DEVELOPMENT OF AN INCIDENT RESPONSIVE SPATIAL DECISION SUPPORT SYSTEM FOR THE HAJJ

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A thesis submitted to

The Faculty of Graduate Studies and Research

in partial fulfillment for the degree of

Doctor of Philosophy

Department of Geography

Ottawa University

Ottawa, Ontario

April, 1996

ISBN 0-612-16400-4

UNIVERSITÉ D'OTTAWA
UNIVERSITY OF OTTAWA

Acknowledgments

Few worthwhile endeavors can be done without help and contribution of others. In this respect, many people have contributed substantially during my graduate studies, and I am very grateful to them. It is impossible to identify every person by name. However, I would like to express my warmest gratitude and appreciation the following persons.

Special thanks to Professor David Douglas, my supervisor, for his continuing support and encouragement during the course of my studies and writing of this thesis. Additional mention must be made of his arrangements for my field trip to Indianapolis, Indiana, USA. I am also indebted to Professor Konrad Gajevski for help during the initial stages of my studies. Professor Roger Roberge deserves special recognition for providing materials related to risk assessment and analysis, and sincere appreciation is extended to Professor Andre Langlois for his assistance on many occasions. Warm words and thanks to all of the professors and staff of the Department of Geography, Ottawa University, for their continuing support and encouragement.

I would like to express my appreciation to Professor Fraser Taylor from Carleton University, and President of Carleton International. I have always benefited from discussion with him where valuable advice was needed.

Dr. Mosaad Allam, Director of Geographic Information Systems and Services Division (GISSD), Natural Resources Canada (NRCan) also deserves special thanks. He has always devoted time to exchange ideas related to my work, and has been my richest source of knowledge. Dr. Louiselle St-Lauraent, from NRCan, GISSD, provided valuable support as we worked together during my study. Without her contributions and hands-on training, this project would have been impossible to complete. She devoted time and much effort to explain and help along the way. Special thank is due to Mr. Jeff Labonté, from NRCan, GISSD, for reading and exchanging ideas and suggestions of this study. Mr. Garry Labelle, from NRCan, Geodetic Survey Division (GSD), deserves thanks for scanning the base map of the study area. Ms. Carole D'Aoust-Martin, from Canadian National Railway (CN), assisted in converting the scanned raster file from RLC to HRF format. Otherwise, digitizing the map would be a year long project by itself. Appreciation is passed to Mr. Mike Morrow, from Impact Research Group Ltd., for providing authorization to use softrisk program in my project. Thanks to Ms. Janet Waterman, from Impact Research Group Ltd., for her hands-on training with softrisk program at the Ottawa International Airport. Warm thanks also goes to Lynn Sutherland, from Alberta Research Council, Calgary, Alberta, for sending video tape and documentation of Heuristic Emergency Response Management Expert System (HERMES).

During my visit to Indianapolis, Indiana, USA, many individuals and institutions provided essential information and valuable suggestions. I would like to thank the following people from Marion County Emergency Communications Agency (MECA) for their help and support. Mr. Linn Piper, Head of MECA; Mr. Robert Zickler; Mr. Tim Dugan; Mr. Andy Gillespie; Mr. Peter Beering; Mr. Wayne Morgan; Mr. Mike Russo; and Mr. Bill Smith.

I also found myself grateful to the people of Umm Al-Qura University, Department of Geography. Special thanks is extended to Dr. Ramzi Al-Zahrani, Head of the Department. Also, special thanks to Mr. Meraj Mirza, who was generous enough to provide materials related to my studies. During my field trip to Makkah Al-Mukaramah, Dr. Al-Zaharani and Mr. Meraj took me for a tour in the Holy Sites and provided thorough answers to the many questions I asked.

During my research trip to Riyadh, Saudi Arabia, I engaged in numerous useful and informative discussions with many public officials. I found myself greatly indebted to Major General Morayyea Al-Shahrani, the Military Survey Department (MSD), for providing crucial information. I also would like to thank Mr. Abdulrahman Al-Assaf, and Mr. Abodiab, Hussain, from MSD. I am grateful to Mr. Mansor Al-Turky and Mr. Saud Al-kholaiwy, from General Directorate for General Security (GDGS). Warm thanks to Dr. Majdi Al-Tokhy and Mr. Mohammed Al-Karni, from General Directorate for Civil Defense (GDCD), for their suggestions and comments on my project.

I also extend my special thanks to Mr. Abdulla Shedayed, Assistant Deputy Minister of Surveying and Land Department of Ministry of Municipal and Rural Affairs (MOMRA) for providing the digital database for Makkah Region. I am also indebted to Mr. Mohammed Al-Rajhi, and Mr. Stuart MacRitche, from MOMRA, for supplying the digital databases for the Arafat study area. Appreciation is passed to Mr. Rida Bafagih, from Ministry of Communications (MC), for providing numerous reports and studies related to the Hajj. I am also grateful to Mr. Abdullah Al-Hazza, from Saudi Red Crescent

Society (SRCS), for informative discussions and materials regarding the activities of SRCS during the Hajj season.

During the field trip to Makkah Al-Mukkarmah, Saudi Arabia, many individuals in many organizations provided useful materials. I am thankful to Mr. Fida Abdulfatah and Mr. Khalid Abu Najy, from Makkah Emirate (ME), for furnishing information related to the Supreme Hajj Committee. Special thanks to Mr. Arif Gadi, from Makkah Municipality (MM), Mr. Sindi, Abdullah from Ministry of Hajj (MH), and Mr. Rashad Zubaidi, from General Union for Cars (GUC). I also would like to thank the people of HRC for supplying numerous reports and studies related to the Hajj and its activities.

I also would like to express my personal thanks to my friend Dr. Badrinath K M who read my work and gave insightful feedback and suggestions. I would like to express my appreciation for Dr. Mowaffag Alboug for his unexpected contact from the U.S. We engaged in numerous useful conversations over the telephone exchanged ideas and suggestions concerning emergency management in the Holy Sites. He also sent some important material related the subject of this study.

Special thanks to my wife Modi, my daughters Monirah and Amel, and my son Mohammed, for their patience, support and understanding. They are the people who scarified many things in support of my studies.

I also would like to express my appreciation to my sponsor Imam Mohammed bin Saud Islamic University and the Saudi Education Mission in Ottawa for allowing me the opportunity and making my study possible.

List of Abbreviations

AAT	Arc Attribute Table.
ASMD	Aerial Survey and Mapping Department.
CDS	Central Department of Statistics.
CHC	Central Hajj Committee.
CN	Canadian National.
DCDSTF	Digital Cartographic Data Standards Task Force.
DD	Data Dictionary.
DFD	Dataflow Diagram.
DMTP	Deputy Ministry for Town Planning.
DSD	Data Structure Diagram.
DXF	AutoCad's Drawing Interchange Format.
ERD	Entity Relationship Diagram.
ES	Expert System.
ESRI	Environmental Systems Research Institute.
GDCD	General Directorate for Civil Defense.
GDGS	General Directorate for General Security.
GDTP	General Directorate for Traffic Police.
GIS	Geographic Information Systems.
GISSD	Geographic Information Systems and Service Division.
GPS	Global Positioning System.
GSD	Geodetic Survey Division.
GUC	General Union for Cars.

HERMES	Heuristic Emergency Response Management Expert System.
HRC	Hajj Research Center.
HTC	Hospital Treatment Capacity.
IJGIS	International Journal of Geographic Information Systems.
IMSIU	Imam Mohammed Bin Saudi Islamic University.
IRSDSS	Incident Responsive Spatial Decision Support System.
KSA	Kingdom of Saudi Arabia.
MC	Ministry of Communication.
ME	Makkah Emirate.
MECA	Marion County Emergency Communications Agency.
MFNE	Ministry of Finance and National Economy.
MH	Ministry of Health.
MI	Ministry of Interior.
MM	Makkah Municipality.
MOMRA	Ministry of Municipal and Rural Affairs.
MPMR	Ministry of Petroleum and Mineral Resources.
MRC	Medical Rescue Capacity.
MSD	Military Survey Department.
MSI	Medical Severity Index.
MTC	Medical Transport Capacity.
NRCan	Natural Resources Canada.
OC	Operations Committee.
PAT	Point Attribute Table.
RLC	Run Length Compressed.
RMS	Risk Management System.

RSC	Research and Studies Center.
SC	Steering Committee.
SCOOT	Split Cycle Offset Optimization Technique.
SG	Statistical Group.
SHAC	Supreme Hajj Affair Committee.
SHC	Supreme Hajj Committee.
SML	Simple Macro Language.
SR	Saudi Riyal.
SRCS	Saudi Red Crescent Society.
SRSC	The Saudi Remote Sensing Center.
TC	Total Capacity.
UAU	Umm Al-Qura University.
URISA	Urban and Regional Information Systems Association.

ABSTRACT

This study provides a framework and general guidelines for the development of an Incident Responsive Spatial Decision Support System (IRSDSS) using a geographic information system approval. The system designed is for disaster response operations of the Saudi Red Crescent Society during the Hajj season. In recent years, a number of serious disasters have occurred during the Hajj and the need for a superior response system to deal with such events and minimize their consequences is evident. Such a response system will rely on increased use of automation in the communications and in some way to include geography.

The Hajj is a special religious gathering that takes place at the last month of the lunar calendar every year. The Hajj has particular settings and characteristics not the least of which is its magnitude in terms of number of pilgrims, physical settings, and length of time. During this period the Saudi Red Crescent Society has specific needs and requirements to manage emergency situations and incidents. The settings and needs of disasters are evaluated and analyzed when developing IRSDSS system and data models presented in this study. Structured analysis methodology is applied, and various modeling tools are used to satisfy the objectives of this research.

The primary objective of this study is to examine the applicability of geographic information systems for dispatching resources in response to disasters. Two scenarios are developed to test who should respond first to an incident and what resources should be

deployed to that incident. The system is tested under various incident magnitudes, using the Arafat Holy Site as a pilot area. The determinant factors used to answer the questions posed by the scenarios are: the optimal path to the incident location, capacity of the Saudi Red Crescent Society stations, and the magnitude of the incident.

The findings of this research indicate that the geographic information systems technology, in its current state of vendor practices, does not provide complete facilities to support the objectives of the scenarios developed in this study. To demonstrate acceptable solutions to these issues, further data manipulation and analysis are undertaken and special additional C code programs are written for this purpose. When these programs are integrated with geographic information systems technology, they yield an effective spatial reference system that could be used by the Saudi Red Crescent Society for disaster response during the Hajj season.

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Chapter One

1. Introduction

1.1 Background:

An emergency can be defined as an abnormal occurrence which may cause significant damage to property, the environment, or result in human suffering. An emergency occurrence requires prompt timely action based on planning, preparedness and response. Emergency management has been defined as the discipline of applying science, technology, planning, and management to deal with emergency events (Drabek and Hoetmer 1991). Emergency management also involves critical decision-making capacities and responsive action in relatively short periods of time. Emergencies can be classified under three general categories namely: natural, man-made and technical / accidental.

By nature, emergencies are unpredictable and uncertain events. However, responses to emergencies are handled in different ways based on different settings. For 911 operations in urban settings, the distribution of emergency facilities and the methodology of handling emergencies are permanent and institutionalized. For special events such as major sports events or social gatherings, response to emergencies are handled at a different level. The number of persons attending and the location of the activity require a different allocation of emergency resources and response planning. Such events usually take place in urban or semi-urban settings and allocation of facilities is determined by the location of such events. For the Hajj period, time, space, and number of pilgrims, as well as religious practices require a different level of emergency planning, preparedness, response and recovery. Participation of the Hajj is fixed to a certain time of the Higri calendar year. Physical space is limited and the number of pilgrims is over two million. The pilgrims also have to comply with essential components and obligations of the Hajj. This represents a difficult challenge to the authorities who plan and allocate emergency facilities and proper response to emergency occurrences, noting that the type of emergency also determines the range and the amount of response resources required. Although there is a distinction between emergencies and disasters (Drabek and Hoetmer 1991), in this study an emergency or a disaster is referred to as an incident with a large magnitude which requires extraordinary response efforts. For the purpose of this document each will be used synonymously.

In recent years geographic information systems have been used to process information in many areas of specialization, including real time applications (Laurini and Thompson 1992, Jeffery and Estes 1990). Geographic information systems were found to be useful in reducing or eliminating redundant activities, providing better data management, facilitating rapid access, and allow sharing of data for more comprehensive information analysis (PTI and ICMA 1991). They were also found to improve productivity, to help increase capacity for data storage and manipulation, to improve the planning process and to enhance communication (Antenucci et al.1991). Geographic information systems also have facilities to accelerate responses to queries in an accurate and consistent manner (PTI and ICMA 1991).

It has been observed that the proper use of geographic information systems can further enhance and improve emergency management, thus minimizing the effects of emergencies on people's lives, property and the environment (Ramachandran and Naadimuthu 1989, Johnson 1992, Gronlund et al. 1994, and others). While others in the field of emergency management, have found that geographic information systems can assist in identifying possibilities and providing solutions for emergency planning, preparedness, and response and recovery (Gatrell and Vincent 1990).

1.2 The Problem:

During the Hajj period, the mass gathering and movement of pilgrims can at times lead to injury, death, and damage to property and the environment. In recent years there have been a number of major incidents that have occurred during the Hajj which resulted in high human casualties. Several examples, that are further discussed in chapter three, include:

- the Iranian incident 1987, a man-made incident that resulted in loss of 402 lives and as many as 649 persons wounded (The Ottawa Citizen 1994);
- fire incidents in 1987, 1988, and 1990 that were unintentional but man-made incidents which resulted in mass destruction of property (Al-Amri 1995);
- the Al Mu'aisim tunnel incident in 1990, which resulted in loss of 1,426 lives (The Ottawa Citizen 1994); and
- the Jamarat incident in 1994, where overcrowding resulted in loss of over 800 lives (The Ottawa Citizen 1994).

Generally, the type of disasters that may occur during the Hajj season can be classified into two categories:

1) disasters that affect people and property which include floods, fires, storms, earthquakes and earth slides, and accidents (cars and aircraft); and

2) disasters that <u>only</u> affect people which include epidemics, poisons (food, water, gas, chemical substances), and terrorist acts. (Kingdom of Saudi Arabia, Ministry of Health 1994).

The Hajj is controlled by two major factors which contribute substantially to the problem. First is the number and origin of pilgrims arriving to perform Hajj. The second is the physical, religious and time settings of Hajj.

Growth in the number of persons participating in the Hajj has increased substantially. In 1930 about 30,000 Moslems came from abroad to perform Hajj. By 1992 this number increased to over one million. Further, a great deal of the Hajj participants arrive from outside the Kingdom of Saudi Arabia, joining Saudi residents in observing the Hajj. In the future the number of pilgrims is expected to increase, placing greater demands on emergency related services.

Future projections concerning the number of pilgrims is difficult to determine. Using conservative annual growth rates of less than 1% the number of pilgrims by the year 2000 is expected to be 1.8 million. By the year 2020, the estimated figure would reach 2.3

million. In the more recent past, such as in 1982 and 1983, the number of pilgrims was in excess of two million. Other estimates place the number of pilgrims to be between 3.5 and 4.5 million by the year 2000 (Pasha 1982). Regulation to control the number of pilgrims arriving to perform Hajj, which would subsequently reduce emergency occurrences, is a solution that is political and legislative in nature, and one which must interplay with the religious norms.

The rapid increase in the number of pilgrims has placed a great deal of demand on services and accommodations during the Hajj season. In response, the Saudi government has given a high priority to development and utility projects in the Holy Lands used during the Hajj. Makkah Al-Mukaramah and Almadinah and other Holy Sites are undergoing a rapid pace of development and modernization. As a first priority efforts were made to secure Hajj routes and the safety of pilgrims. Secondary were expansion and development projects that grow exponentially with the increased number of pilgrims. Additional details of some of these projects are presented in chapter three.

The increasing number of pilgrims along with their diverse origin and characteristics contributes to the challenging task of minimizing emergencies and risk during the Hajj. Pilgrims represent various ethnic groups and come from all corners of the world bringing different cultures, background, and languages. These diverse characteristics often contribute to emergency situations and perhaps suppress efforts to improve the precautionary and response services provided during the Hajj. Several difficulties include:

- limited health awareness;
- lack of familiarization with weather conditions;
- limited knowledge of the correct performance of Hajj; and
- a lack of safety and prevention awareness.

Of these difficulties heat exhaustion and sunstroke are major causes of deaths during the Hajj season. Weather induced health difficulties vary as temperatures can reach 45° C when Hajj season coincides with summer. If the pilgrims fail to take the necessary precautionary measures they can be severely affected by these types of illnesses (Al-Hazzaa 1989, and Ministry of Health, Yearly Health Reports 1984 - 1993).

Based on Islamic law, the Holy Sites are surrounded by religious boundaries. Hajj activities must take place within these boundaries. For example, standing within the boundaries of Arafat area is one of the compulsory Hajj pillars[1]. The time, space and sequence of Hajj activities are predetermined by the Moslem faith and must be followed by all participants to fulfill all of the Hajj rites. The area of Arafat is 1368 hectares. The landuse within Arafat varies and includes: residential use by pilgrims, transportation, government, businesses, and religious activities. In general, residential landuse by pilgrims is less than 40% of the total area of Arafat Holy Site. The problem remains centered around the mass gathering of people in area of limited size.

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[1] A pillar is an essential component of the Hajj which must be observed by all pilgrims. If a pillar of the Hajj is missed the Hajj is said to be void.

Limited physical space and the mass volume of persons leads to a major issue concerning the interaction between pedestrians and motor vehicles. Problems occur as mass movements of pilgrims and vehicles proceed either towards or between the Holy Sites. Planned movement of pedestrians is primarily to occur along two pedestrian pathways that connect each Holy Site from Arafat to the Holy Mosque inside Makkah Al-Mukaramah. Still, Abduh et al. (1991) have reported that 10% of pedestrians use the vehicle network during movement from Arafat to Muzdalifah. At the same time, Abdulmajied and Barhameen (1992) have reported that over 50,000 vehicles were used to transport more than one million pilgrims from Arafat to Muzdalifah during 1992 Hajj season. The consequences of these interactions are traffic accidents and traffic flow congestion.

Due to these circumstances, disasters are expected during the Hajj season. Many government agencies are mandated to prepare for and respond to these types of events in an efficient and timely manner. Among the more important agencies is the Saudi Red Crescent Society, who have the responsibility to deploy resources to disaster locations and provide medical services. The Saudi Red Crescent Society must deploy resources based on the magnitude of the disaster and the capacity of their emergency stations to handle the situation. Critical to the deployment is accessing the location based on an optimal path within the confines of a congested road network and the mass movement of pedestrian within the Holy Site areas. Efforts are further hampered by not only the volume of persons and the limited space, but a lack of emergency routes and familiarization of Red Crescent personnel with locations and routes.

The Saudi Red Crescent Society uses conventional methods for incident planning, allocating resources, responses, and dispatch of its personnel and vehicles. Such methods tend to be slow and can be inefficient. In addition, the Saudi Red Crescent Society continuously evaluates and analyzes previous incident(s) and related information. From such analysis it is hoped that previous mistakes can be avoided and lessons learned from experience.

The research of this thesis deals with the development and design of an incident responsive spatial decision support system that applies geographic information systems technology for the operations of the Saudi Red Crescent Society during the Hajj season.

Research Hypotheses:

The Hajj season can be viewed as a mass migratory issue of a temporal nature. Disasters during the Hajj period are a multi-dimensional problem with various elements. The number of pilgrims with various characteristics reside in limited areas and crowded for a short period of time. Religious practice results in mass movement of people within the city and from one Holy Site to another. All of this leads to various emergencies. When an incident happens, there is a need to respond in relatively short period of time to reduce the consequences of such an incident. Information processing and the decision-taken are critical. Currently, geographic information systems technology has the scope and ability to bring geography and information together under an umbrella. Hence, the suggestion to use geographic information systems to reduce emergency response time and to improve emergency management is a natural progression. The general hypotheses of this study are:

1) geographic information systems have the facilities to provide ready access and generate spatial data, as well as provide quick, more accurate, and more consistent responses to queries; and

2) integration of geographic information systems technology into a decision support system, would help cope with the most current incident in the light of lessons learned and past experience.

Design and development of a geo-referenced system using geographic information systems can improve incident response and enhance emergency management. It will also improve the current practices of the Saudi Red Crescent Society during the various phases of an incident during the Hajj season and analysis of incidents during pre and post Hajj planning. The proposed research provides the means to store and document such information in an efficient and consistent manner.

Objectives of the Study:

The primary objective of this thesis is to provide a framework for the design and development of an incident responsive decision support system for the Saudi Red Crescent Society operations during the Hajj period. To overcome time constraints for decision-making during disasters, a comprehensive layered system can integrate physical locations, time dynamics, behavioral elements, statistical aspects, and other related information into the process. Based on this objective the following goals will be achieved:

1) to contribute to the efforts made by the Saudi Red Crescent Society to augment existing conventional methods of handling disasters. There is overwhelming evidence indicating that human decision-makers tend to perform poorly under emergency situations involving extreme uncertainty and stress (Belardo and Wallace 1989, and Comfort 1985);

2) to develop appropriate models that are applicable to disaster response during the Hajj period. This requires evaluation and analysis of user, system, and data requirements. Development of such models must take into consideration the unique characteristics of the Hajj requirements. The road network, the location and capacities of Saudi Red Crescent Society stations, medical facilities and evacuation centers are the basic elements of the model;

3) to generate disaster response scenarios which can be used throughout the various phases of disaster. Generating such scenarios must consider traffic plans, impedance, and other aspects which may affect traffic flow through the road network.

4) to simulate incident response by identifying the incident location, determining the optimal paths to reach the incident location, and generating the optimal paths from incident location to medical facilities and evacuation centers. Dispatching of emergency service vehicles from the nearest center to the scene and to the medical facilities; and

5) to use the results of this study to improve emergency planning and management. By taking into account its findings and recommendations, the Saudi Red Crescent Society can further improve its emergency practice during the Hajj season.

By achieving these goals, response time can be improved and the incident responsive decision support system can help professionals to respond to emergencies properly.

Research Methodology:

The design and development of an incident responsive decision support system is a process of creating an appropriate information system that would improve emergency management practices employed by the Saudi Red Crescent Society. The proposed incident responsive decision support system developed in this research was divided into four phases as shown in figure 1.5.1. These phases are preliminary, analysis, data conversion, and scenario development. This methodology is similar to the system development life cycle and structured analysis.

Each phase consists of several steps and functions to be planned, implemented and documented during system development. Table 1.5.1 outlines the type of activities and tasks to be carried out. However it is important to note that overall system development is an overlapping process. As such, some activities will commence concurrently and an element of change will be carried out during the entire system development. Revisions and modifications are therefore required and considered throughout the development process.

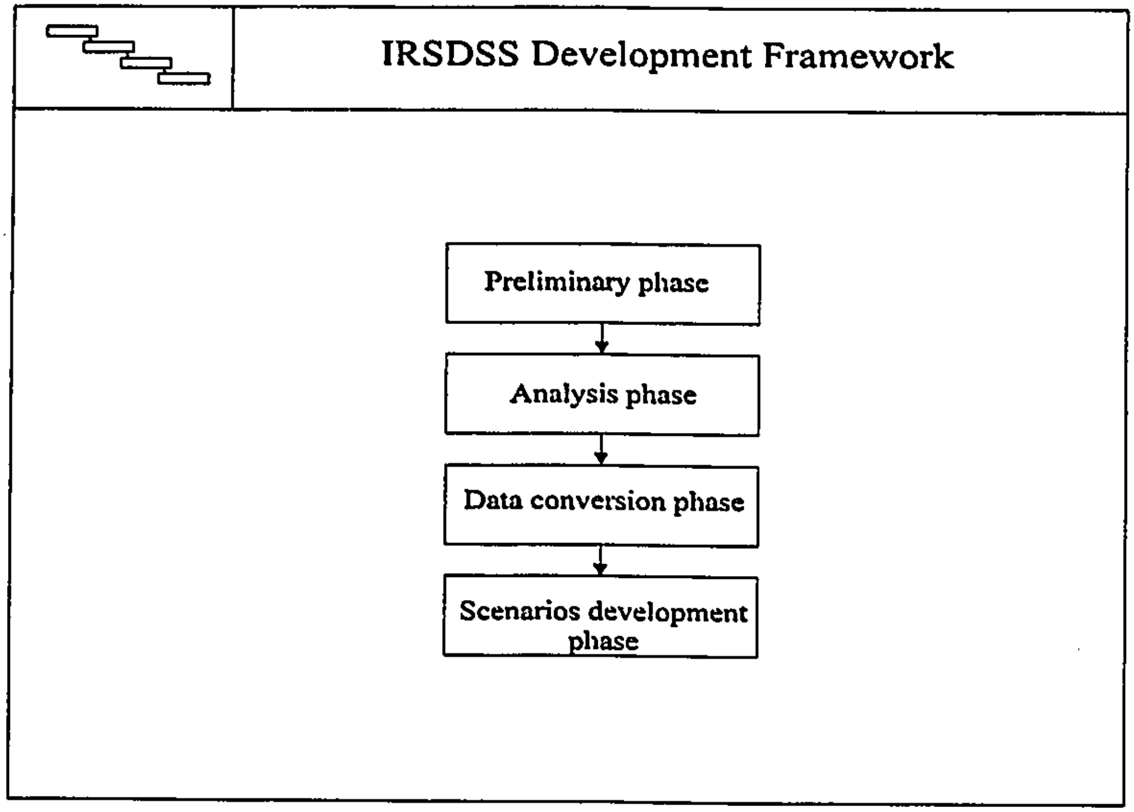

Figure 1.5.1: System Development Framework

Table 1.5.1: Acitivities and Tasks of IRSDSS Development

Phase	Activities	Tasks
Preliminary	Problem Definition:	• Identify the potential users of the system • Identify the nature of the problem • Determine the scope of the system • Set objectives of the system • Identify the sources of data • Conduct initial feasibility study
Analysis	Requirements Analysis:	• Conduct user needs analysis • Analyze system requirements by developing:

		– environmental model; and – behavioral model • Analyze data requirements by developing: – entity-relationships diagram; – data dictionary; and – data structure diagram.
Conversion	Data Conversion	• Collect data through: – filed trip and field observation; – interviews and meetings; and – questionnaire. • Specify software and hardware • Design database • Conduct emergency response
Scenarios	Scenarios Development and Testing.	• Set the objectives of scenarios • Test for single incident • Test for multiple incidents

Scope of the Study:

The scope of this study is to provide a framework and guidelines to the design of an incident responsive system for the operations of the Saudi Red Crescent Society during the Hajj season. The mandate of the Saudi Red Crescent Society is to respond to disaster occurring during the Hajj season and to provide a wide range of emergency services to pilgrims during the Hajj period. During the data collection phase some information on emergency management was not available which imposed some limitations to the study. However, the data collected from the Ministry of Health, the Ministry of Municipal and Rural Affairs, the General Directorate for Traffic Police, the Hajj Research Center, and others was used in the present research.

In addition to the above mentioned elements, the following procedural and methodological limitations are also worth noting.

The proposed incident responsive decision support system is designed as an independent system from any specific hardware and software platform[2]. This will provide the Saudi Red Crescent Society the opportunity to select whatever platform suitable for its operations. However, a serious investigation into specific platforms will be required in the future.

The Arafat Holy Site was chosen as a pilot area during the scenarios development and testing phase. It is one of the three major Holy Sites and marks one of the focal points of the Hajj. All pilgrims must be in the Arafat area during the 9th day of Du-Alhijjah month of the lunar calendar also known as (the Standing day at Arafat or *Waqfah)*.

Limiting the scope of this study to the above applications gives the opportunity to focus on the modeling and analysis aspects to further enhance and improve emergency management of the Saudi Red Crescent Society. However, a full of operational IRSDSS based on this research is possible for all other emergency applications, as the framework along with methodologies and principles of this study provide a foundation for system implementation.

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[2] For simulation purposes, PC ARC/INFO™ GIS was used to test the IRSDSS design and methodologies.

Thesis Organization:

This study is divided into eight chapters. Chapter one provides a general background of the research domain. Chapter two is background information and review of related literature in the field of emergency management, emergencies and the Hajj, and literature related to the use of information technology for emergencies. Chapter three provides a general background to the Hajj and the study area. In this chapter, a brief description of Makkah Al-Mukaramah physical settings is presented. In addition, the Hajj and its related activities are described as well as emergencies that may occur during this season. Also, a description of Arafat Holy Site as a study area is presented. These first three chapters provide a background to the research domain and the Hajj.

Chapter four through seven discuss the various aspects of system development. Chapter four begins with the preliminary phase which identifies the potential users of the system, highlights the nature of the problem, defines the scope of the system and its objectives, as well as a feasibility study. Chapter five is concerned with analysis, including: user needs analysis, system requirements, and data analysis. Data conversion and database design are discussed in chapter six. Some functional aspects of the system, in particular the dispatch and response function, are presented in chapter seven. Conclusions and recommendations are presented in chapter eight.

Chapter Two

2. Background Information

2.1 Introduction:

Emergency management is an interdisciplinary area of study involving the social, environmental and mathematical sciences (Drabek and Hoeltmer 1991). Applying knowledge from these diverse fields requires in depth understanding of the principles of each. In addition, knowledge about emergency situations and response, as every emergency has its unique characteristics and manifestations, make studying emergency management both challenging and interesting. From each emergency event new experiences are gained for rescuers as well as for researchers. As emergencies have significant social impacts, scientists are interested in searching for effective solutions for everyday problems.

Emergency management is the process in which authorities effectively prepare and respond to mitigate the effects of emergency events. A priority of emergency management is reducing the number of casualties and damage to property. The process of emergency management includes four recursive phases of activities, as follows: planning, preparedness, response, and recovery. Each element of the process is inter-related with particular importance placed on planning for response. Managing emergencies for mass gatherings such as religious services, sports activities and special events deserves attention because in these cases people gather for only short durations with characteristically limited physical space and limited emergency response facilities. Further, people are beyond their normal condition which may increase the likelihood of accidents due to emotional religious involvement in the holy event, ignorance, fear, or unfamiliarity of the situation or surroundings.

An additional element of emergency management is the ill-defined nature of most problems, combined with the uncertainty of timing and severity of nature. As a result the sequence of events from emergency are often unpredictable (Schmidt et al. 1985).

The Hajj is an important activity for the believers of Islam. Hajj means taking the journey to Makkah Al-Mukaramah with the intention to fulfilling the Hajj rites. During the Hajj, people from around the world gather for a five day period to perform their religious duty. This mass gathering represents a real challenge to authorities to prepare and plan for emergencies during this season. During the Hajj many government agencies are involved in emergency management. In addition, almost every Saudi government agency is involved in conducting research related to the planning, prevention, and management of difficulties faced during the Hajj.

Major events such as sport activities share some similarities as well as a few differences with a major religious gathering such as the Hajj. To investigate these differences and similarities in the context of emergency management, a field trip to

Indianapolis, Indiana, USA was undertaken to observe emergency management at the Indianapolis 500 mile automobile race that takes place annually.

This chapter includes the exploratory Indianapolis field trip as well as formal review of related literature and information technology. It begins with a review of the Indianapolis field study. Next, the major literature related to emergency management is reviewed followed by a review of studies and reports related to emergency management during the Hajj period. The chapter concludes with a review of recent case studies related to the use of information technology and other related research for emergency management.

2.2 Indianapolis Field Study:

It is a general presumption that emergency response systems are better developed in North America and that there was much experience to be examined and shared. The research began by searching for situations that may have some similarities to the Hajj but where it was expected that emergency response systems were well developed. Several types of event were considered. For example, the Olympic Games, where sizable amounts of money are expended to avoid emergencies either accidental or deliberate. However, the Olympic Games do not recur in the same place every time and the location of their activities maybe conducted in or outside an urban setting.

The Indianapolis 500 automobile race was considered and reviewed in this study as it shares some similarities to the Hajj in that it recurs at the same location every year. A three day field trip from May 27 - 29, 1994 was undertaken to probe the magnitude of the problem and solution process. The purpose of the field trip was to gather information on emergency management and to obtain first hand experience on emergency handling during a major sporting event.

Indianapolis is a city in the U.S. Midwest of about 1.2 million inhabitants. It hosts the Indianapolis 500 automobile race every year, and has done so since 1916, except for two years during World War I and four years during World War II. This major sports event attracts almost one half million spectators, all of whom gather in one place to witness this event. During the race weekend, the city is enlarged by spectators in tents, campers, motor homes, and recreational vehicles. In this mass gathering the probability of emergency occurrences imposes a real challenge for authorities who must be prepared for the management and handling of incidents. Approximately eighteen agencies are involved in emergency management during this event. Coordinating the efforts to ensure effective incident management is the Marion County Emergency Communications Agency (MECA), established in 1991. MECA is an agency with a telecommunication systems which oversees all communications between the participating agencies and has five branches distributed throughout the city.

During this field trip, several interviews were conducted with key officials associated with the auto race. Appendix A provides a list of individuals interviewed. The trip provided an opportunity to discuss emergency management with key individuals involved in the process. In this regard, several meetings regarding emergency management were conducted during the race weekend. Also, the trip included a helicopter flight over the crowds entering the stadium on the morning of race day as well as views of emergency routes, facilities, and the necessary grounds for the sporting event. During the rest of the day the author was permitted to use emergency routes and observe response procedures.

Specific emergency information on emergency management and handling were collected during this field trip. Such information includes emergency plans for various agencies associated with the auto race, medical services for the mass gathering and related special events.

This field study provided an excellent backdrop to the current research. Several observations were realized. It was observed that this major sport event takes place in urban and semi-urban, and controlled settings. It was also observed that emergency management and preparedness has improved over several decades. However, it was observed that information technology in use for communication, coordination and response is an advanced 911 type system. GIS technology, although valuable decision-making tool, was not used. Although, the Indiana emergency handling and response system does not have the GIS component many individuals and key officials expressed a strong desire to adopt GIS technology in the future. Further, response efforts and people are distributed throughout the city and not necessarily tied to specific locations. Efforts are transient as even the timing of the sport event itself could be changed if necessary.

2.3 Literature Review:

2.3.1 Emergency Management:

In the general field of emergency management, a number of studies have been conducted (Lang and Lang 1976, Foster 1980, Whitehead 1989, Waugh 1990, Drabek and Hoetmer 1991, and others). These studies outline the nature of emergency occurrences and highlight various phases of emergency activities. Some of these studies are reviewed in the following sections.

Drabek and Hoeltmer (1991) edited a book entitled ***Emergency Management Principles and Practice for Local Governments.*** It highlights the history and foundation of emergency management and conceptualizes the daily operations and legal issues of emergency management. The emphasis of this study is on how local governments should deal with natural disasters and man-made incidents. It also presents an emergency program which examines the role of organizational principles and practices that could be of benefit during emergencies at the local level and how efforts could be coordinated at the community, state, and federal levels.

Drabek and Hoetmer (1991) define emergency management as:

> "... the discipline and profession of applying science, technology, planning, and management to deal with extreme events that can injure or kill a large number of people, do extensive damage to property, and disturb community life. (p: xvii).

According to Drabek and Hoetmer (1991), there is a distinction between emergencies and disasters in the field of emergency management. Emergencies are normal events that do not require extraordinary efforts beyond the capacity of responsible agency or authority. Emergencies include events such as: house fires, burglaries, broken water pipes, heart attacks, ...etc. Such events usually do not exceed the scope of the standard operating procedures of most local fire, police, emergency medical service, and public work departments.

Disasters, on the other hand, are larger in scope and magnitude than normal events. Disasters require extraordinary efforts beyond the standard procedures of involved emergency service agencies. Disasters may include such events as earthquakes, floods, chemical explosions, terrorist acts, ...etc. It is also possible that they can result from a gradual progression of normal emergency occurrences such as the spread of fire beyond control.

In another study, Waugh (1990) made several observations regarding terrorism and emergency management. The author compares terrorist violence to major natural and technological disasters. This study is an attempt to link terrorist violence management to the general model of emergency management. In particular, it examines the political environment in terms of preparing for, mitigating, responding to, and recovering from violent acts. Although it deals with issues of national and international nature, it focuses on the current American anti-terrorism policy and how effective is it in fulfilling the emergency management functions.

According to a study by Lang and Lang (1976), the basic goal of planning for emergencies is to prevent events from occurring and from turning into disasters. They emphasize that emergency planning is an important phase of emergency management. This phase may include a set of priority goals and allocation of available resources within the framework of these priorities, and the development of routines in anticipation of contingencies where characteristics and requirements can be predicted.

Furthermore, advanced preparation and planning efforts reflect either specific or general strategies: Specific strategies presuppose that major elements in the situation can be predicted in advance. Under these strategies, the plan should identify the objectives to be achieved, allocate priorities, prescribe the risks and costs to be incurred, and fix the appropriate procedures. According to the authors, there is also a need for effective communication of information so that the needs can be assessed quickly and resources can be matched accurately in order of priorities. In addition, there will be pre-described procedures which to constitute adaptive responses for those situations that can be anticipated. Finally, under any specific strategy, prior commitments are important as they impose some degree of rigidity.

On the other hand, general strategies are geared towards flexibility to cope with situations that can not be predicted in advance. The emphasis under general strategies is planning using a priority of goals. The allocation of resources and means of achieving specific goals remain at the discretion of those in the best position to judge. Measures embodying a general strategy are designed to stimulate resourcefulness by providing special incentives for innovation and initiative. The weakness of a general strategy is the difficult task of coordinating the spontaneous adaptive responses made by individuals and subgroups with one another. Lack of control may lead to complete breakdown of procedures under some circumstances.

A study by Schmidt et al. (1985) presents a tri-purpose emergency model for emergency planning. The authors argue that the tasks of emergency planning include rigorous definition of situations and categories such as fire, explosion, toxic releases, ...etc., and identification of response sequences for events. Further the model requires identification of the individuals and their needed information for executing response decisions. Finally, it is important to recognize the possibility of multiple, compound, or escalated occurrences and their required response.

According to the authors, emergency preparedness encompasses those actions designed to ensure successful plan implementation. This depicts clarifying the familiarity of participants and their understanding of purpose and logic of the plan. It also implies clarifying the scope of authority and responsibilities of participants, and the willingness of participants to carry out their critical roles. Finally, preparedness involves solving jurisdictional disputes between participants or agencies. The authors argue that emergency management and decisions depend primarily on accurate and timely information. Availability of this information plays a vital role and management of emergency response must specify the source of information, the means of its provision, the point of reception, and the means of transmitting it.

The above reviewed studies provide a theoretical background to the general field of emergency management. The emphasis of these studies is on emergency preparedness, planning, response and recovery. These are primary planning and policy issues which are important to understand the overall function of emergency management. This research, in its broad scope, will benefit from such materials to better plan and model the proposed IRSDSS system. However, none of these studies addresses the specific purpose of this study which is designing a dispatching and responsive system for mass gathering during the Hajj season.

2.3.2 Risk Assessment:

In most situations or events risks can not be eliminated completely unless that situation is entirely avoided. Roberge (1983) distinguishes between voluntary risk and involuntary risk. Voluntary risk involves choosing to engage in an activity that has inherent known risk which is not part of one's daily routine activities. Involuntary risk, on the other hand, arises whenever in the course of normal activities a certain risk occurs.

Several studies have been conducted under the general concept of incident assessment and management in various situations (Roberge and Roberge 1986, de Boer et al. 1989, De Lorenzo et al. 1989, Martinez 1992, and others). For example, Roberge (1983) developed the Risk Management System (RMS) which consists of three components:

- ***The physical system:*** it aims to determine associated physical risks present in the system.
- ***The economic system:*** it aims to calculate the cost associated with different levels of risk reduction.
- ***The value system:*** it aims to determine the level of risk acceptable to society.

Taking the decision to perform the Hajj and make the journey to the Holy Lands may be considered a voluntary risk. There is also a certain degree of involuntary risk as well. Looking at the risks and dangers of the Hajj through such RMS can provide many insights, especially as it relates to the interplay and balance between the -physical system- (as described in the introductory chapter), the -economic system- (how much the Saudi Government and others may want to invest in safety), and the -value system- (how much the Saudi society and pilgrims are willing to accept level of risk as part of their religious experience). The objective of this thesis is to develop an incident management and dispatching system in the context of existing emergency related services. The RMS model described above is a valuable tool for risk assessment. However, its practical applications are beyond the scope of the current study.

de Boer et al. (1989) define a disaster from a medical point of view as " a destructive event that causes so many casualties that extraordinary mobilization of medical services is necessary". Based on this concept, they formulated a scoring system to quantify an event. The system is called the Medical Severity Index (MSI).This system could be used to assist the situation during the management stage of an emergency situation.

The MSI is calculated as the product of the casualty load and the severity of incident compared with the available total capacity of the medical services. If the final results is greater than 1.0, then the event is considered to be a disaster and the available medical resources cannot cope with the situation. Additional support in this case is needed from other medical services in neighboring regions. de Boer et al. (1989) calculate the MSI from three parameters.

- ***Casualty load:*** it refers to the number of sustained casualties and can be designated as N.
- ***Severity index***: it refers to the severity of an event and can be represented by S. From a medico-organizational point of view, casualties can be divided into:
  - category 1: dead and the dead-on-arrival;
  - category 2: life-threatening cases demanding immediate attention;
  - category 3: non-life-threatening cases requiring hospital treatment; and
  - category 4: casualties not requiring hospitalization.

  The calculation of S is difficult, since classification of casualties for each category is influenced by many factors including the nature of incident. However, de Boer et al (1989) argue that earthquakes, railway accidents, fires, terrorist bombings, and aircraft crashes compromise more than 50% of casualties of categories 1, 2, and 3. Casualties of floods and volcanic eruptions are more of category 1. While civil disturbances involve more casualties of category 4. In general, S is scored between 0.5 and 1.5 depending on the severity of wounded casualties. If seriously wounded casualties are to be expected, S is scored as 1.5. If only many slightly injured are to be expected S is scored as 0.5.

- ***Capacity of medical services:*** it refers to the total medical services available. The capacity of medical services is divided into three phases:
  - Medical Rescue Capacity (MRC): the MRC refers to medical care at the site. The MRC depends on the amount of professional medical help at the site and can be expressed as the number of doctors, nurses, and experienced paramedics in addition to materials and equipment available at the disaster site. It is assumed that a team are professionals compromising a surgeon, an anesthesiologist, and two nursing staff that can deal with 10 casualties under category 2 and 3 per hour. Under certain circumstances such as poor weather conditions the capacity to handle casualties will be less than 10.
  - Medical Transport Capacity (MTC): it refers to transportation and distribution of casualties from categories 2 and 3. The MTC depends on the number of ambulances with drivers, the ease of evacuation, and the distribution scheme. The MTC can be expressed in numbers, since the number of available ambulances is a known figure. It is assumed that each ready-to-go ambulance is capable of transporting and distributing two casualties per hour.
  - Hospital Treatment Capacity (HTC): the HTC refers to the treatment provided to casualties in the hospital. The HTC depends on the total number of surgeons, anesthesiologists, operating rooms, intensive care beds, residents, and the like. In general, The HTC score is estimated as 3% of the total number of beds for general hospitals.

All these capacities mentioned are based on a normal conditions for roads, the weather, and working hours. Moreover, the capacities are expressed per unit of time per hour. Under disaster conditions, medical professionals and others can work efficiently for a maximum of eight hours (de Boer et al. 1989). Therefore, to obtain the Total Capacity (TC) of medical services the MRC, MTC, and HTC should be multiplied by 8. These capacities also represent a synchronized chain of events and should be equal to one another, even if one capacity is smaller than the others. In this case the lowest capacity determines the capacity of the whole chain. After the casualty load (N), the severity of incident (S), and the total capacity TC of the medical services MRC, MTC, and HTC are quantified, then the medical severity index MSI can be defined as: (N)(S)/TC.

Some aspects of the MIS such as HTC and MTC exhibit some relevance to this study. The HTC and MTC were used to calculate the capacity of the Saudi Red Crescent Society (SRCS) stations and medical facilities in the study area and are reflected in the data model developed in the data needs analysis.

2.3.3 Emergencies and the Hajj:

As noted previously, many Saudi government agencies and departments participate in Hajj activities and the management of this event. Among these agencies are the General Directorate of Civil Defense (GDCD), Ministry of Communications (MC), Ministry of Municipal and Rural Affairs (MOMRA), and Umm Al-Qura University (UAU) among others. One of the more active bodies in the area of the Hajj and its related issues is the Hajj Research Center (HRC) of the UAU in Makkah. This center was established in 1975 at King Abdulaziz University in Jeddah. It began with a team of researchers from different specializations who conducted studies to improve conditions and services provided to the pilgrims. In 1983 the center was transferred, by a royal decree, from King Abdulaziz University to the UAU. Since then the HRC has carried out research and studies related to Hajj in many different areas (Kingdom of Saudi Arabia, Ministry of Information). All of these agencies are active in conducting research and studies in areas concerning Hajj activities. These activities include Hajj management, emergency management, road network construction and services among other issues. Some of their studies and reports are reviewed in the following sections.

In 1984, the Deputy Ministry for Town Planning (DMTP) of MOMRA produced a comprehensive development plan for the Makkah Region (Kingdom of Saudi Arabia, Ministry of Municipal and Rural Affairs, Deputy Ministry for Town Planning 1984). Volume 8 of this plan is devoted exclusively to the Hajj. It discusses the significant aspects of Hajj and provides a frame of reference for the consideration of Hajj needs in the strategy planning for Makkah planning region. It also highlights the many characteristics and elements of Hajj as they must be understood and considered for the appropriate planning to be accomplished.

Several other studies have been conducted in the area of emergency planning, preparedness as well as response and recovery. A major cause of emergency situations during the Hajj is fire. Almost every year fires are recorded in tent camps or residential areas. One of the active government bodies conducting research and studies in this area is the Research and Studies Center (RSC), of GDCD. It has conducted field studies during the Hajj since 1987 and produced a series of reports which aim to find better methods and overcoming problems facing fire fighters.

Improving the methods of fire fighting in the Holy Sites area is detailed in one of the reports by the RSC (Nasier et al. 1991). This study evaluated past, present and future fire fighting procedures and practices. The study also provided additional recommendations for regulations and precautionary measures to prevent and lessen the consequences of many types of emergency occurrences. As a major recommendation a central control room was established during the Hajj period with representatives from the various agencies involved with emergency management. This center was meant to ensure effective coordination among those agencies in the event of emergencies of large magnitudes.

Another report was presented by Nasier et al. (1991) which described methods of dealing with fire in the Holy Sites (Mina area). The purpose of this report was to outline the most effective methods and strategies to protect pilgrims and their properties from fire. Several precautionary measures were recommended.

In 1992, the RSC also conducted a study to identify barriers and difficulties preventing the movement of fire fighters in the Holy Sites (Al-Abri et al. 1992). According to this report the main problem can be attributed to the traffic congestion. Traffic plans, drivers, pilgrims, pilgrims guides and transportation systems and companies each contributes in various ways to the problem. Emergency teams, with their knowledge and experience in handling emergencies, also have a role to play. The report suggests finding other alternatives, such as expanding the area and capacity of the Holy Sites to accommodate the growing number of pilgrims, will have a direct impact. Also, the study suggests improving the transportation system and emergency management procedures.

It has been recognized that pilgrims can be exposed to many different accidents and illnesses during their movement between the Holy Sites. Weather conditions, interaction between vehicles and pedestrians, and the spread of contagious diseases, are all contributing factors to dangers faced by pilgrims. Al-Hazzaa (1989) outlines the influence of these and other factors such as the distribution of medical services, traffic plans, transportation system, water services, lost and found services, health awareness, religious guidance and awareness of environmental influences.

In another study, Bafakih et al. (1991) outline the significance and impacts of interaction between vehicles and pedestrians in Arafat area. This study distinguishes between two different modes of interaction; the first is that between pedestrian and vehicle pathways inside Arafat area, and the second is pedestrian movements on vehicle roads between Arafat and Muzdalifah areas. The study investigates the causes of such interaction and attributes the problem to various reasons, most notably the simple fact that most pedestrians (65% included in the survey) did not know that pedestrian ways existed.

The pre-hospital stage is an important phase of emergency management. Providing victims with on-the-spot medical treatment or transporting patients to the nearest medical facility are critical issues. In handling both types of services, emergency related medical services have to be planned and coordinated effectively. Time and availability of resources play a major role when dealing with medical emergencies for mass gatherings. Al-Hazzaa (1987) emphasizes the importance of efficient spatial distribution of resources as well as effective use of communication systems. This study provides a general plan for transporting patients to medical facilities and highlights all necessary instructions to be implemented during emergencies.

A more thorough study by Al-Harthy (1988) outlines the importance of emergency medical services as a comprehensive integrated system which is based on effective planning. In this study availability of well trained human resources, appropriate transportation and communication systems, availability of medical resources, and an effective emergency management system are all essential aspects for emergency response. In the follow-up study in 1990 Al-Harthy discusses the SRCS activities, human resources, common diseases, and the ideal methods of transporting patients during the Hajj. The author suggests use of special roads established for emergencies and other essential services. The author also highlights the importance of reorganizing vehicle parking zones, increasing health awareness, improving services along pedestrian ways, improving the efficiency of traffic plans and increasing the effectiveness of the medical working force.

A study by Authman (1987) discusses the importance of establishing a well designed evacuation plan. Most importantly the author argues that evacuation centers should be located within the Holy Sites boundaries since most pilgrims, even if they are severely injured, may refuse to be evacuated outside the Holy boundaries as many believe that this would violate the purpose of their religious duty. In Arafat site, the author suggests allocating eighteen evacuation centers with a maximum capacity of accommodating 31,250 people. Similarly, Zamzami (1990) also recognizes the role of evacuation plans as an essential part of emergency management. This particular paper highlights the direct influence of administrative and technical barriers as well as indirect environmental barriers on establishing an effective evacuation plan during the Hajj season.

