analysis system, PC-based accident location and analysis system (PC-ALAS). The PC-ALAS involved identification of location “node numbers” from cumbersome node tables or paper/CAD maps. The system also lacked the facility of spatial display. Thus, the user created query results can be viewed in tabular format as well as in graphical format. The GIS-ALAS was developed as two products: the Explore ALAS, which includes a free GIS viewing tool and an extensive database of crash locations and their characteristics, and the ArcVIEW-ALAS, which allows customization using a dedicated programming language.
Both the programs were designed to use the same database in order to maintain uniformity (Souleyrette et al. April 1998).

A cost-effective, user friendly GIS-based safety analysis tool is developed by researchers at the Florida State University (Sando et al. 2007). The tool is designed specially for law enforcement officers in Florida. It can be used to create crash shapefiles using two location methods: GPS Coordinates, Street Information. The tool can be used to perform numerous crash analyses and create maps by performing queries on the Traffic Criminal Software database. It can be used to identify high crash locations and to design appropriate countermeasures. One important feature of GIS that makes it different from other program used in the field of traffic safety is the ability to perform spatial inquiry. The researchers indicate that the increasing influence and use of GIS can be attributed to its ability to support the process of decision making.

Researchers at University of Nevada, Las Vegas have developed automated computerized tools to identify pedestrian high crash locations (Krishna Kumar Kannimangalam 2004; Uddaraju 2006). These tool help identify high pedestrian crash location based on crash density and other crash factors. In addition, the tools assist the user with the selection of appropriate countermeasures in order to improve pedestrian safety. The tools provide a sequence of tasks to be followed before the selection of treatment. Another GIS-based tool developed assisted planners and engineers to identify
and understand mid-block pedestrian crashes (Cui 2000). The tool was used to evaluate the potential of spatial clustering techniques and nearest neighbor method to identify high mid-block pedestrian crash locations.

A multi-modal transportation planning tool (MTPT) is designed for the Georgia Department of Transportation (GDOT). The tool uses the available database to assist in the analysis of transportation requirements of rural areas. It can be used to identify potential implementation constraints and develop a prioritized project list based on mode. A GIS-based software as used to display results spatially. The tool can be used to evaluate six modes of transportation: local transit, intercity bus, commuter and passenger rail, aviation, bicycles and pedestrian and highway (Dixon et al. 2001, 275-283). The tool can be used to perform simple analyses like querying the available data to complex analyses including prioritization of project scenarios using iterative GIS decision support methods. The tool is currently being used to evaluate existing facilities and identify essential improvement projects.

A tool to manage traffic signals information and signalized intersection coordination was developed by the researchers at Georgia Institute of Technology (Sarasua 1994, 54-63). GIS was integrated with TRANSYT-7F for the purpose. The advantage of the tool was that it resulted in faster analysis since the GIS system provided automatic of data such as street distances and upstream traffic volume. The intersections to be managed can be directly selected from the GIS graphic display. The tool also assists in generating
link-node diagram. Signal data can be accessed by selecting the required intersection on the map display. In addition the tool helps select intersections with excessive delays, low level of service or high number of maintenance activities in a short amount of time.

2.3. Online data analysis

In general, computer networks and the internet have offered better interactivity and connectivity among diverse groups (Bapna and Gangopadhyay 2005, 1-12). GIS has been used to spatially display locations for quite some time. The development of an online crash database that provides users access to analyze crashes and then map results using GIS can provide safety engineers a better understanding of alternatives and help them design appropriate countermeasures to improve safety.

Integrated online databases help with improving organization of the data. Since the data are available on the internet, data sharing is made easier and less time consuming without duplication (http://gis2.esri.com/library, www.quickbase.com/p/features/overview.asp). The need to wait for data to be received from another source can be eliminated. All officials and companies deal with the same data. This helps minimize problems related to erroneous data. In addition to web databases, web-mapping also provides online viewing of maps that eliminates installation of mapping software on every desktop.

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The Indianapolis, Indiana, Department of Public Works used tabular databases without any graphical representation to track their projects. The most difficult task using this system was to ensure that conflicting projects were not scheduled in overlapping areas (for example, a road resurfacing project followed by a sewer maintenance that required the road surface to be removed.) One other challenge with that tabular database was the lag between the input time and the time the change would be reflected in the system. The department then developed a web based GIS tracking system to better manage their projects. The web-based system helped visually track the progress of the projects in a real-time environment and helped the city's public works staff members to locate, draw and edit projects.

The GIS system helped staff pull-up integrated maps within a small amount of time that provides a real-time look at the project area which in-turn improves planning and reduces the possibility of duplication, conflicts, and waste. The time lag could be eliminated with this approach and the project area could be modified in real-time to accommodate changes with short lead times. The staff members have the ability to pull mailing lists in a short period of time, from the database for construction notices. Another important feature of the system is that all the data are embedded in the browser during configuration. Thus, there is no need to pull data from various disparate sources. The system was made available to all city employees with internet access. With this system, the city has experienced an
increase in usage and return on investment for the data capture and system infrastructure. The city benefited from this system since no software needed to be purchased for each user (Jeff Albee, Brad Christensen 2006/2007).

In a research conducted by Smith et. al. (2005), an electronic citations application that could be used by the police to maintain information on a central server to preserve accuracy and improve efficiency was developed. Officers used laptops with cellular digital packet data cards, card insertion scanners and global positioning system (GPS) units to enter information for citations. The information with the GPS data was then transferred to a central repository through wireless connection for further analyses. In addition to the geographic information system (GIS) mapping technologies and the Critical Analysis and Reporting Environment (CARE) software, the electronic citation application helped officers to statistically analyze crash and citation locations. This system provided a better understanding of the problem areas. In addition it was found that the system resulted in reduced time to solve specific crimes (Smith et al. 2005, 477-479).

Bapna and Gangopadhyay [2005] designed a web-based GIS system that can provide online crash information and statistical information for commercial vehicle crashes for the state of Maryland. It was designed to display specific geographic locations, period and time of crash, crash severity and cost per crash and more. The number of crashes could be reduced by providing appropriate information to the enforcement personnel and
managers of road infrastructure. This information was provided by a five-tier architecture that acquires data from the database and displays the data required on the web according to user defined criteria. The system provides the user with options to map, drill deeper, print report and e-mail. Due to the involvement of a number of agencies, daily updates were not accommodated. Hence, sometimes the user may be aware of recent events than that is available on the system (Bapna and Gangopadhyay 2005, 1-12).

The Highway Safety Research Center (HSRC) of the University of North Carolina has developed a Crash Data Query Website (www.hsrc.unc.edu/crash/index.cfm). The website provides crash data for 4 years: 2001 through 2004. The website is designed to provide users access to general crash data and the ability to generate results based on various conditions using the query builder. The query builder helps create outputs of crash data based on crashes, vehicles or people. The crash data can be further categorized according to statewide, county, city, troop or division wise. Queries include the ability to classify crashes based on injury type, day, hour, road character, and weather conditions. The results are displayed in tabular format. The website does not provide the ability for spatial analysis.

The Federal Railroad Administration - Office of Safety Analysis has designed a website that provides online data related to railroad safety. (http://safetydata.fra.dot.gov/officeofsafety/Query/Default.asp). The website includes data through the years 1975-2007. The website provides users the
ability to view general crash data, build queries, view statistical information, download data, and generate reports. The website also offers users the ability to display trends for a maximum of three years. The query capabilities included requires the user to specify the type of crash and cause of crash. In addition, the website provides ability to choose statewide, county wise crash data. The results are generated in tabular format. The results table includes number of crashes in each year and their variation over the three year period.

The Highway Safety Research Group (HSRG) at Louisiana State University developed a website that provides crash statistics and reports. (http://lhsc.lsu.edu/default.asp). The website contains yearly traffic crash reports. The user can perform queries depending on a number of factors. Queries can be developed according to four categories that included the following attributes: location, vehicle, time, and people. Further, the query can be designed to include the type of crash. The query builder can be used to classify data on a yearly basis, vehicle type, day of crash, gender, etc. Once the query is run, the results are displayed in a tabular and in graphical format.

The website for Royal Society for Prevention of Accidents provides online counts for home and leisure crashes for the years 2000 through 2002 around the UK. (www.hassandlass.org.uk/query/index.htm). The user is provided with options to select the type of crash, type of injury, age, gender, place of crash to perform queries. Depending on the selection, the number of crashes
found based on the criteria is displayed in a tabular format for each year. The website for Center of Disease Control and Prevention provides Web-based Injury Statistics Query and Reporting System (WISQARS). The website provides the user an interactive database system that provides customized reports of injury-related data broadly classified into fatal and nonfatal injuries for the years 1981-1998 and for the years 1999-2004. The result of the user defined query is a table providing the number of injury/death, population total and an age adjusted rate. The data are obtained from National Center for Health Statistics (NCHS) and other sources. ([www.cdc.gov/ncipc/wisqars](http://www.cdc.gov/ncipc/wisqars))

The National Highway Traffic Safety Administration (NHTSA) has designed a web-based encyclopedia that provides online access to the Fatality Analysis and Reporting System (FARS) data analysis. The website provides general trends classified based on crashes, vehicles, people and states in addition to query building. ([www-fars.nhtsa.dot.gov](http://www-fars.nhtsa.dot.gov))

The Las Vegas Metropolitan Police Department's (LVMPD) community crime mapping website provides crime information about crimes for a maximum of 60 days depending on the most recent date for which data are available on the website for the LVMPD's jurisdiction. The website allows user to create queries based on crime type, location and time (number of days prior to the most recent date for which data is made available). The user can generate results for crashes by selecting "Accidents" as crime type. Crashes
can be queried by providing either address of the location, street names or search distance. The user is then prompted to select the time duration. The results for the user defined are displayed on the map with highlighted points indicating crash locations. Using the identify tool, the user can select particular crime of intersect. The website will then display the attributes of the selected crime(s) in a tabular form. If more than one crime is displayed at the same location, then the attributes will be provided for all the crimes. As stated earlier, the attributes of the crash includes crime type which is "accident" for all traffic crashes, date, time and location. The report generated includes the summary of all the crashes identified based on the user defined query criteria. (www.lvmpd.com/crimeviewcommunity/)

A system to extract different GIS datasets from online mapping systems was developed by researchers at the Oklahoma State University. The system was developed integrating ArcIMS with C#.Net language. ArcIMS is software program that provides dynamic maps, GIS data and services via the Web. The website developed provides interactive, internet-based map service for the analysis, data capture, and route-tracing functions that are applicable to transportation systems in addition to the ability to download required data (Chudiwale 2005).
CHAPTER 3

SYSTEM ARCHITECTURE AND DESIGN

Transportation safety analyses and improvements deal with large quantities of data that come from various sources. The integration and analyses of these data need special considerations. The data associated with traffic safety are used by the employees of public sector organizations such as governmental agencies, city public works etc., private sector and also the general public. These vast amounts of data are helpful in understanding the crash history, and the reasons associated with the occurrence of crashes at different locations. Maintenance and data usage call for the proper design of the databases, and analysis tools, which in turn require knowledge about the users and their needs.