It is clear that the transportation system in the Holy Sites is key element in emergency management. Emergency related activities such as, emergency routing, patients transportation, evacuation, traffic control, movement of pilgrims from one site to another and other activities utilize the road network. As such, the efficiency of the road network and the capacity to move people and vehicles have a central role to play during emergencies. In this regard, a number of studies have been conducted to investigate and evaluate the road network in the holy areas during the Hajj season. For example, the MC has published a series of reports reflecting results of an annual symposium between 1985 and 1990, and continues to conduct research in this area.

In the MC series of studies Abdulgani (1986) suggested a general plan for the transportation system in the Holy Site areas. It emphasizes the use of effective transportation management and organization to provide better services to pilgrims. It identifies five different transportation modes that could be used during the Holy period, including walking, public transportation, pilgrims and private vehicles, and service vehicles. Due to space and time requirements, this article emphasizes the use of public and walking modes as the most suitable methods for the movement of pilgrims.

Another study by Aisa et al. (1987) focuses on the limited time component during the movement of pilgrims from the Arafat to the Muzdalifah site. To overcome the time constraint this study suggests adapting a well established transportation planning procedure. It emphasizes the need for revising mobility plans and improving traffic signs and devices as well as using mathematical models to evaluate their benefits. Another general transportation study is made by Alrahman and Abdulalh (1989). It provides a general transportation strategy for movement of pilgrims, residents, and goods within the various religious, economic, and social framework of the Hajj. The influence of time, space and religious practices on such movements are also outlined and discussed

Al-Muhammadi (1988) study recognizes the traffic problem and the difficulties it imposes for implementing emergency plans. The author highlights the importance of reorganizing the movement of vehicles and people as well as improving safety regulations during the season. A study by Al-Mashaby and Shabieb (1989) suggested a different transportation and traffic plan in the Holy Sites. These authors proposed dividing the Holy Sites into purpose oriented zones to avoid the interaction between pedestrian, vehicles, and other services. They suggested dividing Arafat area into ten zones; eight for vehicles, one for pedestrian and one for other services. Each area would then be served with its own road.

Abdulmajied and Barhameen (1991 and 1992) conducted two studies in 1991 and 1992. These evaluated vehicular movement during the *(Nafrah)* from Arafat to Muzdalifah. Both studies aimed to solve the congestion problems along the Arafat - Muzdalifah roads. Based on the surveys conducted during the Hajj, the level of service of each road, as well as the level of service of all roads combined was inadequate. A number of strategies and alternatives were suggested to improve the level of services.

A more recent study is ***Management of Hajj Mobility Systems.*** by Al - Yafi (1993). In this book, an attempt is made to provide an overview of the Hajj and some of its problems. Particular reference is made of the specific problems of mobility during the Hajj. It proposes a solution using management logistical techniques. Overall, it is a valuable source of information for in depth study of the mobility system in the Makkah Al-Mukaramah area.

Vehicle parking in Arafat area is another problem due to the large number of vehicles. This results in congestion and parking problems for both authorities and pilgrims. Al-Adulqaader (1988) discusses these issues and introduces some engineering models to solve difficulties and suggests solutions to facilitate the movement of vehicles in Arafat area.

Each of the reviewed studies provides insight to emergency management in the Holy Sites during the Hajj season. Reoccurring main themes of these studies are emergency planning preparedness, response and recovery. However, most of these studies suggest some theoretical solutions and present alternatives, modifications, or improvements to existing systems such as the road network and expansion of the Holy Sites. However, none of these studies addresses the issue of emergency services dispatching and response, which is the focus of this research.

2.3.4 Information Technology:

The use of information technology for emergency management has gained popularity in recent years. Applications of the technology have been used for simulation and training purposes during emergencies as well as management tools to assist throughout the emergency life cycle. During this research work a number of research and case studies were reviewed some of which are discussed in more detail in the following sections.

A study by Dangermond (1989) provides a description of network analysis, network data construction, and network function in a Geographic Information System (GIS) environment as a means to provide efficient simulations for emergency management purposes. Network simulation has many applications in emergency management, including:

- evaluation of road networks by combining capacities for each road for a series of emergency situations;
- selection of locations for new emergency facilities through creation of emergency response districts;
- evaluation of potential sites for emergency vehicles to minimize response time;
- interactive dispatch of emergency vehicles; and
- identification of emergency vehicle routes for disaster plans.

Dangermond argues that the flow through networks is important for emergency management, and network simulation provides an effective means for analyzing such flows. GIS-based network simulation software can be used for allocation, districting and routing over any fabric of interconnected linear features (termed a network). Arc capacities, barriers to movement, directional impedance, turn impedance, and combinations of these factors can all be modeled. Manipulation of associated attribute files, creation of address file, and address matching can also be accomplished.

According to this study, network software generally serves the following primary functions:

- ***Routing***: determining the optimal paths for the movement of resources through a network. Each route is defined by specifying the origin and destination points.
- ***Allocation***: finding the nearest center minimum (travel cost) for each link in a network. For example, allocation functions can be used to find the nearest fire station for each street in a city.
- ***Address matching***: that is termed geocoding relating data in tabular address files to geographic locations on maps.

A study by Ramachandran and Naadimuthu (1989) highlights the response phase and planning procedures for an ambulance crops. The authors present a systematic process and model for emergency simulation purposes. Time and location as well as resources are primary factors in this model. Dividing the area, allocating resources, and calculating emergency response times are analyzed thoroughly. The final results of the model is the calculation of the waiting time of the injured person and the servicing time (busy time) of the ambulance. Periodic analysis allows reasonable evaluation of resources available, times required and constant update of information to reduce the waiting time of customers.

The authors also describe the conceptual structure of the system. In the basic sense, the system consists of three databases. The first database holds information regarding the zone, home base of ambulance, and call type. The second database evaluates and checks the status of resources. Finally, the system inputs various type of information into a third database which can be used for periodic analysis that is necessary to maintain an efficient emergency response system.

How GIS can help in a hypothetical situation of a train accident carrying chemical materials is described by Beriwal (1992). In this article, a series of the most likely asked questions in such situation were presented, these questions included resources, people, equipment as well as characteristics of the accident. The aim of the study was to assist emergency personnel carryout their duties and control the situation. The author provokes the use of GIS in the field of emergency management by utilizing the various functional capabilities of GIS for storing, manipulating, and displaying spatial data.

Other authors have concluded that GIS technology has the potential to be used in managing natural disasters such as hurricanes, earthquakes, wildfire, ...etc. (Scholton 1990, Charles and Jr 1992, Mclaren 1992, Battista 1994, Gronlund et al. 1994, and others.). The premise of these studies is to outline how GIS can be used in such situations where events are unpredictable and uncertain. The majority of the authors argue that GIS can play an important role in many phases of disaster planning and response (Johnson 1992, Hale 1992, and Gronlund et al. 1994). Further, GIS can provide key assistance in the early stages of recovery by aiding the damage assessment process (Mclaren 1992).

A more encompassing study by Johnson (1992) outlines GIS applications in emergency management. In particular, Johnson analyzes the role of GIS as applied to the disaster life cycle and its several phases from hazard analysis, vulnerability analysis, mitigation, preparedness, prediction and warning to recovery. He concludes that GIS is a valuable tool for decision-making throughout the disaster life cycle as each of its phases can be geographically referenced and requires mapping and analysis.

Another example in the use of GIS for earthquake management is provided by Mclaren (1992). The author studied the experiences of the Pacific Gas and Electric Company in using GIS for utility services in Northern California County after a 1989 earthquake. Specifically, he discusses how GIS can be used in aiding the evaluation of the effects of large magnitude future earthquakes. The focus is on spatial database organization and structure and GIS software functionality with some information regarding analysis and impact assessment of such events.

Gronlund et al. (1994) illustrate the role that information technology such as GIS and Expert System (ES) could play to improve fire management practices. Their argument is based on a prediction and preparedness approach. Using the Grouders Mountain State Park as a case study, the authors argue that the manual methods of identifying high risk areas are inefficient and there is a need for more formal procedures to deal with the problem of emergencies in State Park. The authors develop a formal procedure to generate fire management scenarios using GIS and ES concepts and techniques. The approach is based on fire risk, assessment of projection needs, and generation of management scenarios. The authors demonstrate that the system could have a direct impact in fire management at the local, regional, and national level by linking the system with other information systems that exist at these levels. Technically, linking GIS with ES may help in building an intelligent fire management decision support system.

A study by Hale (1992) provides a lengthy description of the destructive effects of Hurricane Hugo in Carolina in 1989. This mass destruction caused the Federal and South Carolina State governments to evaluate preparedness, response, and recovery activities, which resulted in a series of recommendations made by the Emergency Management Review Panel. One of the major recommendations made by the panel was to implement GIS technology at the county and state level to ensure an adequate flow of geo-referenced information during future disasters. System development and implementation in the future will be based on user needs assessment and spatial information needs analysis for emergency management.

Recently two studies have been conducted on the use of GIS for special events and mass gathering. Alvaredo and Gomes (1992) describe the use of GIS for the Summer Olympic Games security in Barcelona, Spain. A GIS Security System was designed by the Gurdia Civil to assist decision-making for national security during the Olympics. However, the application focused on the Games. Phases of system implementation and its major functions were presented. User needs analysis, database design and entry, and application development were highlighted. The use of the system for traffic management, resource allocation, monitoring VIPs, and terrain analysis were also described. The authors note that the system has an important role to play for disaster management in the future.

The other study is by Blackmon et al. (1993) which highlights the role of information technology in the forthcoming Olympic Games in Atlanta Georgia, USA in 1996. At these Games the expected gathering of more than two million people poses a real planning and management challenge to authorities. Transportation planning is a major issue in the Olympic Games. Transportation demand includes: athletes, family, and general spectators transportation as well as regular city transit and transportation services. Although the authors discuss in detail the need for effective transportation planning, they make no direct reference to the use of GIS. Instead, they mention an integrated information system to handle sports and related activities.

2.4 Justification for Research:

Emergency management is both a challenging and interesting task to society at large. The first hand experience in emergency management and handling through a field trip to Indianapolis for the sport event (Indy 500) provided a good example of the practical problems associated with this work. Although this study helped establish a framework for this research, the physical settings of the city, the nature and duration of this special activity, and the number of people coming make handling emergencies at this event very different from that of the Hajj. In addition to the magnitude of the event, the Hajj has greater space restrictions and more severe time constraints which obligate the movement of large number of people at fixed time periods. As well the diversity of the pilgrims makes emergency management and handling different than this and other of special events in North America.

Scientists and researchers from different fields of specialization have a particular interest in minimizing the consequences of emergency occurrences. A number of studies have been reviewed in the general field of emergency management and risk assessment. They provide insight into the general area of emergency management. Their focus on planning and policy issues. However, they do not provide a practical solution to the problem of using information technology for dispatching and response. A number of studies related to emergency during the Hajj season have been reviewed. Their proposed solutions are theoretical in nature. From the literature reviewed, there seems to be a recognition of the important role of GIS for emergency planning and management. Still, none of these case studies addresses the particular and practical issue of dispatching and responding to emergencies for mass gatherings.

The need for information technology for emergency dispatching and response has only recently being recognized. The above studies highlight some of the aspects related to routing and dispatching problems, especially the study by Dangermond (1989) where he discusses the issue within the context of using ARC/INFO™[3] GIS software. But he does not provide any practical solutions to such questions as which station should be dispatched first, nor how many stations should be dispatched to the incident scene, which are the kinds of problems this research attempts to answer. The other studies suggest the use of GIS for disasters in hypothetical situations and do not necessarily address the issue of dispatching and response in particular and practical examples. This research builds upon and adds elements to the highly developed emergency response field. The use of GIS technology as a decision-supporting tool for emergency management, transportation network modeling, calculating the optimal path and determining the fastest route are considered. Further, the spatial component of GIS makes it indispensable tool for emergency response and dispatch of resources. This study takes advantages of the state-of-the-art of GIS technology and makes use of its various functionalities.

The main focus of this research is on designing an IRSDSS for dispatching SRCS resources during the Hajj season, in the context of the unique religious elements, of geography, characteristics, and settings. An IRSDSS that requires a different set of modeling and design for responses based on a GIS system.

[3] ARC/INFO GIS system is trademarked and owned by Environmental Research Institute of Redlands, California, USA.

Chapter Three

3. Background to the Hajj and Study Area

3.1 Introduction:

All Moslems aspire to visit the Holy city of Makkah Al-Mukaramah in the Kingdom of Saudi Arabia (KSA). It hosts the Holy Mosque of Islam (*Almasjid Alharam)*, the Ancient House (*Ka'aba)*, and the Holy Sites of: Mina, Arafat, and Muzdalifah. Makkah Al-Mukaramah was the birthplace of the Prophet Mohammed, and it is also where he received the revelation of the Holy Quran at the *Hiraa* Cave. Makkah Al-Mukaramah is the spiritual Capital of Islam, so every year millions of Moslems make a pilgrimage journey to the Holy land to perform the Hajj.

The Hajj is a religious duty and is the fifth pillar of Islam. It can be considered an international Islamic conference where Moslems from different ethnic, cultural, and traditional backgrounds gather every year to perform the Hajj rites. This gathering and performance of Hajj activities gives Makkah Al-Mukaramah distinct characteristics, as every year it experiences the most dramatic demographic change for a very short period of time.

In this chapter, the characteristics of Makkah Al-Mukaramah as a Holy City and a description of Hajj activities that take place every year are presented. The management and organization of Hajj activities are also discussed. In addition, the types of emergencies and their causes are also presented. The chapter concludes with description and discussion of the Arafat pilot area selected for this research study.

3.2 Geography:

Makkah Al-Mukaramah is located in the western part of Saudi Arabia known as the Hijaz region as shown in figure 3.2.1. Geographically, it lies on the intersection of latitude 21° 25' N and longitude 39° 49' E. The city is located on a rugged landscape consisting of mostly solid granite hills, at times reaching 300 meters (1000 feet) above sea level. The city is in the valley of Abraham, and surrounded by mountain ranges to the east, west, and south. Along the north are the Al-Falaq and Qu'aqi'an mountain ranges, while the Abu Hudidah mountain range is along the west, the Kuday mountain is along the south and Abu Qubais and Khindimah mountains lie to the south east.

The climate of Makkah Al-Mukaramah area is generally hot and arid. The temperature reaches a maximum of 45° C in July and 35.5° C in January. The minimum recorded temperatures are 33° C in July and 24.5° C in January, while average temperatures are 37.5° C in July and 29.5° C in January. Rainfall is averaging 37 mm per annum.

The city of Makkah Al-Mukaramah consisted of an area of about 5 km^2 in 1955. However, due to rapid development over the past few decades, the area has increased to about 180 km^2 (not including the Holy Sites of Mina, Arafat and Muzdalifah).

According to the latest Saudi Arabian census, Makkah Al-Mukaramah is inhabited by over 600,000 residents. During the Hajj season this number increases dramatically to over 2,500,000. When Hajj is over, the population reduces to its normal size with some fluctuation from time to time, as visitors come to perform (*Umra*), sometimes known as the small Hajj. Umra, although tied to certain ritual activities, is not tied to a specific time and can be performed at any time of the year and as many times throughout the year.

3.3 The Hajj:

In a literal sense, Hajj means taking the direction of a destination. In Islam, Hajj means making the journey to Makkah Al-Mukaramah with the intention of fulfilling the Hajj rites. Each physically, financially and mentally capable Moslem male or female is required to perform Hajj at least once in his / her life time, as specified by Allah in the Holy Quran:

> *"Pilgrimage thereto is a duty men owe to God, those who can afford the journey..."* (Sura III,v. 97).

In addition, Muslim and Al-Nisaae reported that the prophet Mohammed said:

> *"O Muslims! Allah has enjoined Hajj on you; so perform it."*

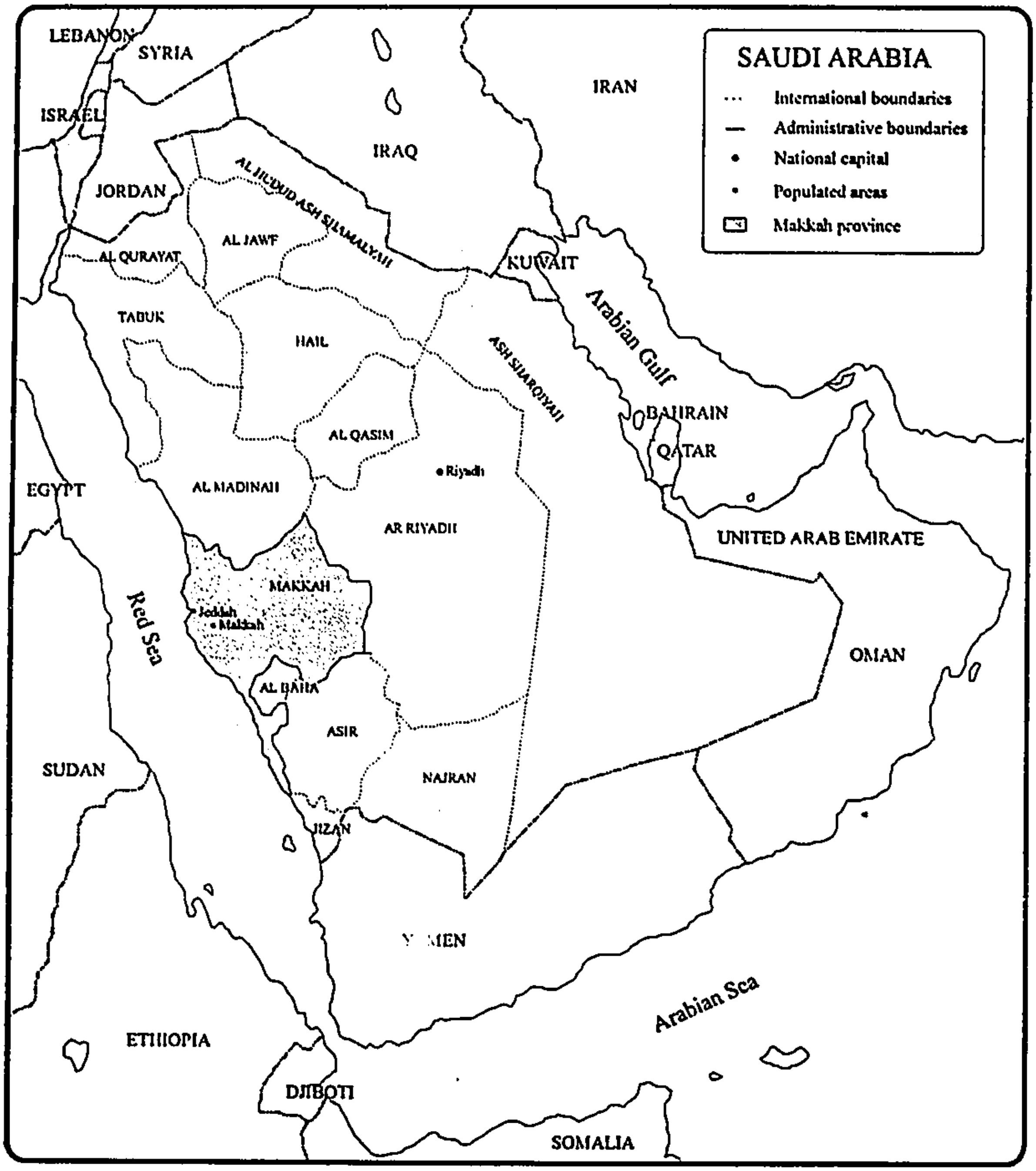


Figure 3.2.1: Makkah Al-Mukaramah Area

As noted, approximately two million people from different cultures, languages, traditions, and ethnic backgrounds come to the City of Makkah to perform Hajj. The most recent statistics of Hajj participants are shown in table 3.3.1, where the rate of growth of visitors arriving to Makkah and its surrounding Holy Places for the period of 1978 - 1992.

Table 3.3.1: Number of Pilgrims between 1978 - 1992

Year	Residents	Foreign	Total	Growth rate %
1978	1069184	830236	1899420	100
1979	1217169	862520	2079689	9.49
1980	1136742	812892	1949634	-6.25
1981	1063812	879368	1943180	-0.33
1982	1158000	853555	2011555	3.52
1983	1497795	1013911	2511706	24.86
1984	744807	919671	1664478	-33.73
1985	738015	851761	1589776	-4.49
1986	743757	856718	1600475	0.67
1987	658938	960386	1619324	1.18
1988	616801	762755	1379556	-14.81
1989	692435	774560	1466995	6.34
1990	817234	827236	1644470	12.10
1991	908084	720102	1628186	-0.99
1992	856138	1014141	1870279	14.87
Average	917838	864970	1782807	0.89

Using the data from the table, it is apparent that the number of domestic pilgrims has declined since 1983. This can be attributed to many factors but, perhaps most important, is the legislation which restricts the number of times one can perform Hajj in five years. In other words, a person can perform the Hajj only if five years have passed from his / her last performance.

3.3.1 Essential Components and Obligations of Hajj:

As noted, the Hajj is the fifth pillar of Islam, which are referred to under the Islamic laws (*Shari'a*) as a series of prescribed acts. The Hajj consists of several essential ritual components that must be completed as well as several obligations that should be performed. The following are the ritual components of Hajj:

- *ihram:* wearing the required apparel for the Hajj;
- *standing at Arafat:* during the 9th day of Du-Alhijjah;
- *sa'i:* striding for seven laps between the hills of Al-Safa and Al-Marwa; and
- *circumambulating the Ka'aba for seven laps:* marking the end of the Hajj known as (*Tawaf Al-Ifadah*):

Missing or omitting performance of one of these components invalidates the Hajj altogether. The Hajj is said to be incomplete unless they are all performed.

Obligations of the Hajj that each pilgrim should perform include the following:

- *ihram from (Miqaat):* wearing the required garment for Hajj before passing specified locations outside Makkah Al-Mukaramah;

- *spend a night at Muzdalifah:* during the 9th day of Du-Alhijjah;
- *throw a prescribed number of pebbles:* at the specific times and at the particular locations known as *Jamarat*;
- *spend the nights of the days of Tashriq at Mina*;
- *circumambulate the Ka'aba:* Farewell Tawaf; and
- *shaving and shorting of the hair.*

Omitting or missing one of the above obligations does not necessarily invalidate the Hajj. However, if a pilgrim misses one of these obligations, he / she must make a sacrificial offering.

3.3.2 Time and Space Components of Hajj:

As mentioned earlier, the Hajj takes place at certain times and at certain locations. In this regard, time and space become fundamental aspects of the phenomenon that are fixed. The Hajj can begin as early as the first day of the tenth month (Shawwal) and ends on the fourteenth day of the twelfth month (Du-Alhijjah). Although, this time-frame may seem long, as it extends for approximately two and half months, the major events and activities of the Hajj take place within five days beginning on the 9th day and ending on the 14th day of Du-Alhijjah.

Space is also an integral part of Hajj, as activities are performed in specific locations within Makkah Al-Mukaramah. These locations are bounded by an invisible religious borders based on the Moslem faith. One begins the Hajj by making the trip to the God's house in Makkah Al-Mukaramah. Next, pilgrims perform Tawaf which is circumambulating the Ka'aba, that is followed by performing Sa'i, walking in hurried steps between the hills of Al-Safa and Al-Marwa. These Hajj functions are performed by all pilgrims upon arrival to the Holy city. They take place inside the grounds of the Holy Mosque and are not necessarily tied to any specific time.

Waquuf at mount Arafat, which requires pilgrims to stop during the 9th day of Du-Alhijjah. It is at this point that the Hajj begins in earnest for all pilgrims within Makkah. As it is considered the first day of the Hajj, it is also at this stage that specific time and space restrictions apply to each pilgrim performing the Hajj. After stopping at mount Arafat, pilgrims depart to Mozdalifah and collect pebbles to throw at the symbolic devils in the Valley of Mina, in the completion of all of the Hajj rites. What is most critical, is that these functions involve the movement of millions of people and thousands of vehicles in a very short time (Alsawydani et al. 1995).

3.3.3 Hajj and other Activities:

Hajj and other activities such as major sporting and cultural events have some similarities and a few differences. The general concept of a mass gathering and the requirement for provision of services and accommodation are similar. However, the number of people gathered and type of services required also represent some of the differences. Comparison of the types of activities and the physical setting along with other aspects is shown in table 3.3.3.1.

Table 3.3.3.1: Comparison between Hajj and other Activities

Settings	Hajj	Sports	Oil
Physical setting			
Time	Fixed	Pre-determined	Un-determined
Location	Fixed	Pre-determined	Un-determined
Setting	Open	Urban/Semi-urban	Urban
Activities			
Type	Religious	Recreational	Safety
Duration	Fixed	Controlled	Controlled
Emergencies			
Occurrence	Unpredicted	Unpredicted	Unpredicted
Observation	Planned	Planned	Planned
Response	Difficult	Moderate	Moderate
Verbal Communication	Difficult	Moderate	Easy
Facilities			
Type	Varies	Varies	Varies
Duration	Temporary	Determined	Permanent
Use of GIS technology	Applicable	Applicable	Applicable

In addition, considering the unique characteristics and settings of Hajj, incidents and their required responses may differ from those that usually occur at major sporting or cultural events for the following reasons:

- the open space environment of the Holy Sites;

- the large number of pilgrims with diverse backgrounds;
- the interaction between pedestrian and vehicles; and
- the level of institutionalized response services.

At a typical sporting or cultural event, the planning and allocation of emergency resources, and responses can be implemented based particular knowing quantities. The population density, the characteristics and distribution of participants, and the accessibility of the road network are significant factors when planning for emergencies. Unlike such circumstances, people gather and perform Hajj activities in an open space environment, where great number of people are in constant movement within this open but limited environment. Planning and allocation of resources, and even response to an incident, is difficult to deal with. Difficulties in response can be attributed to traffic congestion, traffic plans, drivers habits, pilgrims, guides, and to the transportation system itself.

3.4 Hajj Organization and Management:

Because over two million pilgrims perform Hajj every year, tremendous responsibilities and obligations are imposed upon the Saudi government and its various agencies to provide the best possible services. Ensuring the safety and well being of pilgrims and residents of Makkah Al-Mukaramah is critical, while allowing the correct observation of the Hajj rites is of paramount importance as well. Since the unification of Saudi Arabia in 1932, Makkah Al-Mukaramah and Almadinah and other Holy Sites continue to undergo a rapid pace of development and modernization. The Saudi government has made extensive commitments to upgrading the area of Makkah Al-

Mukaramah for pilgrims participating in the Hajj. A first order of investment was made to secure travel routes of the Hajj and to ensure the safety of pilgrims. Concurrently, and at present, the government has invested heavily in facilitating the arrival, transportation, feeding, and accommodation of pilgrims performing the Hajj functions.

The Saudi government has given a high priority to development infrastructure and utilities projects in this area. Table 3.4.1 shows some of these major projects and their related costs. Most important projects include upgrading of the two Holy Mosques and the Sacred Places, including connected utilities, roads, tunnels, and other infrastructure at a cost totaling over Saudi Riyals (SR) 29 billion (approximately 7.7 billion US$).

Table 3.4.1: Projects in the Two Holy Mosques Including Utilities

Project	Total costs (SR)
Extension and upgrade of the Two Holy Mosques, including buying land necessary for the extension.	5,894,998,000
Mina project development and projects of the Ministry of Hajj and the Municipality of Makkah for the construction of tunnels, roads, water towers and automatic slaughterhouses, in addition to expropriation costs.	11,619,365,000
Madinah municipal projects, including improvement and upgrading of roads surrounding or leading to the prophet's mosque.	2,406,698,000
Highway projects in the Hajj areas of Makkah and Madinah.	9,085,302,000
Total (1 US $ = 3.75 SR)	29,006,363,000

Source: Kingdom of Saudi Arabia, Ministry of Information, (no date) P:31.

3.4.1 Hajj Management:

The organization and management of the Hajj are complex and considered as an important matter to the Saudi government. Almost all government agencies are involved in Hajj activities in one way or another. In recognition of the importance of the Hajj, King Fahad bin Abdulaziz named himself Khadim Al Haramin Al Sharifain or (Custodian of the two Holy Mosques).

The management of the Hajj and its related activities are mandated to a number of committees with specific authorization to implement Hajj related policies (Al-Gamdi et al. 1985). Each committee operates independently with linkage to the higher order committee. The committees are composed of several subcommittees each directing a specific activity related to the Hajj. Figure 3.4.1.1 shows the hierarchical structure of Hajj administrative and controlling system. The two most important committees are the Supreme Hajj Committee (SHC) and the Central Hajj Committee (CHC).

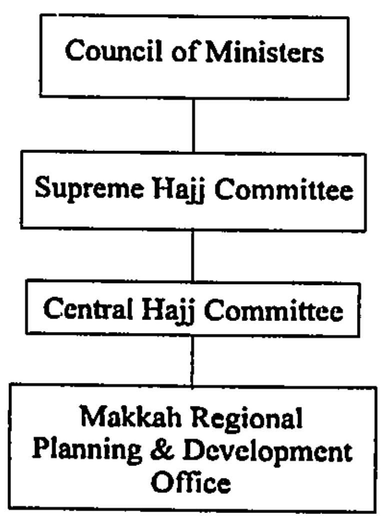


Figure 3.4.1.1: Hajj Management

3.4.1.1 Supreme Hajj Committee:

The Supreme Hajj Committee is the highest committee in the Hajj administrative system, and it reports directly to the Council of Ministers for formulation and implementation of polices and other financial matters. The SHC has the Minister of Interior as its president and the Emir of Makkah as its vice president. It also includes the membership of seven ministers, from the following ministries: External Affairs, Planning, Urban and Rural Affairs, Finance and National Economy, Communications and Transport, Hajj, and Industry and Electricity. The Director of Haramin and Chief of Public Safety are also members of this committee. Beside these formal members, the Ministers of Post, Telegraph and Telephone, of Higher Education (Hajj Research Center), and of Commerce are indirect participants of the committee (Al-Gamdi et al. 1985).

The primary mandate of the SHC is to study and carry out policies ordered by the Council of Ministers. It also evaluates recommendations and policies of the CHC as well as approving and regulating Hajj plans prepared by the Hajj administrative organizations and operational bodies.

3.4.1.2 Central Hajj Committee:

The Central Hajj Committee represents the next level of Hajj administrative authority. It is presided over by the Emir of Makkah and Deputy Emir of Makkah acts as vice president. It includes in its membership representatives from functional or operational departments and agencies, these include ministries of: Finance, Health, Commerce, Electricity, the Saudi Arabian Public Transportation Company, the General Directorate of

Roads, Civil Aviation, Water and sewerage Board. Other members include: the Mayor of Makkah, the Chief of Red Crescent Society, and the General Director of the Mina Project. The CHC also includes other sub-committees such as the Technical Sub-Committee, the Land Distribution an Allotment Sub-Committee, and other Hajj planning Sub-Committees of Makkah, Almadinah, and Jeddah.

The primary role of the CHC is to study and approve the Hajj plans prepared by individual government and non-government bodies to produce an overall master Hajj plan. This master Hajj plan is then submitted to the SHC for approval and provision of financial sanctions (Al-Gamdi et al. 1985).

3.5 Emergencies during the Hajj:

During the Hajj season many incidents occur resulting in injury, death and / or damage to property. The most recent data concerning incidents is provided in table 3.5.1, that illustrates the number of deaths from incidents during the period of 1989 and 1993.

Table 3.5.1: Number of Deaths in Makkah and the Holy Sites between 1989 - 1993

Location	1989	1990	1991	1992	1993
Inside Hospital	476	242	223	547	368
Outside Hospital	631	382	193	438	311
Total	1098	624	416	985	679

Source: Kingdom of Saudi Arabia, Ministry of Health (1993).

The following observations can be made from this table:

- the total number of deaths reported fluctuates yearly, but is significantly high;
- death cases outside of hospitals in 1989 and 1990 are higher than those reported inside hospitals;
- death cases reported outside of hospitals in 1991, 1992 and 1993 are less than those inside hospitals reflecting some improvement in level of emergency services and response; and
- more than 50% of deaths have occurred outside hospitals.

Exhaustion, sunstroke, disorientation, discomfort and even death are caused by a combination of many factors. Among these are: high temperatures (reaching approximately 45° C during the summer) combined with low precipitation; high concentration of people in certain areas, such as Mercy Mountain and Namirah Mosque areas; mass movement between the Holy Sites along with interaction between people and vehicles; and the overall health condition of pilgrims. While difficult to describe the amount of confusion and movement within the limited space, figure 3.5.1 provides an example of the interaction between vehicles and pedestrians and the severe limitations on space during the Hajj.

The Ministry of Health takes extraordinary preventative measures to ensure the safety of pilgrims. Each year, the ministry provides pilgrims with health care whether they are resident of Saudi Arabia or not. A great deal of effort is made to protect pilgrims as well as the residents of Makkah Al-Mukaramah from the spread of contagious diseases. Treatment for regular health care regiments are also provided for pilgrims.

Figure 3.5.1: Interaction between Vehicles and Pedestrians during the Hajj.

In addition to minor emergencies, many disasters occur during the Hajj. There have been a number of major incidents that have resulted in high casualties. Among them are the following:

- the Iranian incident 1987, a man-made incident that resulted in loss of 402 lives and as many as 649 persons wounded (The Ottawa Citizen 1994). This incident and its dramatic results was due a demonstration of about 155,000 Iranian pilgrims. The demonstration turned violent and many people were killed;
- fire incidents in 1987, 1988, and 1990 that were unintentional but man-made incidents which resulted in mass destruction of property (Al-Amri 1995). Almost every year a fire is recorded in a tent camp or pilgrim residential areas. These are primarily due to crowding and food preparation activities;
- the Al Mu'aisim tunnel incident in 1990, which resulted in loss of 1,426 lives (The Ottawa Citizen 1994). This incident was due an electric power failure which resulted in suffocation and death of many people; and
- the Jamarat incident in 1994, where overcrowding resulted in loss of over 800 lives (The Ottawa Citizen 1994). Overcrowding and panic were the major causes of this incident, where pilgrims died when they were knocked from a crowded overpass.

3.6 Study Area:

Arafat area was chosen as the pilot area for this study and shown in figure 3.6.1. It is located at the intersection of 21° 21' 50" N and 39° 58' 30" E, located slightly to the south east of Makkah City. Arafat is one of three Holy Sites where the majority of Hajj activities take place. Arafat is significant where pilgrims perform Waquuf, where all pilgrims must stop during the 9th day of the Du-Alhijjah month. After sunset, pilgrims immediately depart to the Mozdalifah area, during a ritual called (*the nafrah*). The distance between the two sites is approximately seven kilometers, and the movement of people and vehicles between these two Holy Sites causes great congestion and constitutes an important pressure point in the whole process of Hajj.

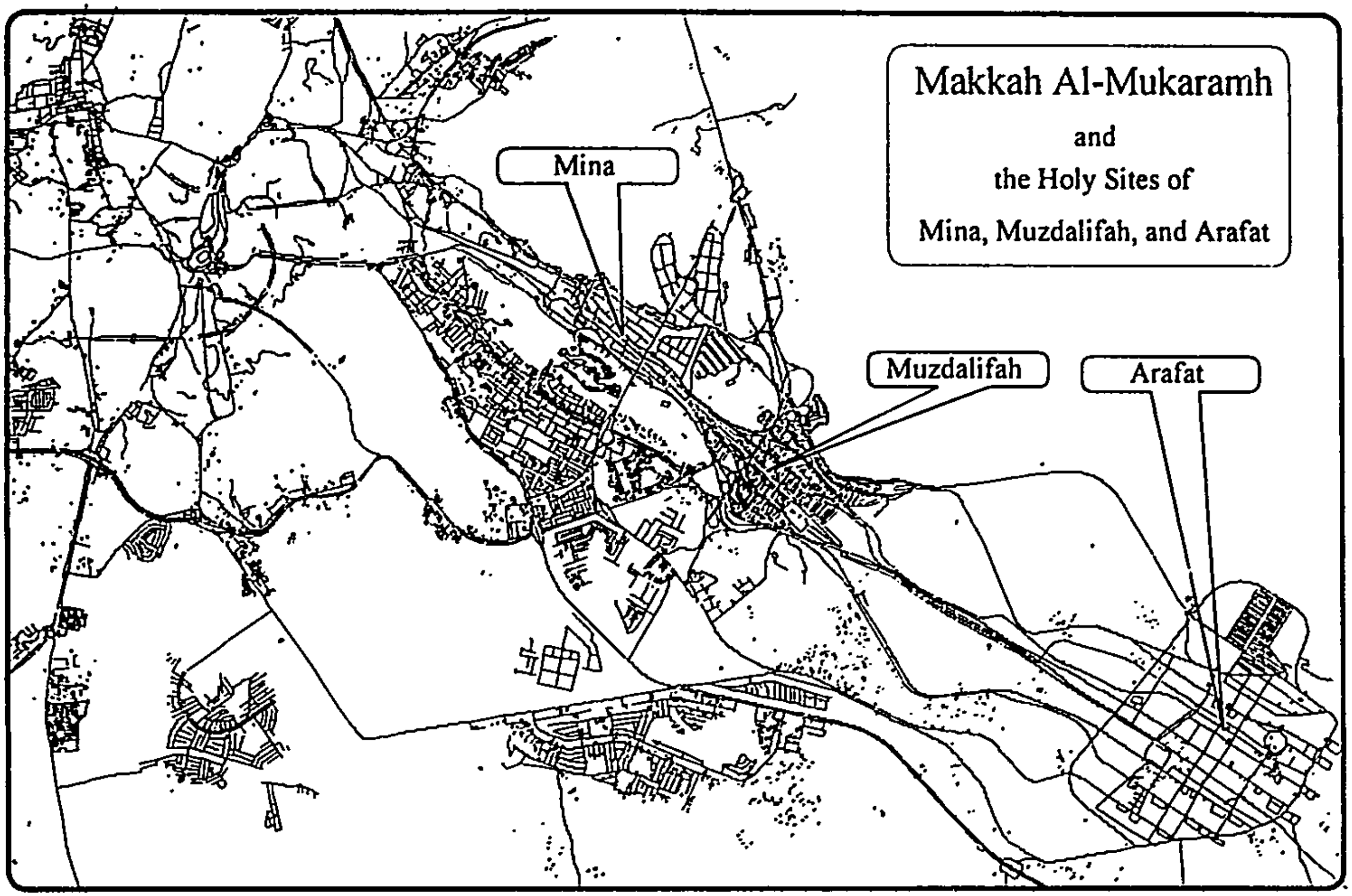


Figure 3.6.1: Arafat and other Holy Sites

Arafat has an area of approximately 1368 hectares within its religious boundaries (Al-Shamrani 1988). The total area of land used is about 1124 hectares, representing 82% of the total area. Table 3.6.1 provides details of the landuse within the study area. Using the data from the table, it is apparent that tent camps are the dominant landuse accounting for 37%. Next is the road network for about 29%. Car parks represents approximately 15% followed by pedestrian ways 7%. Namirah Mosque and Mercy Mountain come last with 0.7% each.

Table 3.6.1: Landuse Types in Arafat Area 1988.

Landuse	Area m^2	Percentage
Tent camps	4168262	36.63
Government services	1315228	11.55
Road Network	3245579	28.52
Car Parks	1659211	14.58
Pedestrian Ways	829606	7.3
Namirah Mosque	80937	0.71
Mercy Mountain	80937	0.71
Total	11378749	100

Source: Al-Shamrani, (1988) P:39.
* Landuse area is converted from hectares to square meters.

During the Hajj the density of pilgrims in Arafat is high as shown in table 3.6.2. Overall, the density of pilgrims is about 0.2 person/m^2 for the total area of Arafat. If one consider the tent camps only, the density of pilgrims increases to about 0.5 person/m^2.

Arafat is served by three hospitals, forty health care centers, one sunstroke center, and fourteen red crescent stations, in addition to other services within its core. Care is made to ensure that adequate health care facilities are provided. In this regard, table 3.6.2 shows the area served by health care facilities. As noted each hospital serves an area of about 277494 m^2 , approximately 1.7 x 1.7 km. Each health care, sunstroke, and red crescent center serves an area of about 163223 m^2, or 0.4 x 0.4 km. In general a pilgrim is able to access facilities as soon as they depart from their tent. Most equipment and personnel can be moved to other locations where they are needed.

Table 3.6.2: Density of Pilgrims and Other Medical Services in Arafat Area.

Landuse m^2	Pilgrims' Residential Use	%	Density Person/m^2	RC & HC /m^2	Hospital /m^2
11378749	4168262	30	0.5	163223	2774794

* Total land use and pilgrims residential use is based on the 1988 landuse Al-Shamrani, (1988).
* Pilgrims density is based on the average pilgrims of 2 million.
* Hospital, RC and HC services are based on the open space areas only.

The road network and the location of emergency facilities play a key role in facilitating the foundation of the IRSDSS. The Arafat area has several types of roads within its core to meet the demands of pedestrian and automobile traffic. Some of the roads are for exclusive use of pedestrians while others are designated as shared routes for pedestrians and automobiles. In addition, the pilot area has a high speed traffic ring road around the perimeter of the area. The high speed road is connected to an interior network through a series of intersections and interchanges. These serve as transfer points to move traffic from one type of road system to another, thus satisfying the requirements for local and long distance traffic. The ring road is also used for moving local traffic when the interior network is fully utilized thus it becomes a holding reservoir for pedestrians and vehicles.

Roads within the study area are with varying widths and conditions. Road widths range from approximately five meters to eighteen meters for vehicles, and pedestrian road widths may be up to thirty meters. The road surface are paved and well maintained. The road network is maintained periodically to ensure its efficiency for flow of traffic.

3.7 Summary:

Millions of Moslems from all walks of life perform the Hajj each year. With the arrival of pilgrims significant demographic and landuse changes occur in Makkah Al-Mukaramah and its surrounding Sacred Places. In response to these facts, the Saudi government and its various agencies give a high priority to the Hajj and its related activities. This includes: a number of expansion and development projects, provision of basic services, infrastructure but most important to this study, administrative planning and emergency services.

A complex hierarchical administrative system has been established to provide pilgrims with the best possible services and conditions. The system consists of various administrative levels ranging from Council of Ministers to the Makkah Regional Planning and Development Office.

Health care services and planning for emergencies are also major efforts on the part of the Saudi government. Various preventative and precautionary measures are taken to prevent emergency and disaster occurrences. However, regardless of these efforts, serious emergencies and disasters still occur causing injury and death to pilgrims and significant damage to property. Fires, terrorist acts, weather conditions, the high concentration of pilgrims, the spread of contagious diseases, the overall health conditions of pilgrims, and lack of effective verbal communications contribute substantially to the problem. Rescue efforts to aid emergency situations are severely restricted by the conditions of weather, number of persons, religious activities and severe time and physical space variables.

The area of Arafat was chosen as the pilot area for this study. Its significance is related to time and space restrictions, and its major role in the Hajj performance. Notable are the need for all pilgrims to collect in Arafat during the 9th day of Du-Alhijjah and the requirement to move to Muzdalifah before dawn.

Chapter Four

4. Preliminary Phase

4.1 Introduction:

The primary function of a preliminary evaluation phase is to study the feasibility of system development (Capron 1986), from which will result the process of system development. Conducting the feasibility study for the proposed IRSDSS required identifying each potential user of the system. In addition, the feasibility study required an evaluation of the problems with the emergency operations of the SRCS during the Hajj. Defining the scope and the objectives of the system were important issues during this stage. An added element was geographic data, an integral part of developing any spatially referenced system. The sources and quality of geographic data also had to be identified and assessed thoroughly. This is particularly true in the case of the SRCS, who do not produce or have such data within its departments. An initial justification analysis was also considered as an important aspect during this stage of system development.

This chapter identifies the potential users from and within the SRCS. It then proceeds to define and evaluate the problem with existing emergency management practices employed by the SRCS. Determining the scope of the system and setting its primary objectives were the next steps. Followed by identification and evaluation of sources and quality of spatial and attribute data to support system development. The chapter concludes with presentation of a justification analysis. Each of the steps in the preliminary phase are shown in figure 4.1.1.

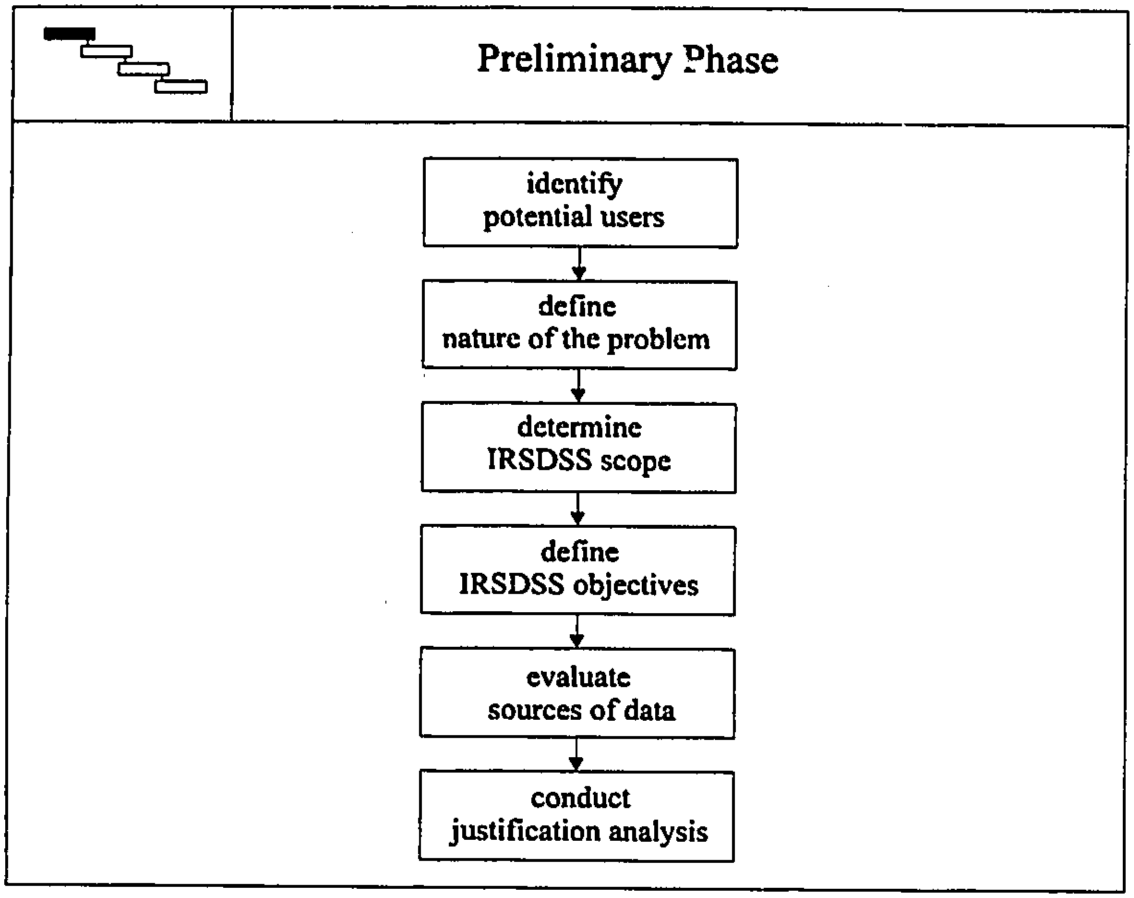


Figure 4.1.1: Preliminary Phase

4.2 Potential Users:

The Saudi Red Crescent Society has a significant role to play during the Hajj season. It was founded in 1953 as a charitable organization that offered support to Hajj pilgrims (Al-Hazzaa 1995). In 1963 a royal decree was issued which made the SRCS the primary public ambulance service for the entire Kingdom. SRCS independently or in cooperation with other government agencies provides the community with the following services during disaster incident (Al-Hazzaa 1995):

- triage and treatment for the victims of disasters and mass casualty incidents;
- stabilization and transportation of victims to medical facilities;
- provision of medical care for patients, during transport to medical facilities or medical care in the field;
- assistance with vehicular rescue, and cooperation with other agencies to provide incident command and scene control, in addition to cooperation with other agencies for research on rescue activities during disasters and mass casualties;
- provision of community health information, relief, and public education;
- contribute support to other government bodies in the operation of relief centers for the distribution of food, water, clothing, shelter.
- operations of field medical facilities serving the general public; and
- general support of the health care system by providing additional medical personnel as required.

At present, the SRCS manages 150 ambulance's stations, operated by 1828 Emergency Medical Technicians, 84 Advanced Emergency Medical Technicians, and eight Paramedics (Al-Hazzaa 1995). The medical care provided by the SRCS may range from advanced life support medical services to general first aid and health services During the Hajj season of 1994, 65 stations were positioned in the Makkah and Holy Sites area to provide extensive emergency medical services and relief operations to pilgrims (Kingdom of Saudi Arabia, The Saudi Red Crescent Society 1994). In recognizing the problems and the need for an IRSDSS, it is important to highlight the many functions and activities of the SRCS during the Hajj season. As these lead to identification of potential users of the system.

Each year the SRCS prepares a program for its Hajj operations. This program includes the management and administrative structure of the SRCS, the division of activities to working levels as well as the distribution of its working force and their locations throughout the Makkah Al-Mukaramah area. Figure 4.2.1 shows the structure and division of activities of the SRCS during the Hajj period. The structure consists of several committees and working groups. The top level of these committees and groups is the Supreme Hajj Affairs Committee (SHAC), that formulates and oversees all SRCS Hajj related policies and operations. Policy and general planning for the Hajj program is provided by the Steering Committee (SC) that has the following responsibilities:

- to evaluate and monitor emergency medical services according to prepared service forms;
- to study and investigate all matters referred by other committees and groups; and
- to evaluate all aspects of the Hajj program and to submit the program to the SHAC to consideration of the following year's Hajj program.

Operations Committee (OC) handles much of the operations under the Hajj program. It is probably the one of more important committees to assist in the foundation of the IRSDSS. It has the following responsibilities:

- to determine the range of each SRCS station operations;

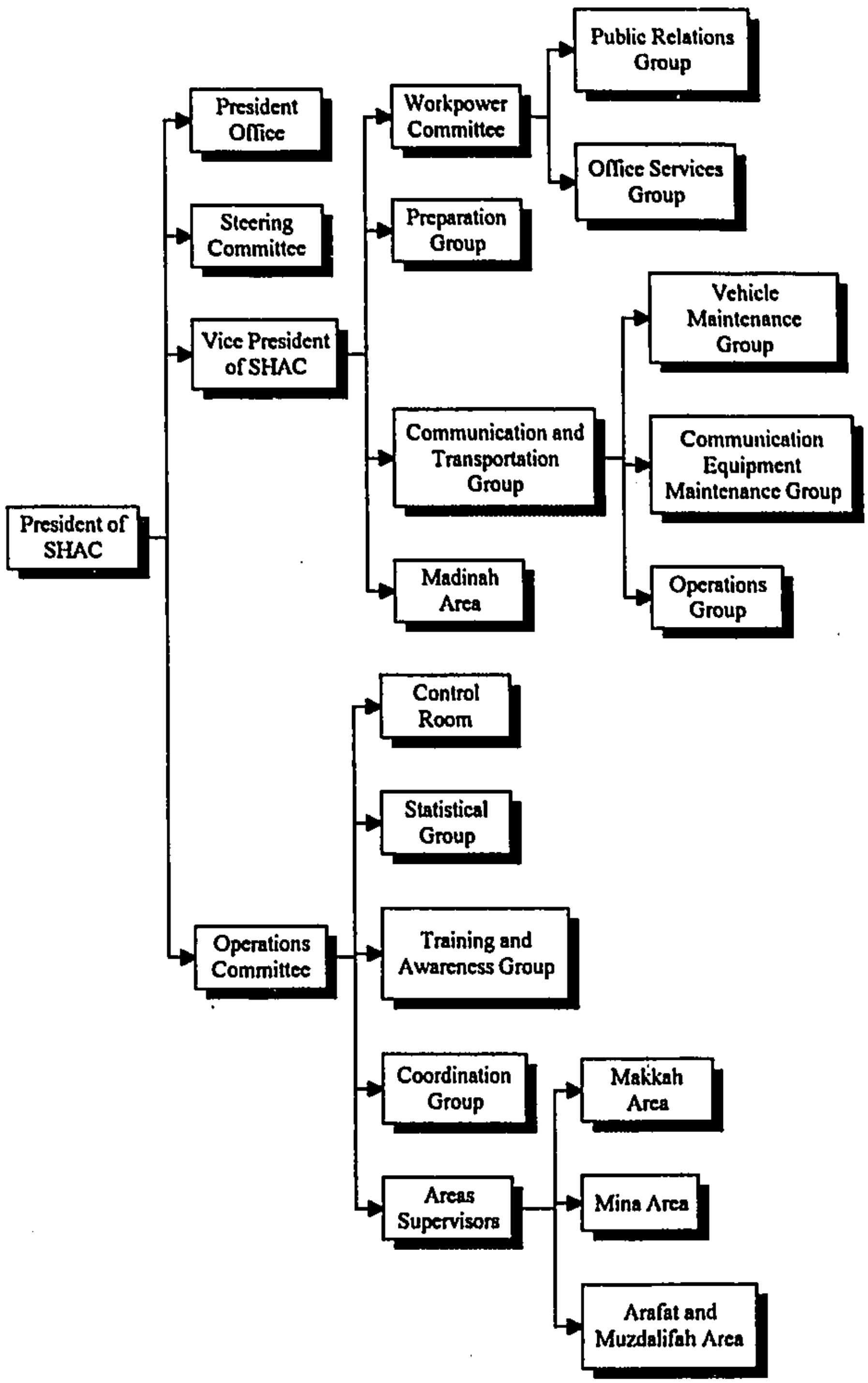


Figure 4.1.2: Administrative Structure of SRCS during the Hajj.

- to design an operational and emergency plan for each station, as well as assist the need for additional support where needed;
- to design the necessary categories for emergency types and medical services and to coordinate activities with other groups;
- to prepare a daily emergency statistical report and a comprehensive report at the end of Hajj season; and
- to organize and manage emergency communications and services.

An important group within the SRCS is the Statistical group (SG) who are concerned with the following issues of activities:

- designing and providing the necessary statistical reports and forms for other groups with guidelines for standardizing statistical data format;
- collecting the SRCS statistical data by obtaining information directly from the stations and from areas supervisors;
- compiling statistical information of the SRCS stations during the Hajj in Makkah and the Holy Sites. Information is classified according to station size, incident type, nature of diseases and their causes, and response time and location; and
- evaluating the performance of emergency vehicles using patient rescue reports which include the rate of frequency to medical facilities and the number of rescued incidents.

Each of the above mentioned committees and groups are potential users of the system for their emergency related operations. In this regard, the OC is likely to be the extensive user of the proposed IRSDSS. Its mandate is directly associated with emergency response activities.

4.3 The Nature of the Problem:

When SRCS is notified about an emergency incident the information originates from an authorized control room, they then respond to the incident with limited information, intuition and informal experience respond. Conventional paper maps are used to identify the incident location, and the nearest SRCS station. In addition to an individual's knowledge about the existing transportation network, paper maps are used to dispatch emergency vehicles and personnel to the scene. The routes to the nearest medical facilities, if the situation requires transporting patients, are also determined in this fashion.

The difficulty with the existing response methods is that responding to the incident is a complex issue, as the traffic plans and direction of traffic flow change continuously and determining the optimal route where the conditions present becomes complicated. Documenting emergencies becomes important as these become statistics and information used to respond to the next incident. In essence, these were the lessons learned for future service and response efforts. However, such information is recorded, collected and compiled manually, thus important information such as emergency type, location, response time, and other related data are often not available for long periods, in many instances following the end of the Hajj period.

In addition, humans tend to perform poorly under situations involving extreme stress (Belardo and Wallace 1989, and Comfort 1985). Thus, mistakes could be made and opportunities lost, as response efforts rely on limited information of differing qualities. In the nature of incidents the consequences are high.

The problems with the operations of SRCS can be characterized as follows:

- response to emergency operations by the SRCS are carried out manually;
- conventional maps are being used for emergency management and response; and
- the SRCS activities and performance during the Hajj are documented manually.

Overall, uses of conventional methods tend to be slow, and the need for an automation becomes a necessity. The IRSDSS developed by this research can be a valuable contribution to SRCS's efforts to enhance their emergency management mechanisms.

4.4 IRSDSS Scope:

The operations of the SRCS during the Hajj involve several key aspects. These include management and administrative aspects, such as creating and updating data for the SHAC, as well as preparing and dealing with emergency events. The primary scope of the IRSDSS is to help the SRCS professionals to response to emergencies in an efficient manner. Therefore, its scope is limited to the automation of emergency response and dispatch operations, as follows:

- determining the geographic range of each station; and
- managing emergency response and dispatching operations.

4.5 IRSDSS Objectives:

The objective of the IRSDSS is to provide the SRCS with an automated flexible incident emergency response system. The IRSDSS should include the following features:

- improved emergency response and dispatch time;
- precise incident response maps for routing; and
- reliable emergency reporting and documentation facilities.

It is presumed that emergency response times can be improved using the IRSDSS over conventional methods. If the SRCS response personnel are provided timely and accurate information, then system should assist them to respond properly. Generating emergency maps is a prime feature of the system. In addition, the system should be designed to generate the following three types of maps:

4.5.1 Response Maps:

Dispatch of personnel and resources to an incident scene or to medical facilities requires the use of emergency response maps. These types of maps are particularly critical since some of the SRCS personnel may not be familiar with the Hajj areas because they come from different parts of the country. In consideration of these elements response maps should contain directions to the incident scene and / or medical facilities. As such the response maps must include the following:

- the incident location;

- direction to the nearest SRCS station;
- the road network;
- the shortest path to the incident;
- location to medical services centers and evacuation centers; and
- other secondary data.

4.5.2 Geographic Range Maps:

Geographic range maps probably required before the Hajj season as part of the planning and preparation process. These maps will assist the evaluation of the SRCS services and performance based on its size, resources and capacity. Using location, population densities, and proximity analysis the IRSDSS will asses the adequacy of service delivery. The system will have the capability to generate geographic range maps with the following features:

- the SRCS stations locations;
- the geographic range of each station; and
- road network.

4.5.3 Traffic Maps:

Traffic maps are important to record the movement of vehicles in and out of the Holy Sites, and to monitor the traffic flow throughout the Hajj period. During the mass movement of pilgrims, incidents happen, and there is a need to generate traffic flow maps to assist in the dispatch of emergency vehicles to the incident scene. This type of map can also be used by the traffic police or any other agency dealing with traffic or the flow / movement of pilgrims. The IRSDSS will provide traffic maps with the following features:

- road network; and
- traffic flow directions.

4.6 Sources of Data:

It is accepted that geographic data is an integral part of developing a spatially referenced system. Since this type of data is not usually produced or available within the SRCS organization, it is important to identify potential sources of such data. Various agencies such as MOMRA, the Military Survey Department (MSD) of the Ministry of Defense and Aviation, and Ministry of Petroleum and Mineral Resources (MPMR) are major sources of maps in Saudi Arabia.

MOMRA for example, is a major source of medium and large scale maps ranging from 1:500 to 1:25000. The ministry has already started a conversion process of producing these maps in digital format as well as conventional paper maps. In fact, for this research project a digital spatial database was obtained from MOMRA for emergency dispatch simulation in the Arafat study area.

Until recently, the Aerial Survey and Mapping Department (ASMD) at the MOPMR was considered the primary source of mapping services in the KSA. Its mapping production included, topographic maps for the entire country, thematic maps from data furnished by government agencies, and large scale maps for use in town planning, road design, and other purposes. That role has now been taken over by the MSD which under its mandate, is required to take over map production and services for both military and civilian applications at scales from 1:25 000, 1:50 000, and 1:250 000. At present, MSD actively produces and collects digital data for map production and other related activities.

Aerial photographs within the Kingdom are also available from MOMRA. Urban cities and large villages have been covered by aerial photographs at scales of 1:5000 - 1:50 000. Aerial photographs can be used to generate photo mosaics orthophoto maps in digital and conventional map production, and to update existing maps. MSD is responsible for conducting all aerial surveys in the Kingdom.

Satellite remote sensing is also another valuable source of geographic data. In this regard, the Kingdom has its own receiving station for satellite data. The Saudi Remote Sensing Center (SRSC) of King Abdulaziz City of for Science and Technology (KACST) operates a receiving station and processes data from LANDSAT TM and MSS, the SPOT HRV sensor and the NOAA/TIROS AVHRR sensors (Al-Ankary 1991). Remotely sensed data which can be interpreted and processed by information technology, are becoming an important source of geographic data.

In addition to the above mentioned sources of geographic data, there are others who supply valuable data related to the Hajj. The Central Department of Statistics (CDS) of the Ministry of Finance and National Economy (MFNE) publishes statistical year book. This book covers a wide range of statistics including those of: physical features, education, health, social services, industry, ...etc. CDS also publishes Hajj statistics every year. While the Ministry of Interior (MI) produces a yearly pilgrims' survey. The HRC also conducts a wide range of studies and research related to various aspects of Hajj.

As mentioned earlier, the SRCS does not produce geographic data within its departments. However, the SRCS could use the above public sources of geographic data to develop the IRSDSS. These potential sources could supply the necessary data either to create the digital base maps or to update the already existing ones.

4.6.1 Data Quality:

Having identified the sources of geographic data, the question of how reliable the data becomes a central issue. Emergency response requires spatial data with high quality, that can be defined as 'fitness for use' (Chrisman 1991). This definition has been adopted by the US National Committee Digital Cartographic Data Standards Task Force (DCDSTF) as well as other Canadian, British and French bodies related to data standards. Spatial data quality is a measure against error, and the higher the quality, the greater potential use of the information. Spatial data quality issues include positional accuracy, attribute accuracy, lineage, logical consistency, completeness, resolution, and timeliness.

Accuracy is defined as the degree of exactness actually possessed by the data (Lodwick et al. 1987). Positional accuracy is a measurement of the variance of the position of a map feature from the true position of the entity (Antenucci et al. 1991). There are two classes of positional accuracy, relative or precision and absolute or bias accuracy. Relative accuracy is a measure of the accuracy of individual features on a map when compared to other features on the same map. Absolute accuracy is a measure of the location of features on a map compared to their true position on the earth's surface. Many observed data are not perfectly accurate due to the process of map production and the inherent difficulties in representing three dimensional objects on a flat surface. Accuracy standards are generally stated in terms of an acceptable tolerance for example 5 -10 meters and a specific proportion of measured features must meet the criteria. The map scale is an important factor in determining map accuracy.

Positional accuracy can be tested on four levels: deductive estimates, internal evidence, comparison to the source, and comparison to an independent source of higher accuracy(Antinucci et al. 1991). Deductive estimates refer to potential errors that may occur and are propagated in each step of map production. Internal evidence involves the use of tests based on repeated measurement and elimination of redundancy in measurement. Comparison to the source is the most common technique for testing accuracy. It involves producing test plots that are overlaid and registered to a source document. Comparison to a higher source of accuracy involves comparison to a well-defined, known number of points using a set of rules.

Attribute accuracy maybe measured in a fashion similar to that of positional accuracy (Antinucci et al. 1991). Burrough (1986) distinguishes between qualitative and quantitative accuracy. Qualitative accuracy refers to whether nominal variables or labels are correct, and quantitative accuracy refers to the level of bias in estimating the values assigned.

Logical consistency refers to how well logical relations among data elements are maintained (Aronoff 1989). Logical consistency for digital graphic data can be tested by measuring specific characteristics, such as line intersections where intended, duplicate lines, over or undershoots in intersections, size of polygon, or space between lines (Antenucci et al. 1991). Checking for logical consistency is an important factor in the computer age. Although there is no standard measure for logical consistency, it is best addressed before data entry into a GIS. In this regard, there are a number of tests which can be used to enhance consistency between data elements. One of these tests is the manual practice of an experienced cartographer visually to check for logical consistency, i.e. checking a slight gaps in intersections or duplicate lines. Another important test procedure is a topological test. Using a topological model in a GIS serves as an example of logical consistency checking, where the system can detect flaws in the data structure, such as missing boundaries or unlabelled polygons (Chrisman 1991).

A map is a model or abstraction of the real world. It can not contain all of the details found in reality. Subsequently, the database in a GIS will posses a degree of incompleteness. Aronoff (1989) classified completeness into three categories; completeness of coverage, classification, and verification. Completeness of coverage is the proportion of details available for the area of interest. Completeness of classification is an assessment of how well the chosen classification is able to represent the data.

Completeness of verification refers to the amount and distribution of field measurements or other independent sources of information that were used to develop the data. Generally, there are no standard methods or techniques to asses the aspect of completeness in a GIS. However, completeness of classification, for example, can be evaluated with reference to a standard classification or to a specific emergency application. Checking for completeness of coverage can be conducted by verifying objects that appear in the database with external list of features. For example, a test can be performed to check whether the database included road segments or rest stations. Finally, completeness of verification, although not easy, can be reported as a separate map showing the location and type of verification used for the data collected (Aronoff 1989).

Data resolution is defined as the degree to which closely related entities can be discriminated (Lodwick et al. 1987), while spatial resolution is the smallest object that can be discerned. In this sense, image resolution is the ground area covered by picture elements (pixels). For thematic maps, the resolution is the size of the smallest object that is represented, termed the minimum mapping unit (Aronoff 1989). For emergency applications, spatial data can be structured in both raster or vector format. In a vector based data structure, point, line and polygon data is represented by x and y coordinates. An example is road network that can be represented using vector format as a series of connected lines. In a raster structure spatial data is represented by a regular grid of cells. Generally, as the size of the cell decreases the resolution increases. However, increased resolution requires more storage space. It is important to note as well that resolution can affect accuracy. If high accuracy data is stored in a computer system that provides low resolution for numbers, then accuracy will degrade.

Time is an important additional factor which affects data quality. Generally, the reliability of data decreases with age. For geographic phenomena that change relatively quickly over time, such as demographic information, the date of acquisition is an important attribute. However, line elements of data can lead to powerful analysis tools, where data of differing time periods can be overlaid to detect change as well as compare for accuracy by completeness of fit for objects that exist in both data periods.

The lineage of data is also an important element, as it provides history, the source of data, and the equipment used to process the data (Aronoff 1989). Sources of spatial data can vary from analog maps, field survey, aerial photographs, remotely sensed data, ...etc. Similarly, equipment used to capture and process the data vary significantly. Each variable can introduce elements of error in the data, which affects its quality.

Assessing the quality of spatial data depends on the type of application and the intended use of the data. For the particular application of emergency response during the Hajj period, it is important to develop the IRSDSS using high quality and up-to-date spatial data. While all elements of data quality mentioned above are important, accuracy, resolution, and timeliness would seem the more pressing.

4.7 Justification Analysis:

It has to be noted that justification analysis of developing a GIS based system is not an easy task (Reeve et al. 1986, and PTI and ICMA 1991). In general terms, there are often some measurable costs and benefits of developing the system, however there are also intangibles and improved effectiveness that can not be easily measured or quantified (Antenucci et al. 1991).

The attempt made in this section is not to answer whether the IRSDSS is worth its cost, but rather to highlight benefits of the system that will accrue to the SRCS. This will include the impact of the IRSDSS on the SRCS staff and operations, which does not necessarily fit the conventional cost/benefit model. The SRCS will gain the following benefits from implementing the IRSDSS:

- reduction or elimination of redundant activities;
- enhanced data management;
- improved access, sharing of data, and comprehensive information analysis;
- improved productivity of the SRCS personnel and response time;
- increased capacity for data storage and manipulation;
- improved future planning, analysis, and communication;
- development of new automated products, such as maps reports; and
- more consistent more accurate response to queries.

It is also important to highlight predicted costs that maybe associated with the development of the system. Such costs may include database development, hardware, software, and other organization related costs (Alsawydani 1992). The following cost elements are part of the IRSDSS.

1) Database development:

Database development estimated to account for more than 50% of system cost. This may include one or more of the following depending on data availability:

- initial acquisition costs to obtain the data set, i.e. ground survey, aerial photographs, field survey, ...etc.;
- cost of mapping process, i.e. labor, and production of digital and hard copy maps;
- cost of data conversion, i.e. digitizing, scanning, and editing;
- cost of data modeling, i.e. database structure for both spatial and attribute data; and
- cost of database development, usually involving labor and verification.

2) Hardware costs:

Associated costs with typical required hardware may include the following:

- personal computers and workstations;
- file servers and computer servers;
- data storage devices;
- terminals;
- scanners and digitizers;
- printers and plotters;

- data communication equipment (networking);
- facility modification and environment control; and
- annual maintenance cost.

3) Software costs:

Costs associated with the software needed to develop the system may include the following:

- operating system software;
- core GIS software;
- application software, i.e. specialized packages for specific analysis; and
- device software, i.e. communication software.

4) Operational costs:

- annual maintenance cost;
- training costs; and
- expenses resulting from planning through implementation of the system.

4.8 Summary:

The SRCS is an active participant in support of emergency management during the Hajj. Its primary function during the Hajj is to provide medical care to pilgrims. Its operations are managed through a comprehensive hierarchical administrative structure. The working groups within this structure have been identified as potential users of the IRSDSS, as they will provide input and receive output from the system.

As observed difficulty with the SRCS operations during the Hajj is the use of conventional methods to handle emergencies. These tend to be slow and affect the overall performance of the SRCS. With these considerations, the scope of the IRSDSS have been defined as a responsive system, where the objectives will help SRCS professionals respond to emergencies in an efficient and timely manner. In achieving such goals, the IRSDSS will generate various types of maps and decision support information that can be used throughout an incident life cycle.

The development of the IRSDSS is not feasible without geographic data of an acceptable quality. Many public sources of such data have been identified. However, SRCS must be aware of the quality of the data intended for use in support of their operations. Data quality issues include: positional accuracy, attribute accuracy, lineage, logical consistency, completeness, resolution, and timeliness. An initial justification analysis has been made and it highlights some of the costs and benefits associated with the development of the IRSDSS.

Chapter Five

5. Analysis Phase

5.1 Introduction:

The preliminary phase has revealed that it is both feasible and attractive to develop the IRSDSS for emergency operations of the SRCS during the Hajj period. The purpose of this chapter is to analyze and model the functional requirements of the IRSDSS, as shown in more detail in figure 5.1.1. A framework of these functional requirements is presented to satisfy the initial objectives of the system.

The various user, system and data requirements are analyzed and modeled using several modeling tools. The section that addresses user requirements answers how SRCS professionals conduct their jobs and how they respond to emergencies and disasters during the Hajj. It has been presented under three sub-categories of :pre-Hajj functions, response functions and evaluation and analysis functions.

The next section discusses the system requirements and answers what the system should do to meet the user requirements. The behavior of the system is modeled using environmental and behavioral models (Capron 1986, and Yourdon 1989). The environmental model defines the environment beyond the system or external stimuli. In other words, it provides an overall view or pictorial representation of the system and its interaction with users. The behavioral model represents the internal functions of the system. In other words, it consists of various levels which are a decomposition of the environmental model and the user defined requirements. Data flow diagrams have been used to model inputs and outputs of the system by means of developing the environmental and behavioral models.

Building on user and system requirements, the final section addresses data requirements which discusses how data can be modeled to meet both user and system requirements. Entity relationship diagrams, data dictionary, and data structure diagrams have been developed to represent the data analysis required to design the IRSDSS.

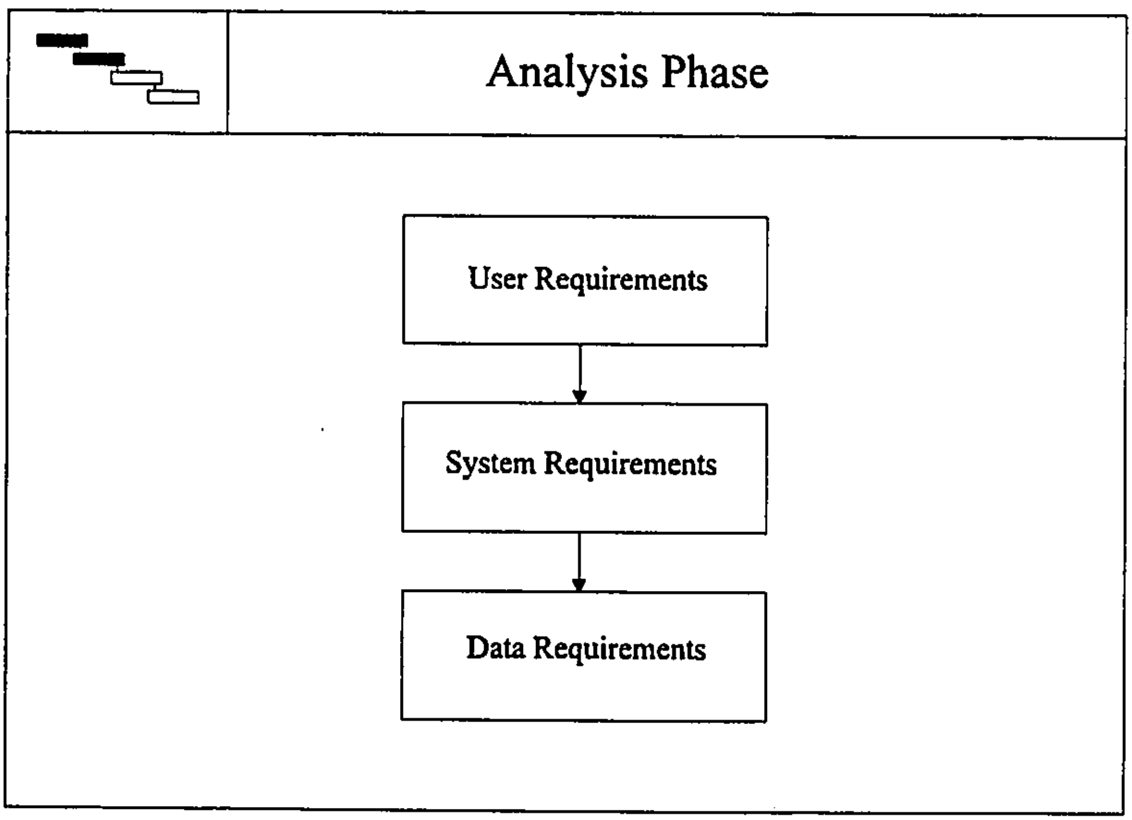


Figure 5.1.1: Analysis Phase

5.2 User Requirements:

User requirements are provided through analysis of SRCS functional requirements. According to the SRCS Hajj program, their mission during the Hajj can be divided into three distinct phases, as follows: pre-Hajj functions, response functions, and evaluation and analysis functions. Several tasks and assignments are performed by the various committees and groups of SRCS during these phases each of which are discussed in more detail in the following sections.

5.2.1 Pre-Hajj Functions:

As indicated in the preliminary phase, the pre-Hajj requirements are of a pre-planning or preparation nature. The type of preparation at this stage may include updating emergency plans, creating or updating of Hajj management committee data, updating the locations of the SRCS stations, determining the geographic range of each station, updating medical services locations and evacuation centers as well as designing the appropriate symbols for emergency services.

Some of these tasks are managerial and administrative in nature and may not require the use of a spatial referencing system except for allocating resources and designing the appropriate symbols for those resources. In addition, these types of operations are not explicitly assigned to particular groups according to the Hajj program. At present, requirements of such tasks changes annually, however they are performed by planning committees. This committee may take the responsibility of all pre-Hajj planing activities. For the purpose of designing the IRSDSS, it is assumed that a committee exists and will perform these functions.

5.2.2 Response Functions:

Once the SRCS has been assigned its resources and mobilizes its staff and equipment, its real mission to deal with emergencies begins. It also begins to operate in close cooperation with other government and non-government agencies working on Hajj related activities. Figure 5.2.2.1 shows the various representatives in the Civil Defense control room including the SRCS (Kingdom of Saudi Arabia, Ministry of Health, 1994).

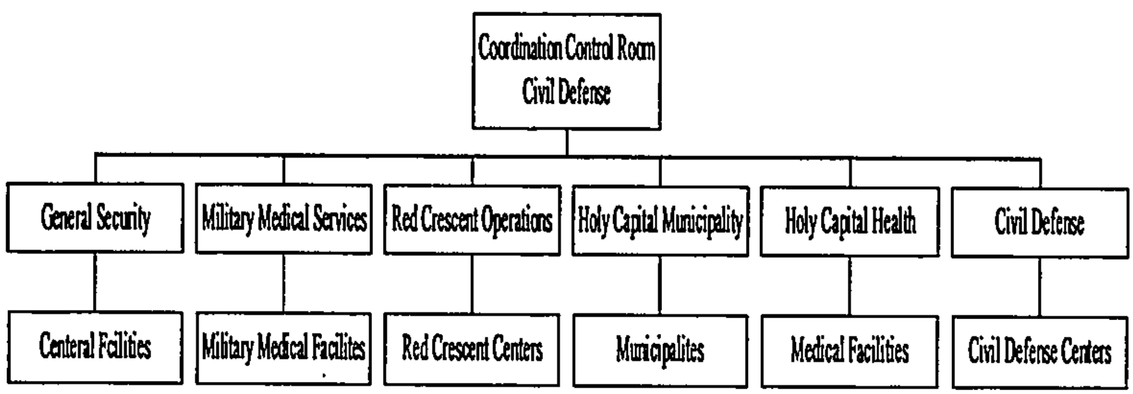


Figure 5.2.2.1: The Civil Defense Control Room During the Hajj

The sequence of response events start when an incident occurs. Normal occurrences such as sunstroke or heat exhaustion may not require large response from all parties. This type of event is handled by the nearest medical facility or in field treatment groups. Since the areas in the Holy Sites are limited in size, the distribution of medical facilities is adequate for normal incident occurrences. A pilgrim in need of medical treatment has access to such facilities within walking distance. Therefore, under normal circumstances there is no apparent demand for massive response. However, when an event occurs involving more than thirty casualties a disaster is declared (Kingdom of Saudi Arabia, Ministry of Health 1994). Subsequently, the disaster plan is activated and the situation dramatically changes.

Under a disaster situation the emergency incident response operations of the SRCS begins. In the control room, once a call for emergency response is received, as much accurate information as possible is collected. This may include incident call types, that is, personal contact, telephone calls, an observation team or any other means of communication. Such information is useful for immediate response as well as for future planning and preparation for emergencies. Future analysis of such information indicates which mode of communication is more effective for incident notification.

Next, the incident type or category is determined. According the Ministry of Health, disasters can be classified into two categories. 1) a yellow category that means the number of casualties is more than thirty and less than fifty, or 2) a red category that means the number of casualties is more than fifty (Kingdom of Saudi Arabia, Ministry of Health 1994). This type of classification is required by the MH to distinguish between different kinds of disasters. The response to each category differs in terms of the amount of response resources employed and who should respond to the incident.

Information regarding disaster type is also required, that is, flood, fire, storm, poisons, ...etc. This information is necessary t determine the type of response and treatment to be provided. The number of wounded victims will vary according to disaster type. Thus providing in-field treatment, transporting patients to the nearest medical facilities or evacuation centers, are determined on the disaster type. The number of expected sustained casualties is also determined at this stage. This affects the range and scope of response required. The number of casualties is usually determined based on the disaster type and severity of an incident. For effective incident management, the date, starting, and ending time of the incident are also recorded.

Based on the information gathered about the incident, the next step is to analyze and respond to the situation. Resources should be deployed to the scene. Any disaster occurrences with large magnitude would exceed the capacity of all SRCS stations. According to de Boer et al. (1989), each ready-to-go ambulance is capable of handling two casualties per hour under normal condition of weather, working hours, and road network. Thus, any incident involving more than 100 casualties, would exceed all the capacities of SRCS stations. For example, the total number of vehicles operating at Arafat Holy Site is 46. If an incident happened in that area involving more than 100 victims, all stations are capable of handling only 92 victims per hour. However the SRCS is not operating alone. Many other medical and emergency services are also required to respond and provide services during disaster response efforts. The focus of this research study is on the operation of the SRCS during the Hajj and other emergency services are not considered.

Incident location is determined based on the initial notification. The nearest SRCS station to the incident location, that should respond first, is then notified. The shortest path to the scene is then determined using conventional maps. Since there are no designated emergency routes, the shortest path is determined according to existing traffic plans. Equipment and personnel are then dispatched to the scene. If the situation warrants transporting victims to the nearest medical facility or evacuation center, the routes to such facilities are chosen and communicated to the respondent station(s). The response time to the incident depends on selecting the optimal path to the scene. The greatest benefit of an automated IRSDSS may be gained during this phase. Generating digital maps for emergency response is essential to improving response and dispatch time, and as well as overcoming human errors.

5.2.3 Analysis and Evaluation Functions:

The OC, in addition to, the SG, SC, and SHAC require various types of emergency reports. For example, the OC is required to generate a number of emergency reports either on a daily basis or at the end of Hajj season. These reports are then sent to other committees or groups for further evaluation and analysis. The SG and SC take responsibility for evaluating the overall performance of SRCS operations during the Hajj. Once the Hajj is over, planning for the next year's Hajj starts immediately. The functions presented above are further itemized and included in the event list presented in the system requirements section.

5.3 System Requirements:

The system requirements phase is a process which defines the overall functions of the system (Yourdon 1989). Such process includes definition of the external and internal behavior of the system that is based on the initial objectives of the system outlined in the preliminary phase and the user requirements. In more precise terms, the overall process of interaction between the IRSDSS and the users is analyzed and modeled. Environmental and behavioral models are used to analyze and model how the system should function to satisfy user demands. More precise elements of system requirements are modeled using Dataflow Diagrams (DFD).

The DFD consists of (Yourdon 1989):

Processes: (bubbles, functions, transformations) represent the various functions that the system carries out. Functions transform inputs into outputs. They are represented graphically as circles.

Flows: connect processes. They represent the information that the system requires as input and/or the information they generate as output. They are represented graphically as curved arrows of direction. The direction of the arrows indicates the flow of required information.

Data Stores: represent database files and are represented graphically by two parallel lines.

Terminators: show the external entities (users) with which the system communicates. They are represented as rectangles.

5.3.1 The Environmental Model:

The environmental model defines the interaction or interface between the system and its environment. In other words, the environmental model represents the elements or actions that originate outside of the system. It precisely defines the inputs and outputs from the system. The environmental model consists of a statement of purpose, event list, and context diagram.

5.3.1.1 The Statement of Purpose:

As indicated earlier, the purpose of the IRSDSS is to improve incident response time as well as to generate various types of maps and reports in support of incident response activities. These include response maps, geographic range maps, traffic maps, evacuation maps as well as management reports.

5.3.1.2 Event List:

The following is a general list of SRCS requirements. It represents the functional requirements of the SRCS based on its functions noted previously. It is important to note however, that some of the events presented in this list are not explicitly or necessarily performed by the SRCS. In these cases, they are suggested as improvements to emergency management and response activities.

- the Planning Committee updates data of the SRCS stations resources, including: station location, geographic range, number of personnel, number of ambulances, address, and the capacity.

- the Planning Committee updates data of medical facilities, including: facility name, address, number of beds, and medical capacity. Medical capacity is calculated as number of beds multiplies by 3% (de Boer et al. 1989). If the number of beds is 1000, the medical capacity is 30 patients.

- the Planning Committee updates evacuation centers related information, including: the name of the center, address, and capacity.

- the control room receives a notification about an incident and determines its nature. Notification about an incident could be via personal contact, telephone calls, observation team, or another means of communication. The nature of the incident involves specifying its category as a normal or disaster event, the number of expected casualties, disaster type, and severity of the incident. The severity of the incident is scored as 0.5 if the number of expected casualties is low to 1.5 if the number of expected casualties is high.

- the control room sends information about an incident to all stations and dispatches resources to the scene. This type of information encompasses determining the incident location, and the optimal path to the scene from all stations. The optimal path is based on traffic flow and plans.

- the control room records the time and date of the incident which includes the time of start and end of the incident.

- if there is a need to transport victims to the medical facilities or evacuation centers, the control room determines the optimal path to such facilities according to traffic plans, and reports of the traffic police.

- the control room generates a daily incident report and an overall emergency report at the end of Hajj season.

- the Steering Committee requests a daily incident report and an overall emergency report at the end of Hajj season.

- the Statistical Group requests a daily incident and an overall emergency report at the end of Hajj season for further analysis and evaluation.

- the SHAC receives an overall emergency report (C) at the end of the Hajj season.

From the event list, it is possible to construct the context diagram which is the last component of the environmental model.

5.3.1.3 Context Diagram:

The context diagram is represented by the DFD, which is a pictorial and textual representation of the major system functions. The IRSDSS context diagram is shown in figure 5.3.1.3.1. It consists of a single circle (bubble) which represents the entire system and takes the name of the system (IRSDSS). It also includes five terminators or external entities. These are Control Room, SC, PC, SG, and the SHAC. Eighteen flows exist in the context diagram showing data inputs and outputs. They illustrate events in which the system must respond or produce a response. They also note the flow of data transported between terminators. In summary, flows indicate inputs caused by and initiated by the terminators, and outputs caused or initiated by the system.

While this diagram shows the external entities and the overall functions of the system and the flow of data, the importance of terminators varies. Clearly the Control Room is the dominant player who directly interacts with the system, especially during emergency occurrence. By contrast, the SHAC interacts indirectly with the system by requesting an overall Hajj performance report.

5.3.2 The Behavioral Model:

The behavioral model is part of the DFD which represents the internal functions of the system. It is based on the initial context diagram and the event list (the required SRCS emergency response activities). In essence, it is a decomposition or partition of the context diagram into different levels. This leveling scheme helps separates the functions into their various components and defines the major functions of the system. The IRSDSS behavioral model consists of four levels, each represents a subsystem or module of the system.

As shown in figure 5.3.2.1, the IRSDSS zero level diagram consists of five terminators as in the context diagram, three bubbles, eighteen flows and one data store. Similar events are being aggregated into three groups represented by three bubbles numbered from 1 to 3. These bubbles represent the subsystems or functions of the IRSDSS. They communicate with external entities through flows indicating the inputs and outputs of each process.

Bubble 1 (Manage incident) is concerned with processing incident related information and is connected to the Control Room external entity through four flows indicating inputs and outputs. Bubble 2 (Manage reports) handles emergency reports and connected to four external entities through eleven flows. Bubble 3 (Manage facilities) communicates with PC through three flows, that update medical facilities and related information about SRSC stations. All three processes have inputs and outputs to and from the single data store at this level i.e. the IRSDSS database.

Each of the above processes is decomposed further to indicate specific functions or actions. Process 1 (Manage incident) is further partitioned as shown in figure 5.3.2.2. In this IRSDSS level one diagram, four processes with one external entity (Control Room), and one data store (Incident) are present. The Control Room is connected to the processes through four flows indicating inputs and outputs. Bubble 1.1 (Treat notification) handles emergency notification types. Bubble 1.2 (Process nature) manages the nature of the incident including its category, type, severity as well as number of casualties and other related information. Process 1.3 (Manage timing) is concerned with the date and timing of an incident. Function 1.4 (Manage dispatching) is a function which is responsible for dispatching resources to the scene, or transporting patients to the medical facilities. Note that this particular function of the IRSDSS is tested by response and dispatch simulation provided in this study later. Each of the processes at this level write to the Incident and Network databases.

As shown in figure 5.3.2.3, bubble 2 (Manage reports) is partitioned into two processes with four external entities in IRSDSS level two diagram. Four data stores are present in this diagram: Incident, Intersec, Network, and Station. Function 2.1 (Generate overall report) is concerned with generating an overall emergency report at the end of Hajj period. This type of report is required by SC, SHAC, and SG. Bubble 2.2 (Generate incident report) processes and generates a daily incident report which is required by all committees except the PC which is not present at this level.

The final IRSDSS process 3 (Manage facilities) is divided into three functions as shown in figure 5.3.2.4. The first is updating related data about SRCS stations such as their location, their geographic range, number of personnel and ambulances as presented by process 3.1 (Update station data). The second function, update of Medical facilities information is shown by process 3.2 (Update medical data).The final function, update of related data about evacuation centers, is represented by bubble 3.3 (Update evacuation data). All processes at this level read and write to three data stores: Network, Evac, and Intersec.

5.4 Data Requirements:

Having presented the user and system requirements, the remaining aspect of the IRSDSS conceptual development is to analyze and model the essential data to meet these requirements. The road network is the primary spatial feature which has to be modeled for emergency applications. In this regard, the road network is represented by weighted and connected graphs to accommodate various emergency applications. The intention here is not to develop a generic road referencing model, although it has most of the necessary data for such a model, rather it is to design a model to support specific applications of emergencies. The road network is composed of the following elements:

- nodes representing intersections and crossing points;
- identifier coordinates for each node;
- linkages between the start and end of nodes representing road segments;
- identifiers for every link; and

- weighted attribute information to each node and segment.

Road related attributes can be classified according to the following (Lee and Krakiwsky 1989):

Static attributes: which refer to information that will not change frequently such as: road name, road type and classification, address range, traffic, capacity, number of lanes, direction, width, length, grade, limits on structural clearance, weight restriction, turn radios, and speed limits.

Predictive information: which refers to attributes that can be predefined such as: scheduled road construction and maintenance, lane and control based on time of day, day of week and holidays, average travel time and road closure due to special events, and seasonal road surface conditions and daily rush hour traffic.

Dynamic information: which includes information that changes rapidly and at times unexpectedly, such as: accidents, traffic congestion, road surface condition and weather conditions. This information typically changes in a relatively short period of time and requires constant update.

Data requirements are also shaped by emergencies that impose a location routing problems which. are composed of the following elements or sub-problems (Bowerman et al. 1991):

- facility location i.e. fire department, police station, evacuation center;
- allocation of user i.e. incident location; and
- vehicle routing.

These are the three primary aspects that were considered when building the network data model for emergency applications during the Hajj. However, there are additional related characteristics for the road network that must also be considered.

Nodes or intersections carry pedestrians and vehicles and the right of way is shared. Traffic control technologies such as Split Cycle Offset Optimization Technique (SCOOT) (Hunt et al.) demonstrate that no control methodology is possible whenever there is a steady stream of traffic or a super saturated network. Under such conditions neither signs nor signals are honored by traffic. The stop control is assumed at intersections to account for delays and travel times to reach the incident area. Turn penalties for left, through and right are added to account for various types of movements in an ideal state and are negated in consideration of the pedestrian traffic which blocks entire roadways. In general, all 'U' turns are banned for the traffic movement to prevent the double counting of movement along the link whenever a barrier is introduced at an intersection.

Links are another important component in network wide traffic flows. In the case of the road network during the Hajj, the problem is far more complex and defies the current established methods and procedures for the following reasons:

1. road widths vary greatly within the network and roads are shared by pedestrians and vehicular traffic at the same time;

2. stop and go situations dominant in the network; and

3. presence of a distribution other directional vehicles like buses.

Travel time and speed limit are the general impedance functions used in transportation network modeling. The current state of the traffic, such as road conditions and vehicular volumes, are the one that governs the above. Data used in this study is static by nature. Hence using travel time or speed limit will result in hypothetical values. Distance is taken as impedance for travel and constant multiplier of unity is assumed as an adjustment factor. This will simplify the adjustment factor to the most recent data and make the system more dynamic. Therefore it is adopted.

The SRCS stations, medical facilities, and evacuation centers are modeled as point data with associated attribute information necessary to support emergency response activities. The road network as well as emergency facilities are modeled using Entity Relationship Diagram (ERD), a data dictionary and data structure diagrams,. these models are described in the following sections.

5.4.1 Entity Relationships Diagram:

The entity relationship diagram is a network model that describes the data stored in the system at a higher level of abstraction (Yourdon 1989). It highlights how data should be structured and modeled and also outlines the relationship between the various elements of data. The ERD is an important modeling tool as it emphasizes the relationships between data stored in the DFD presented earlier. The components of the ERD are:

Object types: representing a collection or set of objects (things) in the real world, depicted graphically by a rectangles.

Relationships: representing the relationships between objects, a set of connections between objects and depicted graphically by diamonds.

Attributes: representing the descriptive information about objects, depicted graphically as ellipses.

Figure 5.4.1.1 shows the ERD for the IRSDSS. It consists of the six entities that are the stores in the DFD presented in system requirement section. The relationships between these entities are indicated as one to one or one to many relationships. For example, the road network has many intersections and many incidents can happen in one intersection. This kind of relationship is reflected as means to model the data required to produce a functional system. Each entity also has been given attributes or data elements. A description of these elements is described and presented in the data dictionary in the following section.

5.4.2 Data Dictionary:

The data dictionary is an organized list of all data elements that are pertinent to the system (Capron 1986 and Yourdon 1989), those necessary to satisfy the user and system requirements. It forms a foundation of the database and provides a precise description of data items along with their range, unit, and source. The information in the data dictionary is critical for system development and implementation. Tables 5.4.2.1 through 5.4.2.6 represent the data dictionary of the IRSDSS. Finally, an incident report form is represented in figure 5.4.2.2 which shows the various elements which might be included in the incident report.

5.5 Summary:

This chapter has presented analysis of the structure and design framework of the IRSDSS. The overall concept of system development is based on assessing user, system, and data functional requirements. Each of these issues have been analyzed, evaluated and modeled using various modeling tools such as dataflow diagram, entity relationship diagram, data structure diagram, and data dictionary.

The SRCS requirements have been identified as pre-Hajj, response, and evaluation and analysis functions. Some of these tasks may not require exclusive use of a spatially referenced system, for example the pre-Hajj functions, as they involve planning and preparation which are administrative activities. However, response functions are the type of activities that need such a system, as they are concerned with response and dispatch of resources over extended geographic areas. Evaluation functions are the outcome of evaluation of both pre-Hajj and response tasks. Various committees and groups who perform these functions have been identified as users who will provide input and receive output from the IRSDSS system.