Transportation engineers and safety analysts use crash data as one of the important keys for safety analyses. Crash data can also be used to identify high risk locations and study the contributing factors that led to the crashes at these high risk locations. The results of these analyses can be then used to allocate resources in order to improve the safety at these locations. In addition to the identification of high crash locations and the number of crashes, it is also useful to map them for spatial analyses to improve the
understanding of these data.

An interactive computerized tool is developed in this research that would assist users to expedite the process of crash analyses. In addition, an application is developed to create a signalized intersection database that would include key intersection related information. Further, another tool, similar to the crash analysis tool is developed in order to facilitate analyses of signalized intersections. These two analysis tools are then integrated. This chapter provides details of the tools developed. The following aspects are considered during the design process and are explained in detail further.

1. Functional needs
2. Data types, sources and collection techniques
3. Analytical framework
4. Software and hardware requirements, and
5. System outputs

3.1. Functional Needs

As previously stated, transportation safety is of interest to a broad range of constituents including the general public, elected officials, public administrators, advocacy groups, and practitioners. The Analysis of crash data is an important element in understanding and improving safety. Transportation safety engineers require information about the number of crashes, their spatial and temporal distribution, as well as their causal factors to develop appropriate countermeasures. Crash databases are

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typically maintained by state Departments of Transportation (DOTs) or local agencies such as Police Departments. These databases typically include many details about the crashes and their causal factors. These databases are very large in size since individual crash records contain numerous data elements and because there are thousands of records for each year. Managing these databases is critically important to support safety analyses.

The analyses that can be performed depend on data availability and the level of details included in the database. Macro level analyses and micro level analyses are mainly two kinds of data evaluations that can be performed for transportation safety. Micro level analyses involve examination specific to small areas, such as at individual intersections. On the other hand, macro analyses include larger spatial extents and might include a number of links, nodes and areas. In addition to spatial analysis, transportation safety analyses typically include studies over a period of time.

It is important for all users to use a consistent and preferably a common, database in order to maintain uniformity and minimize confusion. Thus, it is advantageous to provide accessibility to the same data to all users who need such information. This will help with the timely availability of data and avoid differences in the data used, improve productivity, and minimize delays resulting from waiting for the necessary data. As mentioned earlier, displaying data spatially helps with understanding the information and for scale related issues. In addition, it should also be remembered that the
software and hardware components used for the design should be easily available to all those concerned. The development of a crash analyses system should address the aforementioned considerations. The development of the system is discussed next.

3.2. Data types, sources, and collection techniques

System design includes identification of the data required, their formats and the analysis to be performed on the data. Also, the format required to present the results must be identified before the development of the analysis tool. The data types required, their availability and their sources are discussed in this section.

3.2.1 Data types and sources

Depending of the availability and need, data can be classified into four major types: desired data, existing data, obtainable data, and surrogate data. The data required for the application development is termed as desired data. Existing data include data that are readily available from any data source that could be used. Obtainable data are those that can be acquired although not readily available. Surrogate data are those that might be used at situations where existing, obtainable or surrogate data are not available.

In this research, crash data obtained from the Las Vegas Metropolitan Police Department (LVMPD) were used for the development of the crash data analysis tool. The crash database obtained included details of crashes for the
The time period October 2003 through May 2006 for the Las Vegas area including the City of Las Vegas, City of North Las Vegas and unincorporated parts of Clark County. Figure 3.1 shows the map of Nevada and the location of Clark County. The database includes crash attributes spread over seven tables. The list of crash attributes tables are shown in Table 3.1. The data were geocoded for spatial display using the Crossroads Software (http://www.crossroadssoftware.com/). The street center line data available from the Clark County GIS Management Office (GISMO) were included for spatial understanding of the crash locations and their distribution (http://gisgate.co.clark.nv.us/gismo/gismo.htm).
Table 3.1 Crash Database Tables obtained from LVMPD

<table>
<thead>
<tr>
<th>No.</th>
<th>Name of Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Collision</td>
</tr>
<tr>
<td>2</td>
<td>Condition</td>
</tr>
<tr>
<td>3</td>
<td>Location</td>
</tr>
<tr>
<td>4</td>
<td>Non Motorist</td>
</tr>
<tr>
<td>5</td>
<td>Occupant</td>
</tr>
<tr>
<td>6</td>
<td>Party</td>
</tr>
<tr>
<td>7</td>
<td>Vehicle</td>
</tr>
</tbody>
</table>

The data required for the signalized intersection analysis tool were not completely available. A part of the database was obtained from Stantec Consultants. This database included details about intersections which were signalized prior to July 2006. The intersection database consisted of 368 signalized intersections. In order to complete the database, an application was developed to collect details about the newly signalized intersections in the Las Vegas valley. Fifty five newly signalized or reconfigured intersections were identified that are currently maintained by the Clark County Department of Public Works. The data tables included in the signalized intersection database are listed in Table 3.2. The information collected is then used along with street center line data obtained from GISMO for spatial display.
Table 3.2 List of Tables used for Signalized Intersection Data Collection

<table>
<thead>
<tr>
<th>No.</th>
<th>Table Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Intersection</td>
</tr>
<tr>
<td>2</td>
<td>Intersection legs</td>
</tr>
<tr>
<td>3</td>
<td>Supports</td>
</tr>
<tr>
<td>4</td>
<td>Mast Arms</td>
</tr>
<tr>
<td>5</td>
<td>Beacons</td>
</tr>
<tr>
<td>6</td>
<td>Intersection Photos</td>
</tr>
</tbody>
</table>

The third application developed was called the signalized intersection analysis tool. This application tool was designed to identify intersections based on their unique IDs or by the names of the two streets forming the intersection. The signalized intersection data collected in addition to the data obtained from Stantec Consultants were then used for the analyses. The crash data analysis tool and the signalized intersection analysis tool were then integrated. Additional data required included the street centerline shapefiles that were downloaded from the Clark County GIS Management Office (GISMO).

3.2.2 Data Collection Techniques

Data collection techniques can be either location-based or non-location based. Data collection with the use of mobile mapping applications such as GIS, Geographic Positioning System (GPS), remote sensing, etc. can be classified as location based techniques since they require the data collection to include information about the spatial coordinates of the features. Non-location based data collection techniques include bar-coding, radio frequency
identification, vehicle data collection, etc. In this research, data collection was required for developing the signalized intersection database. For the intersection database development location based data collection technique was used. These technologies mainly included the GIS and the GPS technologies and are explained in detail.

GIS: A GIS can be defined as a collection of computer hardware, software, and geographic data used for capturing, managing, analyzing, and displaying data on a geographic reference (http://www.gis.com/whatisgis/). A GIS facilitates the development of maps to geographically display data, in addition to other available formats like database views and model views. GIS software programs typically include powerful tools that support the analyses of spatial data. The spatial coordinates of features are the key to integrating features and their attributes from disparate data sets. In general a GIS can be described as a computerized database management system used for applications involving features with spatial distribution.

GPS: A GPS utilizes a constellation of satellites to determine the current time and location in terms of longitude, latitude, and altitude based on the observations of signals transmitted from the satellites (http://www.gps.gov/). The system requires signals from a minimum of 4 satellites to accurately determine the location of a feature. GPS have been widely used for applications involving geographic positioning since the location determined is
not influenced by weather, and thus can be obtained with a high degree of consistency and accuracy,

ArcPAD: ArcPAD is software for mobile GIS and field mapping applications that uses handheld and mobile devices (http://www.esri.com/software/arcgis/arcpad/index.html). ArcPAD also provides users the ability to capture, analyze, and display geographic information, without the use of paper map books. ArcPAD provides field personnel database access, mapping, GIS, and GPS integration capabilities via the handheld devices. Data collection with ArcPad is fast, easy, and significantly improved with immediate data validation and availability.

3.3. Analytical Framework

This section describes the development of the application tools. This section is divided into four sub-sections. First, the framework for the development of the crash data analyses application will be described followed by the framework for the signalized intersection data collection tool. Then, the signalized intersection analysis tool will be described. Lastly the Empirical Bayes methodology for statistical analysis will be presented.

3.3.1 Crash Data Analysis Tool Development

The crash data analysis tool was developed using Visual Basic.Net Software. The structure of the crash database is illustrated in Figure 3.2. The database consists of eight primary factors that may be used in the analyses.
Each of these factors in turn has various options. For simple analyses, queries may only need to evaluate a single factor. More complicated queries would require combining individual factors. Other types of analyses may be based on specific intersections. This would require identifying intersections based on the names of cross streets. In addition to these predefined queries, it would be useful to permit the user to define queries based on fields in the crash record. The tool provides the users to select from four options as shown in Figure 3.3.
Figure 3.3 Structure of the Crash Data Analysis tool
Analyses of the crash data requires the user to select one of the options shown in Figure 3.2. Each of these options independently queries the crash database after leading the user through a more specific criteria selection process. Once the factor to be included in the query is chosen, the user is provided with options to choose crash database based on the year, and the format to present the results of the query. Results can be viewed in two formats: a table or a map. Results in the tabular format can be further exported to an Excel spreadsheet in order to provide for additional analyses and print options. The crashes identified based on the query factors are displayed in map format with the help of ArcIMS. Currently, the map format
can be accessed from computers connected to the Clark County intranet network.

The map display uses the street centerline shapefile, which is obtained from GISMO, in a line format, and a crash shapefile, which is created from the database obtained from the LVMPD, in a point format. The query factors and the database need to be selected by the user. However, in user defined query option, the user can define the time period. Depending on the time period selected by the user, multiple databases are queried at the same time. The map option for displaying results is provided for single factor query, multiple factor query and for query using street names. For the map display, all the crashes in the selected database will be displayed with the crashes selected by the query shown as highlighted points. Since the user defined query option provides the user with choices to select multiple databases for the analyses, the result format in the form of a map could not be developed for this option using the ArcIMS.

The tabular format for results has nine columns: crash number, collision date, collision time, street 1 name, street 2 name, crash type, crash severity, location specifying if the crash occurred at an intersection or not. If not at an intersection, the ninth column provides the distance and direction from the closest intersection. Each of the query options is described in detail in following sections.
3.3.1.1 Single Factor Query

The single factor query option provides the user with eight selection criteria as listed in Table 3.3. These options are further divided into a number of subsequent choices and are explained in detail later. If the option chosen by the user is a single factor query, then, only one factor will be included for querying the crash database. Thus it cannot be combined with any other factors. Fatal crashes are one example of a single factor query criteria under the severity type. Similarly, crashes that occurred at intersections are considered as single factor query choice under the location criterion.

Table 3.3 Single Factor Query Criteria

<table>
<thead>
<tr>
<th>No.</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type of crash</td>
</tr>
<tr>
<td>2</td>
<td>Day of week</td>
</tr>
<tr>
<td>3</td>
<td>Time of day</td>
</tr>
<tr>
<td>4</td>
<td>Severity</td>
</tr>
<tr>
<td>5</td>
<td>Crash Location</td>
</tr>
<tr>
<td>6</td>
<td>Number of Vehicles</td>
</tr>
<tr>
<td>7</td>
<td>Roadway Classification</td>
</tr>
<tr>
<td>8</td>
<td>Contributing factors</td>
</tr>
</tbody>
</table>

1. Type of crash

Motor vehicle crashes may be categorized into several types based on the nature of the interaction between vehicles involved in the crash. Analyses of the types of crash with respect to roadway, traffic control and environment...
related factors are essential part of road safety assessment. Crashes occur due to number of causal factors. For example, intersection signalization might be an important factor for rear end collisions, speed might be a key factor for angle collision, driver factors such as inattentive driving might be important in explaining single vehicle crashes. Identifying the main contributing factors help develop and deploy appropriate countermeasures. The crash database obtained considered nine categories under the crash type. These are listed in Table 3.4. All nine options were provided in the crash analyses application tool.

<table>
<thead>
<tr>
<th>No.</th>
<th>Crash type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Head-on</td>
</tr>
<tr>
<td>2</td>
<td>Rear end</td>
</tr>
<tr>
<td>3</td>
<td>Backing</td>
</tr>
<tr>
<td>4</td>
<td>Angle</td>
</tr>
<tr>
<td>5</td>
<td>Rear to rear</td>
</tr>
<tr>
<td>6</td>
<td>Sideswipe meeting</td>
</tr>
<tr>
<td>7</td>
<td>Sideswipe overtaking</td>
</tr>
<tr>
<td>8</td>
<td>Non collision</td>
</tr>
<tr>
<td>9</td>
<td>Unknown crash type</td>
</tr>
</tbody>
</table>

2. Day of the week

Typically, the traffic volumes on roadways in urban areas vary across days of the week, with marked differences often being noted between weekdays and weekends. In order to provide for such analyses, options to select days are provided under the “day of week” query criterion.
3. Time of the day

Crash occurrence and their contributing factors vary differently at different times of the day. In order to provide for better understanding and query options, collision time was divided into four groups of six hour periods as listed in Table 3.5.

Table 3.5 Choices for Time of Day

<table>
<thead>
<tr>
<th>No.</th>
<th>Time periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12:00 AM to 6:00 AM</td>
</tr>
<tr>
<td>2</td>
<td>6:00 AM to 12:00 PM</td>
</tr>
<tr>
<td>3</td>
<td>12:00 PM to 6:00 PM</td>
</tr>
<tr>
<td>4</td>
<td>6:00 PM to 12:00 AM</td>
</tr>
</tbody>
</table>

4. Severity

Transportation safety engineers work to improve safety by reducing the number of collisions and/or by reducing the severity of crashes. Thus, it is important to identify those locations at which collisions involve fatalities or high severity crashes. Also, in order to perform cost-benefit analyses of safety improvements, it is necessary to identify the number of crashes and their severity. Typically, crashes are recorded in safety databases under one of the following three categories: fatal, injury, or property damage only. Consequently three choices are provided in the application developed.
5. Crash Location

Two categories are made under the crash location criterion: at intersection and non-intersection. An option to build query based on these two options are provided in the developed tool.

6. Number of Vehicles

Analyzing crashes based on the number of vehicles helps address safety issues related to driver, roadway and traffic control characteristics. For example, if a location or stretch of roadway experiences a 'high' frequency of single vehicle crashes, identifying the location would help to get to roadway design factors that may be contributing to this situation. Five options are provided in the application developed. These are: single-vehicle crashes, crashes involving two vehicles, three vehicles, four vehicles, and multi-vehicle crashes (crashes involving more than four vehicles).

7. Roadway Classification

Certain crash types could be influenced by the roadway configuration. For example, head-on collisions might be greater on two-way undivided roadway when compared to two-way divided road type. Also, the presence of median barriers on divided roadways possibly provides additional safety and minimizes such crashes. Hence, it is useful to analyze crashes based on roadway configuration. Five options are provided in the tool developed as listed in Table 3.6.
Table 3.6. Choices for Roadway Configuration

<table>
<thead>
<tr>
<th>No.</th>
<th>Roadway configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Two-way undivided</td>
</tr>
<tr>
<td>2</td>
<td>Two-way divided, unprotected</td>
</tr>
<tr>
<td>3</td>
<td>Two-way divided, median</td>
</tr>
<tr>
<td>4</td>
<td>One-way</td>
</tr>
<tr>
<td>5</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

8. Contributing factors

Contributing factors are recorded in crash reports by the investigating law enforcement officer to identify the cause(s) of the crash. The identification of proper countermeasures calls for a recognition of contributing factors. These factors can be either driver related or vehicle related factors. In the application tool developed, six choices are provided as shown in Table 3.7. These six factors were identified, based on a ranking of the contributing factors, for each of the available crash databases.

Table 3.7 Contributing Factors

<table>
<thead>
<tr>
<th>No.</th>
<th>Contributing Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Apparently normal</td>
</tr>
<tr>
<td>2</td>
<td>Failure to yield right of way</td>
</tr>
<tr>
<td>3</td>
<td>Failure to maintain lane</td>
</tr>
<tr>
<td>4</td>
<td>Driver inattentive/distracted</td>
</tr>
<tr>
<td>5</td>
<td>Hit and run</td>
</tr>
<tr>
<td>6</td>
<td>Following too closely</td>
</tr>
</tbody>
</table>
3.3.1.2 Multi factor query

The single factor query allows the user the choice of only one factor at a time. However, often it becomes necessary to identify crashes based on multiple factors. An example of multiple factor queries is the identification of head-on crashes that resulted in fatalities, that occurred on Sundays between 6:00 PM and 12:00 AM. The single factor query is not designed to support such query choices. In the multiple factor query option, all the choices provided for single factor query can be combined as shown in Figure 3.4. The user is provided with the option to select any number of factors to query the crash database.

As stated previously, the multiple factor query option allows the user to choose query factors from eight main categories: type of crash, day of the week, time of the day, severity, number of vehicles involved in the crash, roadway configuration, and contributing factors. The options under the primary categories are connected through an "or" loop and the choices under the different primary categories are connected through an "and" loop. Thus, if the user selects "head-on collision" and "rear-end collision" under "type of crash" and "fatal" under the "severity" choice, the query will select crashes due to head-on collision or rear-end collision. Both these types of crashes are then combined with severity type, "fatal". However, the user can select only one database based on year. The default format to display results is set to "table". The user can change the format of results to "map," if needed.

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Figure 3.5 Multiple Query Choices
3.3.1.3 Query using street names

This option provides the user the ability to select a particular street or intersection for analyzing the crash history. In order to query the crash database, the user can either select one street name, or an intersection, by selecting the names of two streets that intersect. If the user selects only one street name, then the application would generate a list of crashes that occurred on the selected street without regard to the cross streets. On the other hand, if the user selects two streets that intersect, crashes that occurred at that intersection will be selected, in addition to the non-intersection crashes that occurred around the selected intersection which are associated with the street names selected by the user. The user also needs to specify the database and format in which the results will be presented. This part of the application is illustrated in Figure 3.5.
3.3.1.4 User defined query

The user defined query option provides the user with the ability to choose factors to be included in the query, based on specific needs. The main difference between the multiple factor query and the user defined query is that the latter allows the user to select the “from” and the “to” date for the query. Only those crashes that occurred during the selected period will be displayed. Although a number of factors can be combined in the multiple factor query option, the user can only select one database at a time based on the year. However, in the user defined query choice, multiple crash databases can be queried at once. Figure 3.6 shows the user defined query form.
3.3.2 Signalized intersection data collection tool

The analysis tool was developed using the Environmental Systems Research Institute’s (ESRI) ArcPAD Application Builder. The intersection data collection was partially completed by Stantec Consultants. They developed a database for 368 signalized intersections. However, this intersection database did not contain details about the newly signalized intersections in Clark County. In order to obtain the same, the ArcPAD Application Builder is used to develop a tool to collect information about the
newly signalized or re-configured intersections. The procedure followed to develop the data collection tool is described next.

The data collection tool used by Stantec Consultants was obtained in order to maintain similar database structure. The tool included intersection and signal supports shapefiles. The shapefiles contained the details of the 368 intersections as collected by Stantec Consultants. The database was then modified to fit the needs of the Clark County Public Works Department by omitting repetitive attribute columns. The newly identified intersections were then added to the existing shapefile using ArcPAD. The supports form as shown in Figure 3.6 was built using the VB interface in the ArcPAD application builder. The application is designed such that when the user enters the attributes of the intersection/supports, the details are directly added in the corresponding databases. The application is developed to collect only intersection and support attributes. The other details related to the intersection are collected using the traditional paper and pen method and subsequently entered in the lab into the database later.
The intersection data collected included information about the following items, each of which is discussed in detail.

1. Intersection
2. Signal supports, Controller cabinets and Service pedestals
3. Intersection approach / Leg related data
4. Mast arms
5. Beacons/Signal heads
6. Intersection approach / Leg photos
1. Intersection

The intersection attributes collected are listed in Table 3.8. The intersections are identified with a unique three digit (numeric) identification number. All the fifty five new or re-configured intersections identified by Clark County were inventoried. These intersections are assigned numbers starting with 501.