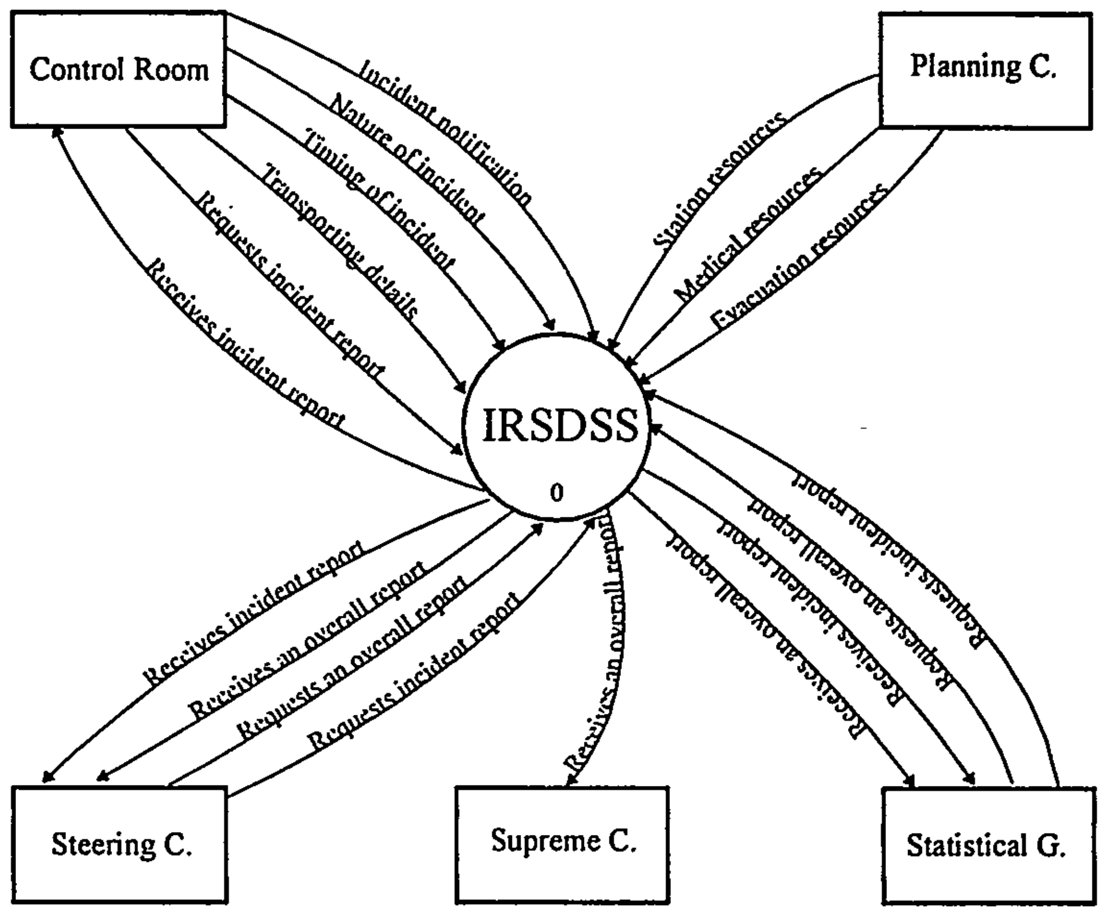


Figure 5.3.1.3.1: IRSDSS Context Diagram

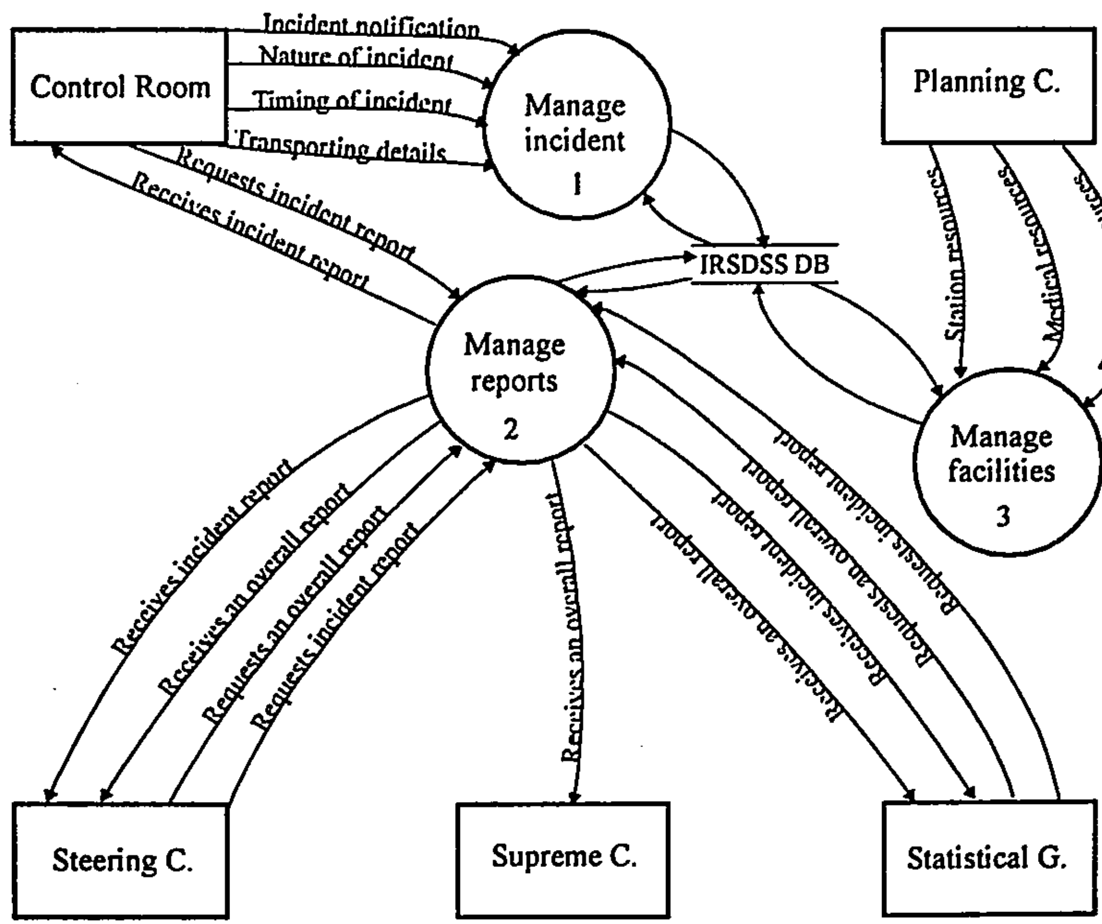


Figure 5.3.2.1: IRSDSS Zero Level Diagram

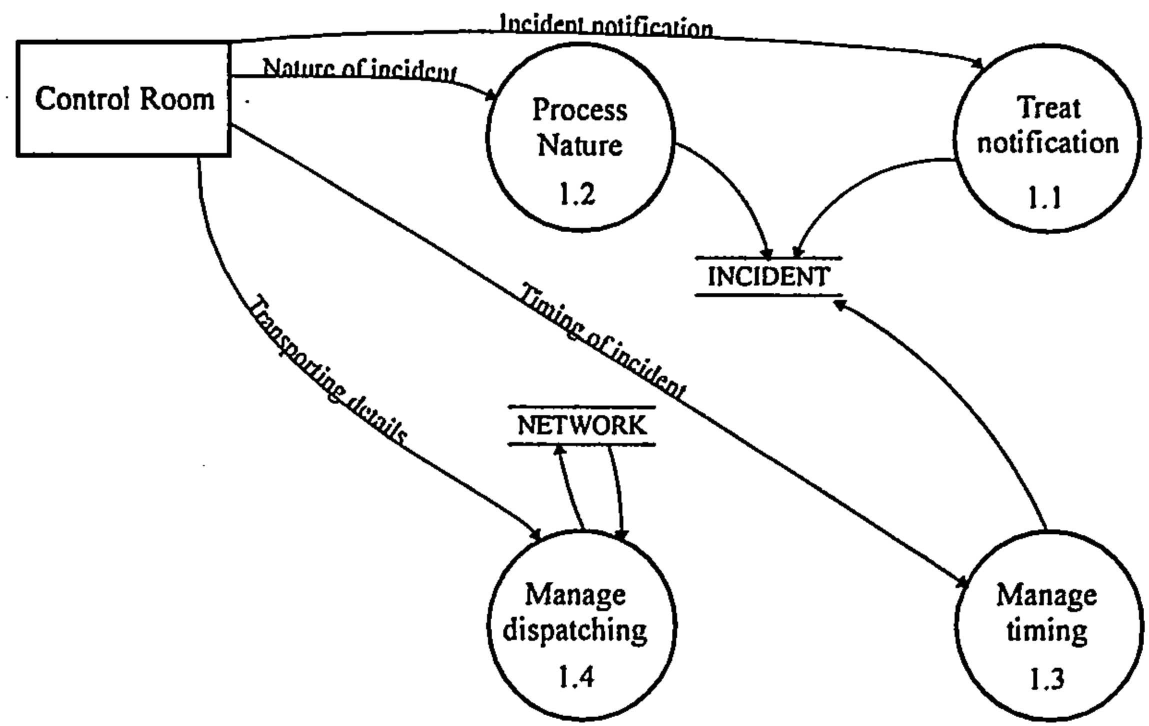


Figure 5.3.2.2: IRSDSS Level One Diagram

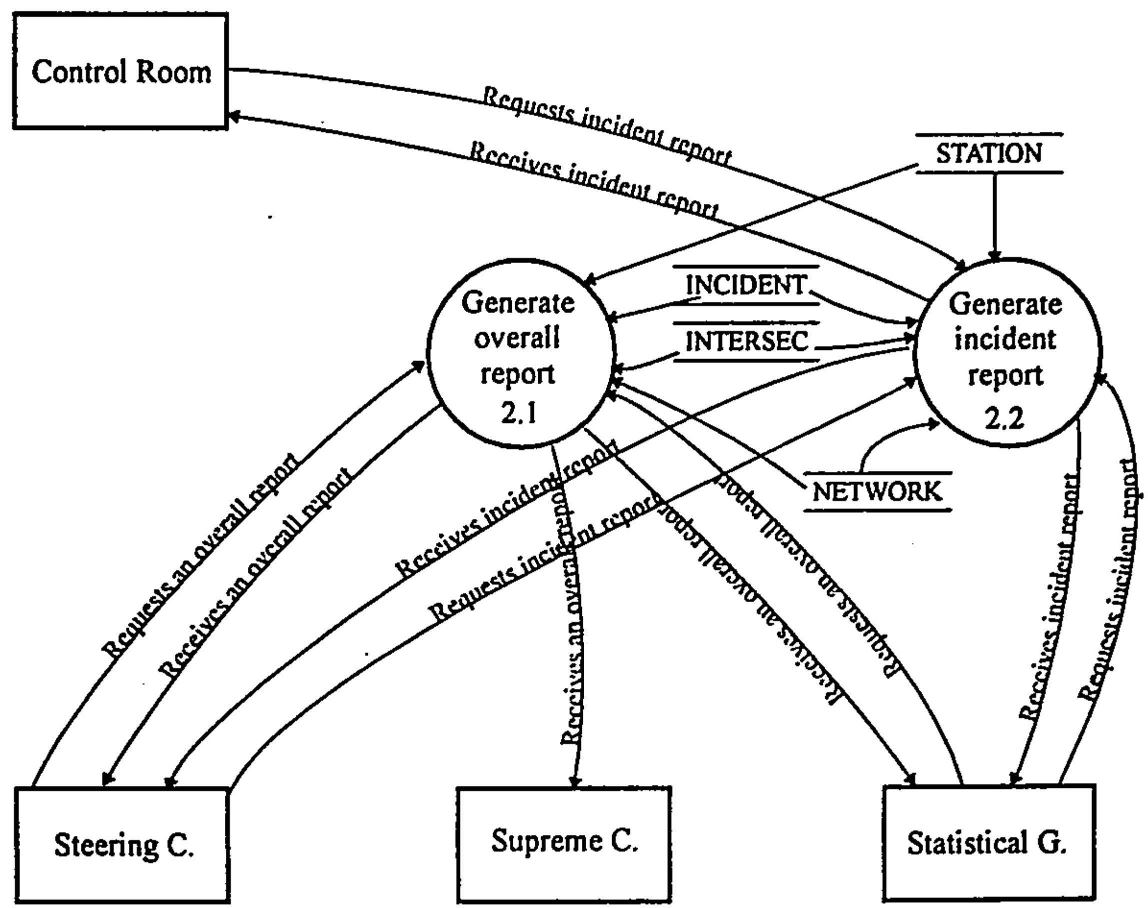


Figure 5.3.2.3: IRSDSS Level Two Diagram

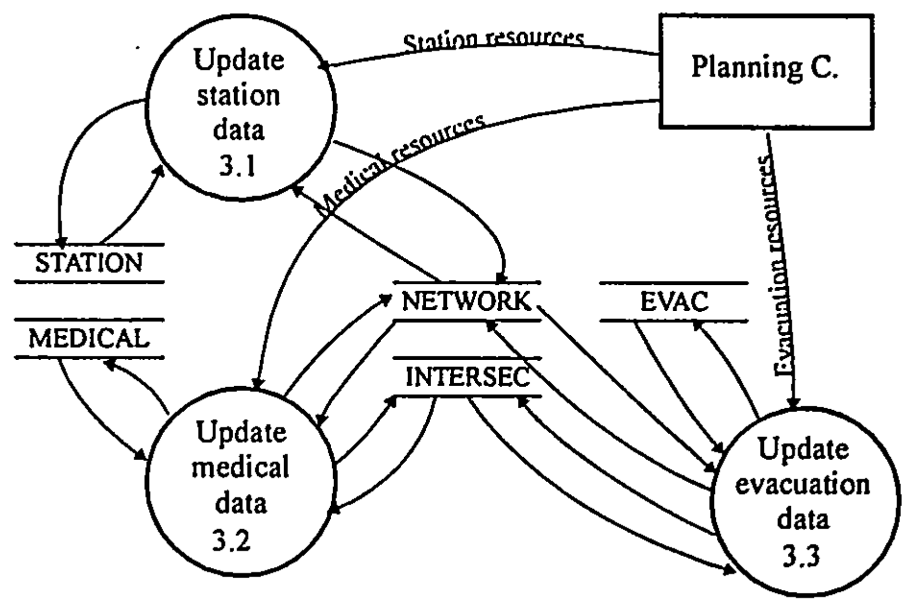


Figure 5.3.2.4: IRSDSS Level Three Diagram

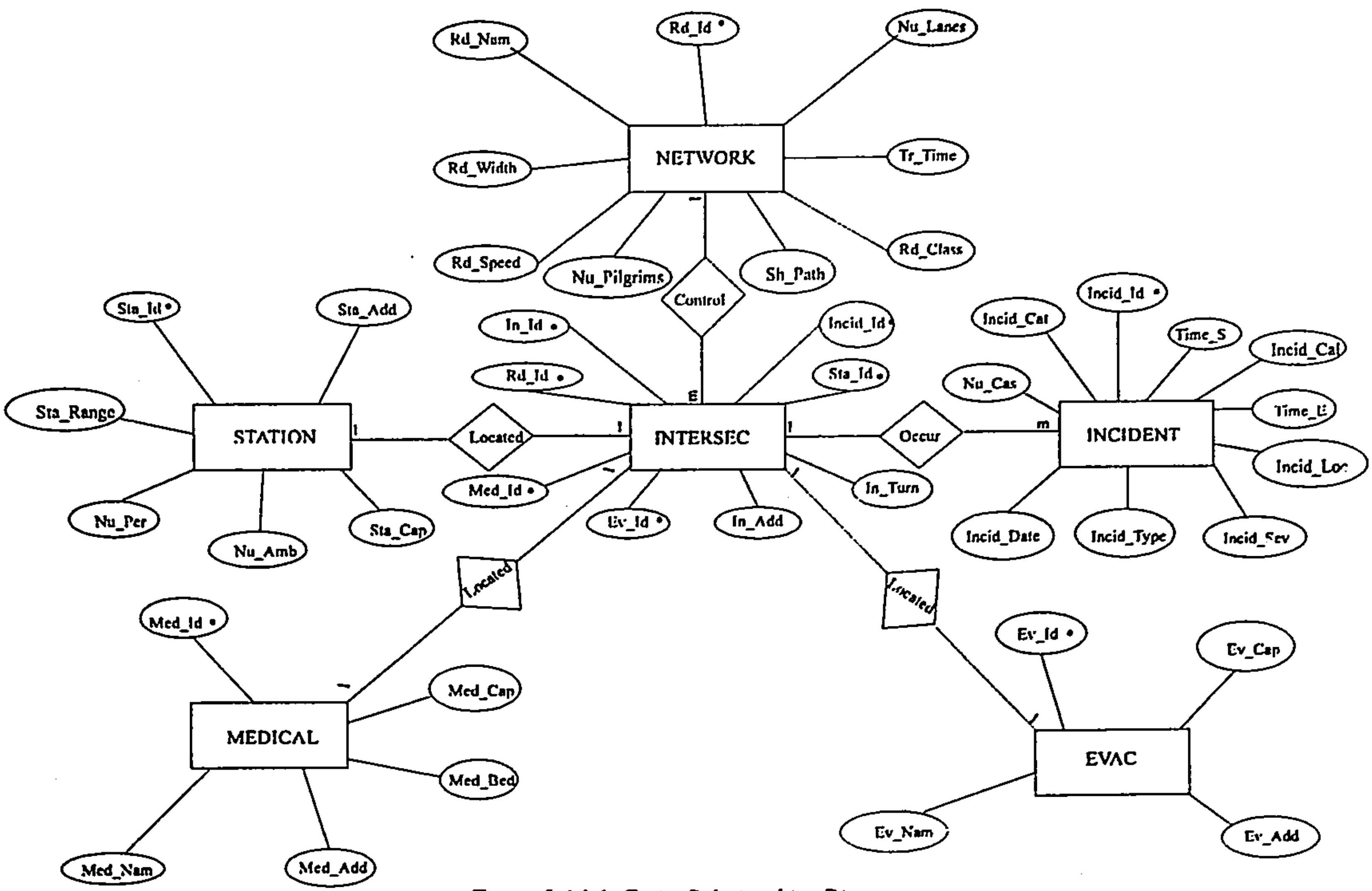


Figure 5.4.1.1: Entity Relationships Diagram

Table 5.4.2.1: Data Components Description of Incident Database File.

Item	Description	Content	Range	Unit	Source
Incid_Id	Unique identification number		0 - 100	Numeric	As assigned by control room
Incid_Cat	Incident category identification 1 = normal occurrence (sun stroke) 2 = normal occurrence (heat exhaustion) 3 = normal occurrence (other) 4 = disaster yellow (number of casualties > 30 & < 50) 5 = disaster red (number of casualties > 50)	[1|2|3|4|5]	1 - 5	Numeric	As assigned by control room
Nu_Cas	Number of expected casualties			Numeric	As assigned by control room
Incid_Date	The date of incident occurrence	[d/m/y]		Date	As assigned by control room
Time_S	The starting time of an incident	[h/m/s]		Time	As assigned by control room
Time_E	The ending time of an incident	[h/m/s]		Time	As assigned by control room
Incid_Sev	Severity of an incident calculated as 0. 5 = low number of casualties is expected 1.0 = medium number of casualties is expected	[0.5|1.0|1.5]	0.5 - 1.5	Numeric	As assigned by control room

<table>
<tr><td></td><td>1.5 = high number of casualties is expected</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Incid_Type</td><td>Disaster type based on Ministry of Health classification

1 = flood 2 = fire 3 = storm 4 = earthquake

5 = collision 6 = epidemic 7 = poison 8 = terrorist</td><td>[1|2|3|4|5|6|7|

8]</td><td>1 - 8</td><td>Numeric</td><td>As assigned by control room</td></tr>
<tr><td>Incid_Loc</td><td>The location of an incident based on the address given by the operator</td><td></td><td></td><td>Alphabetic</td><td>As determined by control room or GIS system</td></tr>
<tr><td>Incid_Cal</td><td>Incident notification via

1 = personal contact 2 = telephone call

3 = observation team 4 = other</td><td>[1|2|3|4]</td><td>1 - 4</td><td>Numeric</td><td>As determined by control room</td></tr>
</table>

Table 5.4.2.2: Data Components Description of Station Database File.

Item	Description	Range	Unit	
Sta_Id	Unique identification of a station i.e. Arafat 1, Mina 1, Muzdalifah 1, and Makkah 1.		Alphanumeric	As assigned by SRCS
Sta_Add	Address of SRCS station based on the nearest intersection. Two streets are used to identify the address		Alphabetic	As assigned by SRCS
Nu_Per	Number of personnel in each SRCS station	1 - 100	Numeric	As assigned by SRCS
Nu_Amb	Number of Ambulances in each SRCS station	1- 15	Numeric	As assigned by SRCS
Sta_Cap	The total medical capacity of each station per hour	4 - 30	Numeric	Measured as number of ambulances * 2
Sta_Range	The geographic range for each SRCS station		Meters	Based on SRCS requirements

Table 5.4.2.3: Data Components Description of Evac Database File.

Item	Description	Range	Unit	Source
Ev_Id	Unique identification number	1 - 100	Numeric	User defined
Ev_Nam	The name of the evacuation center		Alphabetic	User defined
Ev_Add	Address of evacuation center based on the nearest intersection. Two streets names are used to identify the address		Aphabetic	User defined
Ev_Cap	The total capacity of the evacuation center	1 - 3000	Numeric	As assigned by Ministry of Health

Table 5.4.2.4: Data Components Description of Medical Database File.

Item	Description	Range	Unit	Source
Med_id	Unique identification number	1 - 100	Numeric	User defined
Med_Nam	Name of the medical facility		Alphabetic	As assigned by Ministry of Health
Med_Add	Address of medical facility based on the nearest intersection. Two streets names are used to identify the address		Alphabetic	User defined
Med_Bed	Number of beds in the medical facility	1 - 1000	Numeric	As assigned by Ministry of Health
Med_Cap	The total medical capacity of the medical facility	1 - 500	Numeric	Measured as number of beds * 3%

Table 5.4.2.5: Data Components Description of Network Database File.

Item	Description	Range	Unit	Source
Rd_Id	Unique identification number	0001 - 9999	Numeric	User defined
Rd_Nam	Name of the a road segment		Alphabetic	As assigned by the Municibality
Rd_width	The total width of a road segment from shoulder to shoulder	1 - 30	meters	As measured by road engineer
Rd_Speed	Speed limit on a road segment		km/hr	As measured by traffic police
Rd_Class	Functional class of a road segment 1 = Arterial road 2 = Major road 3 = Main street 4 = Secondary street 5 = Tertiary street 6 = Pedestrian way	1 - 6	Numeric	As assigned by the Municipality

Tr_Time	The total travel time to travel a road segment		Numeric	Measured as length/speed
Nu_Lanes	The total number of lanes of a road segments in both directions	1 - 9	Numeric	As measured by road engineer
Nu_Pilgrims	The number of pilgrims on a road segment in both directions		Numeric	Calculated as percentage of the total number of pilgrims to the percentage of each road segment
Sh_Path	The shortest path from all stations to the incident location			As calculated by the GIS system

Table 5.4.2.6: Data Components Description of Intersc Database File.

Item	Description	Range	Unit	Source
In_Id	Unique identification number	0001 - 9999	Numeric	User defined
Incid_Id	Unique identification number	1- 100	Numeric	As assigned by control room
Sta_Id	Unique identification of a station i.e. Arafat 1, Mina 1, Muzdalifah 1, and Makkah 1.		Alphanumeric	As assigned by SRCS
Med_Id	Unique identification number	1- 100	Numeric	User defined
Ev_Id	Unique identification number	1 - 100	Numeric	User defined
Rd_Id	Unique identification number	0001 - 9999	Numeric	User defined
In_Add	Address of an intersection. Two streets are used to identify the address of an intersection		Alphabetic	As assigned by the Municipality
In_Turn	Turn in intersection values are	1 - -1	Numeric	As assigned by the traffic police

	1 = turn is permitted - 1 = turn is not permitted			

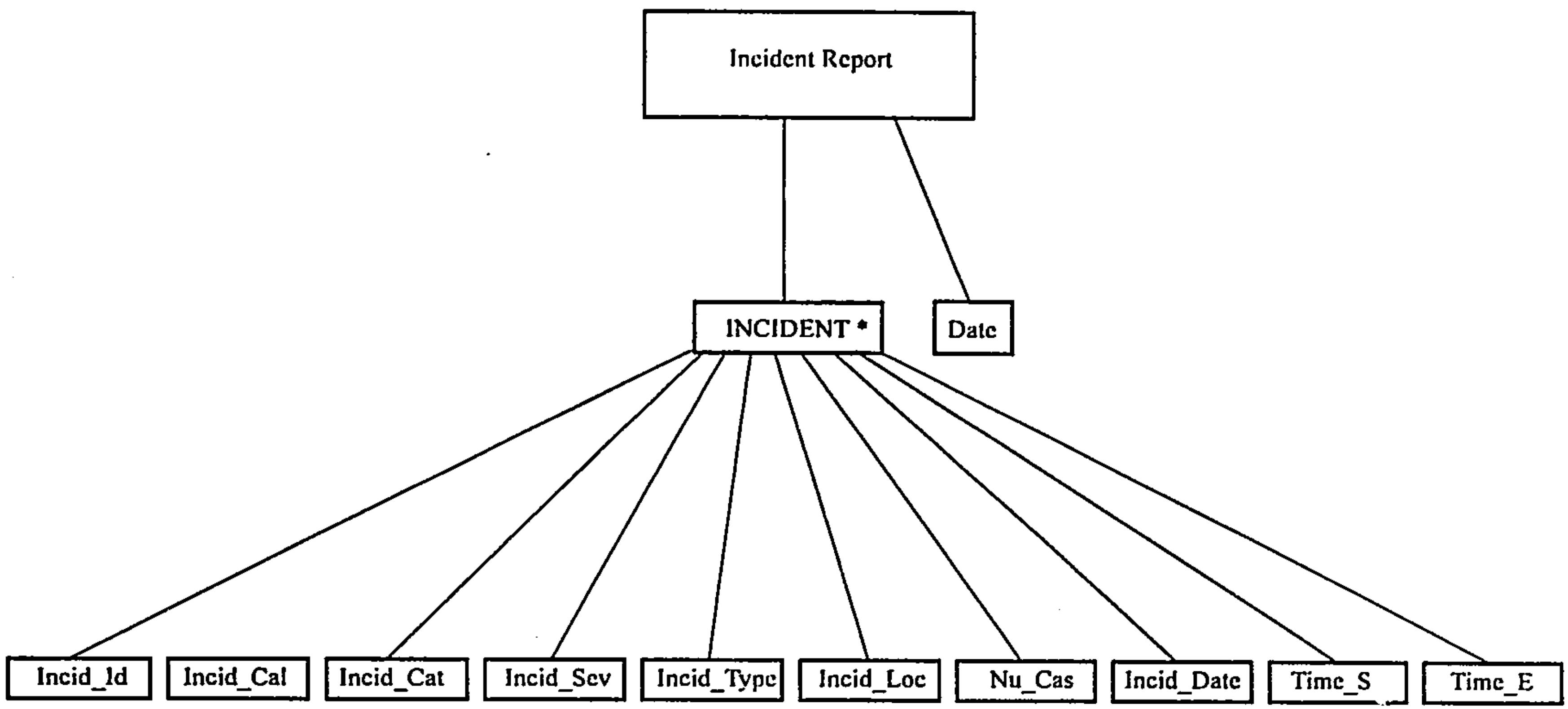


Figure 5.4.2.2: Data Structure Diagram of Incident Report

The system's functional requirements have been analyzed and modeled. Internal and external behavior, and major functions of the system have been defined. The major functions of the system have been grouped under three categories as follows: incident, facilities, and report management. These functions have been divided to indicate their specific actions. This process consists of four levels of division. The dataflow diagram was used as the basic modeling tool to identify the functions of the system.

To meet users and system requirements, data needs were analyzed and modeled. This included both spatial and attribute data. The distinct characteristics of the Hajj were considered when modeling the data. In particular, the road network characteristics and the traffic plans implemented during the Hajj season, which are influential factors to consider when modeling the data. For example, traffic control technology such as SCOOT demonstrates that no control methodology is possible when a steady stream of traffic or a super saturated networks is encountered. Under such conditions, it was observed that neither signs nor signals are honored by traffic for the period under consideration.

Chapter Six

6. Data Conversion Phase

6.1 Introduction:

Having outlined the structure and framework of the IRSDSS in the analysis phase, the step hereafter is to design the conversion of data to support disaster dispatch and response applications. In order to develop the appropriate database, spatial and attribute data were collected for the Arafat area during a field trip to Saudi Arabia. This data included: conventional paper maps, plans, as well as some digital spatial database in addition to various studies, reports and documents related to the subject of this thesis.

PC ARC/INFO™ was chosen as the core GIS platform for data conversion, and simulation of emergency dispatch. PC ARC/INFO™ was selected as the most cost effective and efficient system for data conversion and dispatch simulation. The system was chosen because of accessibility and it also has a NETWORK™ program that allows network modeling and address matching. Further, various layers of data were created which include the road network, medical facilities, SRCS stations, and evacuation centers. The design of the coverages was intended to support the intended simulation.

The database was designed according the data model presented in the previous chapter. For the purpose of this chapter, and study, the data conversion process is presented in general terms. The focus is on the problems encountered and the solutions used to address such problems during this process.

The balance of the chapter describes the process of data collection, development of hardware, software specifications, and database design. Simulation of disaster dispatch is examined at the end of this chapter. These steps of data conversion phase are shown in figure 6.1.1.

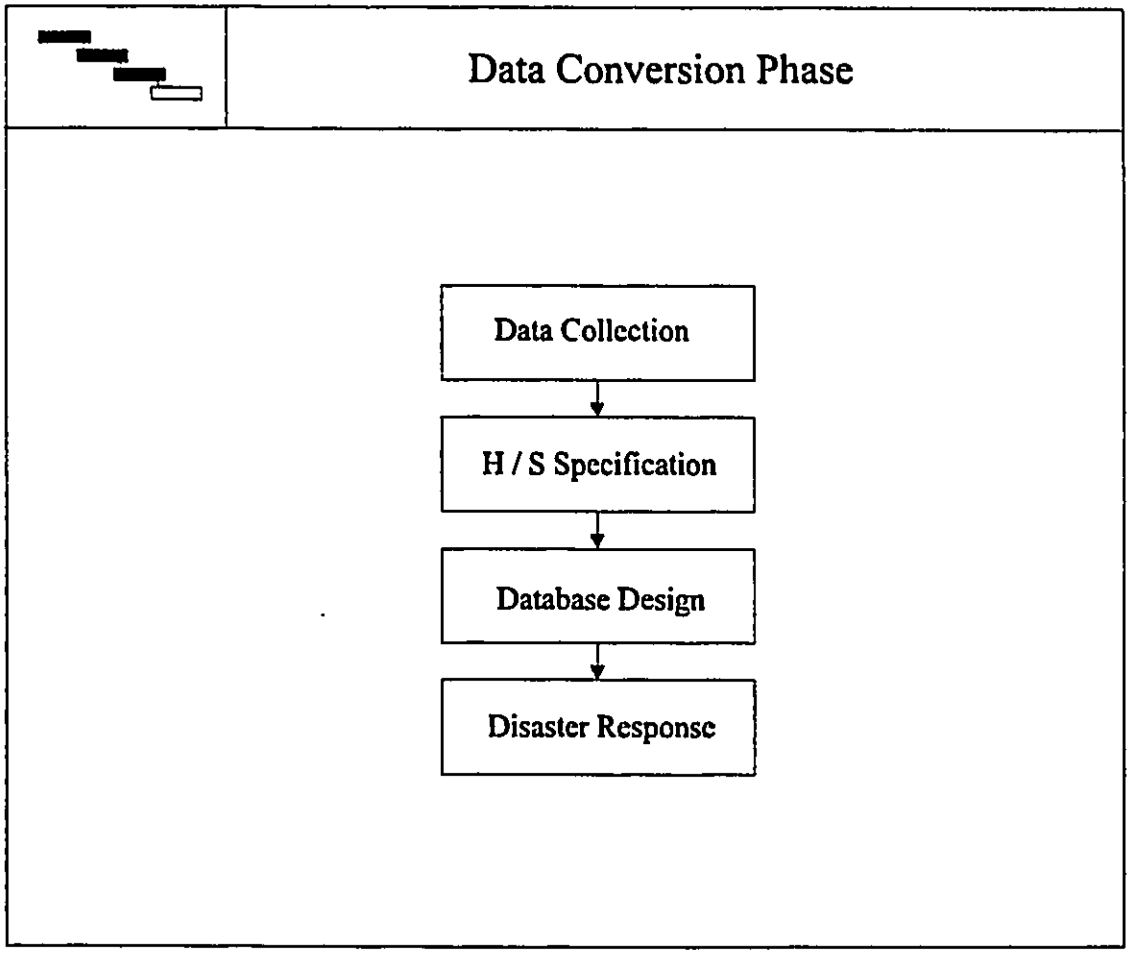


Figure 6.1.1: Data Conversion Phase

6.2 Data Collection:

The majority of data for this study was collected for the Arafat area during a field trip to Saudi Arabia. The trip was to the capital city of Riyadh and the Holy city of Makkah between November 1 and December 30 of 1994. Various information regarding emergencies during the Hajj season as well as spatial and attribute data for the study area was collected. In general, the information collected can be categorized as follows:

- spatial data sets;
- attribute data sets; and
- emergency management and handling information.

The information was assembled by interviews, a questionnaire, and personal meetings. Individuals and key emergency officials in both Riyadh and Makkah Al-Mukaramah cities were interviewed to solicit relevant emergency data. Appendix A provides a list of individuals interviewed. Appendix B contains the questionnaire form used to obtain emergency management related information. In addition to these efforts, a site visit to the Arafat area was conducted. Information regarding the road network, medical and emergency facilities was gathered through observation and field notes. Further, more specific details of the spatial data collected during this field trip is presented in the following sections. This data was used to develop the databases for the IRSDSS.

Generally, the data sets which are used in this study are classified according to their general categories, content, format, scale, projection, and date of compilation. The following is a list of data:

- **Data set**: Topographic map sheet 3921 - 21 SR;
  - *Data set category:* Topography.
  - *Content:* Control data, topography, network, built up areas.
  - *Format:* Conventional paper map.
  - *Supplier:* Military Survey Department.
  - *Scale:* 1:25,000.
  - *Projection:* UTM.
  - *Date compiled:* 1988.

- **Data set:** Guide map;
  - *Data set category:* Arafat guide map.
  - *Content:* Public services, guide services for pilgrims, medical services, and road network.
  - *Format:* Conventional paper map.
  - *Supplier:* Hajj Research Center.
  - *Date compiled:* 1993.

- **Data set:** Detailed chart;
  - *Data set category:* Arafat detailed chart.
  - *Content:* Saudi Red Crescent stations and road network.
  - *Format:* Conventional paper map.
  - *Supplier:* Saudi Red Crescent Society.
  - *Date compiled:* 1994.

- **Data set**: Arafat Area;
  - ***Data set category:*** Arafat area.
  - ***Content:*** Civil Defense stations and medical services.
  - ***Format:*** Conventional paper map.
  - ***Supplier:*** General Directorate of Civil Defense.
  - ***Date complied:*** 1993.

- **Data set**: Arafat Area Detailed Plan;
  - ***Data set category:*** Traffic flow.
  - ***Content***: Road network, traffic directions and emergency facilities.
  - ***Format***: Conventional paper map.
  - ***Supplier***: General Directorate of Traffic Police.
  - ***Date compiled***: 1994.

- **Data set**: Makkah region.
  - ***Data set category:*** Various spatial features.
  - ***Content:*** Various spatial features.
  - ***Format:*** Digital in SIF format.
  - ***Supplier:*** Ministry of Municipal and Rural Affairs.
  - ***Scale:*** Spatial features digitized from 1:25,000 source maps.
  - ***Projection:*** UTM.
  - ***Date compiled:*** 1994.

In addition to the above mentioned spatial data sets, various other reports and studies were collected from different government agencies. These include: emergency plans, traffic plans, and other studies related to Hajj activities produced by many government and non government agencies.

6.3 Hardware and Software Specification:

To accomplish the objectives of emergency dispatch simulation and testing, the following software hardware configurations are selected. The selection is based on the availability and cost effectiveness of the elements. These configurations however, do not necessarily reflect the appropriate platform of any specific system to be implemented in Makkah. Such a system would obviously be more generously financed and would be subject to procurement procedures considered normal in Saudi Arabia. This system by contrast, is designed to serve as a cost effective demonstration.

- A PC system operating under Windows95™ and DOS version 7.0™ from Microsoft Corporation was used as a platform.
- Analysis PC ARC/INFO™: PC ARC/INFO version 4.3D™, developed by Environmental System Research Institute (ESRI). It is a fully functional GIS system, used as the core system for the creation, manipulation and analysis of various spatial coverages.
- ArcView 2.1™: ArcView 2.1™ from ESRI is a desktop mapping and GIS tool. It enables selection and display of different combination of data as well as visualization of information. This software operates on PC ARC/INFO™ database format. It is used as a front end system to display the analysis and simulation results.

- Microsoft Access™ version 7.0: a fully functional relational database management system developed by Microsoft Corporation. It provides data definition, manipulation, and control was used for the creation and manipulation of the attribute databases.

An additional software package used is the Simple Macro Language (SML™), included with PC ARC/INFO™. SML was used to serve two primary purposes. First, to automate repetitive procedures and tasks performed for database input and output processing. Second, to develop and implement the different response scenarios.

6.4 Database Design:

The development of the database, in particular the spatial database was the most time consuming task during the implementation of the simulation of emergency response. It accounted for approximately 75 percent of the time of this phase. Using PC ARC/INFO™, four coverages were created along with their attribute information.

The database was designed according to the logical data models outlined in the analysis phase. The procedures adopted to convert the data into the physical design of the database are presented in this section. The procedures presented are particular to the GIS used, and may differ if other GIS systems are used in the future. The focus of the section is on the problems encountered during the conversion process and the solutions used to address such problems.

The procedures used to develop the database involved the following steps:

- data conversion;
- data editing;
- error checking;
- building topology structure; and
- integrating attribute data.

Data conversion involved the capture of spatial data from various formats and entering it into PC ARC/INFO™. Coverages in ARC/INFO™ can be created using several procedures, once digital data is converted into the ARC/INFO™ format using the data conversion routine supplied with the system. Since the digital data set was dated and some spatial features were missing, a digitizing process was initiated to incorporate the missing spatial data from other data sets.

Once the spatial data was entered into the system, it required editing to make it usable for analysis. This process involved correcting undershoots and overshoots of line segments by using ARC/INFO™ to identify digitizing errors and dangling nodes which refer to unconnected nodes of dangling arcs. In other words, if an arc does not close properly, or was digitized past an intersection, it will be registered as a dangling node. While this process is relatively simple, it is a time consuming procedure to edit and correct errors in the database.

Further, an additional error checking procedure was established before constructing the topology. A printout of the spatial database was produced and compared to other data sets to ensure its completeness. The rational was that disaster operations require high quality and an errorless database to support sound and effective decisions.

After entering the data and checking for errors, the topology was constructed to establish the relationship between spatial features. Using Build and Clean commands of PC ARC/INFO™, the topology was constructed. In this process ARC/INFO™ creates AAT (Arc Attribute Table) and PAT (Polygon Attribute Table) files to register spatial topology. The AAT and PAT files are database files which store thematic data about coverage features (ESRI 1990a). Thematic data about arcs and polygons is stored in separate AAT and PAT files for each coverage. Attributes can be added to these tables and are linked to each feature by the unique User-Id. PC ARC/INFO™ also creates two additional data files for each coverage. These are TIC and BND files. The TIC file contains the coordinates of the registration points for the coverage and the BND file contains the minimum and maximum coordinates of the coverage. These files are used for registering and scaling the coverage (ESRI 1990a). The last step in creating the database involved the integration of attribute information to spatial features.

6.4.1 Network Coverage:

The network coverage was initially created by converting road segments from SIF format to ARC/INFO™ format. This SIF data file, supplied by MOMRA, contained SIF files for four map sheets of the Makkah region. The entire database is approximately 20 MB in size. It includes various spatial features. However, only the road segments were extracted and converted to create the network coverage. Edge matching between map sheets was performed to join the road segments into one database. Other data in this data set was not relevant for the intended application of disaster response.

A major problem with this database was that it was not up-to-date, in spite of the fact it was compiled in 1994. Where necessary, some of the road segments were added by digitizing from the Arafat Area Detailed Plan supplied by the General Directorate for Traffic Police (GDTP). Once the road network database was completed, analysis determined that the network within the pilot area consisted of approximately 241 nodes and 411 links. The next step involved spatially registering, error checking and topologically structuring the road segments.

The following step involved geographically coding the attribute data. During the coding process, two major problems were encountered. One was the coding of traffic directions in the network. In the study area, there are 2866 possible right turns, left turns, straight through, and 'U' turns, at the 241 intersections. Each possible turn had to be coded as 1 if the movement is permitted and -1 if the movement is not permitted. Also, all pedestrian ways had to be coded as -1 as vehicles are not permitted to enter such pathways. Because the traffic plan changes twice during the (Standing day 'Waqfah'), this required coding of 5736 possible turns for the two stages of traffic plans.

The majority of coding was completed using the Turntable command of PC ARC/INFO™. However, coding all possibilities using the Turntable program is not a straight forward process, primarily because it was not possible to code without seeing which intersection being coded. To overcome this problem, the entire network was sketched on mylar. A printout of the node Ids and arc Ids was generated. Such node and arc Ids were then recorded on the mylar. In addition, each possible turn were recorded as an arrow on the sketched network. A similar process is performed for the second stage for traffic movement.

Access™ software from Microsoft Corporation was used to implement the coding process. When the coding process is completed, the file was converted to the dBase format, the native format for ARC/INFO. To ensure a correct and consistent coding scheme, an update query for validation was designed. After coding all possible turns and converting the database file into dBase format, further checking was performed using the ARCEDIT™ program of PC ARC/INFO™. The results were then compared with the actual traffic plans.

The other problem encountered during the integration of attribute data was not technical in nature, however it may determine the state of the entire system. This problem involves the addresses in the study area. The difficulty is that there are no complete addresses in the study area, except some of the street names. The reason for this is that the area is vacant throughout the rest of the year. In responding to this difficulty, two solutions were considered for the geocoding problem. One was to assign new addresses to each street in the network using a numbering scheme for each intersection along with the street name. For example, if the street name was Road No. 9, and it spanned over several intersections, the first node on the road segment was assigned 0 and the last node 100.

The next segment started with 101 and ended with 200, and this process continued for the balance of the road. Based on this numbering scheme, the address of a given intersection would be 100 Road No. 9. Although this solution would be practical for disaster application it was not implemented. This is primarily because if a system is developed, such an addressing mechanism would have to be adopted. Assuming this procedure is adopted by the SRCS, there are no assurances that other agencies will adopt the same addressing scheme.

The other solution possible was to use the available street names along with intersections as reference points. In this scenario, the nodes or intersections would become the primary identification of an address in the network. However, the road segments in the study area are short in length, mostly do not exceed 300 meters. Thus, if an incident happened in the middle of a road segment, it is possible to reference the location to the closest intersection. Using this approach, geocoding was performed based on the street names creating an address file with a relationship between addresses and spatial coverage features. Such a coverage allows identification of location by address.

After completing the data preparation described, the network coverage was ready for disaster response. It is also worth noting that several other applications can benefit from constructing the road network database, including: traffic analysis, transportation planning, and emergency management. Constructing such a network enables transportation planners and traffic analysts to effectively establish efficient traffic plans to minimize congestion. With the addition of more specific attribute information a number of maps can be generated from the network coverage based on a query against the database. An example of such a map is shown in figure 6.4.1.1, a road network map of road functional class.

6.4.2 Point coverages

Three coverages were created for the medical facilities, SRCS stations and evacuation centers. This process involved creating an empty coverage based on the coordinates of the network coverage for each of these facilities. The location of the medical, SRCS stations, and evacuation centers was digitized as point data from the various spatial data sets collected for this study. Attribute information was then added according to the logical data model outlined in the analysis phase.

A problem encountered during the creation of the point coverages was determining the exact location of emergency facilities. Since the simulation of disaster response was conducted over a network, the location of emergency facilities had to be on an end node (intersection). To overcome this problem, two possible solutions were examined. One, was digitizing the location of the emergency facility at the closest intersection. The other solution was to create an artificial link from the nearest intersection to the exact location of the emergency facility.

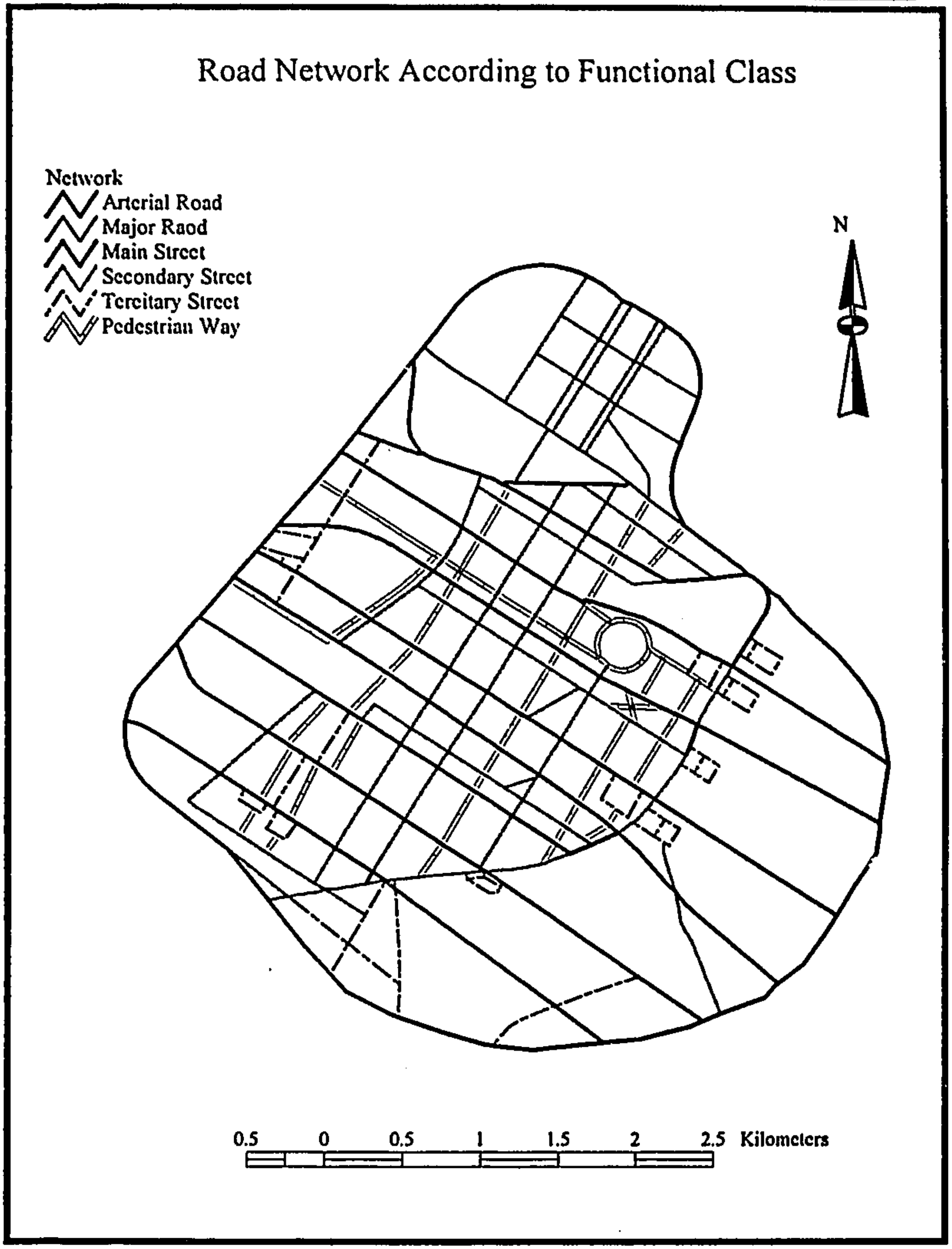


Figure 6.4.1.1 Road Network Based on Functional Class.

For this study, the digitizing solution was adopted, as it allowed proper address matching for simulation and analysis. In addition, considering the high density of the road network in the study area, digitizing the point locations to the nearest intersection did not exceed twenty meters of accuracy, which is an acceptable accuracy for disaster response.

6.5 Dispatching and Response:

The objective of simulating dispatch and response was to test the functionality of GIS technology for emergency response and decision support purposes. Using the Arafat Holy Site and PC ARC/INFO™, the dispatch simulation was based on the following three procedures:

- from an emergency service station to the incident location;
- from the incident location to a medical facility; and
- from the incident location to an evacuation center.

The emergency dispatch process contains several steps, as follows:

- identifying the incident location;
- locating the SRCS stations;
- dispatching resources through the optimal path to the incident scene based on the given conditions at that particular instant in time; and
- determining the optimal path from incident location to medical facilities and evacuation centers, in consideration of the characteristics of the situation.

Using PC ARC/INFO™ to test the dispatch response function, the road network was loaded into the ROUTE module of the GIS. The network coverage was loaded with two important attributes to allow the system to calculate the optimal path from one point to another. These are the distance or travel cost and the traffic plan. The length of a link indicates the distance to travel along an arc in the network. In the study area, there are two modes of traffic flow presented in the data model. One is during the day, when most of the traffic moves toward the area, the other is after sunset, when most of the traffic moves toward Mozdalifah Holy Site. For the dispatch simulation purposes, the second stage traffic plan was loaded where the traffic is at its peak and all pilgrims have depart to the other Holy Site at sunset. Also, additional data loaded into the system was the address information used to assist in identifying the location of interest.

Identifying the location of an incident is the first step in the dispatching process. Incident location, SRCS stations locations, medical facilities locations, and evacuation centers locations are defined as stops. The location of such facilities is determined by the node (intersection) internal number. If an incident occurs in the middle of an arc or a link, the location of such incident will be shifted to the nearest intersection that holds the node number. Therefore, interpolating the location of an incident along an arc is technically not possible.

Determining the location of emergency response facilities, can be accomplished in two ways. Interactively, it was determined using a mouse or a cursor and pointing to the location of the incident. A colored symbol along with the node number was displayed on the screen, indicating the location of the incident. Such an identification process can assist training purposes. However, in reality other more critical information is needed, such as address information, to locate an emergency incident.

The location of an incident was determined using address information as a reference. Once the address was entered into the system, a colored symbol was drawn on the screen that was used as a reference to indicate the incident location. In PC ARC/INFO™ this symbol is tagged as a 'stop', a location along a route at which resources can be picked up or dropped off (ESRI 1990d). In the study area, and as mentioned earlier, addresses impose a serious problem in identifying the location of an incident. If it happens to be an intersection where address is not available, then it is not possible to locate such an incident. However, if more information is given which may help identify the location based on known landmarks or in proximity to known address, then it is possible to identify the location interactively on the screen using a mouse or a cursor.

Under the assumption that a proper address was provided it is possible to add a stop as the incident location. The next step is to identify the location of SRCS stations and medical facilities. The location of such facilities can be added as stops in a similar fashion to locating incident location. However, since the location of such facilities are fixed, another alternative was to load the point coverages which contain their locations. By loading the point coverages, the internal node number of emergency facility locations along with symbol mark were displayed on the screen. Additional facility the system provided was that the location of the SRCS stations and medical facilities can be loaded as stops from an ASCII file which was created to hold their internal node numbers.

Once all the locations of SRCS stations, medical, and other facilities were identified, determining the routes and calculating the optimal paths to the incident scene was the next step in the dispatch simulation. Followed by determining the optimal routes from the incident scene to medical facilities and evacuation centers. The optimal path was calculated using the traffic plan and the distance required to travel along a road segment. The GIS calculates the optimal path based on these attributes which were modeled in the previous chapter. The optimal path between locations was displayed in different colors to help distinguish between different routes. Routes to the incident scene and medical facilities could be saved and used for dispatching purposes. Other valuable information such as specific travel directions and distance of travel could also be generated and saved in an ASCII format for output which could appear as the following:

Directions for route 5

Start at ARAFAT CIRCULAR ROAD

Travel 1712.07 Meters Go straight to NA

Travel 490.30 Meters Turn left to ARAFAT RING ROAD

Travel 636.68 Meters Turn left to ROAD NO 2

Travel 384.50 Meters Turn right to 1ST CROSS ROAD

Travel 388.93 Meters Turn left to ROAD NO 3

Travel 472.40 Meters

Total= 4084.87 Meters

An additional concern to be considered during emergencies involves identification of who should respond to an incident. The GIS however does not provide a direct answer to this problem. It calculates the optimum path between two points. However, there are fourteen different stations and it is desirable to dispatch the closest station with the minimal cost to reach the scene. Although all station locations can be displayed on the screen, what appears closest to the incident may not have the most optimal path to the incident. For example, in figure 6.5.1 the negative numbers indicate that movement is not permitted along a link for whatever reason. The positive numbers represent the impedance or resistance to movement. First observation, would support that station 2 should respond because it is closer to the incident location. However, the accumulative cost from station 1 to the incident is 4 which is 3 less than station 2. In addition, an important consideration for emergency response simulation is the magnitude of the incident. The amount of resources to be dispatched to the scene based on the magnitude of the incident must be considered. It was determining that further analysis and manipulation of data were required to solve these problem.

Taking into consideration the unique settings of the study area, minor emergency occurrences may not require the dispatch of emergency vehicles. It is particularly relevant to consider that the area is only 4 x 4 km^2 that has more than fifty emergency facilities within its core, and is also already congested with traffic. Thus, if a minor incident happen, it could be treated on the spot or at the nearest medical facility, which could be only few meters away.

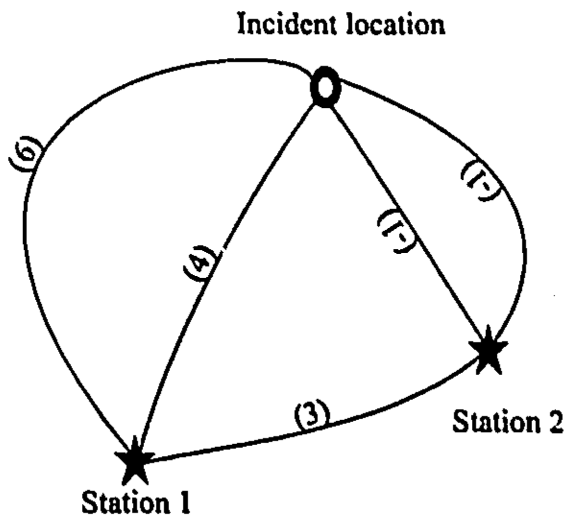


Figure 6.5.1: Single Incident Multiple Response.

The only practical test simulation of the IRSDSS is for dispatch to an incident involving many casualties where resources have to be deployed from several stations regardless of their capacity. To simulate such an extreme situation a SML™ routine was written as shown in Appendix C.1. Such a routine instructed the system to:

- load the network for the second stage of traffic in Arafat area;
- randomly identify the incident location as a stop;
- read the SRCS stations internal node numbers from an ASCII file and add them as stops;
- read the medical facilities internal node numbers from an ASCII file and add them as stops;
- read the evacuation centers internal node numbers from an ASCII file and add them as stops;
- calculate and determine the optimal path from SRCS stations to the incident location;

- calculate and determine the optimal path from incident location to medical facilities; and
- calculate and determine the optimal path from incident location to evacuation center.

A sample output of routes from all stations to the incident location and from incident location to evacuation centers are shown in figure 6.5.2.

The analogy provided indicated that it was not possible to determine which station is closest to the scene. In addition, it was also not possible to determine how may stations should respond based on their capacity and the magnitude of the incident. It leads to the need for further analysis and manipulation of data to respond to such questions. Such issues will be addressed in the next chapter.

6.6 Summary:

To accommodate the dispatch and response simulation of the IRSDSS in Arafat area during the Hajj season, spatial and attribute data was collected during a field trip to Saudi Arabia from different agencies. This data was provided in various formats. Spatial and attribute data was integrated using PC ARC/INFO™ according to the data model presented in the analysis phase. These steps were taken to accommodate the database required to support the simulation of the response and support functions of the IRSDSS.

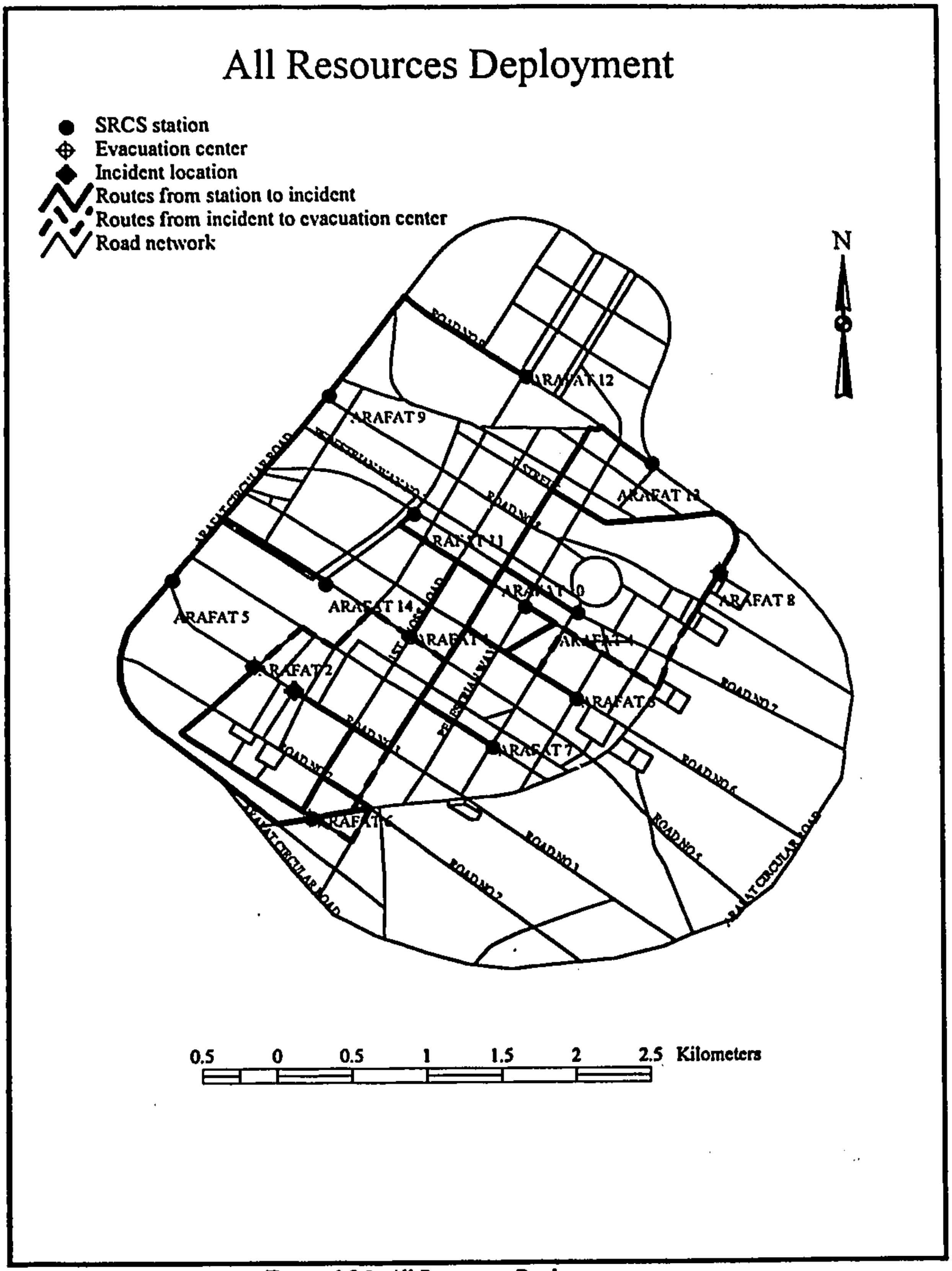


Figure 6.5.2: All Resources Deployment.

During the database design a number of technical and non technical problems were encountered. Technical problems included: the coding of each possible turn for each intersection in the network, another was shifting the location of emergency services to the nearest intersection due to technical limitations of PC ARC/INFO™. While incomplete addresses in the study area were non technical issues which had to be resolved to take full advantage of the GIS technology.

The dispatch process used by the SRCS includes: identifying the incident location, determining the nearest station to the scene, determining the optimal path and dispatching resources to the incident location, and dispatching emergency vehicles to medical facilities and evacuation centers. Each aspect of this process have been tested using PC ARC/INFO™ GIS.

During simulation of the dispatch process, it was found that the GIS provides a facility to calculate the optimal path from origin to destination points based on the data model integrated into the system. However, it does not provide a solution which determines the nearest station to the incident scene. It was also observed that the system does not accommodate the query of how many resources should be dispatched to an incident. At this point under the conditions presented and the data manipulation made, the system can dispatch all resources from all stations regardless of their capacity or proximity to the disaster incident. It is clear that manipulation and analysis of the data under different scenarios were required, and these are presented in the next chapter.

Chapter Seven

7. Scenarios Development and Testing

7.1 Introduction:

The dispatch of SRCS resources in the Arafat area in response to emergency incidents during the Hajj is an important issue. From the analysis and simulation provided in the previous chapter, it is apparent that a GIS does not provide a fully practical solution to the following questions:

- Which SRCS station should respond first to an incident?
- How many SRCS stations should respond to an incident based on their capacity and the magnitude of the incident?

To provide an answer to such questions it was realized that there was a need for further manipulation and analysis of data. In this chapter, an attempt is made to solve this problem under two scenarios with incidents of various magnitudes. The first scenario deals with a single incident. The second scenario deals with multiple incidents. To reach a solution to the problems presented in the scenarios, application specific programs were written in the C computer programming language. To use the results and conduct a simulation using PC ARC/INFO™, an additional series of SML™ routines were written.

This chapter begins with exploring the objectives of the scenarios development to further test the system. It proceeds to elaborate and introduce the problem and its solutions under the first scenario. The second scenario is then presented and discussed at the end of this chapter. These steps toward developing the scenarios are shown in figure 7.1.1.

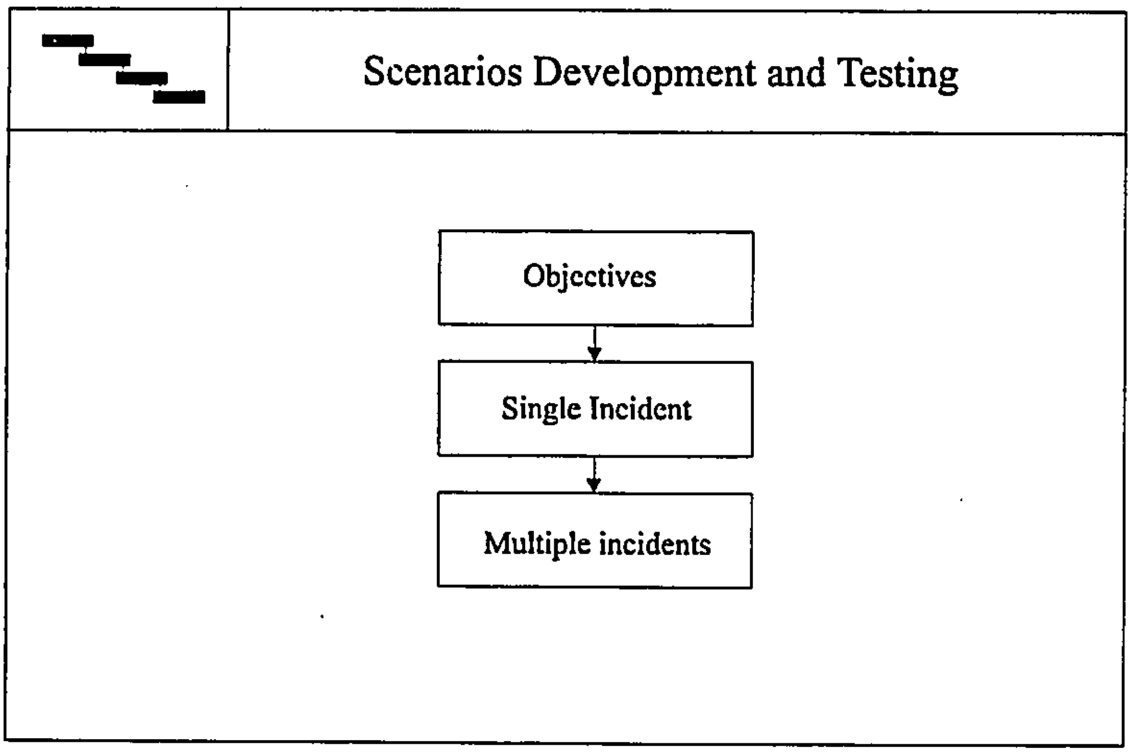


Figure 7.1.1: Scenarios Simulation and Testing

7.2 Objectives:

There are 46 mobile emergency response units in fourteen different SRCS stations in Arafat area. They have a total capacity of handling 92 casualties per hour. The objective of developing scenarios was to simulate the dispatch process of the SRCS as an attempt to answer the following questions:

1) Which of the SRCS stations should respond first to an incident?

2) How many stations should respond based on their capacity and the magnitude of an incident?

The above questions are tested under two scenarios of different incident magnitudes. The objective of the first scenario was to test the system for a single incident requiring multiple responses. The objective of the second scenario was to test the system for multiple incidents which require multiple responses. Under the scenarios a general assumption was made that the disaster incident involved 100 casualties. The selection of 100 casualties as the maximum incident magnitude was based on the following elements:

- the system was already tested for incident involving many casualties in the previous chapter;
- testing for an incident of more than 100 would exceed the total capacity of all the SRCS stations, which is 92; and
- incident of 100 casualties is an extreme situation which would test the limits of the IRSDSS.

For the first scenario, the simulation of dispatch services was tested for normal distributions of 15%, 50%, 85% and 98% of the 100 casualties during a single incident. The magnitude of the incidents under the second scenario are 7% for the first incident and 8% for the second incident, and simulation of dispatch services performed for 15% and 50% for each incident. The percentages are fixed based on median values of 1 σ and 2 σ in a normal distribution. The test cannot be performed for an incident with a magnitude of more than 50% for the second scenario, as it would exceed the maximum capacity of all SRCS stations which is 92. Additionally, and as indicated earlier, the IRSDSS is already being tested for many casualties in the previous chapter.

7.3 Single Incident Multiple Response Scenario:

Under a single incident which requires multiple responses scenario, the dispatch function is from many origins (stations locations) to a single destination (incident location) and from a single destination (incident location) to many destinations (medical facilities and evacuation centers).

The prime issue is that there are fourteen SRCS stations with fixed locations. However, the capacity to handle casualties varies from one station to another. An additional issue is that the incident location is not known as it might happen anywhere in the study area. Based on these circumstances, the optimal path from the station location to the incident location will be different each time an incident occurs. Further, the number of stations that should be dispatched to the scene will also vary based on their capacity and the magnitude of the incident. The problem is illustrated in figure 7.3.1. The station numbers are replaced by characters for simplicity of description.

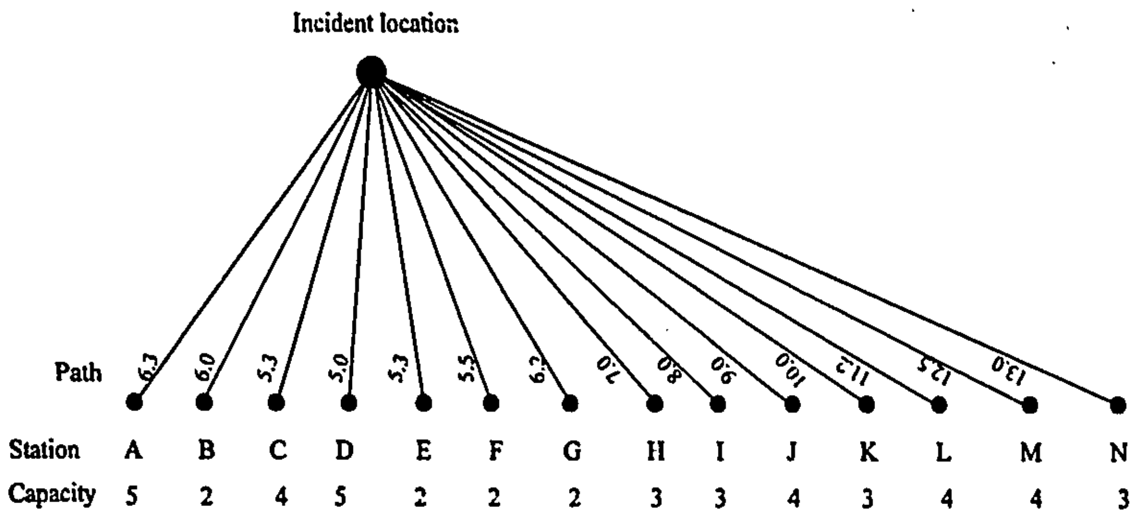


Figure 7.3.1. Single Incident Response.

The approach followed to resolve this issue is as follows:

1) Obtain the optimal path for each station to the incident scene (the optimal path was calculated using PC ARC/INFO™).

2) Sort the optimal path for each station to the incident location in ascending order, and arrange the stations and their capacity according to the sorting mechanism. A bubble sort algorithm was used to sort the optimal path data (Tenenbaum et al. 1990).

3) Assign the required number of stations based on their capacity and the magnitude of the incident. That is under the differing magnitudes of the scenario, 15%, 50%, 85%, and 98% of response resources. The number of stations to be assigned to an incident is determined by adding the capacity of stations until the magnitude of the incident is reached. For an incident with a magnitude of 98%, an extra station will be assigned to the incident as extra support. This is because the magnitude of the incident exceeds the maximum capacity of all stations that is 92.

The results of the analysis to the example presented above are shown in table 7.3.1. The logical representation of the solution used to address this scenario is shown in figure 7.3.2 and 7.3.3. To manipulate and analyze the data and provide a solution to this issue, a C code program was written as shown in Appendix C.1 To simulate the dispatch of response services for this scenario a series of SML™ routines were written as shown in Appendices D.2 through D.6. A sample output of the simulation is shown in figure 7.3.4 for an incident with 50% magnitude.

Table 7.3.1: Single Incident Assignment.

Amount of Resources Dispatched											
15%			50%			85%			98%		
S	C	P	S	C	P	S	C	P	S	C	P
D	5	5.0	D	5	5.0	D	5	5.0	D	5	5.0
C	4	5.3	C	4	5.3	C	4	5.3	C	4	5.3
			E	2	5.3	E	2	5.3	E	2	5.3
			F	2	5.5	F	2	5.5	F	2	5.5
			B	2	6.0	B	2	6.0	B	2	6.0
			G	2	6.2	G	2	6.2	G	2	6.2
			A	5	6.3	A	5	6.3	A	5	6.3
			H	3	7.0	H	3	7.0	H	3	7.0
						I	3	8.0	I	3	8.0
						J	4	9.0	J	4	9.0
						K	3	10.0	K	3	10.0
						L	4	11.2	L	4	11.2
						M	4	12.5	M	4	12.5
									N	3	13.0
									O	3	[illegible]

S = Station, C = Capacity, P = Path.

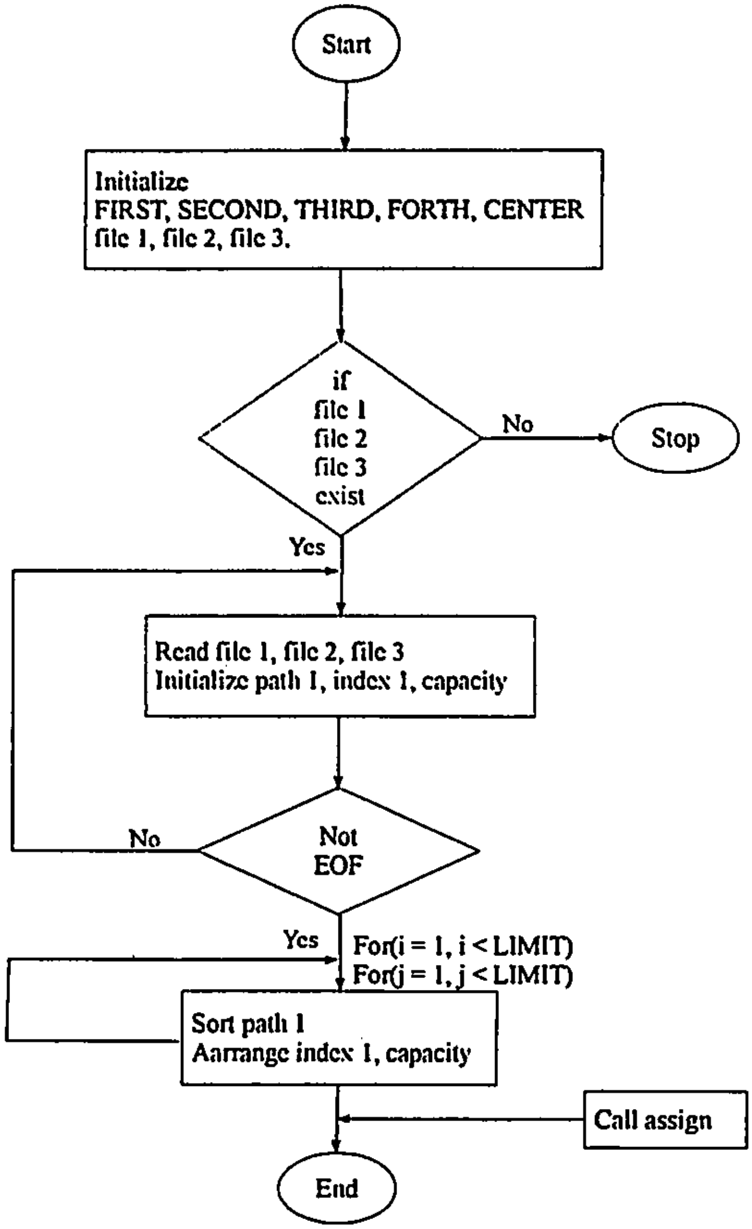


Figure 7.3.2: Single Incident Sorting Representation.

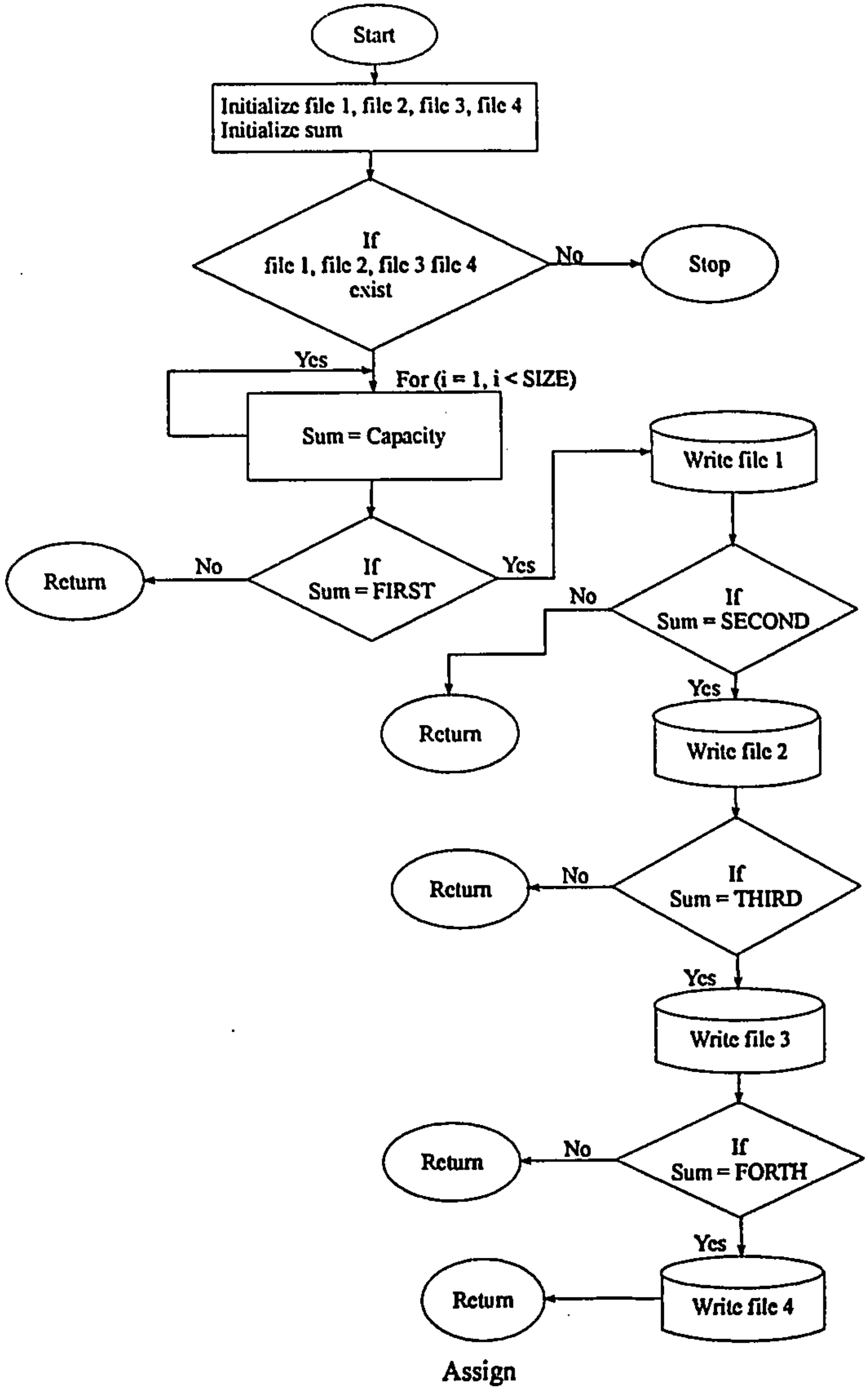


Figure 7.3.3: Single Incident Assignment Representation.

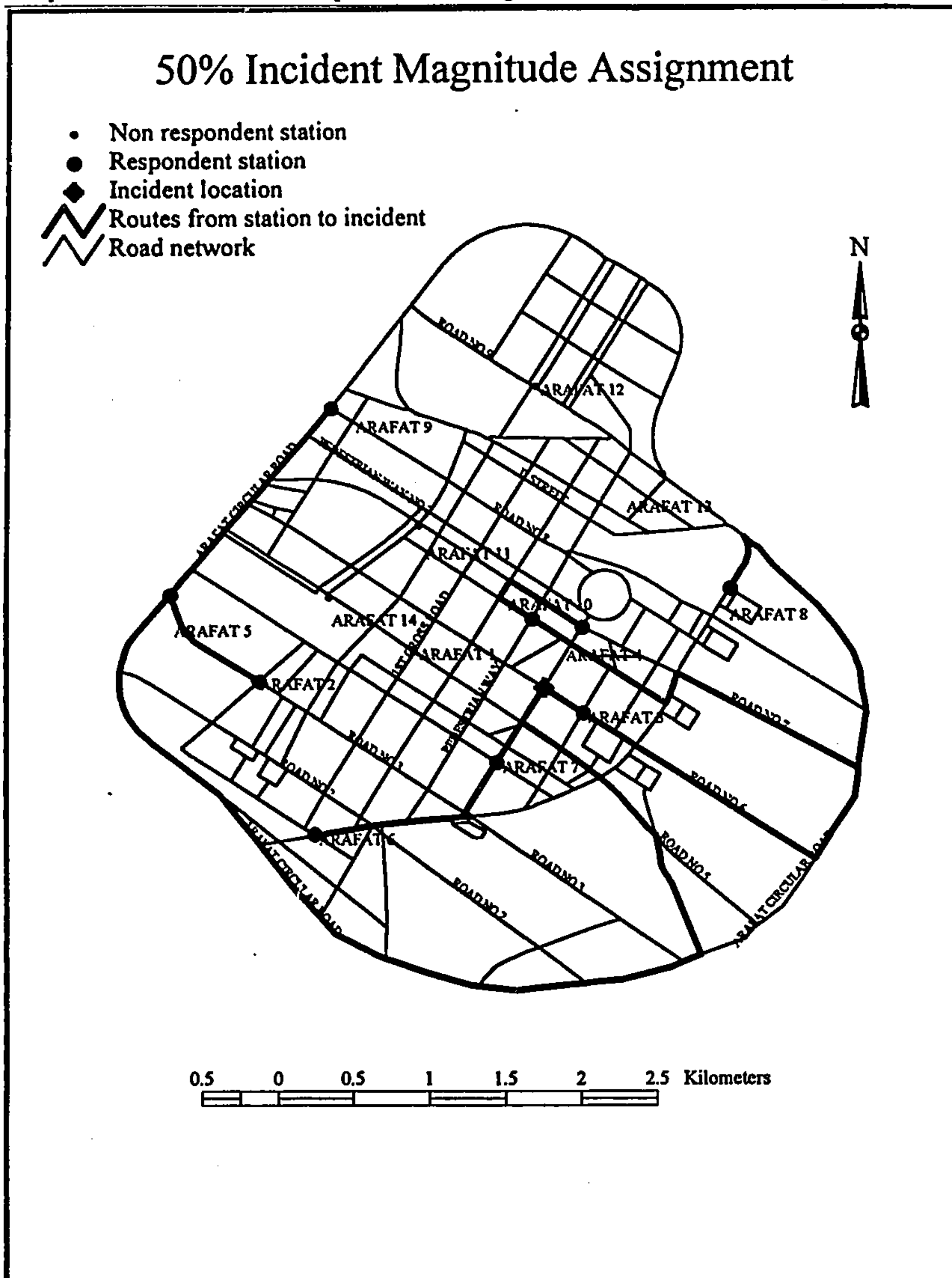


Figure 7.3.4: Single Incident Assignment with a Magnitude of 50%.

7.4 Multiple Incidents Multiple Response Scenario:

Under a multiple incident which requires multiple responses, the dispatch function is from many origins (stations locations) to two destinations (incidents locations) and from these two destinations to many additional destinations (medical facilities and evacuation centers).

This scenario examines the issue of what happens when two incidents occur in the study area. It addresses who and how many resources should be dispatched to the first and second incidents. The magnitude of the incident and the capacity of stations to supply response services are factors in this case. However, resources from each station should not be dispatched to both incidents unless that particular station has extra mobile units which could be dispatched to either incident because of its magnitude. The problem here is far more complicated than the issue presented under the first scenario, where the stations need only to be assigned to single incident based on their capacity and the magnitude of the incident. Figure 7.4.1 illustrates the problem if all resources are dispatched to both incidents. In later sections, this example is used to explain the solution to this issue. The stations numbers are replaced by characters for simplicity of explanation.

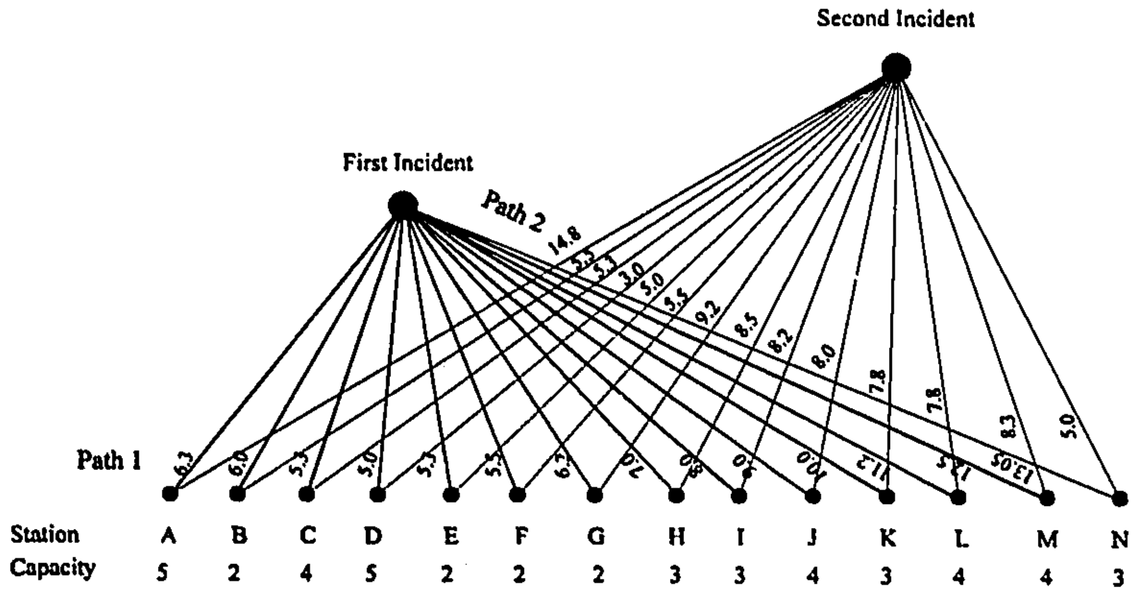


Figure 7.4.1: Multiple Incidents Response.

The approach followed to solve this problem contained four general steps, as follows:

1) Obtain the optimal path data for each station to both incidents. (the optimal path was calculated using PC ARC/INFO™);

2) Sort the optimal path in ascending order to both incidents and arrange stations and their capacity according to the sorting mechanism. A bubble sort algorithm is used to sort the optimal path data (Tenenbaum et al. 1990).

3) Match seven stations with optimal path to the first incident, and match seven stations with optimal path to the second incident; and

4) Assign stations to the first incident based on their capacity and its magnitude, and assign stations to the second incident based on their capacity and its magnitude.

The first step of the solution involved generating the optimal path. Each subsequent step, except the assignment step (step 4) was based on further manipulation of the optimal path data. Step two involved sorting the optimal path data and arranging stations and their capacity to provide response services. An important consideration of step two was to sort the optimal path and arrange the stations and their capacities accordingly, as in some instances, stations with a higher cost optimal path maybe assigned to an incident while other stations with a lower optimal path to that incident maybe assigned to the other incident. This may be particularly true if for instance, the optimal path to both incidents for all stations is in descending order and the optimal path for all stations to the first incident is less than the optimal path to the second incident. Stations with higher cost of their optimal path would be assigned to the first incident instead of assigning stations with minimal path to that incident. Subsequently, the question of which station should respond first would be altered.

Matching seven stations to the first incident and seven stations to the second incident is the third step in the solution for this scenario. By matching seven stations to each incident, this ensures that there are no duplicate stations assigned to both incidents. In addition, this eases the final step in the solution, of the required stations to an incident based on its magnitude.

A more detailed explanation of the solution is presented below:

1) Obtain the optimal path data for each station in response to both incidents.

2) Sort the optimal path data for each station in ascending order for the first incident.

3) Arrange the stations and their capacity according to the sorting mechanism for the first incident.

4) Sort the optimal path data for each station in ascending order for the second incident.

5) Arrange the stations and their capacity according to the sorting mechanism for the second incident.

Logical representation of the sorting and arranging processes of stations and their capacity is shown in figure 7.4.2. For the example presented above, the results of the analysis to this stage are shown in table 7.4.1.

At this stage of analysis, the response stations have been arranged according to their optimal path to both incidents. However, many observations are evident from this table:

1) The optimal path to the first incident is less than the optimal path to the second incident for the same station or vice versa. An example from table 7.4.1 is station A, which has a less optimal path (6.3) to the first incident, and station B, which has a less optimal path (5.5) to the second incident.

Table 7.4.1: Arranged Stations According to Optimal Path.

First Incident			Second Incident		
Station	Capacity	Path	Station	Capacity	Path
D	5	5.0	D	5	3.0
C	4	5.3	E	2	5.0
E	2	5.3	N	3	5.0
F	2	5.5	C	4	5.3
B	2	6.0	B	2	5.5
G	2	6.2	F	2	5.5
A	5	6.3	K	3	7.8
H	3	7.0	L	4	7.8
I	3	8.0	J	4	8.0
J	4	9.0	I	3	8.2
K	3	10.0	M	4	8.3
L	4	11.2	H	3	8.5
M	4	12.5	G	2	9.2
N	3	13.0	A	5	14.8

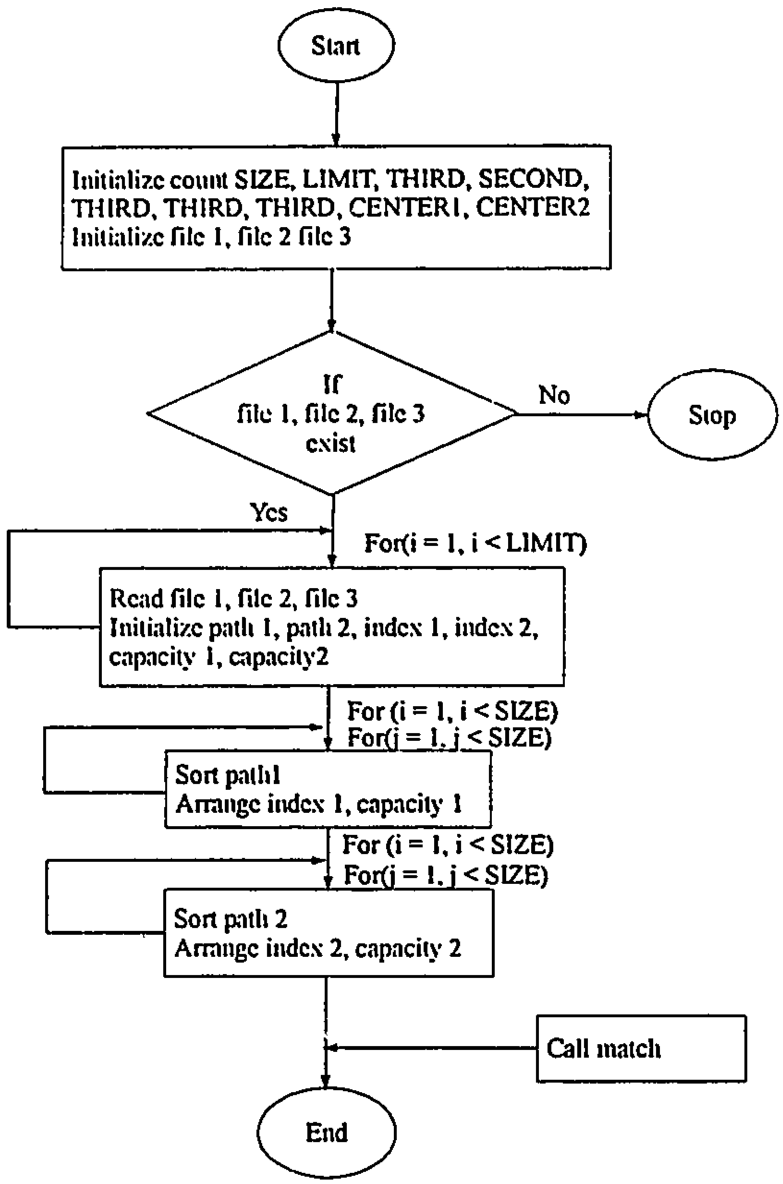


Figure 7.4.2: Logical Two Incidents Sorting Representation.

2) The optimal path to the first incident is greater than the optimal path to the second incident for the same station or vice versa; An example from table 7.4.1 is station B, which has a greater optimal path (6.0) to the first incident, and station A, which has a greater optimal path (14.8) to the second incident.

3) The optimal path to the first and second incidents are equal for the same station. An example from table 7.4.1 is station C, which has equal optimal path (5.3) to both incidents.

This situation imposes a matching problem which was the third step in the general solution. The objective of matching during this step was to match seven stations to the first incident, and match seven stations to the second incident. There could be no duplication of stations to the same incident, while their arranged order should also be maintained. These are important elements of the answer of who should respond first to an incident. The matching problem was solved as follows:

1) Select the first station with minimal path assigned to the first incident and find the matching station assigned to the second incident.

2) Compare the optimal path for the same station to both incidents;

- If the optimal path is less or equal to the first incident, match station to the first incident.

- If the optimal path to first incident is greater than the optimal path to the second incident, assign station to a temporary list. In this case, this station cannot be automatically matched to the second incident because this would alter the order of stations already assigned to the second incident. When the initial comparison is made, the order of this station to the second incident is unknown.

3) Repeat the above steps for the remaining stations while the number of stations matched to the first incident is less than or equal to seven.

A second search and comparison process was made for each station to the second incident. This was necessary to maintain the order of stations assigned to the second incident. The required steps to this aspect of the solution are:

1) Select the first station with minimal path assigned to the second incident and find the matching station assigned to the first incident.

2) Compare the optimal path for the same station to both incidents;

   - If the optimal path is less to the second incident, match station to the second incident.

   - If the optimal path to the second incident is greater than the optimal path to the first incident, assign station to a second temporary list.

3) Repeat the above steps for the remaining stations while the number of stations matched to the second incident is less than or equal to seven.

To this stage in the analysis, the number of stations matched to the first incident or to the second incident was seven or less. As indicated earlier, three different combinations according to the optimal path were expected. The logical solution up to this stage is shown in figure 7.4.3a. To match exactly seven stations to the first incident and seven stations to the second incident further comparison was required, in this case, comparison of the temporary lists.

If the number of stations matched to the first incident is less than seven, the steps required to match the exact number of stations are as follows:

1) The first station in the temporary list for the first incident was selected and compared with the stations already matched to the second incident.

2) If the station was not matched to the second incident, was matched to the first incident.

3) The above steps were repeated for the remaining stations in the temporary list for the first incident.

If the number of stations matched to the second incident is less than seven, the steps required to match the exact numbers of stations are as follows:

1) The first station in the temporary list for the second incident was selected and compared with the stations already matched to the first incident.

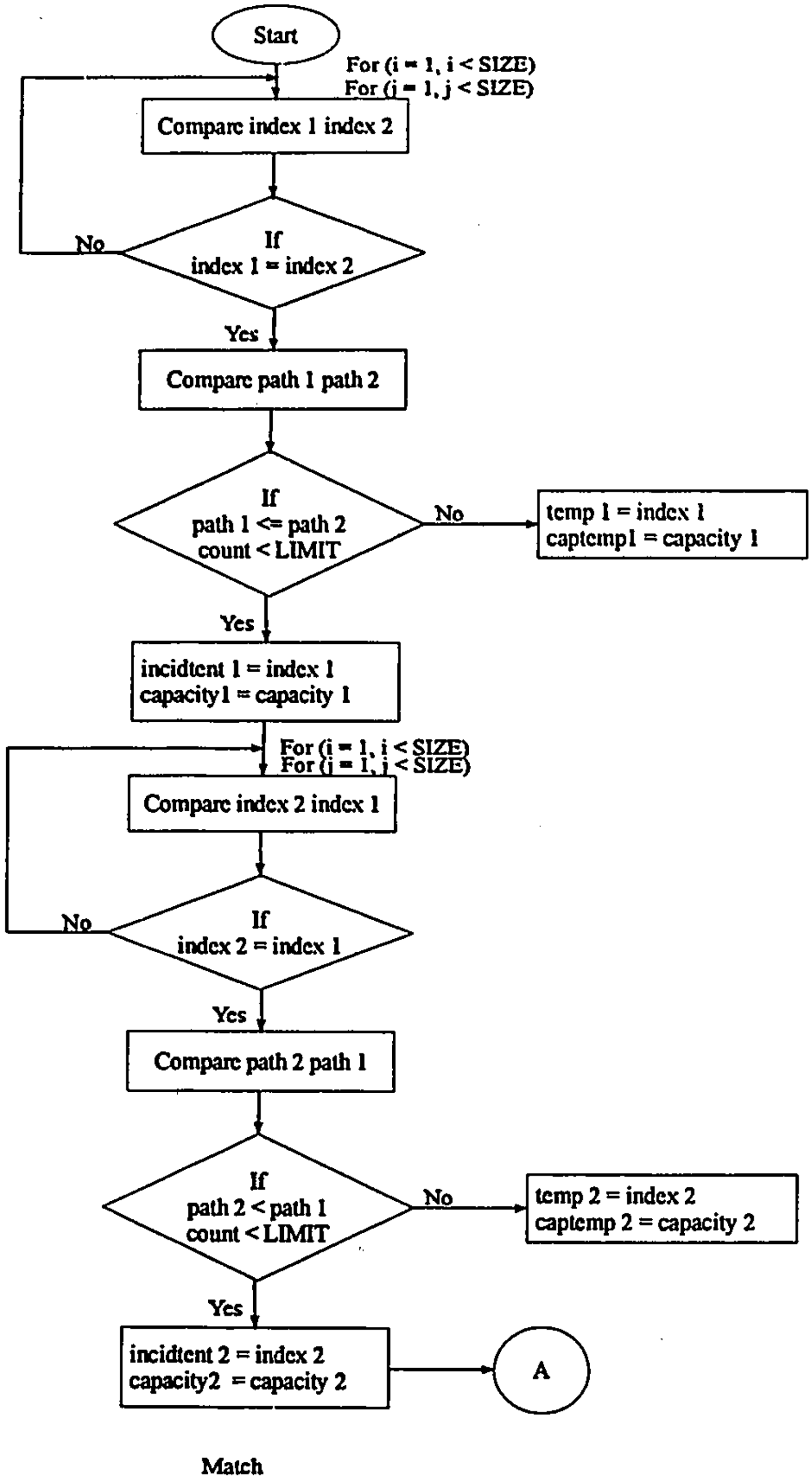


Figure 7.4.3a: Matching Stations to Incidents.

1) If the station was not matched to the first incident, was matched to the second incident.

2) The above steps were repeated for the remaining stations in the temporary list for the second incident.

By conducting such an analysis, the matching problem was solved. Seven stations with least cost path were matched to the first incident, and seven stations with least cost path were matched to the second incident. The logical solution to the second part of the matching problem is shown in figure 7.4.3b. The final results of the matching process for the example are shown in table 7.4.2.

Table 7.4.2: Matching Stations to Incidents

First Incident			Second Incident		
Station	Capacity	Path	Station	Capacity	Path
C	4	5.3	D	5	3.0
F	2	5.5	E	2	5.0
G	2	6.2	N	3	5.0
A	5	6.3	B	2	5.5
H	3	7.0	K	3	7.8
I	3	8.0	L	4	7.8
M	4	12.5	J	4	8.0

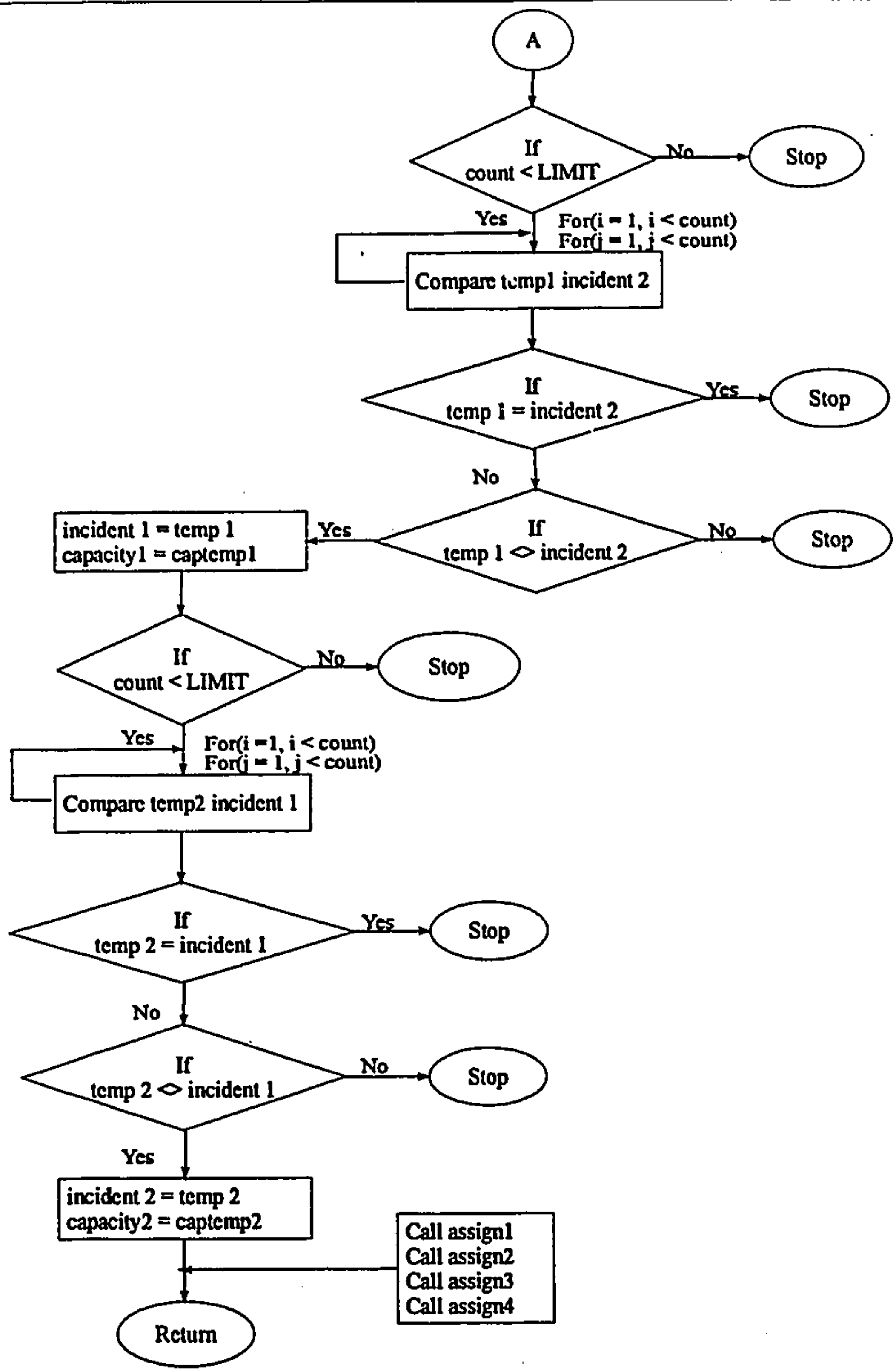
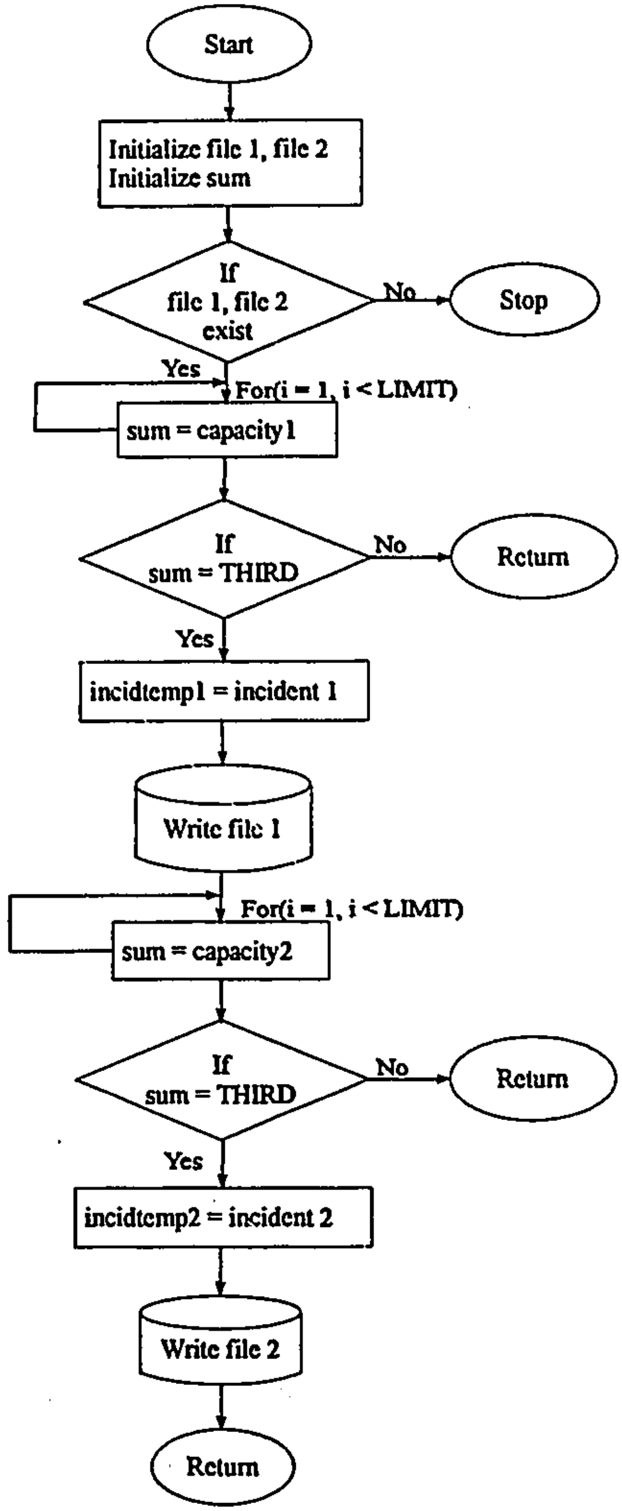


Figure 7.4.3.b: Matching Stations to Incidents.