Table 3.8 Intersection table attributes

<table>
<thead>
<tr>
<th>No.</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Intersection Id</td>
</tr>
<tr>
<td>2</td>
<td>Name of cross street 1</td>
</tr>
<tr>
<td>3</td>
<td>Name of cross street 2</td>
</tr>
<tr>
<td>4</td>
<td>Date</td>
</tr>
<tr>
<td>5</td>
<td>Comment</td>
</tr>
<tr>
<td>6</td>
<td>Creator</td>
</tr>
</tbody>
</table>

2. Signal Support

The signal support table includes twelve attributes as listed in Table 3.9. The signal ID is connected with the intersection ID, which is the unique identification number assigned to that particular intersection, as listed in the intersection table. In order to identify the supports, a simple rule is followed. At each intersection, the support at the northeast corner is numbered first as shown in Figure 3.8. All the other supports are identified with respect to the support in the northeast corner and numbered consecutively in the clockwise direction. The support ID contained the intersection ID followed by the
support number (XXX-YY). This unique support ID is calculated during post processing of the data in the lab. The address of the location of the control cabinet/service pedestal, usually mentioned on the service pedestal is recorded during data collection under the serial ID field. The support pole type is determined primarily by the size of the bolt. Table 3.9 summarizes the different pole types with their respective bolt sizes, heights, number of luminaires, and other comments. Figure 3.9 illustrates some of the pole types.

Figure 3.9 Support nomenclature
Table 3.9 Signal support attributes

<table>
<thead>
<tr>
<th>No.</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Intersection Id</td>
</tr>
<tr>
<td>2</td>
<td>Unique support Id</td>
</tr>
<tr>
<td>3</td>
<td>Date</td>
</tr>
<tr>
<td>4</td>
<td>Pole type</td>
</tr>
<tr>
<td>5</td>
<td>Base</td>
</tr>
<tr>
<td>6</td>
<td>Location</td>
</tr>
<tr>
<td>7</td>
<td>Luminaire</td>
</tr>
<tr>
<td>8</td>
<td>Structure Type</td>
</tr>
<tr>
<td>9</td>
<td>Bolt size</td>
</tr>
<tr>
<td>10</td>
<td>Comment</td>
</tr>
<tr>
<td>11</td>
<td>Flag</td>
</tr>
</tbody>
</table>

(a) Pole type: XX  
(b) Pole type: SP  
(c) Pole type: SL

Figure 3.10 Support pole types
The base type is determined from the type of support pole. Tables 3.10 and 3.11 show the various pole types and base types, respectively. The location attribute column is filled with one of the options chosen from Table 3.12. The luminaire field is used to record the number of luminaires (lights) on that particular support. The structure type is classified into three categories as shown in Table 3.13.

Table 3.10 Pole type attributes

<table>
<thead>
<tr>
<th>No.</th>
<th>Pole</th>
<th>Light</th>
<th>Bolt(inch)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1A</td>
<td>No</td>
<td>0.75</td>
<td>10' height signal stand</td>
</tr>
<tr>
<td>2</td>
<td>1B</td>
<td>No</td>
<td>0.75</td>
<td>7' height signal stand</td>
</tr>
<tr>
<td>3</td>
<td>BR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SL</td>
<td>Street light</td>
<td>1.125-1.25</td>
<td>street light</td>
</tr>
<tr>
<td>5</td>
<td>SP</td>
<td>Special pole</td>
<td>2.25</td>
<td>super shaft custom</td>
</tr>
<tr>
<td>6</td>
<td>XX-20</td>
<td>No</td>
<td>1.75</td>
<td>20' height signal pole (&lt;= 45' mast arms)</td>
</tr>
<tr>
<td>7</td>
<td>XX-30</td>
<td>Yes</td>
<td>1.75</td>
<td>30' height signal &amp; luminaire pole (&lt;= 45' mast arms)</td>
</tr>
<tr>
<td>8</td>
<td>XxA-20</td>
<td>No</td>
<td>2</td>
<td>20' height signal pole (50' - 60' mast arms)</td>
</tr>
<tr>
<td>9</td>
<td>XxA-30</td>
<td>Yes</td>
<td>2</td>
<td>30' height signal &amp; luminaire pole (50' - 60' mast arms)</td>
</tr>
<tr>
<td>10</td>
<td>XXB-30</td>
<td></td>
<td>2.25</td>
<td>30' height signal &amp; luminaire pole (65' - 85' mast arms)</td>
</tr>
</tbody>
</table>
Table 3.11 Support base type

<table>
<thead>
<tr>
<th>No.</th>
<th>Base</th>
<th>Pole type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C</td>
<td>1A, 1B</td>
</tr>
<tr>
<td>2</td>
<td>E</td>
<td>Street light pole</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>School flasher pole</td>
</tr>
<tr>
<td>4</td>
<td>H</td>
<td>XX·30</td>
</tr>
<tr>
<td>5</td>
<td>L</td>
<td>XX·A</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>XX·B</td>
</tr>
<tr>
<td>7</td>
<td>NA</td>
<td>Not applicable</td>
</tr>
<tr>
<td>8</td>
<td>PD</td>
<td>controller cabinet or service pedestal</td>
</tr>
<tr>
<td>9</td>
<td>SP</td>
<td>special pole (ex. DI/Valley View)</td>
</tr>
</tbody>
</table>

Table 3.12 Location of signal support

<table>
<thead>
<tr>
<th>No.</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MC</td>
<td>Median at center of intersection</td>
</tr>
<tr>
<td>2</td>
<td>MCE</td>
<td>Median at center of intersection toward east</td>
</tr>
<tr>
<td>3</td>
<td>MCN</td>
<td>Median at center of intersection toward north</td>
</tr>
<tr>
<td>4</td>
<td>MCS</td>
<td>Median at center of intersection toward south</td>
</tr>
<tr>
<td>5</td>
<td>MCW</td>
<td>Median at center of intersection toward west</td>
</tr>
<tr>
<td>6</td>
<td>ME</td>
<td>Median at east leg of intersection</td>
</tr>
<tr>
<td>7</td>
<td>MN</td>
<td>Median at north leg of intersection</td>
</tr>
<tr>
<td>8</td>
<td>MS</td>
<td>Median at south leg of intersection</td>
</tr>
<tr>
<td>9</td>
<td>MW</td>
<td>Median at west leg of intersection</td>
</tr>
<tr>
<td>10</td>
<td>NE</td>
<td>Northeast corner</td>
</tr>
<tr>
<td>11</td>
<td>NW</td>
<td>Northwest corner</td>
</tr>
<tr>
<td>12</td>
<td>SE</td>
<td>Southeast corner</td>
</tr>
<tr>
<td>13</td>
<td>SW</td>
<td>Southwest corner</td>
</tr>
</tbody>
</table>

Table 3.13 Support types

<table>
<thead>
<tr>
<th>No.</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CNTL</td>
<td>Controller cabinet</td>
</tr>
<tr>
<td>2</td>
<td>SERVP</td>
<td>Service pedestal</td>
</tr>
<tr>
<td>3</td>
<td>SUPP</td>
<td>Signal support</td>
</tr>
</tbody>
</table>
The size of the bolt at the base of the support is determined by physically lifting the sleeve and manually measuring the bolt diameter. Other additional comments are also recorded in the database, when applicable. The flag column consists of either TRC or Stantec, to identify the organization that collected the data.

3. Intersection Leg

The various attributes collected as part of the intersection leg details are listed in Table 3.14. A unique identification number is assigned to each approach of the intersection starting with the intersection ID. Intersection legs are numbered starting with the north leg as 1 and continued clockwise, (East-2, South-3 and West-4) as shown in Figure 3.10. The direction of the leg is also recorded. In addition, the presence/absence of sidewalks is documented. The width of the approach is measured as the distance between the straight curb edges of that particular approach. The stop-to-curb distance is measured as the distance between the straight edge of that approach and the stop bar of the side approach as shown in Figure 3.10.

Table 3.14 Intersection Leg Attributes

<table>
<thead>
<tr>
<th>No.</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Intersection Id</td>
</tr>
<tr>
<td>2</td>
<td>Unique Leg Id</td>
</tr>
<tr>
<td>3</td>
<td>Direction</td>
</tr>
<tr>
<td>4</td>
<td>Pedestrian Crosswalk</td>
</tr>
<tr>
<td>5</td>
<td>Date</td>
</tr>
<tr>
<td>6</td>
<td>Width of approach</td>
</tr>
<tr>
<td>7</td>
<td>Stop bar to Curb distance (ft)</td>
</tr>
</tbody>
</table>
4. Mast Arm

The mast arms are numbered relative to the supports. If the support is connected to more than one mast arms then, the all those mast arms are numbered consecutively. The mast arms are assigned with unique ID (XXX-YY-ZZ) starting with the intersection ID (XXX) followed by the support number (YY) and then the mast arm number (ZZ) as illustrated in Figure 3.11. Other attributes collected for mast arms are listed in Table 3.15. At each intersection, the unique support ID is used as previously mentioned. The length of the mast arm is measured from the point at which the arm connects with the support to the end of the mast arm.
Table 3.15 Mast arm attributes

<table>
<thead>
<tr>
<th>No.</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Intersection ID</td>
</tr>
<tr>
<td>2</td>
<td>Unique mast arm ID</td>
</tr>
<tr>
<td>3</td>
<td>Unique support ID</td>
</tr>
<tr>
<td>4</td>
<td>Arm length</td>
</tr>
<tr>
<td>5</td>
<td>Date</td>
</tr>
</tbody>
</table>

5. Beacon (Signal head)

The different beacon attributes collected are listed in Table 3.16. The beacons are numbered relative to the supports and the mast arms. If the beacon is directly on the support, then the mast arm ID is 00. The beacons are assigned with unique ID (XXX-YY-ZZ-AA) starting with the intersection ID (XXX) followed by the support number (YY), the mast number (ZZ) and ending with the beacon number (AA) as illustrated in Figure 3.12. The beacon
numbers are assigned consecutively starting from the base of the support to
to the end of the mast arm. Beacon heads are classified into seven types as
listed in Table 3.16. The divisions are based on number of signal indicators
and type: solid or arrows. The different signal heads are shown in Figure
3.13. The direction field contains the direction of the vehicular traffic that
particular beacon serves.