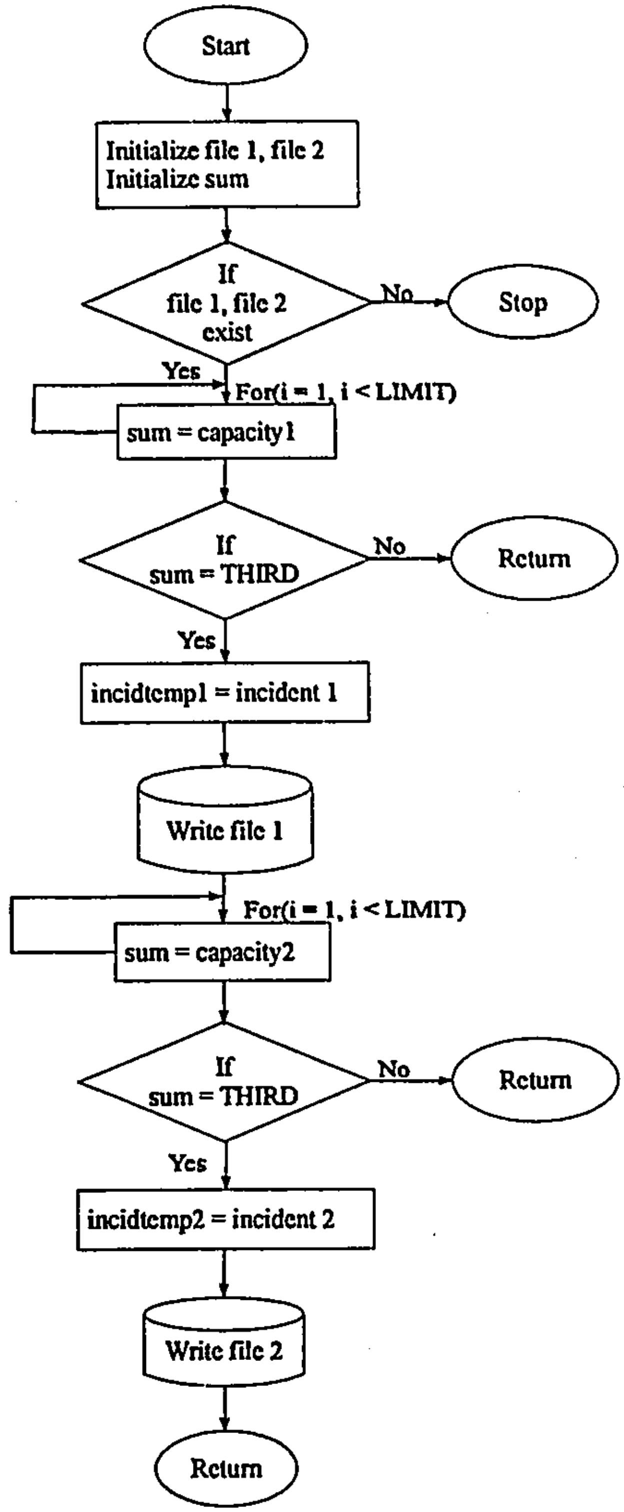
Observation of the results in table 7.4.2 show that station M was matched to the first incident although it has a lower optimal path to the second incident. This is because when the initial comparison was made this station was assigned to the temporary list for the first incident. When this list was compared with the second incident, station M was not found within the second incident, thus it was matched to the first incident to satisfy the requirements of matching assignment.

Once the solution to the matching problem was reached, the next step was to assign the required number of stations to each incident based on its magnitude and the capacity of the stations. This was the fourth and final stage of the solution. Stations were assigned to each incident based on their capacity, for each incident with a magnitude of 7%, 8%, 15% and 25% respectively. Stations were assigned to each incident by adding their capacity until they reached the magnitude of the incident. Under such circumstances both incidents with the above magnitudes will not exceed the total capacity of all stations. The logical solution to the assignment step of the solution is shown in figure 7.4.4 for two incidents with magnitude of 7% and 8% respectively. Figure 7.4.5 shows the logic behind solving the assignment step for two incidents with magnitude of 15%, while figure 7.4.6 shows the assignment step for two incidents with magnitude of 25%. The results of the analysis for the 15% and 25% examples are shown in tables 7.4.3 and 7.4.4. However, the assignment process would be different if each incident has a magnitude of 50%, as they would exceed the total capacity of all stations. Under such circumstances, the following observations can be made with regard to assigning the appropriate number of stations to each incident based on their capacity.



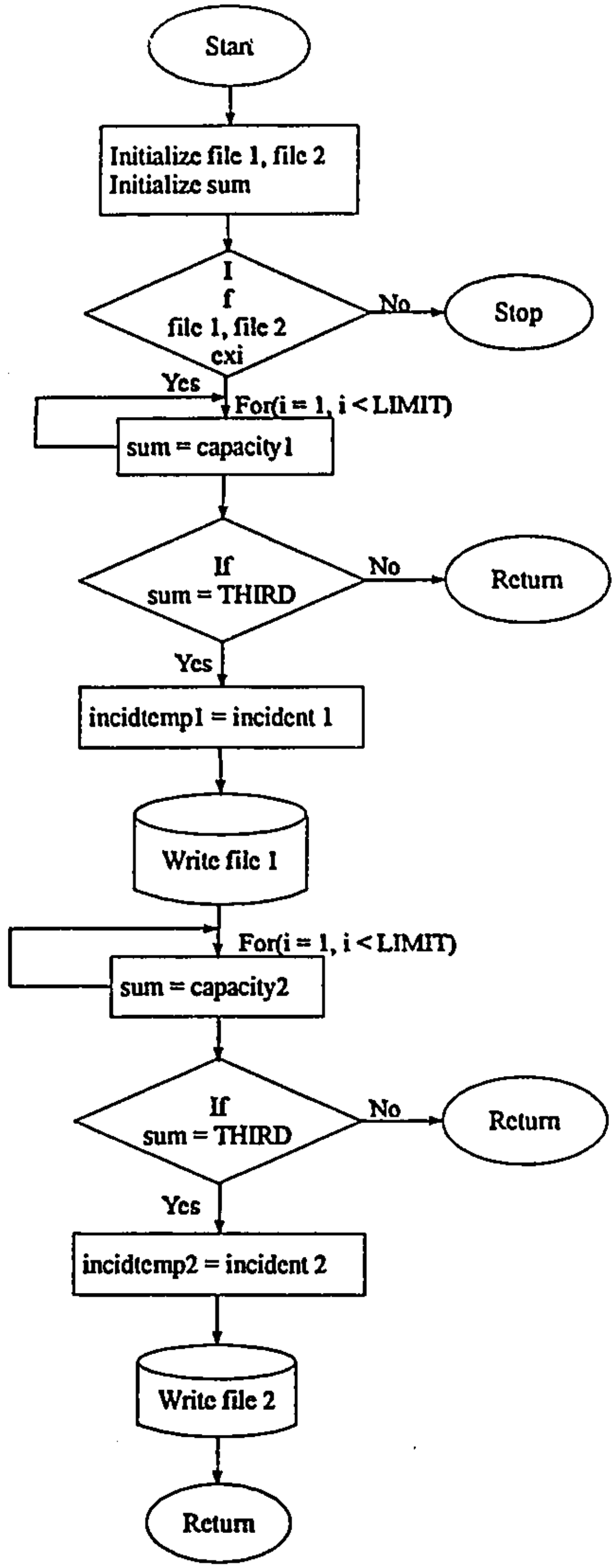
Assign1

Figure 7.4.4: 7% and 8% Assignment Representation.



Assign2

Figure 7.4.5: 15% Assignment Representation.



Assign3

Figure 7.4.6: 25% Assignment Representation.

Table 7.4.3: First Incident Assignment.

7% Magnitude		15% Magnitude		25% Magnitude		50% Magnitude	
Station	Capacity	Station	Capacity	Station	Capacity	Station	Capacity
C	4	C	4	C	4	C	4
		F	2	F	2	F	2
		G	2	G	2	G	2
				A	5	A	5
						H	3
						I	3
						M	4
						O	2

Table 7.4.4: Second Incident Assignment.

8% Magnitude		15% Magnitude		25% Magnitude		50% Magnitude	
Station	Capacity	Station	Capacity	Station	Capacity	Station	Capacity
D	5	D	5	D	5	D	5
		E	2	E	2	E	2
				N	3	N	3
				B	2	B	2
				K	3	K	3
						L	4
						J	4
						P	2

1) The total capacity of the seven matched stations to the first incident maybe less, equal, or greater than the magnitude of the incident.

2) The total capacity of the seven matched stations to the second incident maybe less, equal, or greater than the magnitude of the incident.

Considering the observations presented above, further manipulation and analysis of data was required to assign the right number of stations to each incident. The solution to this scenario was accomplished using the following steps:

1) Add the capacity of each station matched to the first station:

   - If the total capacity is equal to the magnitude of the incident, assign stations to the first incident.

2) Add the capacity of each station matched to the second station:

   - If the total capacity is equal to the magnitude of the incident, assign stations to the second incident.

The total capacity of all stations is 92, and the total magnitude of both incidents is 100. Since there are a number of combinations expected, further analysis was required:

1) If the total capacity of matched stations to both incidents is less than the magnitude of both incidents, assign an extra station to both incidents as extra support.

2) If the total capacity of matched stations to the second incident is greater than its magnitude, assign the extra capacity of station(s) to the first incident.

3) If the total capacity of matched stations to the first incident is greater than its magnitude, assign the extra capacity of station(s) to the second incident.

The logical solution steps noted above are shown in figures 7.4.7a, 7.4.7b, and 7.4.7c. The results of the analysis for the example are shown in table 7.4.3 and 7.4.4.

To this end, a solution to the problem presented in the second scenario was reached. To perform data analysis and manipulation, a C code program was written as shown in Appendix C.2. PC ARC/INFO™ was used to simulate two incidents with a 25% magnitude as shown in figure 7.4.8. The SML™ routines used for this simulation are shown in Appendices D.7 through D.9.

7.5 Summary:

The issue of dispatching SRCS resources during the Hajj season in Arafat area has been examined under two different scenarios. Because a GIS does not provide a direct answer to such questions as who should respond and how many resources should be deployed to an incident scene, a solution to such questions under these two scenarios was presented.

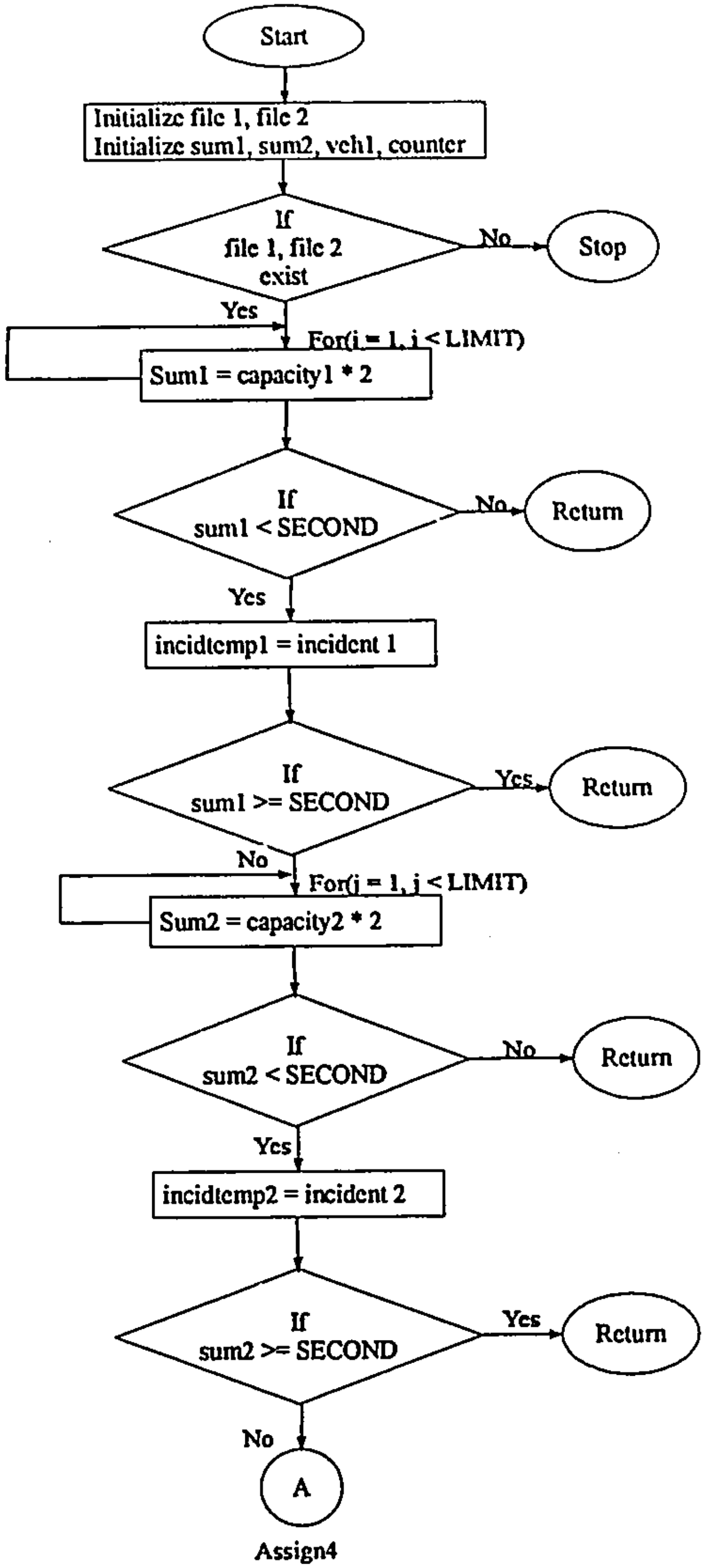


Figure 7.4.7a: 50% Assignment Representation.

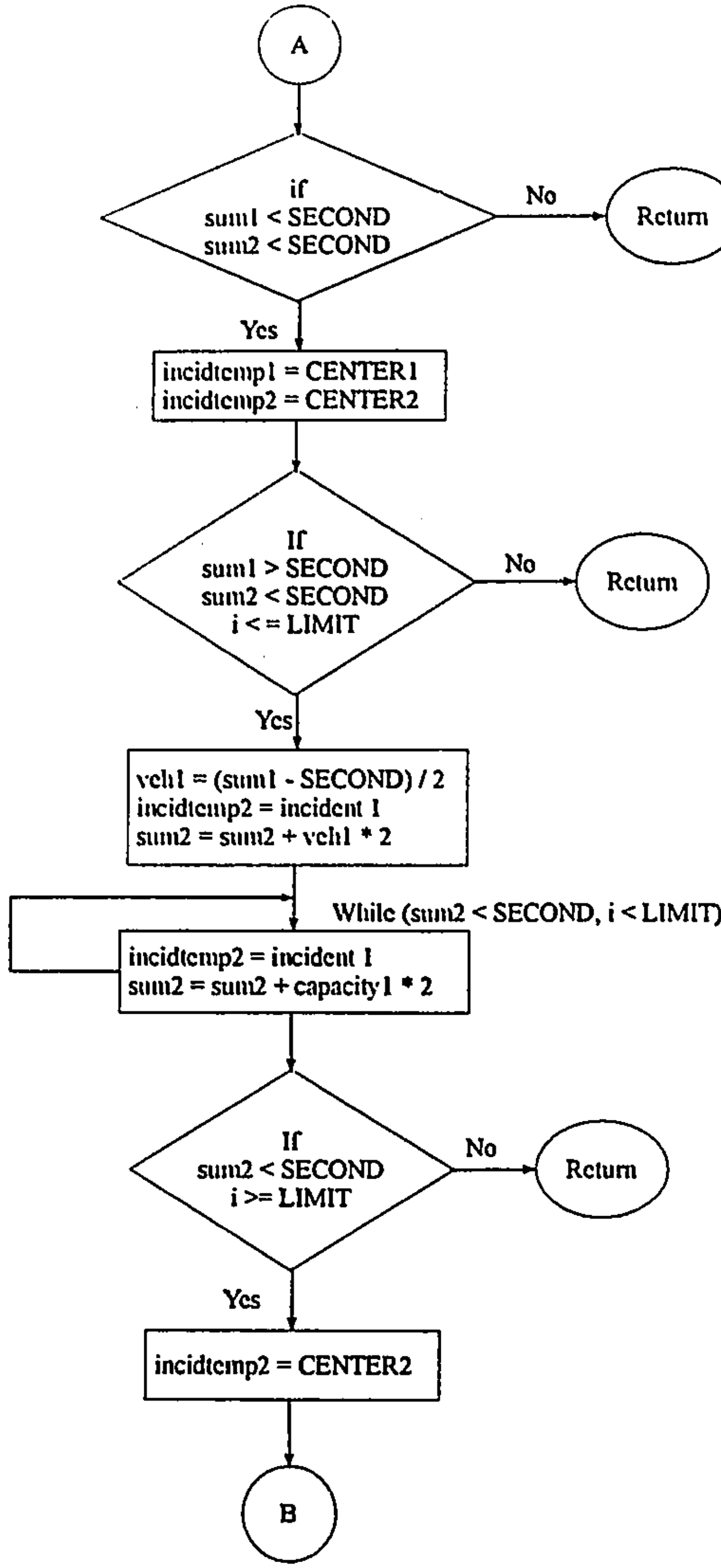


Figure 7.4.7b: 50% Assignment Representation.

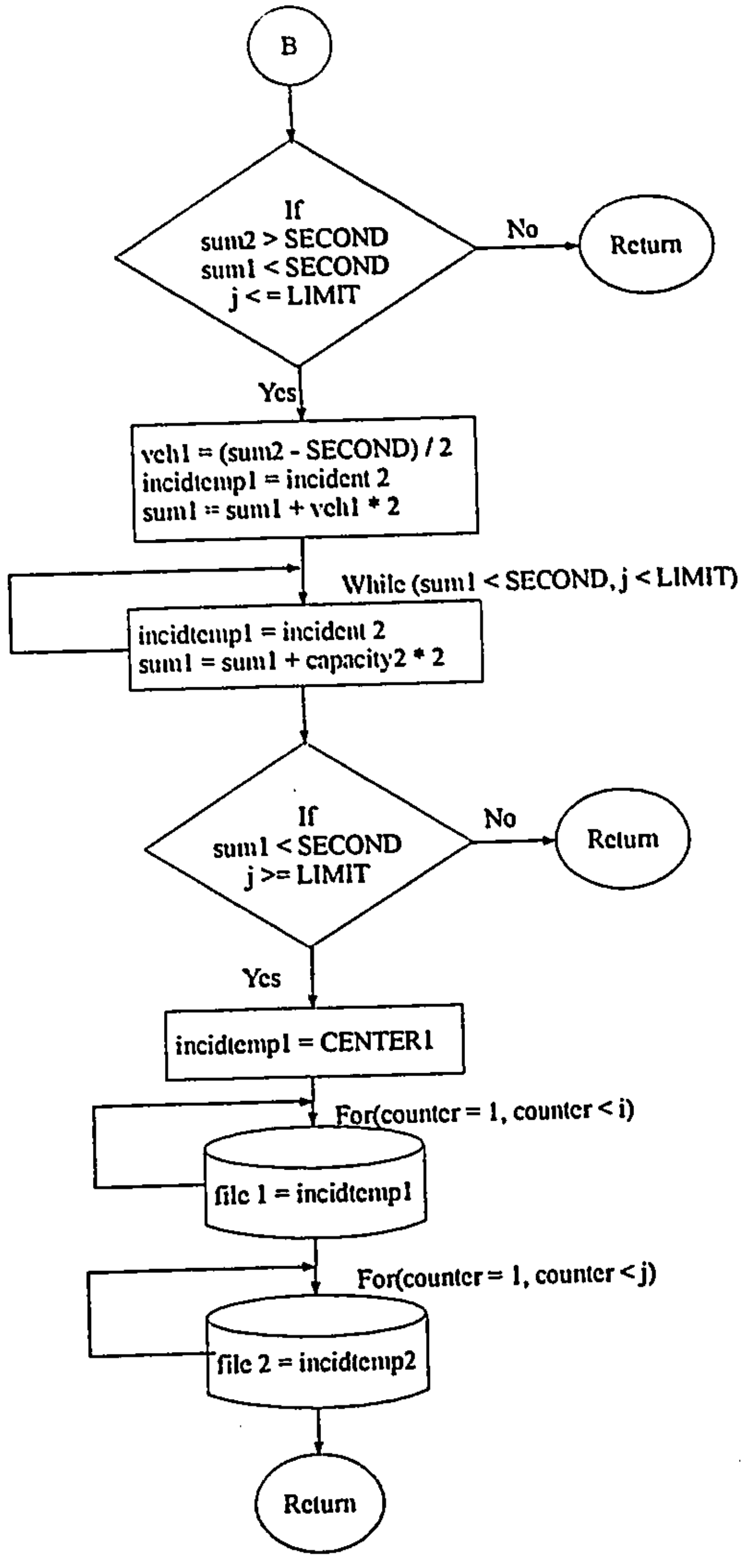


Figure 7.4.7c: 50% Assignment Representation.

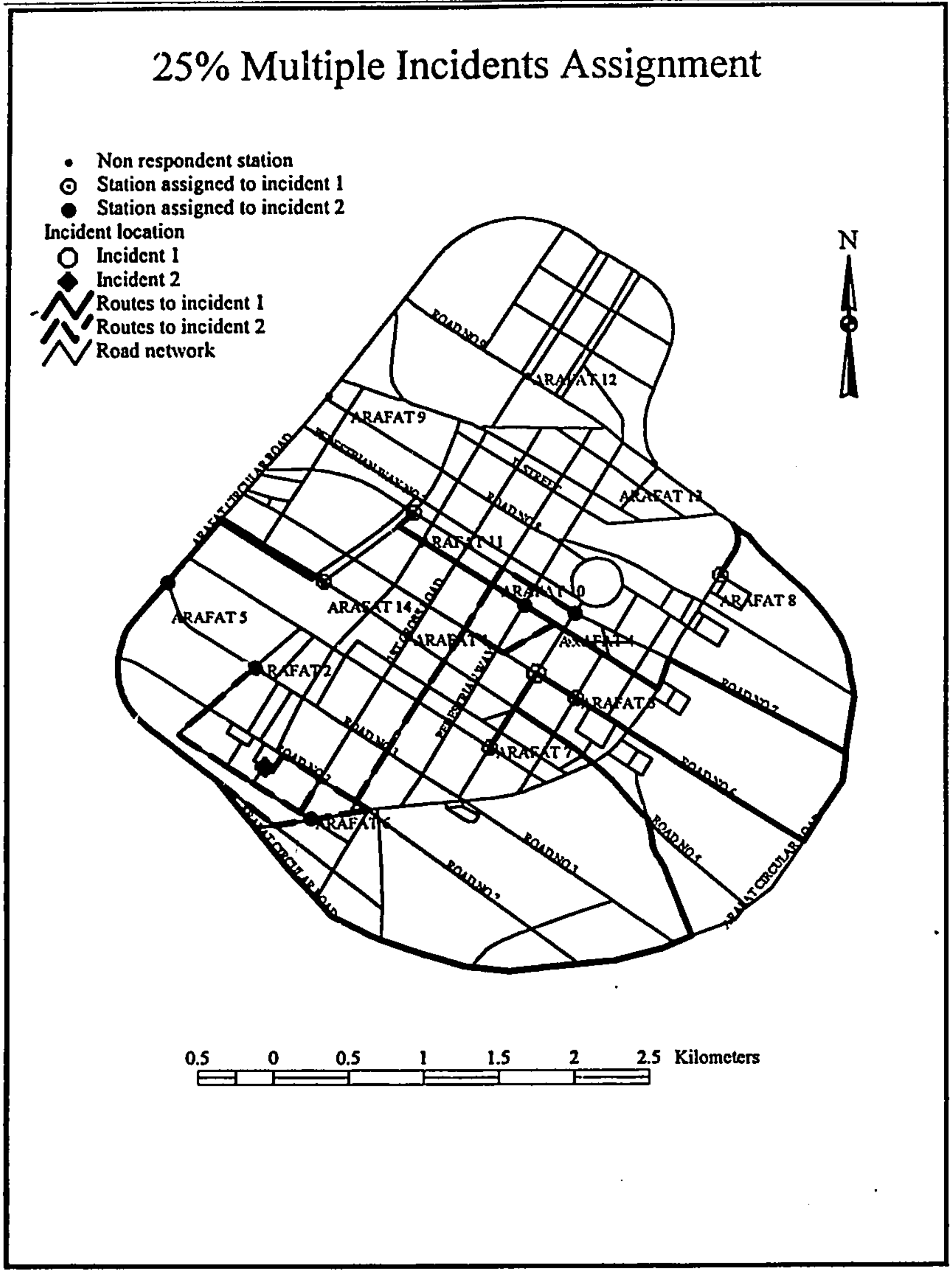


Figure 7.4.8: Multiple Incidents Assignment with a Magnitude of 25%.Each.

The first scenario involved an incident which required multiple responses. The solution was presented for such an incident with several different magnitudes. The solution to this scenario was accomplished using three general steps of analyzing and manipulating the data. First, by obtaining optimal path data for each station to the incident scene. Second, by arranging the stations according to their optimal path to the incident. Third, by determining the number of stations that should respond to the incident according to their capacity and the magnitude of the incident.

The second scenario presented was for two incidents which required multiple responses. The solution for the dispatching under this scenario was accomplished using four general steps. First, by obtaining optimal path data for each station to both incidents. Second, by sorting the optimal path data and by arranging the stations and their capacity according to their optimal path to both incidents. Third, by matching seven stations to the first incident and seven stations to the second incident. Finally, by determining the number of stations that should respond to the first and second incident based on their capacity and the magnitude of the incident.

To reach solutions to these scenarios the data was manipulated and analyzed by writing C programming code, while further routines using SML™ were used to simulate the dispatch of SRCS resources in the PC ARC/INFO™ environment.

Chapter Eight

8. Summary and Recommendations

Emergency management is the professional field of applying science, technology, planning, and management to deal with emergency events (Drabek and Hoetmer 1991). Emergency events are abnormal occurrences which require prompt action and responsive decisions that need to be taken in a short period of time to save lives and property as well as the environment.

The use of information technology, in particular GIS, for emergency management has been recognized in recent years. It has been found to be an effective tool to assist in identifying possibilities and providing solutions in the areas of emergency planning, preparedness, and response and recovery (Gatrell and Vincent 1990). The general assumption of this study has been that a GIS based system could improve incident response and support emergency decision-making of the Saudi Red Crescent Society during the Hajj. While this study was centered around this general assumption it concludes with the following summary and recommendations.

8.1 Summary:

The Hajj is a unique religious gathering which takes place every year during the last month of the lunar calendar. In a short period of time over two million Moslems from across the World gather to perform their religious duty. The mass gathering of the Hajj causes a dramatic demographic change in the Makkah Al-Mukaramah and its surrounding Holy Sites. Specific time, space and religious settings are fundamental aspects of the Hajj. According to the Islamic faith, the majority of the Hajj activities must take place at specific times in an open and limited environment. These settings are fixed which makes emergency and disaster management vastly different from those found in a typical urban (911 response) or semi-urban environment for special events such as major sporting activities.

Emergencies and disasters occur during the Hajj season causing injury death and damage to pilgrims and their property. The mass gathering and movement of pilgrims from one Holy Site to another, traffic congestion and interaction between vehicles and pilgrims, as well as weather conditions influence emergency and disaster occurrences.

The Saudi Red Crescent Society has the primary mission to respond to emergencies to provide relief and medical care to pilgrims. Operational requirements for the response efforts of the Saudi Red Crescent Society during emergency occurrences differ gently. Existing response efforts use conventional methods to dispatch resources to the scene of disasters. These methods tend to be slow, at times ineffective, and an automated system would vastly improve response efforts.

A conclusion of this study found that it was possible to develop an incident responsive spatial decision support system to assist the emergency operations of the Saudi

Red Crescent Society during the Hajj season. However, the development of such a system requires certain modifications and criteria. The user, system, and data requirements have to be analyzed and modeled according to the specific settings and characteristics of the Hajj.

Additionally, the system must have a design to allow for post-Hajj analysis, as the Saudi Red Crescent Society must perform several supporting functions ranging from planning to collecting response statistics and recovery operations. These functions are classified as pre-Hajj, response, and evaluation and analysis functions. The designed IRSDSS can also be used for these planning purposes prior to and following the Hajj. In this regard, the IRSDSS can be used to update the Saudi Red Crescent Society station resources, medical facilities, and evacuation centers and other related data. A final element is performing such activities before the Hajj as a means to update the system database an important concern to ensure proper response to incidents.

The IRSDSS must also be integrated into the emergency response operations process. When an incident occurs, the Saudi Red Crescent Society operations begin and the need for spatially referenced system is clear. Once an incident notification is received via the control room, the SRCS identifies an incident's type, its location, its category, and the number of expected casualties. Using this type of information, the SRCS determines the response range and the amount of response resources required.

At this stage, the IRSDSS can be utilized to determine the dispatch of response resources. The IRSDSS determines the optimal path for response by using the road network from the nearest Saudi Red Crescent Society station to the incident scene. An important consideration is that not all Saudi Red Crescent Society personnel are familiar with the Holy Sites because they come from various parts of the country. For some it maybe the first time they visit the Hajj and Makkah, thus dispatch and response maps are needed to respond to incidents.

The road network is the primary spatial feature used by the IRSDSS for dispatch purposes. It was observed that the road network and traffic flow have certain attributes which have to be contemplated and evaluated when developing the network data model. It was determined that:

1) The road segments and intersections carry pedestrian as well as vehicle traffic, and they all share the same right of way.

2) The road network is often super-saturated and no control methodology seems possible to implement. Consequently, neither signs nor signals are honored by traffic for the period under consideration.

3) The traffic flows change from time to time according to the pilgrims' required movement from one Holy Site to another. Subsequently, traffic control plans, designed by the traffic police, change constantly.

4) Road types and widths vary greatly within the network. At least six types of roads exist in the network ranging from Arterial type of roads to pedestrian path ways, while road widths vary from five meters to thirty meters.

5) There are no routes specifically designated for emergencies within the network.

Each of the above network and traffic flow attributes were considered when developing the IRSDSS data model. Turn penalties for left, through, and straight travel along the network were negated in consideration of pedestrian traffic which at times blocks the entire roadway. In addition, 'U' turns were banned from traffic movement to prevent double counting along the link whenever a barrier was introduced at an intersection.

Based on SRCS user requirements, it was found that the IRSDSS should consist of three major modules or functions. First is an incident management function which controls the incident related information including dispatch and response. Second is a medical facilities and evacuation centers management function which processes the data related to these activities. Third is a reporting and documentation function which processes required information. Each of these modules of the system has various sub-functions that perform specific actions required by the major modules.

After describing the design and foundation of the IRSDSS, there was a need to test its functional aspects to determine its applicability for disaster response under different scenarios. The dispatch function was selected for the test as it reflects both managerial and spatial aspects of the system. The Arafat Holy Site was chosen as a pilot area to conduct the test, as it is significant during the standing day which represents the first day of Hajj. The test also required the conversion of the models into a physical database design. PC ARC/INFO™ GIS was selected as the host GIS system for data conversion and scenarios development and simulation testing. Other supporting software, such as Microsoft Access™ and ArcView™, were also used for data manipulation and display.

During the data conversion process a number of technical and non technical problems were encountered. The most important of these was the lack of complete addressing scheme in the study area. Address is an important attribute which can be used for dispatch and response efforts during disasters, as the location of an incident as well as the location of facilities are determined by their addresses. One of the technical problems detected during the data conversion process was that PC ARC/INFO™ adds the location of an incident or facility as a stop to the closest intersection (node). If an incident occurs in the middle of a link, its location will be shifted to the nearest node. Thus, the exact location cannot be specified precisely. This is a technical limitations of this particular GIS.

The GIS, however, provided a facility to calculate the optimal path from one point to another over the network. The calculation of the optimal path is based on the data model of the system. It also allowed the loading of different attributes as impediments or resistance to movement attributes for proper optimal path calculation.

Real deficiency of GIS based systems is that they do not provide facilities to answer such questions as who or how many resources should be dispatched to an incident, issues that are fundamental during disaster response. In this study, these issues were investigated and resolved under two different scenarios with various incident magnitudes. The issue of who should respond first was determined using the optimal path from station location to the incident scene. The issue of how many resources should be dispatched was based on the capacity of stations and the magnitude of the incident. A general assumption was that the incident was a disaster involving at least 100 casualties. To reach acceptable solutions to such problems, specific C code programs and SML routines were written to analyze and manipulate the data as well as to conduct simulation testing.

The first scenario tested involved a single incident with magnitudes that utilized 15%, 50%, 85% and 98% of response resources. Under this scenario the issue of how many and which resources was resolved by sorting the optimal path for each station to the incident scene in ascending order. At the same time, the capacity and the node numbers of stations are arranged according to the sorting scheme. The next step was to add the capacity of each station and assign the exact number of stations based on the magnitude of the incident, to answer how many resources should be deployed to the scene.

The second scenario tested involved multiple incidents with magnitudes that utilized 7% and 8% of response resources. The problem was further investigated for multiple incidents with magnitudes of 15%, 25%, and 50% respectively. Multiple incidents with magnitudes of more than 50% were not considered, as these would exceed the total capacity of all Saudi Red Crescent Society stations.

Solutions to this scenario were accomplished by sorting in ascending order the optimal path data for each station to both incidents. The station node numbers and their capacities were arranged according to the sorting mechanism. This process could answer who should be dispatched to an incident first, but did not address the possibility that one station could be assigned to both incidents at the same time, which called for an additional step in the general solution to the problem. The additional step into solution involved matching seven stations to the first incident and seven stations to the second incident to ensure that there was no duplication of stations to both incidents. The question of what amount of resources should be deployed to the scene was based on the capacity of stations and the magnitude of each incident. This was accomplished by adding the capacity of each station dispatched to each incident and subsequently assigning the required number of stations to each incident.

8.2 Recommendations:

As with a study of this nature, this study concludes with several recommendations which are explored in the following sections.

8.2.1 Recommendation to Proceed:

It is recommended that the Saudi Red Crescent Society proceed with the development and implementation of the IRSDSS according to the framework and general guidelines provided in this study. Since the various user, system, and data requirements were thoroughly investigated, analyzed and modeled. During the course of this study, the output information and decision support capacities of the IRSDSS are sufficient for successful implementation. However, there is a strong need for the proper political, managerial, and financial support from high level management. The proper training of the Saudi Red Crescent Society staff should be considered essential for full utilization of the IRSDSS. Further, it is recommended that the system be implemented and integrated as part of distributed network. This would allow an efficient and effective emergency response and dispatching of emergency services.

8.2.2 Recommendation Regarding Addresses:

Addresses are important attributes which can be used to identify locations of interest during disasters. As indicated earlier, it was discovered that addresses in the study area were incomplete. To utilize the system to its full potential, the addresses issue must be resolved and an addressing scheme must be implemented. For the Holy Sites, the following address scheme is recommended. Each road or street should be given a name, and each intersection should be given a unique identification number. For example, if a road has ten segments and was provided the name 'Arafat First Road', intersections would be given executive numbers ranging from 0 for the first intersection to 100 for the last intersection. By adopting this or any other addressing scheme, it would not only help the Saudi Red Crescent Society personnel to conduct their emergency operations efficiently, but it would also help other government and non government agencies who provide other essential services.

8.2.3 Recommendation Regarding the Use of IRSDSS

The IRSDSS was designed as an incident responsive spatial decision support system. Its practical use is for dispatch of resources and personnel during disaster response efforts. The system can help to reduce response times and provide directions to those who must move to medical and evacuation facilities. It can also provide valuable decision support during pre and post Hajj planning processes, in addition to other efforts which maybe realized during future investigation. Further implementation of IRSDSS in the Kingdom should include demographic information such as country of origin, gender, age, language, sponsoring agency, Saudi official pilgrim guide, and other relevant information. This will enhance the system's capability to respond to emergencies.

8.3 Scope for Further Research:

This study has opened many avenues for further research efforts. Future research could be conducted in the areas of system development and implementation, including the following areas.

8.3.1 Incident Magnitudes:

In this study the focus of analysis of incident magnitudes was on normal distributions. For the first scenario (Chapter seven), the number of stations to be assigned was based on normal distribution of incident magnitudes that utilized 15%, 50%, 85%, and 98% of response resources. For the second scenario (Chapter seven), the number of stations to be assigned was based on two separate incident magnitudes that utilized 7% and 8%, as well as 15%, 25% and 50% of response resources. In reality, the incident magnitudes may not be fixed to such normal distributions. Further analysis and manipulation of data to assign the required number of stations based on their capacity and the number of casualties, rather than the normal distribution, would be an area for future research.

This study focused on dispatch of mobile units of the Saudi Red Crescent Society based on their capacity and the magnitude of the incident. The dispatch function of the IRSDSS was also tested during simulation from the incident location to medical facilities and evacuation centers. However, no criterion were introduced to test such functions. An area of future research would involve testing and simulation the dispatch function from incident location to medical facilities and evacuation centers. This may require additional modeling and analysis which may include the incident type i.e. fire, explosion, and the type of medical service provided by the medical facility, as well as the capacity of the medical facility. Further, the implementation of the pilot is important to Saudi Arabia and the testing of the scenarios developed in this study using real data is necessary. This would allow a more realistic measurement of the functional capabilities of the system using real data as part of cost/benefit analysis. The comparison of the actual emergency response as well as the simulation time, would be a measure of the benefit of using the IRSDSS. This would yield an efficient assessment of the real utility of the system and test it to its threshold.

8.3.2 Other Applications:

The scope of this study was limited to provide a framework for the design and controlled simulation of an incident responsive spatial decision support system. The IRSDSS was designed for the Saudi Red Crescent Society response operations during the Hajj season. During the Hajj season there are many other government and non government agencies who provide emergency services, including Civil Defense, Police, Municipal services, and others. Investigating the possibility of developing a comprehensive and large scale GIS based emergency IRSDSS to include all emergency services in Makkah Al-Mukaramah and its surrounding Holy Sites is an area for further research. In addition, possibilities of integrating Global Positioning System (GPS) with GIS is an additional area of interest for future research, which may further improve the dispatch function of emergency services during the Hajj.

For this research PC ARC/INFO™ was used for emergency simulation and response. However, the pilot implementation should be tested using other GIS software, in particular, those who have network model where search is done by coordinates. This may overcome the problem of addresses where coordinates might be used instead of addresses to identify locations of particular interest.

Bibliography

- Abdulgani, K. (1986) **Suggested Perspective Plans for Transportation system in the Holy Sites Areas and Makkah Al- Mukaramah during the Hajj.** In: *Events of Transportation Symposium of Hajj*. Makkah: Ministry of Communication: pp 35-54.

- Abdulmajied, A. and Barhameen, S. (1991) **Evaluation of Vehicle Movement during the Nafra (Movement) to Muzdalifah for 1991 Pilgrimage.** The Hajj Research Center, Umm Al-Qura University.

- Abdulmajied, A. and Barhameen, S. (1992) **Evaluation of Vehicle Movement during the Nafra (Movement) to Muzdalifah for 1992 Pilgrimage.** The Hajj Research Center, Umm Al-Qura University.

- Aho, A., Hopcroft, J., and Ullman, J. (1983) **Data Structure and Algorithms.** Addison-Wesley Publishing Company.

- Aisa, S., Al-bani, U., and Al-Sohibani, A. (1987) **Evaluating and Improving Traffic Control Equipment in Arafat Area.** In: *Events of Transportation Symposium of Hajj*. Makkah: Ministry of Communication. 21 - 23 July, 1987: pp 107-23.

- Aitken, P. (1990) **Learning C.** Indiana: SAMS.

- Al-Abdulqaader, A. (1988) **Vehicle Parking Problem in Arafat Area.** In: *Events of Transportation Symposium of Hajj*. Makkah: Ministry of Communication. 5 - 7 June, 1988pp 223-33.

- Al-Abri, A., Abuemah, A., Al-Gasham, A., Abujlaid, S., Husain, A., Al-Mutairi, A., (1992) **Barriers and Difficulties Preventing the Movement of Fire Fighters in the Holly Sites during the Hajj.** Ministry of Interior, General Directorate of Civil Defense.

- Al-Amri, A. (1995) **Responsibilities and Duties of the Civil Defense during the Hajj Season.** (frothcoming).

- Al-Ankary, K. (1991) **An Incremental Approach for Establishing a Geographical Information System in Developing Country: Saudi Arabia.** In: *International Journal of Geographical Information Systems.* Vol.5, No.1. 19991:pp 85-94.

- Al-Farsy, F. (1991) **Modernity and Tradition: The Saudi Equation.** Kegan Paul International.

- Al-Gamdi, A., Al-Seriani, M., Mirza, M. and Kutbi, Z. (1985) **Makkah Al Mukaramah: The Holy Capital**. Makah Al Mukaramah: Al Safa Printing.

- Al-Harthy, S. (1990) **The Ideal Methods of Transporting Patients and Vehicles during the Hajj**. In: *Events of Transportation Symposium of Hajj*. Makkah: Ministry of Communication. 29 - 30 May, 1990:pp 81-90.

- Al-Harthy, S. (1988) **The Ideal Model to Improve Transporting Patients during the Hajj**. In: *Events of Transportation Symposium of Hajj*. Makkah: Ministry of Communication. 5 - 7 June, 1988: pp179-92.

- Al-Hazzaa, A. (1989) **Pilgrims Movement and its Influence on Medical Emergency System during the Hajj in Makkah Al-Mukaramah and the Holy Sites**. In: *Events of Transportation Symposium of Hajj*. Makkah: Ministry of Communication. 25 - 27 June, 1989: pp 295-315.

- Al-Hazzaa, A. (1995) **Red Crescent Society Emergency Management and Disaster Response Activities.** (forthcoming).

- Al-Hazzaa, A. (1987) **Transporting Victims during the Hajj in Makkah Al-Mukaramah and the Holy Sites**. In: *Events of Transportation Symposium of Hajj*. Makkah: Ministry of Communication. 21 - 23 July, 1987: pp 155-82.

- Al-Mashaby, U. and Shabieb, A. (1989) **Suggested Transportation and Traffic Plan in the Holy Sites during the Hajj**. In: *Events of Transportation Symposium of Hajj*. Makkah: Ministry of Communication. 25 - 27 June, 1989: pp 205-28.

- Al-Muhammadi, A. (1988) **Difficulties Facing the Implementation of Plans during Emergencies and Suggested Methods to Overcome them in the Holy Sites.** In: *Events of Transportation Symposium of Hajj*. Makkah: Ministry of Communication. 5 - 7 June, 1988: pp 173-75.

- Alrahman, H. and Abdulaal, W. (1989) **Toward a General Strategy for Transportation during the Hajj**. In: *Events of Transportation Symposium of Hajj*. Makkah: Ministry of Communication. 25 - 27 June, 1989: pp 35-57.

- Al-Ramadan, B. (1993) **A Framework for a National Effort Towards Geographic Information and Geographic Information Systems in Saudi Arabia.** Unpublished Ph.D. thesis, University of Pennsylvania, Pennsylvania.

- Alsawydani, S. Badarinath, K. and Douglas, D. (1995) **GIS Based Emergency Management Plan for Hajj Period.** In: *1995 Canadian Geomatics*, CD-ROM.

- Alsawydani, S. (1992) **A Framework and Conceptual Guidelines for the Implementation of Geographic Information Systems in the Government**

Agencies of the Kingdom of Saudi Arabia. Unpublished M.A. thesis, Carleton University, Ottawa.

- Al-Shamrany, S. (1988) **Landuse in the Holy Sites during the 1988 Pilgrimage.** The Hajj Research Center, Umm Al-Qura University.

- Alvaredo, F. and Gomez, M. (1992) **GIS Supports Summer Olympic Games Security.** In: *GIS World*, August, 1992: pp 58-61.

- Al - Yafi A.(1993) **Management of Hajj Mobility Systems.** Al - Yafi A.

- Ammatiza, P., Hakkert, A. and Affum, J. (1991) **A PC Oriented GIS Application for Road Safety Improvements.** In: *GIS / LIS '91 porceedings*, 28 October - 1 November, 1991. Atlanta: Georgia, Vol 2: pp 528-43.

- Antenucci, J. C., Brown, K., Croswell, P., Kevany, M., and Archer, H. (1991) **Geographic Information Systems: A Guide to the Technology.** New York: Van Nostrand Reinhold.

- Arlook, J. and Skorburg, C. (1993) **Tracking IVHS: Where It's at and Where It's Going.** *Geo Info Systems.* November/December, 1993: pp 39-47.

- Aronoff, S. (1989) **Geographic Information Systems: A Management Perspective.** Ottawa: WDL Publications.

- Authman, M. (1987) **Evacuation Plan in the Holy Sites during the Hajj.** In: *Events of Transportation Symposium of Hajj*. Makkah: Ministry of Communication. 21 - 23 July, 1987: pp 137-47.

- Bafakih, R. and Alagad, A. (1989) **A Better Method of Organizing Domestic Pilgrims.** In: *Events of Transportation Symposium of Hajj*. Makkah: Ministry of Communication 25 - 27 June, 1987: pp 79 -96.

- Bafakih, R., Al-Mufti, R., Abduh, U., and Al-Khadra, A. (1991) **A Study of Pedestrians and Vehicles Interaction in the Arafat Area and on the Roads between Arafat and Muzdalifah.** General Directorate of Studies and Research, Ministry of Communication. Internal Report.

- Battista, C. (1994) **Chernobyl: GIS Model Aids Nuclear Disaster Relief.** In: *GIS World.* March, 1994: pp 32-35.

- Beidler, A. and Williams, R. (1986) **A Local Government Geographic Information System Evaluation Process.** In: *Proceedings of the URISA '86 Conference. Urban and Regional Information Systems Association.* Washington D.C.: Vol. 2: pp168-76.

- Belardo, S., and Wallace, W. (1989) **'Gaming' as a Means for Evaluating Decision Support Systems for Emergency Management Response.** *Proceedings of the SCS Western Multiconference, 1989.* San Deigo: California, 4-6 January, 1989: pp 113-18.

- Beriwal, M. (1992) **Emergency Operations to the Rescue.** In: *GIS World.* March, 1992. Vol.5, No.2: pp 105-06.

- Bilski, A. (1995) **Call to Arms.** *Macleans Magazine*, April 17, 1995: pp 30 -31.

- Blackmon, C., Stone, J., and Dillard, M. (1993) **Automation to Play Critical Role in 1996 Olympic Games.** In: *GIS World,* Speciall Issue. June, 1993: pp 34-39.

- Blair, B. (1992) **Time-Critical GIS.** In: *Geo Info Systems.* May, 1992: pp 25-35.

- Bollens, S. and Drummond, W. (1986) **Land Data Systems: Defining a Research and Dissemination Program.** Lincoln Institute of Land Policy.

- Bowerman, R., Calamai, P., and Hall, G. (1991) **The Space filling curve with Optimal Paratitioning Heuristic for the Vehicle Routing Problem.** *European Journal of Operational Research,* 1991: pp 43-51.

- Brail, R. (1990) **Integrating GIS into Urban and Regional Planning Alternate Approaches for Developing Countries.** In: *Regional Development Dialogue, UNCRD.* Autumn, 1990 Vol.11, No.3: pp 63-77.

- Brathwaite, S. (1988) **Analysis, Design, and Implementation of Data Dictionaries.** McGraw-Hill Book Co.

- Brown, B. and Friedley, D. (1988) **Assessing Organizational Preparedness for a Comprehensive, Distributed LIS/GIS.** In: *URISA-'88 Mapping the Future*, The 26 Annual Conference of the Urban and Regional Information Systems Association, Los Angeles: California, Vol.III: pp 22-36.

- Brown, C. (1986) **Implementing a Geographic Information System What Makes a New Site a Success?.** In: *Proceedings of Geographic Information Systems Workshop,* American Society for Photogrammetry and Remote Sensing, Atlanta: Georgia. April 1-4, 1986: pp 12-19.

- Bruton, M. (1975) **Introduction to Transportation Engineering.** Hutchinson of London.

- Bufough, P. (1986) **Principles of Geographical Information Systems for Land Resources Assessment.** Oxford: Oxford University Press.

- Capron, L. (1986) **System Analysis and Design.** The Benjamin/Cummings Publication Company, Inc.

- Chambers, D. (1989) **Overview of GIS Database Design.** *ARC News,* Vol. 11, No. 2.

- Champhell, H. (1991) **Organisational Issues and the Utilisation of Geographic Information Systems.** Regional Research Laboratory Initiative, Department of Town and Regional Planning, University of Sheffield, Discussion Paper No. 9, March, 1991.

- Charles, C. and Jr., W. (1992) **GIS Aids in Hurricane Planning.** In: *GIS World,* Special Issue. July, 1992: pp 47-52.