![Diagram of Intersection ID 525 with labels: Mast arms, Mast arm #02, Support #02, Beacon ID "525-02-02-02"]

Figure 3.13 Signal head nomenclature

<table>
<thead>
<tr>
<th>No.</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Intersection Id</td>
</tr>
<tr>
<td>2</td>
<td>Support Id</td>
</tr>
<tr>
<td>3</td>
<td>Unique Mast Arm Id</td>
</tr>
<tr>
<td>4</td>
<td>Unique Beacon Id</td>
</tr>
<tr>
<td>5</td>
<td>Head Type</td>
</tr>
<tr>
<td>6</td>
<td>Direction</td>
</tr>
<tr>
<td>7</td>
<td>Date</td>
</tr>
</tbody>
</table>

Table 3.16 Beacon Attributes

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Table 3.17 Signal head types

<table>
<thead>
<tr>
<th>No.</th>
<th>Value</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2SA</td>
<td>2 section arrow</td>
</tr>
<tr>
<td>2</td>
<td>2SB</td>
<td>2 section solid</td>
</tr>
<tr>
<td>3</td>
<td>3SA</td>
<td>3 section arrow</td>
</tr>
<tr>
<td>4</td>
<td>3SB</td>
<td>3 section solid</td>
</tr>
<tr>
<td>5</td>
<td>4S</td>
<td>4 section</td>
</tr>
<tr>
<td>6</td>
<td>5S</td>
<td>5 section</td>
</tr>
<tr>
<td>7</td>
<td>PED</td>
<td>Pedestrian</td>
</tr>
</tbody>
</table>

Figure 3.14 Traffic signal heads
6. Intersection Photo

The intersection photo attributes are shown in Table 3.18. Intersection photos are provided with unique photo IDs. The directions in which the photos are taken are same as the approach direction and are named accordingly, as shown in Figure 3.14.

Table 3.18 Intersection photo attributes

<table>
<thead>
<tr>
<th>No.</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Intersection Id</td>
</tr>
<tr>
<td>2</td>
<td>Unique photo Id</td>
</tr>
<tr>
<td>3</td>
<td>Direction</td>
</tr>
<tr>
<td>4</td>
<td>Date</td>
</tr>
</tbody>
</table>

Figure 3.15 Photo nomenclature
3.3.3 Signalized intersection data analysis tool

Signalizing the intersection is one of the options described by the Manual on Uniform Traffic Control Devices (MUTCD) to improve safety by reducing the occurrence/severity of crashes. However, before an intersection is signalized, its crash history needs to be studied in addition to other factors. Further, the traffic signals at these intersections need to be improved according to changes in traffic volume and other related characteristics. These improvements might include changing left turning phases from permitted to protected and permitted phase. Also, the signal heads/beacons require regular replacement depending on their life spans. The signal heads are also modernized depending on the needs. The development of a database consisting of such details and a tool to perform the required queries to select records from the database can be of use at situations where the intersection operation needs to be analyzed and improved for safety.

The intersection analysis tool developed in this research permits the selection of records based on three criteria and the corresponding forms are shown in Figures 3.15, 3.16, and 3.17.

1. Intersection number
2. Names of the intersection cross streets
3. Multiple intersection attributes
Load Intersection ID by clicking the "Load Intersection ID" button. Select the required ID from the dropdown box. The selected ID is displayed in the Textbox beside the "Selected Intersection ID". Click "Next" to proceed.

Figure 3.16 Intersection selection by Intersection ID

Load street names using the "Load Names" button. Select required names from the drop-down box. Street 2 must intersect Sheet 1.

Figure 3.17 Intersection selection by cross street names

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Figure 3.18 Multiple attributes selection for intersection analyses
If the user selects one of the first two options, two tables are generated. The first table shows the intersection ID, street names, and information on who collected the data. The second table shows details of the intersection legs which include intersection ID, direction, width and, the presence/absence of pedestrian signals. An option is provided to display the intersection spatially using ArcIMS in map format. The intersection and corresponding support details are shown as points in the map view on a layer consisting of street center line shapefile. Further, the tool provides the user with the ability to generate details of the corresponding supports, mast arms, beacons and photos of the selected intersection. All these details can be further exported to an excel spreadsheet for additional review and analyses.

3.3.4 Integration of the data analysis tools

Two data analysis tools: the crash data analysis tool and the intersection analysis tool were developed in this research. These two applications had to be used independently for analyses purposes. In order to minimize the time needed to generate the required data from the two applications, the tools are integrated. The common fields between the two databases are the street names. The crash database consisted of street names expressed in different ways. For example: Flamingo Road is also recorded as Flamingo, and Flamingo Rd. In addition, number of errors were also found in the way the road names were spelled, such as Falmingo and Flamiingo. Thus, it was difficult to connect to the intersection database from the crash analysis tool.
On the other hand, the crash database was made accessible through the intersection data analysis tool by integrating the two analysis tools developed under the name of “Safety Study.”

After a particular intersection is selected based on intersection ID or its street names, the user is provided with an option to view intersection related attributes and a link to connect to the crash database. With the link option, the user can perform queries on crash database on yearly basis. The crash database can be analyzed based on all the eight selection criteria as described in the single factor query choice in the section 3.3.1.1. However, the resultant data are confined to crashes at the intersection selected in the intersection analysis application.

3.3.5 Toolbars developed for the applications

The application tools developed in this research help user to perform queries on crash database and signalized intersection database. A number of choices are provided in the application based on user requirements. The menu bar as shown in Figure 3.18 is developed to help user to navigate from one form to other. Each command is explained in detail further.

![Application menu bar](image)

Figure 3.19 Application menu bar
- **Home** The "Home" link helps user to navigate to the start of the analyses, where the option to start a query is provided. The user can then select crash analyses or the intersection analyses as needed.

- **Start a Query** Two choices are provided in the "Start a query" link: query crash database, and query intersection database. The two links are further linked to different query choices as shown in Figure 3.19. Each link opens the query factor selection page corresponding to the user selected query type.

![Option to query crash database](image)

![Option to query intersection database](image)

Figure 3.20 Toolbar for navigation

- **Help** The help link is designed to provide general information about using the application developed.

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• Close  This link is provided to end the application.

The results generated for the query selected by the user may include number of crash records presented in tabular form. A status bar was developed in help user navigate through the records displayed as shown in Figure 3.20. The |< and >| buttons moves the cursor to the first and the last record in the table, respectively. The < and > buttons moves the cursor to the previous and the next record, respectively depending on the currently selected record in the table. The status bar also displays the number of the current record in addition to the total number of records displayed in the table.

![Status bar](image)

Figure 3.21 Status bar

3.4. Software and hardware requirements

The crash data analysis tool can be used to query the crash database based on factors selected by the user. The output generated by the tool is a list of accident numbers that result from the queries identified based on the user selected factors. The results generated can be used for further analyses. The signalized intersection data collection tool is developed to create a database that includes details of intersection attributes. In order to help
perform such analyses using the database developed, a data analysis tool is
developed. Various hardware elements and software programs were used
during the development of these tools which are discussed next.

The software components used for developing the tools include Visual
Basic.Net, Microsoft Access, ArcIMS, ArcPad Application Builder, ArcGIS
and Microsoft Excel. The hardware components include Tablet PC, GPS
Handheld, GPS receiver and Olympus stylus 400 camera, measuring wheel.
The Tablet PC, GPS Handheld, and GPS receiver were used to collect GPS
data. The camera was used to collect pictures at the signalized intersections.
The measuring wheel was used for measuring the intersection details such as
the width of intersection legs, stop-to-curb distance and the length of mast
arms. The software programs used are discussed in details further.

Visual Basic.Net

Visual basic.Net is an object-oriented computer programming language
improved from Visual Basic. Visual Basic is an event driven programming
language developed from BASIC. Visual Basic is used to build graphical
client application interfaces with the help of buttons and forms. Visual
basic.Net requires the .Net framework to be installed for program execution
(www.microsoft.com).

Microsoft Access

Microsoft Access software known as Microsoft Office Access is a relational
database management tool from Microsoft. This software is used to manage
large amounts of data. This software is compatible with structured query languages (SQL) and thus can be used to perform queries and also develop small applications (www.microsoft.com). One important use of Access is that it facilitates for easy data sorting.

ArcIMS

Internet Mapping is a powerful tool that allows users to communicate and utilize common data by making data available on the internet/intranet. Internet mapping is used to convert dynamic/static spatial data into visually enabled web displays, provide spatial query capabilities and interactive displays. One such internet software is ESRI's Arc Internet Map Server (ArcIMS). The maps generated using ArcIMS are of two kinds: static images that allow panning and zooming. On the other hand, interactive maps include layers that can be turned on or off, additional options to perform queries on attributes are included. All the map related services are processed on the server where the data are stored in the form of shapefiles (www.esri.com/arcims).

ArcPad Application Builder

According to ESRI, ArcPAD application builder is a development framework used to build custom applications for mobile GIS. The various tasks that can be performed using the ArcPAD application builder include the following (www.esri.com/arcpad).

- Develop forms for data collection in the field with data integrity.
- Develop new toolbars with built-in and custom tools.
- Build applets for field specific applications.
- Build programs that interact with ArcPad software's internal objects.
- Develop extensions to support new file formats, GPS receivers, projections, etc.

ArcGIS

ArcGIS integrates three applications which include ArcMap, ArcCatalog, and ArcToolbox (www.esri.com/software/arcgis). Using these applications the user can create maps, perform queries, analyze spatial relations, edit feature shapes and attributes, and manage data. ArcMap is mainly used to create maps to visualize spatial data. ArcToolbox is used to define projection coordinates for the crash data obtained. ArcCatalog is used to convert the access database to shapefiles for use in ArcMap and ArcIMS

Microsoft Excel

Microsoft Excel is a program from Microsoft which allows users to easily store, organize and manipulate data in order to perform calculations, produce graphs and perform simple statistical analysis using data stored in rows and columns known as a spreadsheet. Microsoft Excel 2003 edition was used in the application developed in this research. The program required a computer with a memory of 128 MB or greater, 150MB of available hard disk space, CD-ROM or DVD-ROM with an operating system of windows XP or newer.
The queried results can be exported to Excel for further manipulations, analysis, and printing.

3.5. System outputs

This section describes the outputs generated by using the developed tools. The crash analysis tool provides the user with the ability to select from four options as described previously. The output generated is a list of accident numbers satisfying the criteria selected by the user. This list can be viewed in two formats: table or map. The table format provides the user an option to export the results to Microsoft Excel for further analyses. The map format permits the spatial display of the generated results using ArcIMS. Using ArcIMS options, the database can be further queried based on different criteria.