- Clarke, A. (1991) **GIS Specification, Evaluation, and Implementation.** In: D. Maguire, M. Goodchild, and D. Rhind (eds.) *Geographical Information Systems Principles and Applications, Longman Scientific Technical,* Vol.1: pp 477-88.

- Chris, C. (1989) **Parcel User Driven Approach to GIS Database Design.** In: *Symposium Proceedings Geomatics II A Future in the Making,* Montreal: CISM, November, 9-10: pp 43-52.

- Chrisman, N. (1991) **The Error Component in spatial Data.** In: D. Maguire, M. Goodchild, and D. Rhind (eds.) *Geographical Information Systems Principles and Applications, Longman Scientific & Technical,* Vol1: pp 165-74

- Chrisman, N., Cowen, D., Fisher, P., Goodchild, M., and Mark, D. (1989) **Geographic Information Systems.** In: G. Galie, and C. Willmott (eds.) *Geography in America.* Ohio:Merrill Publishing Company: pp 776-96.

- Clymer, A. (1983) **Simulator for Planning Action Against Emergencies.** In: *Proceedings of the Conference on Emergency Planning.* San Diego: California, 27-29 January, 1983: pp 3-9.

- Coll, D. (1990) **Development of Equipment and Techniques: Microcomputer Graphics Environments.** In: D. Taylor (ed.) *Geographic Information Systems: The Microcomputer and Modern Cartography.* Pergmon Press: pp 39-59.

- Comfort, L. (1985) **Information Search Processes in Emergency Management: Computer Simulation as Means of Improving Organizational Decision-Making Capacity.** In: *Proceedings of the Conference on Emergency Planning.* San Diego: California. 24-26 January, 1985: pp 41-45.

- Cooper, F. (1984) **Geographic Information System for Transportation. The Changing Role of Computers in Public Agencies.** In: *URISA.* August, 12-15, 1984: pp 144-53.

- Dangermond, J. (1985) **Network Allocation Modeling for Emergency Planning.** In: *Emergency Planning, Proceedings of the Conference on Emergency Planning,* Simulation Series. January, 1985. Vol. 15, No.1: pp 101-06.

- Dangermond, J. (1989) **Personal Computer Based Network Simulation Software for Emergency Management.** In: *Proceedings of the SCS Western Multiconference, 1989,* San Diego: California. 4-6 January, 1989: pp 57-61.

- Dangermond, J. (1990) **The Organizational Impact of GIS Technology.** In: *Geographic Information Systems: An Assessment of Technology, Applications, and Products,* S.E.A.I Technical Publications, Vol.2: pp 340-58.

- Date, C. (1990) **An Introduction to Database Systems.** Addison-Wesley Publishing Company, Inc. Vol.1, Fifth Edition.

- Davis, W. (1989) **The Impact of Computer Trends on Geoprocessing** In: *Challenge for The 1990s GIS, Proceedings for National Conference.* Ottawa: CISM: pp 571-75.

- de Boer, J., Brismar, B., Eldar, R., and Rutherford, W. (1989) **The Medical Severity Index of Disasters.** In: *The Journal of Emergency Medicine.* Vol. 7: pp 269-273.

- De Lorenzo, R., Gray, B., Bennett, P., and Lamparella, V. (1989) **Effect of Crowd Size on Patient at a Large Multipurpose, Indoor Stadium.** In: *The Journal of Emergency Medicine.* Vol. 7: pp 379-384.

- Drabek, T. (1991) **Microcomputer in Emergency Management, Implementation of Computer Technology.** *IBS University of Colorado Programme on Environment and Behaivour Monograph No. 51.* Natural Hazard Center, University of Colorado.

- Drabek, T. and Hoetmer (1991) **Emergency Management: Principles and Practice for Local Government.** ICMA.

- ESRI (1990a) **PC ARC/INFO Starter Kit: User's Guide**. Redlands: California, ESRI.

- ESRI (1990b) **PC Arc Plot User's: Guide.** Redlands: California, ESRI.

- ESRI (1990c) **PC Arc Sif User's: Guide.** Redlands: California, ESRI.

- ESRI (1994) **ArcView: The Geographic Information System for Everyone**. Redlands: California, ESRI.

- ESRI (1990d) **PC Network: User's Guide.** Redlands: California, ESRI.

- ESRI (1990e) **SML: User's Guide.** Redlands: California, ESRI.

- ESRI (1992) **Understanding GIS: The ARC/INFO Method.** Redlands: California, ESRI.

- Ezigbalike, I., Cleman, D., Cooper, R. and McLaughlin, J. (1988) **Managing a Multi-User Land Information System** In: *URISA-'88 Mapping the Future,* The 26 Annual Conference of the Urban and Regional Information Systems Association, Los Angeles: California. Vol.III: pp 55-64.

- Faig, W. and Mclaughlin, J. (1989) **Spatial Analysis and Information Management: A Surveying Engineering Perspective** In: *Challenge for The 1990s GIS, Proceedings for National Conference.* Ottawa: CISM: pp 576-86.

- Faust, N. (1991) **How Atlanta and Georgia Tech Used GIS to Help Win the 1996 Summer Olymbic Games.** In: *GIS / LIS '91 proceedings.* 28 October - 1 November, 1991. Atlanta: Georgia. Vol 2: pp 917-21.

- Frank, A. (1987) **Towards a Spatial Theory** In: *Proceedings of International Geographic Information Systems (IGIS) Symposium: The Research Agenda.* November 15-18,1987. Vol.II: pp 215-28.

- Gatrell, A. and Vincent, P. (1990) **Managing Natural and Technological Hazards the Role of GIS.** Regional Research Laboratory Initiative, Department of Town and Regional Planning, University of Sheffield. Discussion Paper No. 7. August, 1990.

- Goodchild, M. (1991) **The Technical Setting of GIS.** In: D. Maguire, M. Goodchild, and D. Rhind (eds.) *Geographical Information Systems Principles and Applications.* Longman Scientific Technical: pp 45-54

- Goodchild, M. (1987) **Towards an Enumeration and Classification of GIS Functions,** In: *Proceedings of International Geographic Information Systems (IGIS) Symposium: The Research Agenda. Technical Issues and the Research Agenda.* November 15-18,1987. Vol. II: pp 67-77.

- Gounlund, A., Xiang, W., and Sox, J. (1994) **GIS, Expert System Technologies Improve Forest Fire Management Techniques.** In: *GIS World.* February, 1994. Vol. 7, No. 2: pp 33-36.

- Hale, A. (1992) **Hugo's Legacy: Two Years Later.** In: *URISA..* Spring, 1992. Vol. 4, No. 1: pp 73- 77.

- Hennicke, G., Ezigbalike, C. and Bishop, I. (1990) **Spatial Analysis for Accident and Emergency Services.** In: *GIS / LIS '93 proceedings.* November 2-4, 1993. Vol.1: pp 303-11.

- Hunt, P., Robertson, D., Bretherton, R. and Winton, R. **Scoot Traffic Responsive Method of Co-ordinating Signals**. TRRL Report 1094.

- Hobeika, A. and Jamei, B. (1985) **MASSVAC: A Model for Calculating Evacuation Times under Natural Disasters.** In: *Proceedings of the Conference on Emergency Planning.* Simulation Series. 1985. Vol. 15, No.1: pp 23-28.

- Jarvis, J. (1977) **Models for the Location and Dispatching of Emergency Medical Vehicle.** In: T. Willemain, and R. Larson (eds.) *Emergency Medical Systems Analysis.* Massachusetts Institute of Technology: pp 83-100.

- Joffe, B. (1987) **Evaluating and Selecting a GIS System.** In *GIS '87 -San Francisco. Second Annual International Conference, Exhibits and Workshops on Geographic Information Systems.* October 26-30, 1987: pp 138-47.

- Johnson, G. (1992) **GIS Applications in Emergency Management.** In: *URISA.* Spring, 1992. Vol. 4, No. 1: pp 66-72.

- Johnston, D. (1989) **GIS and Regional Government - From the Underground UP.** In: *Challenge for The 1990s GIS, Proceedings for National Conference.* Ottawa: CISM: pp 537-47.

- Kenneth, J. and Vrana, R. (1992) **Dynamic Segmentation Revisited: A Milepoint Linear Data Model.** In: *URISA.* Fall, 1992 Vol. 4, No. 2: pp 94-105.

- Kingdom of Saudi Arabia, Ministry of Health (1994) **Medical Evacuation Plan during the Hajj.** Ministry of Health.

- Kingdom of Saudi Arabia, Ministry of Health (1984) **Yearly Health Report**. Ministry of Health.

- Kingdom of Saudi Arabia, Ministry of Health (1985) **Yearly Health Report**. Ministry of Health.

- Kingdom of Saudi Arabia, Ministry of Health (1986) **Yearly Health Report**. Ministry of Health.

- Kingdom of Saudi Arabia, Ministry of Health (1987) **Yearly Health Report**. Ministry of Health.

- Kingdom of Saudi Arabia, Ministry of Health (1988) **Yearly Health Report**. Ministry of Health.

- Kingdom of Saudi Arabia, Ministry of Health (1989) **Yearly Health Report**. Ministry of Health.

- Kingdom of Saudi Arabia, Ministry of Health (1990) **Yearly Health Report**. Ministry of Health.

- Kingdom of Saudi Arabia, Ministry of Health (1991) **Yearly Health Report**. Ministry of Health.

- Kingdom of Saudi Arabia, Ministry of Health (1992) **Yearly Health Report**. Ministry of Health.

- Kingdom of Saudi Arabia, Ministry of Health (1993) **Yearly Health Report**. Ministry of Health.

- Kingdom of Saudi Arabia, Ministry of Information (no date) **The Two Holy Mosques and their Architecture during the Saudi Reign**. Ministry of Information.

- Kingdom of Saudi Arabia, Ministry of Information, Information Affairs (no date) **Makkah Al Mukarramah: City and Hajj Guide**. Al Madinah Al Monawarh: Al Madinah Al Monawarh Printing and Publishing Co.

- Kingdom of Saudi Arabia, Ministry of Municipal and Rural Affairs, Deputy Ministry for Town Planning (1984) **Makkah Region Comprehensive Development Plans: Existing Conditions.** Volume 8: Hajj.

- Kingdom of Saudi Arabia, Ministry of Planning (1990) **Fifth Development Plan 1990-95.** Riyadh: Ministry of Planning Press.

- Kingdom of Saudi Arabia, Ministry of Planning (1985) **Fourth Development Plan 1985-90.** Riyadh: Ministry of Planning Press.

- Kingdom of Saudi Arabia, Saudi Red Crescent Society (1994) **Hajj Program 1994.** Riyadh: Saudi Red Crescent Society.

- Laporte, G. (1988) **Location-Routing Problems**. In: B. Golden and A. Assad (eds.) *Vehicle Routing: Methods and Studies*. North Holland: pp 163-97.

- Lnag, K. and Lang, G. (1976) **Planning for Emergency Operations.** In: *Mass Emergencies.* 1976. Vol. 1: pp 107-17.

- Laurini, R. and Thompson, D. (1992) **Fundamental of Spatial Information Systems.** Academic Press Limited.

- Lee, J. (1990) **A Data Model for Dynamic Vehicle Routing with GIS**. In: *GIS / LIS '90 Proceedings.*. Anaheim: California. 7-10 November, 1990. Vol. 1: pp134-43.

- Lee, J. (1988) **Integrating Attribute Data and Graphic Data: A Case Study of a Successful GIS Project for Dover, NH.** In: *URISA-'88 Mapping the Future,* The 26 Annual Conference of the Urban and Regional Information Systems Association, Los Angeles: California. Vol.III: pp 109-116.

- Lee, N. and Krakiwsky, E. (1989) **Development of a Prototype Road Information System.** In: *Challenge for The 1990s GIS, Proceedings for National Conference.* Ottawa: CISM: pp 780-89.

- Lewis, J., O'Keefe, P., and Westgate, K. (1977) **A Philosophy of Precautionary Planning.** In: *Mass Emergencies.* 1977. Vol. 2: pp 95-104.

- Lin, H., and Mark, D. (1991) **Spatio-Temporal Intersection (STIn) and Volumetric Modeling.** In: *GIS / LIS '91 proceedings.* 28 October - 1 November, 1991. Atlanta: Georgia. Vol. 2: pp 982-91.

- Lodwick, G. and Feuchtwanger, M. (1987) **Land-Related Information System.** UCSE Report No. 10010, Calgary: The University of Calgary.

- Martinez, R. (1992) **Super Bowl Safety.** In: *Emergency Medical Services..* January 1992. Vol. 21 No. 1: pp 14-19.

- McDougall, K. (1992) **The Development of a Decision Support System for the Forecasting of Urban Growth and Land Development Using GIS.** In: *ASPRS / ACSM Technical Papers,* Washington, D. C.: August, 3-8 1992. Vol 3: pp 436 - 444.

- Mclaren, M. (1992) **GIS Prepares Utility for Earthquakes.** In: *GIS World.* May, 1992: pp 60-64.

- Meyere, J. (1989) **Training of the GIS Professional.** In: *Challenge for The 1990s GIS, Proceedings for National Conference.* Ottawa: CISM: pp 872-79.

- Mogielnicki, R., Stevenson, K., and Willemain, T. (1977) **Patient and Bystander Response to Medical Emergencies.** In: T. Willemain, and R. Larson (eds.) *Emergency Medical Systems Analysis.* Massachusetts Institute of Technology: pp 39-54.

- Montgomery, G. (1990) **Multiparticipant Project Management** In: *GIS World.* October, 1990. Vol.3, No. 5: pp105-06.

- Montgomery, G. (1990) **Organizing a GIS Multiparticipant Project - Getting Started.** In: *GIS World.* June, 1990. Vol. 3, No.3: pp 62-64.

- Morrison, J. (1989) **GIS: United State Government Agency Perspective.** In: *Challenge for The 1990s GIS, Proceedings for National Conference.* Ottawa: CISM: pp 410-14.

- Nasier, M., Al-Auraini, A., Abdullah, T., Hejazi, Y., and Al-Qahtani, S. (1992) **Protection Methods from Fire in the Holly Sites: "Mina Area" (1992).** Ministry of Interior, General Directorate of Civil Defense.

- Nasier, M., Al-Zaid, A., Al-Abri, A., Abujlaid, S., Al-Husaini, A., Al-Sharabi, F., and Al-Ahmari, K. (1991) **Improving the Methods of Fire Fighting in the Holly Sites Area.** Ministry of Interior, General Directorate of Civil Defense.

- Obermeyer, N., and Pinto, J. (1994) **Managing Geographic Information Systems.** New York: The Guilford Press.

- Openshaw, S. and Brunsdon, C. (1991) **An Introduction to Spatial Analysis in GIS.** In: *1991-1992 International GIS Sourcebook,* GIS World, Inc.:pp 378-79.

- Pasha, H. (1982) **Forecasting Demand for Hajj up to 1420 A. H.** The Hajj Research Center, Umm Al-Qura University.

- Peuquet, D. (1990) **Method for Structuring Digital Cartographic Data in A Personal Computer Environment.** In: D. Taylor (ed.) *Geographic Information Systems: The Microcomputer and Modern Cartography.* Pergmon Press: pp 68-95.

- Palmer, D., Petersohn, F., and Coleman, D. (1988) **Priorities in the Land Information Systems/Networks Development Process.** In: *URISA-'88 Mapping the Future,* The 26 Annual Conference of the Urban and Regional Information Systems Association, Los Angeles: California: Vol.III: pp 108-15.

- Perry, R., Lindell, M. and Greene, M. (1981) **Evacuation planning in Emergency Planning.** Massachusetts: Lexington Books/D.C. Heath & Co.

- PTI and ICMA (1991) **The Local Government Guide to Geographic Information Systems: Planning and Implementation,** PTI (Public Technology Inc.).

- Peters, G. (1984) **Construction Project Management Using Small Computers.** London: The Architectural Press.

- Pressman, R. (1992) **Software Engineering.** New York: McGraw-Hill, Inc. 3ed Edition.

- Ralston, B. (1991) **GIS Key In Transportation Network Analysis.** In: *1991-1992 International GIS Sourcebook, GIS World, Inc.*: pp 405-06.

- Ramachandran, V., and Naadimuthu, G. (1989) **An Expert System Based Simulation Model for Emergency Management of an Ambulance Corps.** *Proceedings of the SCS Western Multiconference, 1989,* San Diego: California, 4-6 January, 1989: pp 105-10.

- Reeve, C. and Smith, J. (1986) **The Varied Viewpoints of GIS Justification: A Survey of Vendors and Users.** In: *Proceedings of Geographic Information Systems Workshop. American Society for Photogrammetry and Remote Sensing.* Atlanta: Georgia. April 1-4, 1986:pp 396-403.

- Roberge, R. (1983) **A Spatial Information System for Predicting Hazard at Railway Crossing.** Department of Geography, University of Ottawa.

- Roberge, R. and Roberge, L. (1986) **Railway Risk Management and the Spatial Allocation of Subsidies: A Casual Analysis.** Department of Geography, University of Ottawa.

- Rosenthal, U. (1989) **Human Factors Influencing Crisis Decision Making.** In: *Emergency Preparedness Canada..* July-September, 1989. Vol. 16, No. 3: pp 12-15.

- Sahab, A., and Abd-Elwahed, M. (no date) **The design of an Integrated Information System that Supports Different Management Levels.** A Report by MOMRA.

- Schmidt, J., Kurstedt, H., Walker, J., and DeBusk, R. (1985) **Tri-Purpose Emergency Management Model.** In: *Proceedings of the Conference on Emergency Planning.* San Diego: California. 24-26 January, 1985: pp 55-60.

- Scholten, H. (1990) **GIS Aids in Irish Fire Prevention Plan.** In: *GIS World.* December 1990: pp 42-47.

- Seaborn, D. (1991) **Enterprise GIS: The Management Challenge.** In: *Proceedings of AM/FM/GIS Navigating the Future.* Conference XIV. San Diego: California. March 24-27, 1991: pp 134-42.

- Sheffi, Y. (1985) **Urban Transportation Network: Equilibrium Analysis with Mathematical Programming Methods.** Prentice-Hall, Inc.Englewood Cliffs: N.J.

- Simkowitz, H. (1989) **GIS in Transportation Planning and Operations.** *Public Works.* July, 1989: pp 62-66.

- Smith, E. (1991) **Creating Digital Road Inventory Maps for the New Brunswick Department of Transportation.** In: *Proceedings of the Canadian Conference on GIS-91.* Ottawa: CISM: pp 473-80.

- Smith, G. and Honeycutt, D. (1987) **Geographic Data Uncertainty, Decision Making and the Value of Information**: In *GIS '87 -San Francisco.* Second Annual International Conference, Exhibits and Workshops on Geographic Information Systems. October 26-30, 1987: pp 300-12.

- Skinner, C., Laacke, R., and Peuquet, D. (1992) **Developing a User-Oriented Natural Resources Decision Support System.** In: *ASPRS / ACSM Technical Papers,* Washington D. C.: August 3-8, 1992. Vol 5: pp 374 - 380.

- Somers, R. (1990) **GIS in Local Government, Where Do You Place the GIS?. In:** *GIS World.* April, 1990. Vol.3, No. 2: pp 40-41.

- Star, J. and Estes, J. (1990) **Geographic Information Systems: An Introduction.** Prentice-Hall, Inc.

- Stevenson, K. and Willemain, T. (1977) **Analyzing the Process of Screening Calls for Emergency Ambulance Service.** In: T. Willemain, and R. Larson (eds.) *Emergency Medical Systems Analysis.* Massachusetts Institute of Technology: pp 55-82.

- Strope, W., Devaney, J. and Nehnevajsa, J. (1977) **Importance of Preparatory Measures in Disaster Evacuations.** In: *Mass Emergencies.* 1977. Vol. 2: pp 1-17.

- Taylor, D. (1990) **Geographic Information Systems: The Microcomputer and Modern Cartography.** In: D. Taylor (ed.) *Geographic Information Systems: The Microcomputer and Modern Cartography,* Pergmon Press: pp 1-20.

- Tenenbaum, A., Langsam, Y., and Augenstein, M. (1990) **Data Structures Using C.** Englewood Cliffs: N. J. Printce Hall.

- The Holy Quran **Sura III**, Ver. 97.

- The Ottawa Citizen (1994) **Dying Pilgrims Plead for Allah's Mercy at Mecca Stampede** May 25, 1994: p: A1.

- Toulan, N. (1993) **Planning and Development in Makkah**. In: A. Hooshang and E. Salah (eds.) *Urban Development in the Muslim World.* Rutgers: the State University of New Jersey: pp 37-71.

- Transportation Research Board (1985) **Highway Capacity Manual.** *Special Report 209* Washington, D. C.

- Vanstone, N. and Ogilvie, M. (1989) **The Interdepartmental Committee - an Efficient Means for Developing GIS policy.** In: *Challenge for The 1990s GIS, Proceedings for National Conference.* Ottawa: CISM: pp 858-64.

- Walker, T. and Miller, R. (1990) **The Technology of GIS.** In: *Geographic Information Systems: An Assessment of Technology, Applications, and Products.* S.E.A.I Technical Publications. Vol.1: pp 31-76.

- Walker, T. and Miller, R. (1990) **Implementing GIS. In:** *Geographic Information Systems: An Assessment of Technology, Applications, and Products.* S.E.A.I Technical Publications. Vol.2: pp 359-78.

- Waugh, J. (1990) **Terrorism and Emergency Management: Policy and Administration.** New York: Marcel Dekker, Inc.

- Waite, M., and Prata, M. (1989) **C: Step-by-Step**. Howard W. Sams & Company.

- Wellar, B. (1989) **Emerging Trends in Structuring and Directing GIS Research.** In: *Challenge for The 1990s GIS, Proceedings for National Conference.* Ottawa: CISM : pp 601-08.

- Wells, R., Hughes, P. and Hattway, B. (1983) **New Technologies for Civil Defense and Fire Fighting Operations. Computer Simulation in Emergency Planning.** In: *Proceedings of the Conference on Computer Simulation in Emergency Planning.* Simulation Series. January, 1983. Vol. 11, No. 2: pp 54-57.

- Whitehead, J. (1989) **Crowd Control can be Critical in Emergencies.** In: *Emergency Preparedness Canada.*. October-December, 1989. Vol. 16, No. 4: pp12-15.

- Wright, D. (1990) **ISIS: Toward an Integrated Spatial Information System.** In: T. Kim, L. Wigging and J. Wright (eds.) *Expert Systems: Application to Urban Planning.* New York: Springer-Verlag: pp 43-66.

- Yourdon, E. (1989) **Modern Structured Analysis.** New Jersey: Yourdon Press.

- Zamzami, A. (1990) **The Ideal Time for Pilgrims Evacuation: Problems and Barriers.** In: *Events of Transportation Symposium of Hajj.* Makkah: Ministry of Communication. 29 - 30 May, 1990: pp 91-100.

- Zillmer, G. (1991) **Implementing GIS Technology: A Management Perspective. In:** *Proceedings of the Canadian Conference on GIS-91.* Ottawa: CISM: pp 271-83.

Appendices

Appendix A: List of Individuals Interviewed

List of Individuals interviewed in the USA and KSA.

Lastname	Firstname	Agency	Purpose of interview	Date	Country
Piper	Linn	MECA	Emergency management	27/05/94	USA
Smith	Bill	MECA	Emergency management	28/05/94	USA
Beering	Peter	EM.	Emergency management	28/05/94	USA
Morgan	Wayne	EM.	Emergency management	29/05/94	USA
Zickler	Robert	EMS	Emergency management	29/05/94	USA
Dugan	Tim	EMS	Emergency management	27/05/94	USA
Russo	Mike	MCSD	Emergency management	29/05/94	USA
Gillespie	Andy	IPD	Emergency management	27/05/94	USA
Al-Shahrani	Morayyea	MSD	Data collection	25/09/94	KSA
Shedyed	Abdullah	MOMRA	Data collection	01/10/94	KSA
Abodiab	Hussain	MSD	Data collection	25/09/94	KSA
Al-Assaf	Abdulrahman	MSD	Data collection	26/09/94	KSA
Al-Tokhy	Majdi	GDCD	Emergency management	20/09/94	KSA
Al-Karni	Mohammed	GDCD	Emergency management	28/09/94	KSA
Al-Haazza	Abdullah	SRCS	Emergency management	15/10/94	KSA
Al-Turky	Mansor	GDGS	Emergency management	11/10/94	KSA
Al-kholaiwy	Saud	GDGS	Emergency management	10/11/94	KSA
Al-Rajhi	Mohammed	MOMRA	Data collection	25/09/94	KSA
Gadi	Arif	MM	Data collection	10/12/94	KSA
Al-Zahrani	Ramzi	UAU.	Field study	02/12/94	KSA
Mirza	Meraj	UAU.	Field study	02/12/94	KSA
Makki	Zuhair	UAU.	Hajj studies	03/12/94	KSA
Al-gamdi	Saad	UAU.	Hajj studies	05/12/94	KSA

Abu Najy	Khalid	ME.	Emergency management	10/12/94	KSA
Sindi	Abdullah	MH.	Emergency management	09/12/94	KSA
Fida	Abdulfatah	ME.	Emergency management	10/12/94	KSA
Zubaidi	Rashad	GUC.	Pilgrims transp. reports	14/12/94	KSA
Bafagih	Rida	MC	Emergency management	22/10/94	KSA
Al-Welaie	Abdullah	IU	General		KSA
Al-Rokaiba	Abdullah	IU	General		KSA

Appendix B: Emergency Management Survey

SURVEY FOR THE DESIGN OF IRSDSS

DURING THE HAJJ SEASON

PART ONE

QUESTIONNAIRE

Introduction

The **objective** of this survey is to identify the major issues concerning emergency management during the Hajj season. This includes issues such as mitigation, preparedness, response, and recovery. It will also contribute significantly to the design and development of a Spatial Decision Support System (SDSS) for emergency response during the Hajj season.

The questions or issues in this survey should be answered by key officials whose directly involved or have some experience with emergency response and management in the Holy city of Makkah Al-Mukaramah and its surrounding Holy Places.

To avoid misunderstanding or confusion of survey contents, it has been divided into four major sections as follows:

Section one: Emergency management.
Section two: Emergency planning.
Section three: Emergency co-ordination.
Section four: Emergency operations.

Each section contains, in addition to the questions, some instructions at the beginning. **Explanation of questions and terms** used in this survey is included in the second part. Please, refer to this part whenever you need an explanation of question or term.

Your completion of this survey will be of great help to finish my study. In addition, the outcomes of this project will be of importance to improve emergency response and management performance during the Hajj season.

Note: If you require a copy of the final results of this study, please check here --------

Name: ____________________
Title: ____________________
Department: ____________________
Organization: ____________________
Address: ____________________
____
Phone #: ____________________
Fax #: ____________________

Information provided will be used strictly for research purpose only and will be treated with complete confidentiality.

SECTION ONE: EMERGENCY MANAGEMENT

AN IDENTIFICATION OF EMERGENCY MANAGEMENT ENVIRONMENT

The objective of this section is to identify emergency management environment. It is designed to evaluate the overall emergency management and organisational issues. It may be filled out by a person who is directly involved with emergency management in the Holy city of Makkah Al-Mukaramah.

NOTE: Please refer to the second part (Explanation of Questions and Terms) whenever you need an explanation of a question or term.

1.1.0 IDENTIFICATION INFORMATION

1.1.1 PERSONAL INFORMATION (It may be completed by an emergency planner or by a person with similar position).

Name: ______________________________

Title: ______________________________

Department: ______________________________

Organization: ______________________________

Address: ______________________________

____

Phone #: ______________________________

Fax #: ______________________________

1.2.0 EMERGENCY MANAGEMENT SECTION

1.2.1 Please list all members of the High Commission for Hajj.

No.	Name	Position	Agency	Responsibility
1				
2				
3				
4				
5				
6				
7				
8				
9				

1.2.2 What is the primary function or purpose of the High Commission for Hajj in relation to emergency management ? (describe briefly).

1.2.3 In case of significant emergency event, who activates the emergency plan if it exists?

Name	Position

1.2.4 Indicate the reasons for which an emergency plan would be activated ?

No.	Reason
1	
2	
3	
4	
5	
6	
7	
8	
9	

1.2.5 List all agencies involved in emergency management and preplanning for Hajj.

No.	Agency	No.	Agency
1		11	
2		12	
3		13	
4		14	
5		15	
6		16	
7		17	
8		18	
9		19	

1.2.6 Is there general guidelines for emergency management decreed by the High Commission for Hajj ?

YES ----   NO ----

If yes, please attach it to the survey.

1.2.7 Please list all the safety factors that affects the selection of pilgrims residential areas.

No.	Distribution factors
1	
2	
3	
4	
5	

1.2.8 Who should be notified about pilgrims condition or status in case of emergency?

No.	Agency / group name
1	
2	
3	
4	

SECTION TWO: EMERGENCY PREPLANNING ISSUES

Preplanning is a key issue in emergency management. Measurement of performance and effectiveness of emergency response will depend largely upon the preplanning process that takes place before occurrence of an emergency. The objective of this section is to determine the role and responsibility of each agency involved in emergency management during the Hajj. Functions, responsibilities, and assignments are primary issues of all concerned agencies during emergencies. Through answers to all of the questions in this section will assist in the development of an emergency plan and the design of the intended integrated management emergency response system. This section is to be completed by all agencies involved with emergency management.

If you have a formal and written emergency plan that covers all the issues mentioned above during all emergency phases; mitigation, preparedness, response, and recovery, please attach this plan along with any other relevant information.

NOTE: Please refer to the second part (Explanation of Questions and Terms) whenever you need an explanation of a question or term.

2.1.0 IDENTIFICATION INFORMATION

2.1.1 PERSONAL INFORMATION (It may be completed by an emergency planner or by a person with similar position).

Name: ______________________
Title: ______________________
Department: ______________________
Organization: ______________________
Address: ______________________
____
Phone #: ______________________
Fax #: ______________________

2.2.0 EMERGENCY PREPLANNING SECTION

2.2.1 Does your agency have an emergency plan designed specifically for Hajj?

YES -----   NO ----

If yes, how often do you update it? Every ---------------------. Please attach it to the survey.

2.2.2 What is the overall mission of your agency during the Hajj ?

No.	Mission
1	
2	
3	
4	
5	
6	

2.2.3 What are the general emergency assumptions you may take into consideration in designing an emergency plan?

No.	Assumption
1	
2	
3	
4	

2.2.4 List all types of emergency events which your agency handles. Please list them according to their priority for response.

No	Emergency type
1	
2	
3	
4	
5	
6	
7	
8	
9	

2.2.5 What are the major difficulties to be dealt with before, during and after an emergency occurrence ?

No.	Before an event	During an event	After an event
1			
2			
3			
4			
5			
6			
7			
8			

2.2.6 What precautionary measures necessary to prevent or lessen emergency occurrences?

No.	Precautionary measures
1	
2	
3	
4	
5	
6	
7	
8	
9	

2.2.7 Please identify all personnel available and their responsibilities and where they can be contacted during an emergency.

Personnel	Responsibility	Contact

2.2.8 What equipment exist in your agency? Please list their type, Number, usage and location.

Equipment	No.	Usage	Location

2.2.9 What communication systems does your agency have?.

Communication system	Usage

2.2.10 Please list any kind of formal training programs ?

Training program	Location	Duration

SECTION THREE: EMERGENCY COORDINATION ISSUES

Coordination is a primary requirement in emergency management. Coordinating the efforts and resources is a determinate factor to ensure proper emergency response. Emergency coordination section aims to analyze and evaluate the level of coordination among the various agencies involved in emergency management during the Hajj.

NOTE: Please refer to the second part (Explanation of Questions and Terms) whenever you need an explanation of a question or term.

3.1.0 IDENTIFICATION INFORMATION

3.1.1 PERSONAL INFORMATION (It may be completed by an emergency planner or by a person with similar position).

Name: ______________________________
Title: ______________________________
Department: ______________________________
Organization: ______________________________
Address: ______________________________
____
Phone #: ______________________________
Fax #: ______________________________

3.2.0 EMERGENCY CO-ORDINATION SECTION

3.2.1 Identify all sites where emergency events most likely to occur during the various phases of Hajj activities. Please associate them with time and date.

Location	Date	Time

3.2.2 Identify the lead agency (s) in the event of a significant disaster situation.

No.	Agency's name	Emergency type
1		
2		
3		
4		

3.2.3 Is there any formal training involving coordination among the many agencies involved in emergency management ?

YES----- NO-----

If yes, please indicate how often this training take place. Every --------------------.

3.2.4 List contact person and name of agency in case of emergency situations with significant magnitude..

No	Contact Person	Agency	Title	Phone No
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				

3.2.5 Please identify all emergency activities that require coordination at multi-agency level.

Type of activity	Agency	Required coordination

SECTION FOUR: EMERGENCY OPERATIONS

This section involves emergency operations. To ensure continuity and effectiveness of emergency management and response, this section aims to investigate the structure of emergency management and handling in the Holy Sites. It includes issues such as structure and distribution of emergency teams, operation of command center, response, evacuation and recovery.

NOTE: Please refer to the second part (Explanation of Questions and Terms) whenever you need an explanation of a question or term.

4.1.0 IDENTIFICATION INFORMATION

4.1.1 PERSONAL INFORMATION (It may be completed by an emergency planner or by a person with similar position).

Name: ______________________________
Title: ______________________________
Department: ______________________________
Organization: ______________________________
Address: ______________________________
____
Phone #: ______________________________
Fax #: ______________________________

4.2.0 EMERGENCY OPERATIONS SECTION

4.2.1 Please indicate how your emergency team are structured or organized.

Team member	Task	Location	Time	Date

4.2.2 Do you use spatial zoning concept for emergency management?

YES ----- NO -----

If yes, please attach charts or maps which contains such divisions along with any other relevant information.

4.2.3 Are there specific routes designated specifically for emergencies during the Hajj.

YES ---- NO -----

If yes, please attach maps and charts which shows these routes.

If no, Why ______________________________

4.2.4. Please, indicate where your command center is located.

Name	Location	Date	Time

4.2.5 Do you utilize any kind of information technology for emergency management

YES ----   NO ----

If yes, please indicate its name and usage in the following table.

No.	Name	Usage

4.2.6 Please explain the procedure you might use to respond to an emergency event.

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

4.2.7 List all evacuation centers in the Holy Places along with contact person or agency in case of emergencies.

No.	Evacuation center	Location	Capacity	Contact Person/Agency
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				

4.2.8 List all services available at the evacuation centers.

No.	Type of service
1	
2	
3	
4	
5	
6	

PART TWO

EXPLANATION OF QUESTIONS AND TERMS

USED IN THE SURVEY

SECTION ONE: EMERGENCY MANAGEMENT

AN IDENTIFICATION OF EMERGENCY MANAGEMENT ENVIRONMENT

1.1.0 IDENTIFICATION INFORMATION

1.1.1 PERSONAL INFORMATION

This question is self-explanatory.

1.2.0 EMERGENCY MANAGEMENT SECTION

1.2.1 Please list all members of the High Commission for Hjj.

This question aims to identify all members of the High Commission for Hajj. As emergencies usually pose a major problem, A centralised approach to handling emergencies is required. Therefore, it is important to determine the key officials who plan and has the authority to make decisions during the major event of Hajj.

1.2.2 What is the primary function or purpose of the High Commission for Hajj in relation to emergency management ?

The High Commission for Hajj may act as a policy group. This question assumes that its primary function is to determine whether an emergency should be declared. And what type of assistance required from other involved agencies to response promptly to an emergency with a large magnitude.

1.2.3 In case of significant emergency event, who activates the emergency plan if it exists?

As part of effective emergency management and response, this question aims to identify the person or agency responsible for activating the emergency plan and other resources available.

1.2.4 Indicate the reasons for which an emergency plan would be activated ?

This question signifies the type of emergency under which an emergency plan would be activated. There are different type of emergency occurrence that may require the activation of the emergency plan. This may include:

- Uncontrolled incident lasting for an extended period of time.
- Incident involving multiple sites.
- sever weather conditions.

- Major fire.
- Mass casualties.
- Explosions
- Terrorist acts.
- Others.

1.2.5 List all agencies involved in emergency management and preplanning for Hajj.

This question aims to identify all agencies involved in emergency management and response. By identifying all the agencies (including voluntary groups), this will help to conduct further interviews with representatives of those agencies. This may result in a better design of a SDSS.

1.2.6 Is there general guidelines for emergency management decreed by the High Commission for Hajj ?

The High *Commission* for Hajj is assumed to be responsible for all type of activities including emergency management during the Hajj. Therefore, it may provide a general guidelines for other agencies instructing them to design an emergency plans. If such general guidelines are being decreed by the High Commission for Hajj, please attach them to the survey.

1.2.7 Please list all the factors that affects the selection of pilgrims residential areas.

Pilgrims come from all over the world with different cultures, languages, and sometimes political interests. This signifies that they should distributed in such away that would ensure minimising conflict among these divers groups to ensure their safety from their arrival to their departure from the country. Please indicate in general terms all the factors which have to be considered in selecting where each group of pilgrims should reside.

1.2.8 Who should be notified about pilgrims condition or status in case of emergency?

This question refers to the organisational arrangement in case of emergency. If pilgrim or group of pilgrims victimised by an emergency event, who should be notified about their status i.e. hajj missions or any other involved mission.

SECTION TWO: EMERGENCY PREPLANNING ISSUES

2.1.0 IDENTIFICATION INFORMATION

2.1.0 PERSONAL INFORMATION

This question is self-explanatory.

2.2.0 EMERGENCY PREPLANNING SECTION

2.2.1 Does your agency have an emergency plan designed specifically for hajj?

Dealing with emergencies during the Hajj period requires an emergency plan that outlines tasks and responsibilities of the emergency teams. Such a plan also should be updated periodically based on the accumulation of experience and historical records. If such a plan exists, please attach it to the survey.

2.2.2 What is the overall mission of your agency during the Hajj ?

This question determines the overall mission or purpose of your agency's participation in the management of emergency during the Hajj. Each agency will have different role to play in this regard. For example, police directorate may have the responsibility of controlling hostile crowds, while fire department has the responsibility of extinguishing massive fire in tent camps.

2.2.3 What are the general emergency assumptions you may take into consideration in designing an emergency plan?

Every emergency plan is usually based upon some general assumption which serve as a general guidelines for the emergency management and response. Therefore, each participating agency has its own emergency plan assumptions. For example, Fire department (Civil Defence) may have the following assumptions:

- Major fire incidence are most likely to occur every year during the Hajj based on historical records.
- Fire incidence may occur in multiple sites at the same time.
- Pilgrims awareness level of hazardous is very low.
- Lack of effective communications with pilgrims may aciculate the situation.
- Difficulties of mobilising resources to the scene due crowds are always present.
- Spatial zoning is an important concept to monitor the situation.

- Others.

1.2.4 List all types of emergency events which your agency handles. Please list them according to their priority for response.

This question aims to identify most of emergency events that usually occur during the Hajj season. Please list them according to their priority for response. Each agency may handle different type of emergencies than others. Please note that in some situations, your agency may act as a lead agency, while in other circumstances it may be considered as a support agency.

2.2.5 What are the major difficulties to be dealt with before, during and after an emergency occurrence ?

Difficulties can always be associated with emergencies. These difficulties which may have various dimensions can be faced before, during or after the incidence. For example, lack of effective planning or precautionary measures may be of the type that can be faced before an incidence. While lack of effective co-ordination or training of staff are difficulties during an incidence. Restoring public order is of the type of difficulties after an emergency event.

2.2.6 What precautionary measures necessary to prevent or lessen emergency occurrences?

Each agency which handles different type of emergency may require some precautionary measures to ensure the safety of pilgrims and their properties. Please list all these measures as applied to the type of emergency you may expect to occur.

2.2.7 Please identify all personnel available and their responsibilities and where they can be contacted during an emergency.

This question aims to identify all available emergency personnel along with the responsibility and contact mode in case of emergency. This includes all personnel whether in the command centre or in the field.

2.2.8 What equipment exist in your agency? Please list their type, Number, usage and location.

This question refers to the number, type usage and location of equipment which are to be used during the Hajj season. All resources are to be included.

2.2.9 What communication systems does your agency have?.

Communication systems are essential tools for emergency management. Please list all types of communication systems in use. This includes radio communications for control, co-ordination, and administrative purposes.

2.2.10 Please list any kind of formal training programs ?

Training is usually a prerequisite for effective emergency management and response especially if it take place in the actual site where emergencies are most likely to occur. If your agency carry on or adopt a formal training policy, please indicate the training program and its duration.

SECTION THREE: EMERGENCY COORDINATION ISSUES

3.1.0 IDENTIFICATION INFORMATION

3.1.1 PERSONAL INFORMATION

This question is self-explanatory.

3.2.0 EMERGENCY CO-ORDINATION SECTION

3.2.1 Identify all sites where emergency events most likely to occur during the various phases of Hajj activities. Please associate them with time and date.

This question refers to all type of emergency events that are most likely, or do occur during the Hajj season. Rank them according to their priority for emergency response. The list should include any type of emergency occurrence, even minor ones.

3.2.2 Identify the lead agency (s) in the event of a significant disaster situation.

In case of significant emergency event(s), one or two agencies may act as lead agencies who may coordinate the efforts and resources of other participating parties. It is most likely that the type of emergency may determine who should be the lead agency. For example, if a fire starts in a tent camp, Civil Defense would be in command of the whole operation, while other agencies would act as support groups.

3.2.3 Is there any formal training involving coordination among the many agencies involved in emergency management ?

As mentioned in question 2.2.10, training plays an important role in the field of emergency management. At the coordination level, training is also required to ensure consistency and effective response to an emergency occurrence. If there is formal training policy, please state that and how often does such training take place.

3.2.4 List contact person and name of agency in case of emergency situations with significant magnitude.

In case of disaster, coordination between policy maker who represent diverse agencies is essential. This question aims to identify those people who have the power and authority to coordinate emergency operations.

3.2.5 Please identify all emergency activities that require coordination at multi-agency level.

This question signifies the importance of coordination during all phases of emergencies. Such phases may include coordination at mitigation, preparedness, response, and recovery levels.

SECTION FOUR: EMERGENCY OPERATIONS

4.1.0 IDENTIFICATION INFORMATION

4.1.1 PERSONAL INFORMATION

This question is self-explanatory.

4.2.0 EMERGENCY OPERATIONS SECTION

4.2.1 Please indicate how your emergency team are structured or organized.

The purpose of this question is to determinate how your emergency team is organized and structured according to the task, location, date and time. Some organization may divide their emergency team into several sub-teams for observational, monitoring and response purposes.

4.2.2 Do you use spatial zoning concept for emergency management?

Zoning is an important concept in emergency management. The use of maps and charts is an effective procedure to monitor and respond promptly to emergencies. If such maps or charts which portray emergency divisions, please attach them to the survey along with any other explanatory information.

4.2.3 Are there specific routes designated specifically for emergencies during the Hajj.

This question aims to determine whether there are specific routes designated specifically for emergency during the Hajj season. If this is the case, please attach maps or charts which show emergency routes.

4.2.4. Please, indicate where your command center is located.

During the Hajj season, there maybe one command center that is used by all participating agencies. However, if you have a separate or mobile command center, please state its name and where is it located during the various phase of Hajj. Even

4.2.5 Do you utilize any kind of information technology for emergency management

Nowadays, information technology is being used extensively in the field of emergency management. This may include database management, spatial information, and decision support systems. If you use any of these or other systems, please indicate that.

4.2.6 Please explain the procedure you might use to respond to an emergency event.

This is a rather general question. You are not expected to answer it in great detail. Explanation of the response exertions in general terms would be enough.

4.2.7 List all evacuation centers in the Holy Places along with contact person or agency in case of emergencies.

The name, location, capacity, and contact person or agency all required pieces of information to evaluate whether these center are adequate to accommodate victims in case of emergencies. Please, provide all these information in response to this question.

4.2.8 List all services available at the evacuation centers.

Clothing, food and medical services are to be provided to victims of emergencies. Please, provide a list of these and any other services available in evacuation centers.