The output capabilities of the crash data analysis tool are illustrated in Figures 3.21 and 3.22 in table format and map format respectively. The total numbers of records in the table are displayed in the status bar. The summary section in the table includes the total number of records, the number of at-intersection crashes and the number of non intersection crashes. The table provides options to sort any data column in ascending or descending order. The query criteria are also displayed for user reference. The “Export to Excel” button allows user to export the results to an Excel spreadsheet for printing and further analyses.
The map format to display the results uses ArcIMS. The results are displayed as highlighted points overlaid on the street center line layer. ArcIMS allows the user to change query options or perform additional queries on the selected layer using the default buttons on the display page. The attributes that can be selected for querying are listed in a dropdown menu. Multiple queries can be built by concatenating different choices.

Figure 3.22 Query results in Table format
Figure 3.23 Query results in Map format
CHAPTER 4

CASE STUDY

As described in the methodology section, tools are developed in this research to facilitate crash data analysis, signalized intersection data collection and intersection data query. The crash analysis tool is used to analyze the crash databases obtained from the Las Vegas Metropolitan Police Department. The signalized intersection data collection tool is used to collect various attributes of the intersections. Data were collected at fifty five newly constructed or reconfigured intersections maintained by the Clark County Department of Public Works. The intersection analysis tool provides the user with options to perform queries on the intersection database. This chapter describes the application of the tools developed.

4.1 Crash Data Analysis tool

The crash data analysis tool provides the user with four query options: single factor query, multi factor query, query using street names and user defined query. Each choice leads the user through the selection of more specific query criteria before the results are generated. The four options are explained with examples in the following sections.
4.1.1. Single factor query

As the name indicates, using this query option the user can select only one factor to be included in the query. The single factor query option allows the user to perform queries based on eight choices. In order to illustrate the single factor query choice in the crash data analysis application, a query was performed to identify collisions involving fatalities during the year 2004. The step by step procedure for this is explained next.

In order to identify fatal crashes, the user needs to select “severity” under the single factor query option as shown in Figure 4.1. Once the user clicks the “next” button, the tool provides three options that are available under the “severity” choice as shown in Figure 4.2. The user needs to choose the required factor to be included in the query, which is “fatal” in this example, and proceed by clicking the “next” button. The tool then leads the user to select the available database based on the year. The user also needs to select the format to display the results. Figure 4.3 shows “2004” as the selected database and “table” as the format to display results. The user can use the “previous” button on the forms to change the initial query choice.
Figure 4.1 Single factor query option

Figure 4.2 Query factor selection interface
After selecting the crash feature, the database year and the format, the user then needs to click the “next” button to proceed. Before opening the next form, the application indicates to the user that the query is in progress with the message box as shown in Figure 4.4. Once the user clicks the “OK” button on the information message box, the results will be displayed based on the query choices and the format for result. Figures 4.5 and 4.6 shows the results in table and map format respectively. The map format output has pan and zoom capabilities.

The query results in the tabular form can be further exported to Microsoft Excel spreadsheet using the “Export to Excel” button as shown in Figure 4.5. The tabular format for results also provides a summary that lists the user defined query choice, number of records displayed, and number of collisions.
at intersections and away from intersections. The results are displayed in the map format using ArcIMS, which provides the user with additional query choices that can be selected from the attributes of the current active layer. In order to perform queries in the map format, the user needs to click “query” button on the left of the map display as shown in Figure 4.6.

![Figure 4.4 Information message box](image)

Figure 4.4 Information message box

![Figure 4.5 Results of the query, Severity: Fatal, Database year 2004](image)

Figure 4.5 Results of the query, Severity: Fatal, Database year 2004

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4.1.2. Multiple factor query

The multiple factor query choice gives the user an option to select more than one query factor. For example, consider the query in which the user needs to generate results that include collisions involving fatalities that occurred during weekends at intersections in the year 2006. Here, four query factors: severity (fatal), Day of Week (Sunday and Saturday), Location (intersection) and year (2006) need to be concatenated. The query options selected for the aforementioned condition is shown in Figure 4.7. According to the user's query condition, the checkboxes for 'fatal' under the 'severity' group, 'Sunday' and 'Saturday' under the 'day' group and 'Intersection' under
the 'location' group are checked. In addition, the 2006 year database and
'table' under the format for results are selected. The results are shown in
Figure 4.8. The results page for the multiple query options includes an
additional, 'View Query Options’ button. This button when clicked opens a
message box listing all the choices that were included in the query as shown
in Figure 4.8. The map format of the results is shown in Figure 4.9. The map
displays all crashes in the year 2006 with those crashes identified by the
query as highlighted points.
Figure 4.7 Multiple query builder form
Figure 4.8 View query criteria and the corresponding message box

Figure 4.9 Multiple factor query results in graphical format
4.1.3. Query using street names

This option requires user to select a single street name or two street names that form an intersection, as the query criterion. The user needs to select the street names from the dropdown list provided on the form. Since there are a large number of streets, the street names were divided into two groups based on the starting letter, A-M and N-Z. The streets starting with the numbers are included in the A-M group. Depending on the user selected query criteria, the corresponding button(s) needs to be clicked to enable the related street names in drop-down boxes.

The street names lists are loaded in the dropdown menu when the corresponding load buttons are clicked. The user selected street names appear in the boxes to the left of the form as illustrated in Figure 4.10. If the user prefers to display crashes along a street, then only the name of the street 1 need to be selected. On the other hand, if the user chooses two streets that intersect, the crashes in and around that intersection will be displayed, i.e., all the crashes that have the street names similar to the selected street names will be identified. The query option requires the user to specify the crash database depending on the year in addition to the format to present the results. As stated previously, once the “next” button is clicked, the user is informed of the progress with a message box. The selection process continues after the user clicks “OK” on the message box.
The “query by street names” option is explained with an example of Maryland Parkway and Flamingo Avenue as the two user selected street names. The “load names A-M” button for the first street name is clicked to activate the corresponding dropdown box, and “Maryland” is selected from the list. Similarly, the “load names A-M” button related to the second street name is clicked to enable the corresponding dropdown box and “Flamingo” is selected. The names “Maryland” and “Flamingo” are displayed in the text boxes as shown in Figure 4.10. In addition, the database for the year 2006, and tabular format for results are selected for this example. When the next button is clicked, the program indicates the progress before the results are displayed as explained earlier.

Figure 4.10 Street names displayed in the corresponding textboxes
The result of this query will include all crashes listed in the database that have “Maryland” and “Flamingo” as street names. The tool is programmed to select all crashes with the selected street names irrespective of the order, i.e. first street name versus second street name. Thus, all crashes in and around the Maryland/Flamingo intersection will be displayed in the results. The databases used for this application include a number of different ways in which the street names appear in the crash database. For example, Maryland Parkway was mentioned as Maryland, Maryland Parkway, Maryland Pky, Maryland Pkwy., Maryland Pkwy.

Thus, when the user specifies “Maryland” as the first street name, the program searches for records with “Maryland” as the complete street name as well as part of the street name in order to display all crashes on Maryland Parkway. The result of this example query is displayed in Figure 4.11. “Maryland” appears as full street name as well as part of the street name in the results. Also, it can be seen that “Maryland” appears in both the first street and the second street column. This indicates that the tool selects records with the selected street names irrespective of the order of street names specified by the user. In this example, crashes with street names Maryland/Flamingo as well as Flamingo/Maryland are selected as seen in Figure 4.11.
4.1.4. User Defined query

The user defined query option is developed to combine multiple crash factors and define the time period for the analysis. Thus, this option provides the user with option to query multiple databases based on the time period defined while building the query. This option provides user with the choice to combine crash type, severity, driver factors and vehicle factors with user selected time period as illustrated in Figure 4.12. The choice does not require user to select factors from all the options provided. For example, if the user does not select any option under the crash type, then the results will include collisions of all crash types. The main advantage of this option is the user can define time periods and generate results for multiple calendar years.
The form includes two boxes, one to specify the start date and the other to specify the end date. For example, if the user selects the start date as January 1st 2004 and the end date as March 31st 2004, and no other query factors, then the results will include all collisions that occurred between January 1st 2004 and March 31st 2004, including both the dates. The begin date is October 1st 2003 and the end date is May 31st 2006, since the data were available only for those time periods.

In all of these query options, unless the user selects contributing factors (driver factors or vehicle factors), the results displayed will consist of unique values. However, if the user selects vehicle or driver factors, depending on the number of vehicles (drivers) involved in the collision, accident numbers might
appear multiple times in the results. This feature is explained with a simple example in the following section considering a query to generate list of fatal crashes that occurred on Mondays in the year 2006. Figures 4.13 and 4.14 shows the factors included in the query. It can be seen that the second query includes all the contributing factors. Figure 4.15 shows the results when the contributing factors are included and Figure 4.16 shows the results when the contributing factors are not included.
Figure 4.13 Query factors that generate unique Accident Records
Figure 4.14 Query factors that generate multiple Accident Records
Figure 4.15 Results showing unique Accident Records

Figure 4.16 Results showing multiple occurrences of individual Accident Records
In Figure 4.16, the accident numbers LVMPD060205-0887 is repeated two times and LVMPD-060430-1727P1 is repeated three times. These results indicate that these collisions involved more than one vehicle and the driver/vehicle factor for each vehicle were recorded in the database. Thus, when contributing factor is added as a query factor, individual records might be displayed multiple times in the results depending on the number of vehicles involved in the collision.

4.2. Signalized Intersection Data Collection tool

The signalized intersection data collection tool is used to collect intersection data attributes. The data collected are stored in six tables: intersection, intersection legs, supports, mast arms, beacons (signal heads) and intersection photos details. The intersection and supports table includes the geo-codes for the signalized intersection location and the support locations respectively. The process of geo-coding and collecting the different attributes are described in the next sections.

The application for the data collection was developed using the ESRI's ArcPad Application Builder Software. First, the tool is used to create data about the location of the signalized intersection with the corresponding street names. In the field, the handheld GPS tool will establish the intersection location once the GPS receives the corresponding geographic coordinates.
Figure 4.17 shows the ArcPad interface that is displayed on the screen of the handheld instrument. This interface will be displayed when the user clicks on the “add a point” button as shown on the Edit tool bar. The current location and date are directly entered into the corresponding database thereby reducing time and eliminating errors while manually entering data. The data collector enters the other details into the form as shown in Figure 4.18. Additional details such as street names are manually entered into the intersection database.

![Figure 4.17 Intersection data collection form](image-url)
Next, the data for the supports tables are collected. These also include geographic coordinates for the locations of supports. The ArcPAD interface developed to record intersection supports data is shown in Figure 4.19. As indicated previously, the location and date are entered automatically when the “add a point” button is clicked on the form shown in Figure 4.17, with the supports layer made active.
On the support interface form, the data collector is provided an option to change the date using a drop-down menu. The Intersection and Support IDs are entered by the user according to the rule described in the methodology. Most of the other support attributes are selected from the dropdown menu choices. After the data are entered on the interface form, the entered data can be viewed by clicking the attributes button on the menu bar as seen in Figure 4.19. The location co-ordinates can be viewed by clicking the "geography" button on the data collection form.
The mast arm and signal head details are manually entered on paper following the rule to number the mast arms and signal heads. The length of the mast arm is measured using a measuring wheel, starting the from the support to which the mast arm is connected and moving away from the support until the mast arm ends as shown in Figure 4.20.

Figure 4.20 Measurement of mast arm length

The signal head IDs were based on the intersection ID followed by Support ID, Mast arm ID and the position of the signal head on the mast arm (if present). If the support is not connected to any mast arms, then the mast arm number was mentioned as '00'. Examples for generating the IDs for signal head on the support and on the mast arm are illustrated in Figures 4.21 and 4.22, respectively. The ID of the signal head circled in Figure 4.21 is 120-03-01-04. Similarly, the ID for the signal head circled in Figure 4.22 is 120-04-00-01. The IDs are calculated during post processing in the lab.
Figure 4.21 Signal head on mast arm

Figure 4.22 Signal head on support pole
4.3. Signalized Intersection Data Analysis tool

The signalized intersection data analysis tool is used to perform queries on the intersection data collected in addition to the data obtained from Stantec Consultants as described in section 4.2. The database consisted of information about location of intersection, the street names as well as their geo-codes. The intersections were also provided with unique IDs. Thus, the analysis tool developed is designed to perform intersection queries based on street names or intersection IDs. In addition to the two choices for performing queries, the option to perform queries based on other factors such as signal head type, support type and other intersection attributes is also provided as the third choice in the multiple attributes query option.

In the multiple attributes query choice, the user can perform queries based on a single attribute or multiple attributes depending on the need. For example, single attribute query request may be to find all supports at signalized intersections with two street lights. A multiple factor query may be to combine supports pole type at signalized intersection with number of street lights. For example, supports with two street lights and pole type XX-30. The process carried out to perform queries based on intersection ID and street names are described in detail in the following sections. In addition, the process carried out to perform the aforementioned multiple choice query is also explained.
4.3.1. Query based on Intersection ID

The signalized intersections available in the database are identified by their unique IDs and listed in the drop-down box as shown in Figure 4.23. However, when the form is displayed, the "load intersection ID" button must be clicked to enable the drop-down box. After the intersection IDs are loaded, the user can select the required intersection ID from the provided list. The selected ID appears in the text box provided in the left side of the form.

In Figure 4.23, intersection ID 4 is selected in the drop-down box and the same appears in the text box. When the user clicks the next button after the ID selection, the signalized intersection database is searched for intersection with ID "4". The user is required to click the "OK" button on the corresponding information message box that appears when the next button is clicked. The information message box is similar to the one in the crash analysis tool. The intersection analysis tool then acts on the requested query and displays the corresponding intersection table and intersection leg table details as shown in Figure 4.24.
Load Intersection ID by clicking the "Load Intersection ID" button. Select the required ID from the dropdown box. The selected ID is displayed in the Textbox beside the "Selected Intersection ID". Click "Next" to proceed.

Selected Intersection ID 4

Text box showing the selected intersection

Dropdown box showing the available intersection ID

Figure 4.23 Query using signalized intersection ID

Figure 4.24 Initial results of the signalized intersection query
The "change query option" button leads the user to the previous form in order to change the selected intersection ID. The "view query options" buttons on the form shown in Figure 4.24 leads the user to view additional details of the intersection, which are divided into four subdivisions: supports, mast arms, signal heads and photos. In addition to these four subdivisions, the "crash data" button provides access to query the crash data at the selected intersection. The "crash data" button will be explained later. The form showing the buttons to lead user to view additional intersection details is shown in Figure 4.25.

Figure 4.25 Form showing buttons to view additional query details
The support details are divided into controller/service pedestal supports and signal supports. The corresponding form appears when the “support detail” button is clicked. The choices are shown in Figure 4.26. The “Other Details” button leads user back to the previous form. Depending on the user’s selection, each of these buttons displays the corresponding details. The tool is designed to provide an information message box before displaying the results which indicates the user that the query is in progress. The tool requires the user to click “OK” on the information message box before displaying the results. The results generated (for intersection ID 4) when the user clicks the “signal support details” and the “control/service pedestal details” buttons are shown in Figures 4.27 and 4.28, respectively. The results generated for mast arm, signal head and photos are shown in Figures 4.29 through 4.31.

![Figure 4.26 The Controller/Service pedestal and signal support buttons](image)

Figure 4.26 The Controller/Service pedestal and signal support buttons
Figure 4.27 Signal supports details for intersection ID: 4

Figure 4.28 Controller/Service pedestal details for intersection ID: 4
Figure 4.29 Mast arm details for intersection ID: 4

<table>
<thead>
<tr>
<th>Arm Details</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>JB-173</td>
<td>JB-66</td>
</tr>
<tr>
<td>JB-176</td>
<td>41</td>
</tr>
<tr>
<td>JB-177</td>
<td>JB-90</td>
</tr>
<tr>
<td>JB-178</td>
<td>45</td>
</tr>
</tbody>
</table>

Figure 4.30 Signal head details for intersection ID: 4

<table>
<thead>
<tr>
<th>Signal Head Details</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>JB-173</td>
<td>JB-66</td>
</tr>
<tr>
<td>JB-173</td>
<td>JB-549</td>
</tr>
<tr>
<td>JB-173</td>
<td>JB-548</td>
</tr>
<tr>
<td>JB-173</td>
<td>NA</td>
</tr>
<tr>
<td>JB-173</td>
<td>JB-539</td>
</tr>
<tr>
<td>JB-173</td>
<td>JB-538</td>
</tr>
<tr>
<td>JB-173</td>
<td>NB</td>
</tr>
<tr>
<td>JB-173</td>
<td>NA</td>
</tr>
<tr>
<td>JB-173</td>
<td>JB-555</td>
</tr>
<tr>
<td>JB-173</td>
<td>JB-552</td>
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<tr>
<td>JB-173</td>
<td>JB-553</td>
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<tr>
<td>JB-173</td>
<td>NB</td>
</tr>
<tr>
<td>JB-173</td>
<td>NA</td>
</tr>
<tr>
<td>JB-173</td>
<td>JB-556</td>
</tr>
<tr>
<td>JB-173</td>
<td>NB</td>
</tr>
</tbody>
</table>

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4.3.2. Query based on Street Names

Since it is difficult to remember the intersections listed in the database based on their unique IDs, the option to query the database based on cross street names is developed. The user is prompted to the form shown in Figure 4.32, which includes two text boxes and two drop-down boxes for selecting street names that are enabled by clicking the corresponding “load street names” buttons. In Figure 4.32, it can be seen that when the user makes a selection, the selected street names appear in the corresponding textboxes.
With the selections made for street names as shown in Figure 4.32, the user has to click the “next” button and “OK” button on the corresponding message which indicates that the query is in progress. The tool then searches for intersection which has “Tropicana” and “Maryland” listed as street names and displays the corresponding intersection attributes as shown in Figure 4.33. Although “Tropicana” is selected as street 1 and “Maryland” is selected as street 2, the results show that the street numbers are reversed. This indicates that the user need not select the street names in the order which is mentioned in the database. The “View Query options” button and the following steps are explained in section 4.3.1.
4.3.3. Query based on multiple attributes

This option provides user with choices to combine different intersection attributes available in the database to perform queries. Intersection attributes such as signal head direction and its type can be concatenated as query factors. In Figure 4.34, the query factors selected include pedestrian signal head facing in the east direction and the support pole type XX-20. As stated previously, once the user selects these factors and clicks the “Next” button, the information message box appears which indicates user the progress. The user needs to click “OK” and wait for the results to be displayed. The results generated are shown in Figure 4.35.
Figure 4.34 Multiple factors selected for intersection query

Figure 4.35 Results for the factors selected in Figure 4.33
The results page provides user with the “Previous” button in order to link to the previous page. This button can be clicked if any changes are needed in the selection query factor.

4.4. Integrating the intersection analysis tool and the Crash analysis tool

The crash data analysis tool and the intersection analysis tool developed in this research can be used to perform queries on the crash database and intersection database separately. In order to integrate both the applications, a link is provided in the intersection analysis tool to connect to the crash database which permits the user to perform queries based on crash attributes. The link becomes accessible after the user selects the intersection to be analyzed. The intersection selection can be carried out either by performing a query based on unique intersection ID or by the selecting the cross street names for the intersection. As previously discussed, the intersection ID, street names, and the intersection leg details are displayed as the initial results of the query. The user is then provided with the “view query details” button that leads to the other intersection attributes which can be viewed separately based on the user's selection. This is in addition to the link to crash data.

The “crash data” button on the intersection analysis tool is designed to provide the user with an option to select the crashes that occurred at the selected intersection. The user can query the crash data based on the type of
crash, day of the week, time of the day, severity of crash, location (intersection/non intersection), roadway classification, number of vehicles involved and contributing (driver/vehicle) factors. The corresponding form is shown in Figure 4.36. This form is similar to the multiple query factors in the crash data analysis tool. The main differences are that the form shown in Figure 4.36 does not include an option to choose the format of the results. This form includes an additional "All Crashes" option. All the crash records generated through this form are for a particular intersection, that was selected by the user. Since the link to view the intersection spatially is provided earlier, a similar link is not provided here. If the user selects the "All crashes" option, the results displayed includes all the crash records at the selected location, both at the intersection as well as non intersection crashes. On the other hand, the user can also select multiple factors to be included in the query. Considering the example of selecting the Intersection ID 4 (Street 1: Andover Dr and Street 2: Tropicana Avenue), and selecting all crashes at the selected location, the results displayed are shown in Figure 4.37. It is seen that in Figure 4.37, all the records contain Andover Dr and Tropicana Avenue as street names. This indicates that the crashes listed occurred at/around the selected intersection. The results consist of multiple records for some of the accident numbers which shows that multiple vehicles were involved in those crashes and the same were recorded in the database.
Figure 4.36 Factors to query crash database

Figure 4.37 Result of querying crash data with intersection ID: 4

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The user can perform new queries with the help of “Start a query” button provided in the menu bar as seen in Figure 4.37. An information message box appears indicating the user to confirm the choice as shown in Figure 4.38. This option was provided during programming because once the user exists from the results page, the results table is erased and is prepared to display results based on the new query choices. The user needs to use the “Export to excel” button if the results generated are needed for further analyses.

![Safety Study](image)

Figure 4.38 Confirmation to start new query
SUMMARY AND CONCLUSION

The purpose of this research was to develop tools to help inventory and perform analyses on transportation related data. The analysis tools were developed using off-the-shelf software such as ArcIMS, MS Access, MS Excel and Visual Basic .Net. The tools developed can be used to analyze crash data and signalized intersection data. Since no database existed that included attributes of newly signalized intersections, a data collection tool was developed for this purpose using the ArcPAD Application Builder. The use of the crash data analysis tool is demonstrated with the help of the crash data obtained from the Las Vegas Metropolitan Police Department. Data were obtained for the time period from October 2003 through May 2006. Various options were provided in the analysis tool to assist user with specific queries. The signalized intersection tool was used to collect data at fifty five newly signalized or reconfigured intersections maintained by Clark County Department of Public Works (CCDPW). The use of the intersection data analysis tool was demonstrated. The key features derived from this research are summarized below.
• Analysis tools were developed using ArcIMS, MS Access, MS Excel, Visual Basic .Net and ArcPAD Application Builder. User friendly options are provided to benefit the end users, in addition to its availability on the intranet.

• Crash data can be queried based on eight different factors depending on the user’s needs. The single factor query option provides the user a choice to evaluate crash records based on single factor. The multiple factor query option can be used to create queries based on more than one crash attribute. The option to query the crash database using street names is provided in the tool to analyze crash history for specific streets or at intersections. In addition, the user defined query choice allows user to select multiple databases for querying.

• The signalized intersection data collection tool is used to collect location information of intersection attributes into two tables: intersection and supports tables. The location (X and Y coordinates) of the intersection and the related supports were recorded using a hand held GPS receiver.

• The intersection analysis tool provides the user options to generate details about intersection attributes based on intersection ID or cross street names.

• The results of queries can be viewed in two formats: table and map. The results displayed in the tabular format can be exported to an Excel spreadsheet for further analyses.
• The use of the analysis tools results in time savings due to reduced amount of time spent by personnel on analysis using crash reports available in paper format.
CHAPTER 6

RECOMMENDATIONS FOR FUTURE WORK

The tools developed in this research can be used by the CCDPW staff to collect signalized intersection details in the future and analyze the crash data and the signalized intersection data. These tools can be used to replace the present methods of analyzing crash records available in the hard copy (paper format) thus resulting in time reduction thereby increase financial benefit due to reduced man hours spent. However, few recommendations to improve the usage of applications are made as follows.

1. The crash data obtained from the Las Vegas Metropolitan Police Department included crash records for the time period; October 2003 through May 2006. Hence, the analysis that can be performed is limited to that time period. Additional data would provide with more accurate results.

2. The attributes associated with signalized intersection database are limited. Details about signal turn-on dates, the kinds of signal heads, recent maintenance dates need to be collected in order to provide for better analyses such as material calculation and proper maintenance.
APPENDIX

Single Factor query Coding:

Dim strquery As String
Dim g1, check As Integer
If Form3.RadioButton8.Checked = True Then
    If RadioButton1.Checked = True Then
        strquery = "select Accident_Number, Collision_date, Format(Coll_Time, 'hh:mm:ss AM/PM') as Collision_Time, Primary_Road as Street_1, Secondary_Road as Street_2, Crash_Type, Crash_Severity, Location, Dist_Dir as Distance from Complete where "
    ElseIf RadioButton2.Checked = True Then
        strquery = "select Accident_Number, Collision_date, Format(Coll_Time, 'hh:mm:ss AM/PM') as Collision_Time, Primary_Road as Street_1, Secondary_Road as Street_2, Crash_Type, Crash_Severity, Location, Dist_Dir as Distance from Complete where "
    ElseIf RadioButton3.Checked = True Then
        strquery = "select Accident_Number, Collision_date, Format(Coll_Time, 'hh:mm:ss AM/PM') as Collision_Time, Primary_Road as Street_1, Secondary_Road as Street_2, Crash_Type, Crash_Severity, Location, Dist_Dir as Distance from Complete where "
    ElseIf RadioButton4.Checked = True Then
        strquery = "select Accident_Number, Collision_date, Format(Coll_Time, 'hh:mm:ss AM/PM') as Collision_Time, Primary_Road as Street_1, Secondary_Road as Street_2, Crash_Type, Crash_Severity, Location, Dist_Dir as Distance from Complete where "
    End If
End If

Else
    g1 = 0
    check = 0
    If Form5.RadioButton50.Checked = True Then
        If g1 = 0 Then
            strquery = strquery + "( Head_On=1 "
            g1 = g1 + 1
            Form7.Label10.Text = "Crash Type: Head On"
        End If
        check = check + 1
    End If
ElseIf Form5.RadioButton49.Checked = True Then
    If g1 = 0 Then
        strquery = strquery + "( Rear_End=1 "
        g1 = g1 + 1
        Form7.Label10.Text = "Crash Type: Rear End"
    End If
    check = check + 1
    If g1 > 0 Then
        strquery = strquery + ")"
    End If
'For Tabular results
    If RadioButton5.Checked = True Then
        If RadioButton1.Checked = True And RadioButton5.Checked = True Then
            Form7.Results1(strquery)
            Form7.ShowO
            Me.HideO
        ElseIf RadioButton2.Checked = True And RadioButton5.Checked = True Then
            Form7.Results2(strquery)
            Form7.ShowO
            Me.HideO
        ElseIf RadioButton3.Checked = True And RadioButton5.Checked = True Then
            Form7.Results3(strquery)
            Form7.ShowO
            Me.HideO
        ElseIf RadioButton4.Checked = True And RadioButton5.Checked = True Then
            Form7.Results4(strquery)
            Form7.ShowO
            Me.HideO
        End If
    End If
'For Map Results
    Dim url As String
    If RadioButton6.Checked = True Then
        If Form3.RadioButton8.Checked = True Then
            If RadioButton1.Checked = True Then
                url = ConfigurationSettings.AppSettings("website") + "layers=010000011101ActiveLayer=1&Query="
            ElseIf RadioButton2.Checked = True Then
                url = ConfigurationSettings.AppSettings("website") + "Layers=000100011101ActiveLayer=3&Query="
            Else
                url = ConfigurationSettings.AppSettings("website") + "layers=010000011101ActiveLayer=1&Query="
            End If
        ElseIf RadioButton2.Checked = True Then
            url = ConfigurationSettings.AppSettings("website") + "Layers=000100011101ActiveLayer=3&Query="
        Else
            url = ConfigurationSettings.AppSettings("website") + "layers=010000011101ActiveLayer=1&Query="
        End If
    ElseIf RadioButton3.Checked = True Then
        url = ConfigurationSettings.AppSettings("website") + "Layers=000100011101ActiveLayer=3&Query="
    Else
        url = ConfigurationSettings.AppSettings("website") + "layers=010000011101ActiveLayer=1&Query="
    End If

ElseIf RadioButton3.Checked = True Then
    url = ConfigurationSettings.AppSettings("website") + "Layers=000010011101ActiveLayer=5&Query=
ElseIf RadioButton4.Checked = True Then
    url = ConfigurationSettings.AppSettings("website") + "Layers=000000111101ActiveLayer=7&Query=
End If
End If

If Form5.RadioButton50.Checked = True Then
    url = url + "Head_on%3D1"
ElseIf Form5.RadioButton49.Checked = True Then
    url = url + "Rear_End%3D1"
    url = url + "&QueryZoom%3DYes"
g1 = 0
End If

Multiple factor query coding:

'Group 1 Start -> CrashType
If Check13.Checked = True Then
    If g1 = 0 Then
        strquery = strquery + "( Head_on=1 "
g1 = g1 + 1
        Query = vbCrLf + "Type of Crash: Head On"
    Else
        strquery = strquery + " or Head_on=1 "
    End If
    check = check + 1
End If
If g1 > 0 Then
    strquery = strquery + ")"
End If
'Group 1 end

'Group 2 Start -> Day
If Check6.Checked = True Then
    If check > 0 And g2 = 0 Then
        strquery = strquery + " and "
    End If
If g2 = 0 Then
    strquery = strquery + " ( Day_of_Week='Sunday' ")
    g2 = g2 + 1
    Query = Query + vbCrLf + " Day of Week: Sunday"
Else
    strquery = strquery + " or Day_of_Week='Sunday' "
    Query = Query + ", Sunday"
End If
    check = check + 1
End If
If g2 > 0 Then
    strquery = strquery + ")
End If
'Group2 end
If RadioButton1.Checked = True Then
    Query = Query + vbCrLf + " Year: 2003"
    Form8.Results1(strquery)
    Form8.Show()
    Me.Hide()
ElseIf RadioButton2.Checked = True Then
    Query = Query + vbCrLf + " Year: 2004"
    Form8.Results2(strquery)
    Form8.Show()
    Me.Hide()
ElseIf RadioButton3.Checked = True Then
    Query = Query + vbCrLf + " Year: 2005"
    Form8.Results3(strquery)
    Form8.Show()
    Me.Hide()
ElseIf RadioButton4.Checked = True Then
    Query = Query + vbCrLf + " Year: 2006"
    Form8.Results4(strquery)
    Form8.Show()
    Me.Hide()
End If
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• Ajit Roy, Ancila Kaiparambil and et. al., "Metallurgical and corrosion behavior of refractory materials for hydrogen generation," TMS Conference, March 13-16th, 2006, San Antonio, TX, USA

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• Ajit Roy, Ancila Kaiparambil and et. al., “Use of refractory materials for hydrogen generation using nuclear power,” MRS Fall 2005, November 28-December 2nd, 2005, Boston, MA, USA
• Ajit Roy, Ancila Kaiparambil and et. al., “Characterization of structural materials for nuclear hydrogen generation,” AiChE Conference, October 30-November 4th, 2005, Cincinnati, OH, USA
• Ajit Roy, Ancila Kaiparambil and et. al., “Metallurgical and corrosion characterization of structural materials for the nuclear hydrogen initiative,” MS & T Conference, September 26-28th, 2005, Pittsburgh, PA, USA
• Ancila Kaiparambil and et. al., “Corrosion behavior of candidate materials for hydrogen generation,” ANS Student Conference, April 14-16th, 2005, Columbus, Ohio, USA.

Thesis Title: Development of a safety analysis and an intersection infrastructure system

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