Appendix C: C Codes for Data Manipulation and Analysis

Appendix C.1: C Code for the First Scenario

```
/**************************************************************************/
/*      This code is for scenario 1 (single incident multiple response).   */
/*      It extracts path data and sorts SRCS stations node numbers         */
/*      according to the shortest path to incident location.              */
/*      It assigns SRCS stations for 15%, 25%, 50%, 98% magnitudes         */
/**************************************************************************/
#include<stdio.h>
#define SIZE 14
#define FIRST 15
#define SECOND 50
#define THIRD 85
#define FOURTH 98
#define CENTER 64
#define C '='
void sort(float *p1, float *p2, int *q1, int *q2, int *c1, int *c2);
void assign(int b[], int c[]);
void main(void)
{
	FILE *fpin1, *fpin2, *fpin3;
	char c;
	int i = 0, j;
	float path1[SIZE];
	int index1[SIZE], capacity[SIZE];

	clrscr();
	if ((fpin1 = fopen("d:\\final\\snario1.inc", "r")) == NULL)
		printf("\nFile cannot be opened");
	if ((fpin2 = fopen("d:\\final\\red.asc", "r")) == NULL)
		printf("\nFile cannot be opened");
	if ((fpin3 = fopen("d:\\final\\capacity.asc", "r")) == NULL)
		printf("\nFile cannot be opened");
	do
	{
		c = fgetc(fpin1);
		if (c == C)
		{
			fscanf(fpin1,"%f",&path1[i]);
			i++;
		}
	} while (c != EOF);
	for (i = 0; i < SIZE; i++)
	{
		fscanf(fpin2,"%d", &index1[i]);
		fscanf(fpin3,"%d", &capacity[i]);
	}
```

```
        fclose(fpin1);
        fclose(fpin2);
        fclose(fpin3);
        for (i = 0; i < SIZE - 1; ++i) /* outer loop controls number of passes */
        {
                for (j = SIZE - 1; i < j; --j) /* inner loop controls each pass */
                sort(&path1[j - 1], &path1[j], &index1[j - 1],
                        &index1[j], &capacity[j - 1], &capacity[j]); /* sorting function */
        }
        assign(index1,capacity);
}
void sort(float *p1, float *p2, int *q1, int *q2, int *c1, int *c2)
{
        float temp;
        int temp1, temp2;
        if (*p1 > *p2)
        {
                temp = *p1;
                *p1 = *p2;
                *p2 = temp;
                temp1 = *q1;
                *q1 = *q2;
                *q2 = temp1;
                temp2 = *c1;
                *c1 = *c2;
                *c2 = temp2;
        }
}
void assign(int b[], int c[])
{
        FILE *fpout1, *fpout2, *fpout3, *fpout4;
        int i, sum = 0, veh = 0;
        int count1 = 0, count2 = 0, count3 = 0;

        if ((fpout1 = fopen("d:\\final\\first1.asc", "w")) == NULL)
                printf("\nFile cannot be opened");
        if ((fpout2 = fopen("d:\\final\\first2.asc", "w")) == NULL)
                printf("\nFile cannot be opened");
        if ((fpout3 = fopen("d:\\final\\first3.asc", "w")) == NULL)
                printf("\nFile cannot be opened");
        if ((fpout4 = fopen("d:\\final\\first4.asc", "w")) == NULL)
                printf("\nFile cannot be opened");

        for (i = 0; i < SIZE; i++)
        {
```

```
            sum += c[i] * 2;
            if (sum < FIRST)
            {
                    fprintf(fpout1,"%d\n", b[i]);
                    count1++;
            }
        if (sum < SECOND)
            {
                    fprintf(fpout2,"%d\n", b[i]);
                    count2++;
            }
            if (sum < THIRD)
            {
                    fprintf(fpout3,"%d\n", b[i]);
                    count3++;
            }
            if (sum < FOURTH)
                    fprintf(fpout4,"%d\n", b[i]);
    }
    fprintf(fpout1,"%d", b[count1]);
    fprintf(fpout2,"%d", b[count2]);
    fprintf(fpout3,"%d", b[count3]);
    if (sum < FOURTH)
            veh = (FOURTH - sum) / 2;
    printf("%d", veh);
    fprintf(fpout4,"%d", CENTER);
    fclose(fpout1);
    fclose(fpout2);
    fclose(fpout3);
    fclose(fpout4);
}
```

Appendix C.2: C Code for the Second Scenario

```
/*************************************************************************/
/*      This code is for scenario 2 (multiple incidents multiple response).      */
/*      It extracts path data and sorts SRCS stations node numbers               */
/*      according to the shortest path to incident location.                    */
/*      Matches seven stations to incident 1, 2. Assigns stations to incidents   */
/*************************************************************************/
#include<stdio.h>
#define SIZE 14
#define LIMIT 7
#define FIRST 15
#define SECOND 50
#define THIRD 25
#define FOURTH 7
#define FIFTH 8
#define CENTER1 70
#define CENTER2 80
#define C '='
void sort(float *p1, float *p2, int *q1, int *q2, int *c1, int *c2);
void match(float a[], int x[], float b[], int y[], int c[], int d[]);
void assign1(int x[], int y[], int m[], int k[]);
void assign2(int x[], int y[], int m[], int k[]);
void assign3(int x[], int y[], int m[], int k[]);
void assign4(int x[], int y[], int m[], int k[]);
void main(void)
{
        FILE *fpin1, *fpin2, *fpin3;
        char c;
        int i = 0; int j = 0;
        float path1[SIZE], path2[SIZE];
        int index1[SIZE], index2[SIZE];
        int capacity1[SIZE], capacity2[SIZE];

        if ((fpin1 = fopen("d:\\final\\snario2.inc", "r")) == NULL)
                printf("\nFile cannot be opened");
        if ((fpin2 = fopen("d:\\final\\red.asc", "r")) == NULL)
                printf("\nFile cannot be opened");
        if ((fpin3 = fopen("d:\\final\\capacity.asc", "r")) == NULL)
                printf("\nFile cannot be opened");

        do                              /* extracts data */
        {
                c = fgetc(fpin1);
                if (c == C)
                {
                        if( i < SIZE)
```

```
                {
                        fscanf(fpin1,"%f",&path1[i]);
                        i++;
                }
                else if ( i == SIZE )
                {
                        fscanf(fpin1, "%f",&path2[j]);
                        j++;
                }
            }
        } while (c != EOF);
        for (i = 0; i < SIZE; i++)
        {
                fscanf(fpin2,"%d", &index1[i]);
                index2[i] = index1[i];
                fscanf(fpin3,"%d", &capacity1[i]);
                capacity2[i] = capacity1[i];
        }
        fclose(fpin1);
        fclose(fpin2);
        fclose(fpin3);
        for (i = 0; i < SIZE - 1; ++i) /* outer loop controls number of passes */
        {
                for (j = SIZE - 1; i < j; --j) /* inner loop controls each pass */
                sort(&path1[j - 1], &path1[j], &index1[j - 1],
                        &index1[j], &capacity1[j - 1], &capacity1[j]); /* sorting function */
        }
        for (i = 0; i < SIZE - 1; ++i) /* outer loop controls number of passes */
        {
                for (j = SIZE - 1; i < j; --j) /* inner loop controls each pass */
                sort(&path2[j - 1], &path2[j], &index2[j - 1],
                        &index2[j], &capacity2[j - 1], &capacity2[j]); /* sorting function */
        }
        match(path1,index1,path2,index2,capacity1,capacity2);
}
void sort(float *p1, float *p2, int *q1, int *q2, int *c1, int *c2)
{
        float temp;
        int temp1, temp2;
        if (*p1 > *p2)
        {
                temp = *p1;
                *p1 = *p2;
                *p2 = temp;
                temp1 = *q1;
```

```
                *q1 = *q2;
                *q2 = temp1;
                temp2 = *c1;
                *c1 = *c2;
                *c2 = temp2;
        }
}
void match(float a[], int x[], float b[], int y[], int c[], int d[])
{

        int temp1[SIZE], incident1[SIZE];
        int temp2[SIZE], incident2[SIZE];
        int capacity1[SIZE], captemp1[SIZE];
        int capacity2[SIZE], captemp2[SIZE];
        int i, j, count1 = 0, count2 = 0, count3 = 0, count4 = 0;
        float *p1, *p2;
        int *k1, *k2, *c1;

        p1 = a;
        k1 = x;
        c1 = c;
        for (i = 0; i < SIZE; i++)
        {
                p2 = b;
                k2 = y;
                for (j = 0; j < SIZE; j++)
                {
                        if (*k1 == *k2)
                        {
                                if(*p1 <= *p2 && count1 < LIMIT)
                                {
                                        incident1[count1] = *k1;
                                        capacity1[count1] = *c1;
                                        count1++;
                                }
                                else
                                {
                                        temp1[count2] = *k1;
                                        captemp1[count2] = *c1;
                                        count2++;
                                }
                        }
                p2++;
                k2++;
                }
```

```
		p1++;
		k1++;
		c1++;
	}

	p2 = b;
	k2 = y;
	c1 = d;
	for (i = 0; i < SIZE; i++)
	{
		p1 = a;
		k1 = x;
		for (j = 0; j < SIZE; j++)
		{
			if (*k2 == *k1)
			{
				if(*p2 < *p1 && count3 < LIMIT)
				{
					incident2[count3] = *k2;
					capacity2[count3] = *c1;
					count3++;
				}
				else
				{
					temp2[count4] = *k2;
					captemp2[count4] = *c1;
					count4++;
				}
			}
		p1++;
		k1++;
		}
		p2++;
		k2++;
		c1++;
	}

	if (count1 < LIMIT)
	{
		k1 = temp1;
		c1 = captemp1;
		for (i = 0; i < count2; i++)
		{
			k2 = incident2;
			for (j = 0; j < count3; j++)
```

```
                        {
                                if (*k1 == *k2)
                                        break;
                                else
                                        k2++;
                        }
                        if (*k1 != *k2)
                        {
                                incident1[count1] = *k1;
                                capacity1[count1] = *c1;
                                count1++;
                        }
                                k1++;
                                c1++;
                }
        }
        if (count3 < LIMIT)
        {
                k1 = temp2;
                c1 = captemp2;
                for (i = 0; i < count4; i++)
                {
                        k2 = incident1;
                        for (j = 0; j < count1; j++)
                        {
                                if (*k1 == *k2)
                                        break;
                                else
                                        k2++;
                        }
                        if (*k1 != *k2)
                        {
                                incident2[count3] = *k1;
                                capacity2[count3] = *c1;
                                count3++;
                        }
                k1++;
                c1++;
                }
        }
        assign1(incident1,incident2,capacity1,capacity2);
        assign2(incident1,incident2,capacity1,capacity2);
        assign3(incident1,incident2,capacity1,capacity2);
        assign4(incident1,incident2,capacity1,capacity2);
}
```

```
void assign1(int x[], int y[], int m[], int k[])
	/* 7% 8% */
{
	FILE *fpout1, *fpout2;
	int i, j, sum1 = 0, sum2 = 0, p;
	int incidtemp1[SIZE], incidtemp2[SIZE];

	if ((fpout1 = fopen("d:\\final\\second11.asc", "w")) == NULL)
		printf("\nFile cannot be opened");
	if ((fpout2 = fopen("d:\\final\\second12.asc", "w")) == NULL)
		printf("\nFile cannot be opened");
	for (i = 0; i < LIMIT; i++)
	{
		if (sum1 < FOURTH)
		{
			sum1 += m[i] * 2;
			incidtemp1[i] = x[i];
		}
		if ( sum1 >= FOURTH)
			break;
	}
	for (j = 0; j < LIMIT; j++)
	{
		if (sum2 < FIFTH)
		{
			sum2 += k[j] * 2;
			incidtemp2[j] = y[j];
		}
		if ( sum2 >= FIFTH)
			break;
	}
	for (p = 0; p < i + 1; p++)
		fprintf(fpout1,"%d\n", incidtemp1[p]);
	for (p = 0; p < j + 1; p++)
		fprintf(fpout2,"%d\n", incidtemp2[p]);
	fclose(fpout1);
	fclose(fpout2);
}
void assign2(int x[], int y[], int m[], int k[])
	/* 15% 15% */
{
	FILE *fpout1, *fpout2;
	int i, j, sum1 = 0, sum2 = 0, p;
	int incidtemp1[SIZE], incidtemp2[SIZE];
```

```
	if ((fpout1 = fopen("d:\\final\\second21.asc", "w")) == NULL)
		printf("\nFile cannot be opened");
	if ((fpout2 = fopen("d:\\final\\second22.asc", "w")) == NULL)
		printf("\nFile cannot be opened");
	for (i = 0; i < LIMIT; i++)
	{
		if (sum1 < FIRST)
		{
			sum1 += m[i] * 2;
			incidtemp1[i] = x[i];
		}
		if ( sum1 >= FIRST)
			break;
	}
	for (j = 0; j < LIMIT; j++)
	{
		if (sum2 < FIRST)
		{
			sum2 += k[j] * 2;
			incidtemp2[j] = y[j];
		}
		if ( sum2 >= FIRST)
			break;
	}
	for (p = 0; p < i + 1; p++)
		fprintf(fpout1,"%d\n", incidtemp1[p]);
	for (p = 0; p < j + 1; p++)
		fprintf(fpout2,"%d\n", incidtemp2[p]);
	fclose(fpout1);
	fclose(fpout2);
}
void assign3(int x[], int y[], int m[], int k[])
	/* 25% 25% */
{
	FILE *fpout1, *fpout2;
	int i, j, sum1 = 0, sum2 = 0, p;
	int incidtemp1[SIZE], incidtemp2[SIZE];

	if ((fpout1 = fopen("d:\\final\\second31.asc", "w")) == NULL)
		printf("\nFile cannot be opened");
	if ((fpout2 = fopen("d:\\final\\second32.asc", "w")) == NULL)
		printf("\nFile cannot be opened");
	for (i = 0; i < LIMIT; i++)
	{
		if (sum1 < THIRD)
```

```
			{
				sum1 += m[i] * 2;
				incidtemp1[i] = x[i];
			}
			if ( sum1 >= THIRD)
				break;
		}
		for (j = 0; j < LIMIT; j++)
		{
			if (sum2 < THIRD)
			{
				sum2 += k[j] * 2;
				incidtemp2[j] = y[j];
			}
			if ( sum2 >= THIRD)
				break;
		}
		for (p = 0; p < i + 1; p++)
			fprintf(fpout1,"%d\n", incidtemp1[p]);
		for (p = 0; p < j + 1; p++)
			fprintf(fpout2,"%d\n", incidtemp2[p]);
		fclose(fpout1);
		fclose(fpout2);
}
void assign4(int x[], int y[], int m[], int k[])
		/* 50 % 50%*/
{
		FILE *fpout1, *fpout2;
		int i, j, sum1 = 0, sum2 = 0, veh1 = 0, veh2 = 0, p;
		int incidtemp1[SIZE], incidtemp2[SIZE];

		if ((fpout1 = fopen("d:\\final\\second41.asc", "w")) == NULL)
			printf("\nFile cannot be opened");
		if ((fpout2 = fopen("d:\\final\\second42.asc", "w")) == NULL)
			printf("\nFile cannot be opened");
		for (i = 0; i < LIMIT; i++)
		{
			if (sum1 < SECOND)
			{
				sum1 += m[i] * 2;
				incidtemp1[i] = x[i];
			}
			if ( sum1 >= SECOND)
				break;
		}
```

```
for (j = 0; j < LIMIT; j++)
{

        if (sum2 < SECOND)
        {
                sum2 += k[j] * 2;
                incidtemp2[j] = y[j];
        }
        if ( sum2 >= SECOND)
                break;
}
if (sum1 < SECOND && sum2 < SECOND && i == LIMIT && j == LIMIT)
        /* not enough resources for both incidents */
{
        veh1 = (SECOND - sum1) / 2;
        veh2 = (SECOND - sum2) / 2;
        sum2 = sum2 + (veh2 * 2);
        sum1 = sum1 + (veh1 * 2);
        incidtemp1[i] = CENTER1;
        incidtemp2[j] = CENTER2;
}
        /* incident 1 has extra incident 2 has less */
if (sum1 > SECOND && sum2 < SECOND)
        /* add resources from last station of incident 1 */
                if (i <= LIMIT)
                {
                        veh1 = (sum1 - SECOND) / 2;
                        incidtemp2[j] = x[i];
                        sum2 = sum2 + veh1 * 2;
                }
        /* add additional stations from incident 1to the incident 2*/
while (sum2 < SECOND && i < LIMIT - 1)
{
        i++;
        j++;
        incidtemp2[j] = x[i];
        sum2 = sum2 + m[i] * 2;
}
/* add additional center if not enough from first incident 1*/
if (sum2 < SECOND && i >= LIMIT - 1)
{
        j++;
        incidtemp2[j] = CENTER2;
}
                /* incident 2 has extra incident 1 has less */
```

```
if (sum2 > SECOND && sum1 < SECOND)
        /* add resources from last station of incident 2 */
                if (j <= LIMIT)
                {
                        veh1 = (sum2 - SECOND) / 2;
                        incidtemp1[i] = y[j];
                        sum1 = sum1 + veh1 * 2;
                }
        /* add additional stations from incident 2*/
while (sum1 < SECOND && j < LIMIT - 1)
{
        i++;
        j++;
        incidtemp1[i] = y[j];
        sum1 = sum1 + k[j] * 2;
}
/* add additional center if not enough from incident 2 */
if (sum1 < SECOND && j >= LIMIT - 1)
{
        i++;
        incidtemp1[i] = CENTER1;
}
        for (p = 0; p < i + 1; p++)
        fprintf(fpout1,"%d\n", incidtemp1[p]);
for (p = 0; p < j + 1; p++)
        fprintf(fpout2,"%d\n", incidtemp2[p]);
fclose(fpout1);
fclose(fpout2);

    }
```

Appendix D: SML Codes for Simulation

Appendix D.1: SML Code for All Stations Response Simulation

```
&REM All stations response simulation
&REM Load the network for the second stage.
READNETWORK NETWORK LENGTH S_STAGE

&REM Load the address coverage.
ADDRESSCOVERAGE NETWORK
DISPLAY 4

&REM Set mapextent to network
MAPEXTENT NETWORK

&REM Draw network according to functional class.
DRAWNETWORK RD_CLASS NETWORK.LUT
 READSTOP STATION # SYMBOL

&REM Single incident dispatch all resources.
&REM Identify incident location randomly and assign the value to var. 1.

&REM Get user response for incident location.
&RES 1 "Enter a random number 1 - 241: "

&REM Add and save stop as an incident location
ADDSTOP %1 4
SAVESTOP INCIDENT

&REM Open the file contains the SRCS stations node numbers as location.
&OPEN RED.ASC

&REM Set variable 3 = 1 for route number.
&SETVAR 3 1

&REM Set variable 4 = 1 for route symbol.
&SETVAR 4 1

&REM Set variable 5 to hold the file name for directions.
&SETVAR 5 "DIREC1.INC"

&REM Loop to assign and process routes and paths from stations to incident.
&LABEL STATION
&REM Read stations locations into var. 2 until end of file.
&READ 2 ENDFILE1
ADDSTOP %2 # 6
ADDROUTE %3 %4
&REM path from station to incident location.
PATH %2 %1
```

```
&REM Save directions to DIREC1.INC.
DIRECTIONS RD_NAM TR_TIME Minutes %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK STATION

&LABEL ENDFILE1
&TYPE "End of file reached"
&CLOSE

&REM Save routes to STAINCID coverage.
SAVEROUTE STAINCID FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE1
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE1 &IF &NE %20 14
REMOVESTOP ALL

&REM Add incident location as stop
ADDSTOP %1 4

&REM Dispatch to medical facilities.
&OPEN MEDICAL.ASC
&SETVAR 5 DIREC1.MED
READSTOP MEDICAL # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO MEDICAL

&LABEL MEDICAL
&READ 2 ENDFILE2
ADDSTOP %2 # 7
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK MEDICAL

&LABEL ENDFILE2
&TYPE "End of file reached"
```

```
&CLOSE

&REM Save routes to INCIDMED coverage.
SAVEROUTE INCIDMED FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE2
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE2 &IF &NE %20 45
REMOVESTOP ALL

&REM Add incident location as stop
ADDSTOP %1 4

&REM Dispatch to evacuation centers.
&OPEN EVAC.ASC
&SETVAR 5 DIREC1.EVA
READSTOP EVAC # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO EVACUATION

&LABEL EVACUATION
&READ 2 ENDFILE3
ADDSTOP %2 # 3
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK EVACUATION

&LABEL ENDFILE3
&TYPE "End of file reached"
&CLOSE

&REM Save routes to INCIDEVA coverage.
SAVEROUTE INCIDEVA FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE3
```

```
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE3 &IF &NE %20 4
REMOVESTOP ALL

&GOTO END
&LABEL END
&RETURN
```

Appendix D.2: SML Code for First Scenario15% Incident Magnitude

```
&REM First scenario 15% incident magnitude
&REM Load the network for the second stage.
READNETWORK NETWORK LENGTH S_STAGE

&REM Load the address coverage.
ADDRESSCOVERAGE NETWORK
DISPLAY 4

&REM Set mapextent to network
MAPEXTENT NETWORK

&REM Draw network according to functional class.
DRAWNETWORK RD_CLASS NETWORK.LUT
 READSTOP STATION # SYMBOL

&REM Single incident multiple response.
&REM Identify incident location randomly and assign the value to var. 1.
&REM Get user response for incident location.
&RES 1 "Enter a random number 1 - 241: "

&REM Add and save stop as an incident location
ADDSTOP %1 4
SAVESTOP INCID1

&REM Open the file contains the SRCS stations for 15% response.
&OPEN FIRST1.ASC

&REM Set variable 3 = 1 for route number.
&SETVAR 3 1

&REM Set variable 4 = 1 for route symbol.
&SETVAR 4 1

&REM Set variable 5 to hold the file name for directions for 15% response.
&SETVAR 5 "FIRST1.INC"

&REM Loop to assign and process routes and paths from stations to incident.
&LABEL STATION1
&REM Read stations locations into var. 2 until end of file.
&READ 2 ENDFILE1
ADDSTOP %2 # 6
ADDROUTE %3 %4
&REM path from station to incident location.
PATH %2 %1
&REM Save directions to FIRST1.INC.
```

```
DIRECTIONS RD_NAM TR_TIME Minutes %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK STATION1

&LABEL ENDFILE1
&TYPE "End of file reached"
&CLOSE

&REM Save routes to FIRST1 coverage.
SAVEROUTE FIRST1 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE1
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE1 &IF &NE %20 %3 + 1
REMOVESTOP ALL
ADDSTOP %1 4


&REM Dispatch to medical facilities.
&OPEN MEDICAL.ASC
&SETVAR 5 FIRST1.MED
READSTOP MEDICAL # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO MEDICAL

&LABEL MEDICAL
&READ 2 ENDFILE2
ADDSTOP %2 # 7
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK MEDICAL

&LABEL ENDFILE2
&TYPE "End of file reached"
&CLOSE
```

```
&REM Save routes to MEDICAL1 coverage.
SAVEROUTE MEDICAL1 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE2
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE2 &IF &NE %20 45
REMOVESTOP ALL
ADDSTOP %1 4

&REM Dispatch to evacuation centers.
&OPEN EVAC.ASC
&SETVAR 5 FIRST1.EVA
READSTOP EVAC # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO EVACUATION

&LABEL EVACUATION
&READ 2 ENDFILE3
ADDSTOP %2 # 3
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK EVACUATION

&LABEL ENDFILE3
&TYPE "End of file reached"
&CLOSE

&REM Save routes to EVA1 coverage.
SAVEROUTE EVA1 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE3
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE3 &IF &NE %20 4
```

```
REMOVESTOP ALL

&GOTO END

&LABEL END
&RETURN
```

Appendix D.3: SML Code for First Scenario 50% Incident Magnitude

```
&REM First scenario 50% incident magnitude
&REM Load the network for the second stage.
READNETWORK NETWORK LENGTH S_STAGE

&REM Load the address coverage.
ADDRESSCOVERAGE NETWORK
DISPLAY 4

&REM Set mapextent to network
MAPEXTENT NETWORK

&REM Draw network according to functional class.
DRAWNETWORK RD_CLASS NETWORK.LUT
 READSTOP STATION # SYMBOL

&REM Single incident multiple response.
&REM Identify incident location randomly and assign the value to var. 1.
&REM Get user response for incident location.
&RES 1 "Enter a random number 1 - 241: "

&REM Add and save stop as an incident location
ADDSTOP %1 4
SAVESTOP INCID1

&REM Open the file contains the SRCS stations for 50% response.
&OPEN FIRST2.ASC

&REM Set variable 3 = 1 for route number.
&SETVAR 3 1

&REM Set variable 4 = 1 for route symbol.
&SETVAR 4 1

&REM Set variable 5 to hold the file name for directions for 50% response.
&SETVAR 5 "FIRST1.INC"

&REM Loop to assign and process routes and paths from stations to incident.
&LABEL STATION1
&REM Read stations locations into var. 2 until end of file.
&READ 2 ENDFILE1
ADDSTOP %2 # 6
ADDROUTE %3 %4
&REM path from station to incident location.
PATH %2 %1
&REM Save directions to FIRST1.INC.
```

```
DIRECTIONS RD_NAM TR_TIME Minutes %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK STATION1

&LABEL ENDFILE1
&TYPE "End of file reached"
&CLOSE

&REM Save routes to FIRST1 coverage.
SAVEROUTE FIRST1 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE1
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE1 &IF &NE %20 %3 + 1
REMOVESTOP ALL
ADDSTOP %1 4

&REM Dispatch to medical facilities.
&OPEN MEDICAL.ASC
&SETVAR 5 FIRST1.MED
READSTOP MEDICAL # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO MEDICAL

&LABEL MEDICAL
&READ 2 ENDFILE2
ADDSTOP %2 # 7
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK MEDICAL

&LABEL ENDFILE2
&TYPE "End of file reached"
&CLOSE

&REM Save routes to MEDICAL1 coverage.
```

```
SAVEROUTE MEDICAL1 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE2
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE2 &IF &NE %20 45
REMOVESTOP ALL
ADDSTOP %1 4

&REM Dispatch to evacuation centers.
&OPEN EVAC.ASC
&SETVAR 5 FIRST1.EVA
READSTOP EVAC # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO EVACUATION

&LABEL EVACUATION
&READ 2 ENDFILE3
ADDSTOP %2 # 3
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK EVACUATION

&LABEL ENDFILE3
&TYPE "End of file reached"
&CLOSE

&REM Save routes to EVA1 coverage.
SAVEROUTE EVA1 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE3
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE3 &IF &NE %20 4
REMOVESTOP ALL
```

```
&GOTO END

&LABEL END
&RETURN
```

Appendix D.4: SML Code for First Scenario 85% Incident Magnitude

```
&REM First scenario 85% incident magnitude
&REM Load the network for the second stage.
READNETWORK NETWORK LENGTH S_STAGE

&REM Load the address coverage.
ADDRESSCOVERAGE NETWORK
DISPLAY 4

&REM Set mapextent to network
MAPEXTENT NETWORK

&REM Draw network according to functional class.
DRAWNETWORK RD_CLASS NETWORK.LUT
 READSTOP STATION # SYMBOL

&REM Single incident multiple response.
&REM Identify incident location randomly and assign the value to var. 1.
&REM Get user response for incident location.
&RES 1 "Enter a random number 1 - 241: "

&REM Add and save stop as an incident location
ADDSTOP %1 4
SAVESTOP INCID1

&REM Open the file contains the SRCS stations for 85% response.
&OPEN FIRST3.ASC

&REM Set variable 3 = 1 for route number.
&SETVAR 3 1

&REM Set variable 4 = 1 for route symbol.
&SETVAR 4 1

&REM Set variable 5 to hold the file name for directions for 85% response.
&SETVAR 5 "FIRST1.INC"

&REM Loop to assign and process routes and paths from stations to incident.
&LABEL STATION1
&REM Read stations locations into var. 2 until end of file.
&READ 2 ENDFILE1
ADDSTOP %2 # 6
ADDROUTE %3 %4
&REM path from station to incident location.
PATH %2 %1
&REM Save directions to FIRST1.INC.
```

```
DIRECTIONS RD_NAM TR_TIME Minutes %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK STATION1

&LABEL ENDFILE1
&TYPE "End of file reached"
&CLOSE

&REM Save routes to FIRST1 coverage.
SAVEROUTE FIRST1 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE1
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE1 &IF &NE %20 %3 + 1
REMOVESTOP ALL
ADDSTOP %1 4

&REM Dispatch to medical facilities.
&OPEN MEDICAL.ASC
&SETVAR 5 FIRST1.MED
READSTOP MEDICAL # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO MEDICAL

&LABEL MEDICAL
&READ 2 ENDFILE2
ADDSTOP %2 # 7
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK MEDICAL

&LABEL ENDFILE2
&TYPE "End of file reached"
&CLOSE

&REM Save routes to MEDICAL1 coverage.
```

```
SAVEROUTE MEDICAL1 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE2
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE2 &IF &NE %20 45
REMOVESTOP ALL
ADDSTOP %1 4

&REM Dispatch to evacuation centers.
&OPEN EVAC.ASC
&SETVAR 5 FIRST1.EVA
READSTOP EVAC # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO EVACUATION

&LABEL EVACUATION
&READ 2 ENDFILE3
ADDSTOP %2 # 3
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK EVACUATION

&LABEL ENDFILE3
&TYPE "End of file reached"
&CLOSE

&REM Save routes to EVA1 coverage.
SAVEROUTE EVA1 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE3
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE3 &IF &NE %20 4
REMOVESTOP ALL
```

```
&GOTO END

&LABEL END
&RETURN
```

Appendix D.5: SML Code for First Scenario 98% Incident Magnitude

```
&REM First scenario 98% incident magnitude
&REM Load the network for the second stage.
READNETWORK NETWORK LENGTH S_STAGE

&REM Load the address coverage.
ADDRESSCOVERAGE NETWORK
DISPLAY 4

&REM Set mapextent to network
MAPEXTENT NETWORK

&REM Draw network according to functional class.
DRAWNETWORK RD_CLASS NETWORK.LUT
 READSTOP STATION # SYMBOL

&REM Single incident multiple response.
&REM Identify incident location randomly and assign the value to var. 1.
&REM Get user response for incident location.
&RES 1 "Enter a random number 1 - 241: "

&REM Add and save stop as an incident location
ADDSTOP %1 4
SAVESTOP INCID1

&REM Open the file contains the SRCS stations for 98% response.
&OPEN FIRST4.ASC

&REM Set variable 3 = 1 for route number.
&SETVAR 3 1

&REM Set variable 4 = 1 for route symbol.
&SETVAR 4 1

&REM Set variable 5 to hold the file name for directions for 98% response.
&SETVAR 5 "FIRST1.INC"

&REM Loop to assign and process routes and paths from stations to incident.
&LABEL STATION1
&REM Read stations locations into var. 2 until end of file.
&READ 2 ENDFILE1
ADDSTOP %2 # 6
ADDROUTE %3 %4
&REM path from station to incident location.
PATH %2 %1
&REM Save directions to FIRST1.INC.
```

```
DIRECTIONS RD_NAM TR_TIME Minutes %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK STATION1

&LABEL ENDFILE1
&TYPE "End of file reached"
&CLOSE

&REM Save routes to FIRST1 coverage.
SAVEROUTE FIRST1 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE1
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE1 &IF &NE %20 %3 + 1
REMOVESTOP ALL
ADDSTOP %1 4

&REM Dispatch to medical facilities.
&OPEN MEDICAL.ASC
&SETVAR 5 FIRST1.MED
READSTOP MEDICAL # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO MEDICAL

&LABEL MEDICAL
&READ 2 ENDFILE2
ADDSTOP %2 # 7
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK MEDICAL

&LABEL ENDFILE2
&TYPE "End of file reached"
&CLOSE

&REM Save routes to MEDICAL1 coverage.
```

```
SAVEROUTE MEDICAL1 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE2
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE2 &IF &NE %20 45
REMOVESTOP ALL
ADDSTOP %1 4

&REM Dispatch to evacuation centers.
&OPEN EVAC.ASC
&SETVAR 5 FIRST1.EVA
READSTOP EVAC # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO EVACUATION

&LABEL EVACUATION
&READ 2 ENDFILE3
ADDSTOP %2 # 3
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK EVACUATION

&LABEL ENDFILE3
&TYPE "End of file reached"
&CLOSE

&REM Save routes to EVA1 coverage.
SAVEROUTE EVA1 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE3
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE3 &IF &NE %20 4
REMOVESTOP ALL
```

```
&GOTO END

&LABEL END
&RETURN
```

Appendix D.6: SML Code for Second Scenario 7% & 8% Incident Magnitude

```
&REM Multiple incidents multiple response 7 & 8%.

&REM Load the network for the second stage.
READNETWORK NETWORK LENGTH S_STAGE

&REM Load the address coverage.
ADDRESSCOVERAGE NETWORK
DISPLAY 4

&REM Set mapextent to network
MAPEXTENT NETWORK

&REM Draw network according to functional class.
DRAWNETWORK RD_CLASS NETWORK.LUT

&REM Identify incidents location randomly and assign the value to var. 1 & 10.
&REM Get user response for incidents location.
&RES 1 "Enter a random number 1 - 241: "
&RES 10 "Enter a random number 1 - 241: "

&REM Add and save stops as an incidents location
ADDSTOP %1 4
ADDSTOP %10 4
&REM Open the file contains the SRCS stations for 7% response.
&OPEN SECOND11.ASC

&REM Set variable 3 = 1 for route number.
&SETVAR 3 1

&REM Set variable 4 = 1 for route symbol.
&SETVAR 4 1

&REM Set variable 5 to hold the file name for directions for 7% response.
&SETVAR 5 "SECOND11.INC"

&REM Loop to assign and process routes and paths from stations to incident.
&LABEL STATION1
&REM Read staitons locations into var. 2 until end of file.
&READ 2 ENDFILE1
ADDSTOP %2 # 6
ADDROUTE %3 %4
&REM path from station to incident location.
PATH %2 %1
&REM Save directions to SECOND11.INC.
DIRECTIONS RD_NAM TR_TIME Minutes %5
```

```
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK STATION1

&LABEL ENDFILE1
&TYPE "End of file reached"
&CLOSE

&REM Remove incident 1 & 2 stops.
REMOVESTOP %1
REMOVESTOP %10
&REM Save stations as stops
SAVESTOP STAT11

&REM Save routes to SECOND11 coverage.
SAVEROUTE SECOND11 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE1
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE1 &IF &NE %20 %3 + 1
REMOVESTOP ALL

ADDSTOP %10 4

&REM Open the file contains the SRCS stations for 8% response.
&OPEN SECOND12.ASC

&REM Set variable 3 = 1 for route number.
&SETVAR 3 1

&REM Set variable 4 = 1 for route symbol.
&SETVAR 4 1

&REM Set variable 5 to hold the file name for directions for 8% response.
&SETVAR 5 "SECOND12.INC"

&REM Loop to assign and process routes and paths from stations to incident.
&LABEL STATION2
&REM Read staitons locations into var. 2 until end of file.
&READ 2 ENDFILE2
ADDSTOP %2 # 6
```

```
ADDROUTE %3 %4
&REM path from station to incident location.
PATH %2 %10
&REM Save directions to SECOND12.INC.
DIRECTIONS RD_NAM TR_TIME Minutes %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK STATION2

&LABEL ENDFILE2
&TYPE "End of file reached"
&CLOSE

&REM Remove incident 1 & 2 stops.
REMOVESTOP %1
REMOVESTOP %10
&REM Save stations as stops
SAVESTOP STAT12

&REM Save routes to SECOND12 coverage.
SAVEROUTE SECOND12 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE2
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE2 &IF &NE %20 %3 + 1
REMOVESTOP ALL

ADDSTOP %1 4

&REM Dispatch to medical facilities.
&OPEN MEDICAL.ASC
&SETVAR 5 SECOND11.MED
READSTOP MEDICAL # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO MEDICAL1

&LABEL MEDICAL1
&READ 2 ENDFILE3
ADDSTOP %2 # 7
ADDROUTE %3 %4
```

```
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK MEDICAL1

&LABEL ENDFILE3
&TYPE "End of file reached"
&CLOSE

&REM Save routes to MED11 coverage.
SAVEROUTE MED11 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE3
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE3 &IF &NE %20 45
REMOVESTOP ALL

ADDSTOP %10 4

&REM Dispatch to medical facilities.
&OPEN MEDICAL.ASC
&SETVAR 5 SECOND12.MED
READSTOP MEDICAL # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO MEDICAL2

&LABEL MEDICAL2
&READ 2 ENDFILE4
ADDSTOP %2 # 7
ADDROUTE %3 %4
PATH %10 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK MEDICAL2

&LABEL ENDFILE4
&TYPE "End of file reached"
&CLOSE
```

```
&REM Save routes to MED12 coverage.
SAVEROUTE MED12 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE4
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE4 &IF &NE %20 45
REMOVESTOP ALL

ADDSTOP %1 4

&REM Dispatch to evacuation centers.
&OPEN EVAC.ASC
&SETVAR 5 SECOND11.EVA
READSTOP EVAC # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO EVACUATION1

&LABEL EVACUATION1
&READ 2 ENDFILE5
ADDSTOP %2 # 3
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK EVACUATION1

&LABEL ENDFILE5
&TYPE "End of file reached"
&CLOSE

&REM Save routes to EVA11 coverage.
SAVEROUTE EVA11 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE5
SELECTROUTE %20
REMOVEROUTE
```

```
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE5 &IF &NE %20 4
REMOVESTOP ALL

ADDSTOP %10 4

&REM Dispatch to evacuation centers.
&OPEN EVAC.ASC
&SETVAR 5 SECOND12.EVA
READSTOP EVAC # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO EVACUATION2

&LABEL EVACUATION2
&READ 2 ENDFILE6
ADDSTOP %2 # 3
ADDROUTE %3 %4
PATH %10 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK EVACUATION2

&LABEL ENDFILE6
&TYPE "End of file reached"
&CLOSE

&REM Save routes to EVA12 coverage.
SAVEROUTE EVA12 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE6
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE6 &IF &NE %20 4
REMOVESTOP ALL
&GOTO END

&LABEL END
&RETURN
```

Appendix D.7: SML Code for Second Scenario 15% Incident Magnitude

```
&REM Multiple incidents multiple response 15% & 15%.

&REM Load the network for the second stage.
READNETWORK NETWORK LENGTH S_STAGE

&REM Load the address coverage.
ADDRESSCOVERAGE NETWORK
DISPLAY 4

&REM Set mapextent to network
MAPEXTENT NETWORK

&REM Draw network according to functional class.
DRAWNETWORK RD_CLASS NETWORK.LUT
&rem READSTOP STATION # SYMBOL

&REM Identify incidents location randomly and assign the value to var. 1 & 10.
&REM Get user response for incidents location.
&RES 1 "Enter a random number 1 - 241: "
&RES 10 "Enter a random number 1 - 241: "

&REM Add and save stops as an incidents location
ADDSTOP %1 4
ADDSTOP %10 4
&REM Open the file contains the SRCS stations for 15% response.
&OPEN SECOND21.ASC

&REM Set variable 3 = 1 for route number.
&SETVAR 3 1

&REM Set variable 4 = 1 for route symbol.
&SETVAR 4 1

&REM Set variable 5 to hold the file name for directions for 15% response.
&SETVAR 5 "SECOND21.INC"

&REM Loop to assign and process routes and paths from stations to incident.
&LABEL STATION1
&REM Read staitons locations into var. 2 until end of file.
&READ 2 ENDFILE1
ADDSTOP %2 # 6
ADDROUTE %3 %4
&REM path from station to incident location.
PATH %2 %1
&REM Save directions tc SECOND21.INC.
```

```
DIRECTIONS RD_NAM TR_TIME Minutes %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK STATION1

&LABEL ENDFILE1
&TYPE "End of file reached"
&CLOSE

&REM Remove incident 1 & 2 stops.
REMOVESTOP %1
REMOVESTOP %10
&REM Save stations as stops
SAVESTOP STAT21

&REM Save routes to SECOND21 coverage.
SAVEROUTE SECOND21 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE1
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE1 &IF &NE %20 %3 + 1
REMOVESTOP ALL

ADDSTOP %10 4

&REM Open the file contains the SRCS stations for 15% response.
&OPEN SECOND22.ASC

&REM Set variable 3 = 1 for route number.
&SETVAR 3 1

&REM Set variable 4 = 1 for route symbol.
&SETVAR 4 1

&REM Set variable 5 to hold the file name for directions for 15% response.
&SETVAR 5 "SECOND22.INC"

&REM Loop to assign and process routes and paths from stations to incident.
&LABEL STATION2
&REM Read staitons locations into var. 2 until end of file.
&READ 2 ENDFILE2
```

```
ADDSTOP %2 # 6
ADDROUTE %3 %4
&REM path from station to incident location.
PATH %2 %10
&REM Save directions to SECOND22.INC.
DIRECTIONS RD_NAM TR_TIME Minutes %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK STATION2

&LABEL ENDFILE2
&TYPE "End of file reached"
&CLOSE

&REM Remove incident 1 & 2 stops.
REMOVESTOP %1
REMOVESTOP %10
&REM Save stations as stops
SAVESTOP STAT22

&REM Save routes to SECOND22 coverage.
SAVEROUTE SECOND22 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE2
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE2 &IF &NE %20 %3 + 1
REMOVESTOP ALL

ADDSTOP %1 4

&REM Dispatch to medical facilities.
&OPEN MEDICAL.ASC
&SETVAR 5 SECOND21.MED
READSTOP MEDICAL # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO MEDICAL1

&LABEL MEDICAL1
&READ 2 ENDFILE3
ADDSTOP %2 # 7
```

```
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK MEDICAL1

&LABEL ENDFILE3
&TYPE "End of file reached"
&CLOSE

&REM Save routes to MED21 coverage.
SAVEROUTE MED21 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE3
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE3 &IF &NE %20 45
REMOVESTOP ALL

ADDSTOP %10 4

&REM Dispatch to medical facilities.
&OPEN MEDICAL.ASC
&SETVAR 5 SECOND22.MED
READSTOP MEDICAL # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO MEDICAL2

&LABEL MEDICAL2
&READ 2 ENDFILE4
ADDSTOP %2 # 7
ADDROUTE %3 %4
PATH %10 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK MEDICAL2

&LABEL ENDFILE4
&TYPE "End of file reached"
```

```
&CLOSE

&REM Save routes to MED22 coverage.
SAVEROUTE MED22 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE4
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE4 &IF &NE %20 45
REMOVESTOP ALL

ADDSTOP %1 4

&REM Dispatch to evacuation centers.
&OPEN EVAC.ASC
&SETVAR 5 SECOND21.EVA
READSTOP EVAC # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO EVACUATION1

&LABEL EVACUATION1
&READ 2 ENDFILE5
ADDSTOP %2 # 3
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK EVACUATION1

&LABEL ENDFILE5
&TYPE "End of file reached"
&CLOSE

&REM Save routes to EVA21 coverage.
SAVEROUTE EVA21 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE5
SELECTROUTE %20
```

```
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE5 &IF &NE %20 4
REMOVESTOP ALL

ADDSTOP %10 4

&REM Dispatch to evacuation centers.
&OPEN EVAC.ASC
&SETVAR 5 SECOND22.EVA
READSTOP EVAC # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO EVACUATION2

&LABEL EVACUATION2
&READ 2 ENDFILE6
ADDSTOP %2 # 3
ADDROUTE %3 %4
PATH %10 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK EVACUATION2

&LABEL ENDFILE6
&TYPE "End of file reached"
&CLOSE

&REM Save routes to EVA22 coverage.
SAVEROUTE EVA22 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE6
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE6 &IF &NE %20 4
REMOVESTOP ALL
&GOTO END

&LABEL END
&RETURN
```

Appendix D.8: SML Code for Second Scenario 25% Incident Magnitude

```
&REM Load the network for the second stage.
READNETWORK NETWORK LENGTH S_STAGE

&REM Load the address coverage.
ADDRESSCOVERAGE NETWORK
DISPLAY 4

&REM Set mapextent to network
MAPEXTENT NETWORK

&REM Draw network according to functional class.
DRAWNETWORK RD_CLASS NETWORK.LUT
&rem READSTOP STATION # SYMBOL

&REM Multiple incidents multiple response.
&REM Identify incidents location randomly and assign the value to var. 1 & 10.
&REM Get user response for incidents location.
&RES 1 "Enter a random number 1 - 241: "
&RES 10 "Enter a random number 1 - 241: "
&REM Add and save stop as an incidents location
ADDSTOP %1 4
ADDSTOP %10 4
&REM Open the file contains the SRCS stations for 25% response.
&OPEN SECOND31.ASC

&REM Set variable 3 = 1 for route number.
&SETVAR 3 1

&REM Set variable 4 = 1 for route symbol.
&SETVAR 4 1

&REM Set variable 5 to hold the file name for directions for 25% response.
&SETVAR 5 "SECOND31.INC"

&REM Loop to assign and process routes and paths from stations to incident.
&LABEL STATION1
&REM Read staitons locations into var. 2 until end of file.
&READ 2 ENDFILE1
ADDSTOP %2 # 6
ADDROUTE %3 %4
&REM path from station to incident location.
PATH %2 %1
&REM Save directions to SECOND31.INC.
DIRECTIONS RD_NAM TR_TIME Minutes %5
&CALCVAR 3 %3 + 1
```

```
&CALCVAR 4 %4 + 1
&GOBACK STATION1

&LABEL ENDFILE1
&TYPE "End of file reached"
&CLOSE

&REM Remove incident 1 & 2 stops.
REMOVESTOP %1
REMOVESTOP %10
&REM Save stations as stops
SAVESTOP STAT31

&REM Save routes to SECOND31 coverage.
SAVEROUTE SECOND31 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE1
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE1 &IF &NE %20 %3 + 1
REMOVESTOP ALL

ADDSTOP %10 4

&REM Open the file contains the SRCS stations for 25% response.
&OPEN SECOND32.ASC

&REM Set variable 3 = 1 for route number.
&SETVAR 3 1

&REM Set variable 4 = 1 for route symbol.
&SETVAR 4 1

&REM Set variable 5 to hold the file name for directions for 25% response.
&SETVAR 5 "SECOND32.INC"

&REM Loop to assign and process routes and paths from stations to incident.
&LABEL STATION2
&REM Read stations locations into var. 2 until end of file.
&READ 2 ENDFILE2
ADDSTOP %2 # 6
ADDROUTE %3 %4
```

```
&REM path from station to incident location.
PATH %2 %10
&REM Save directions to SECOND32.INC.
DIRECTIONS RD_NAM TR_TIME Minutes %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK STATION2

&LABEL ENDFILE2
&TYPE "End of file reached"
&CLOSE

&REM Remove incident 1 & 2 stops.
REMOVESTOP %1
REMOVESTOP %10
&REM Save stations as stops
SAVESTOP STAT32

&REM Save routes to SECOND32 coverage.
SAVEROUTE SECOND32 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE2
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE2 &IF &NE %20 %3 + 1
REMOVESTOP ALL

ADDSTOP %1 4

&REM Dispatch to medical facilities.
&OPEN MEDICAL.ASC
&SETVAR 5 SECOND31.MED
READSTOP MEDICAL # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO MEDICAL1

&LABEL MEDICAL1
&READ 2 ENDFILE3
ADDSTOP %2 # 7
ADDROUTE %3 %4
PATH %1 %2
```

```
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK MEDICAL1

&LABEL ENDFILE3
&TYPE "End of file reached"
&CLOSE

&REM Save routes to MED31 coverage.
SAVEROUTE MED31 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE3
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE3 &IF &NE %20 45
REMOVESTOP ALL

ADDSTOP %10 4

&REM Dispatch to medical facilities.
&OPEN MEDICAL.ASC
&SETVAR 5 SECOND32.MED
READSTOP MEDICAL # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO MEDICAL2

&LABEL MEDICAL2
&READ 2 ENDFILE4
ADDSTOP %2 # 7
ADDROUTE %3 %4
PATH %10 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK MEDICAL2

&LABEL ENDFILE4
&TYPE "End of file reached"
&CLOSE
```

```
&REM Save routes to MED32 coverage.
SAVEROUTE MED32 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE4
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE4 &IF &NE %20 45
REMOVESTOP ALL

ADDSTOP %1 4

&REM Dispatch to evacuation centers.
&OPEN EVAC.ASC
&SETVAR 5 SECOND31.EVA
READSTOP EVAC # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO EVACUATION1

&LABEL EVACUATION1
&READ 2 ENDFILE5
ADDSTOP %2 # 3
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK EVACUATION1

&LABEL ENDFILE5
&TYPE "End of file reached"
&CLOSE

&REM Save routes to EVA31 coverage.
SAVEROUTE EVA31 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE5
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
```

```
&GOBACK REMOVEROUTE5 &IF &NE %20 4
REMOVESTOP ALL

ADDSTOP %10 4

&REM Dispatch to evacuation centers.
&OPEN EVAC.ASC
&SETVAR 5 SECOND32.EVA
READSTOP EVAC # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO EVACUATION2

&LABEL EVACUATION2
&READ 2 ENDFILE6
ADDSTOP %2 # 3
ADDROUTE %3 %4
PATH %10 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK EVACUATION2

&LABEL ENDFILE6
&TYPE "End of file reached"
&CLOSE

&REM Save routes to EVA32 coverage.
SAVEROUTE EVA32 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE6
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE6 &IF &NE %20 4
REMOVESTOP ALL

&GOTO END

&LABEL END
&RETURN
```

Appendix D.9: SML Code for Second Scenario 50% Incident Magnitude

```
&REM Multiple incidents multiple response 50 & 50%

&REM Load the network for the second stage.
READNETWORK NETWORK LENGTH S_STAGE

&REM Load the address coverage.
ADDRESSCOVERAGE NETWORK
DISPLAY 4

&REM Set mapextent to network
MAPEXTENT NETWORK

&REM Draw network according to functional class.
DRAWNETWORK RD_CLASS NETWORK.LUT

&REM Identify incidents location randomly and assign the value to var. 1 & 10.
&REM Get user response for incidents location.
&RES 1 "Enter a random number 1 - 241: "
&RES 10 "Enter a random number 1 - 241: "

&REM Add and save stops as an incidents location
ADDSTOP %1 4
ADDSTOP %10 4
&REM Open the file contains the SRCS stations for 50% response.
&OPEN SECOND41.ASC

&REM Set variable 3 = 1 for route number.
&SETVAR 3 1

&REM Set variable 4 = 1 for route symbol.
&SETVAR 4 1

&REM Set variable 5 to hold the file name for directions for 25% response.
&SETVAR 5 "SECOND41.INC"

&REM Loop to assign and process routes and paths from stations to incident.
&LABEL STATION1
&REM Read staitons locations into var. 2 until end of file.
&READ 2 ENDFILE1
ADDSTOP %2 # 6
ADDROUTE %3 %4
&REM path from station to incident location.
PATH %2 %1
&REM Save directions to SECOND41.INC.
DIRECTIONS RD_NAM TR_TIME Minutes %5
```

```
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK STATION1

&LABEL ENDFILE1
&TYPE "End of file reached"
&CLOSE

&REM Remove incident 1 & 2 stops.
REMOVESTOP %1
REMOVESTOP %10
&REM Save stations as stops
SAVESTOP STAT41

&REM Save routes to SECOND41 coverage.
SAVEROUTE SECOND41 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE1
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE1 &IF &NE %20 %3 + 1
REMOVESTOP ALL

ADDSTOP %10 4

&REM Open the file contains the SRCS stations for 25% response.
&OPEN SECOND42.ASC

&REM Set variable 3 = 1 for route number.
&SETVAR 3 1

&REM Set variable 4 = 1 for route symbol.
&SETVAR 4 1

&REM Set variable 5 to hold the file name for directions for 25% response.
&SETVAR 5 "SECOND42.INC"

&REM Loop to assign and process routes and paths from stations to incident.
&LABEL STATION2
&REM Read staitons locations into var. 2 until end of file.
&READ 2 ENDFILE2
ADDSTOP %2 # 6
```

```
ADDROUTE %3 %4
&REM path from station to incident location.
PATH %2 %10
&REM Save directions to SECOND42.INC.
DIRECTIONS RD_NAM TR_TIME Minutes %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK STATION2

&LABEL ENDFILE2
&TYPE "End of file reached"
&CLOSE

&REM Remove incident 1 & 2 stops.
REMOVESTOP %1
REMOVESTOP %10
&REM Save stations as stops
SAVESTOP STAT42

&REM Save routes to SECOND42 coverage.
SAVEROUTE SECOND42 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE2
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE2 &IF &NE %20 %3 + 1
REMOVESTOP ALL

ADDSTOP %1 4

&REM Dispatch to medical facilities.
&OPEN MEDICAL.ASC
&SETVAR 5 SECOND41.MED
READSTOP MEDICAL # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO MEDICAL1

&LABEL MEDICAL1
&READ 2 ENDFILE3
ADDSTOP %2 # 7
ADDROUTE %3 %4
```

```
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK MEDICAL1

&LABEL ENDFILE3
&TYPE "End of file reached"
&CLOSE

&REM Save routes to MED41 coverage.
SAVEROUTE MED41 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE3
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE3 &IF &NE %20 45
REMOVESTOP ALL

ADDSTOP %10 4

&REM Dispatch to medical facilities.
&OPEN MEDICAL.ASC
&SETVAR 5 SECOND42.MED
READSTOP MEDICAL # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO MEDICAL2

&LABEL MEDICAL2
&READ 2 ENDFILE4
ADDSTOP %2 # 7
ADDROUTE %3 %4
PATH %10 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK MEDICAL2

&LABEL ENDFILE4
&TYPE "End of file reached"
&CLOSE
```

```
&REM Save routes to MED42 coverage.
SAVEROUTE MED42 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE4
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE4 &IF &NE %20 45
REMOVESTOP ALL

ADDSTOP %1 4

&REM Dispatch to evacuation centers.
&OPEN EVAC.ASC
&SETVAR 5 SECOND41.EVA
READSTOP EVAC # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO EVACUATION1

&LABEL EVACUATION1
&READ 2 ENDFILE5
ADDSTOP %2 # 3
ADDROUTE %3 %4
PATH %1 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK EVACUATION1

&LABEL ENDFILE5
&TYPE "End of file reached"
&CLOSE

&REM Save routes to EVA41 coverage.
SAVEROUTE EVA41 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE5
SELECTROUTE %20
REMOVEROUTE
```

```
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE5 &IF &NE %20 4
REMOVESTOP ALL

ADDSTOP %10 4

&REM Dispatch to evacuation centers.
&OPEN EVAC.ASC
&SETVAR 5 SECOND42.EVA
READSTOP EVAC # SYMBOL
&SETVAR 3 1
&SETVAR 4 1
GOTO EVACUATION2

&LABEL EVACUATION2
&READ 2 ENDFILE6
ADDSTOP %2 # 3
ADDROUTE %3 %4
PATH %10 %2
DIRECTIONS RD_NAM TR_TIME MINUTES %5
&CALCVAR 3 %3 + 1
&CALCVAR 4 %4 + 1
&GOBACK EVACUATION2

&LABEL ENDFILE6
&TYPE "End of file reached"
&CLOSE

&REM Save routes to EVA42 coverage.
SAVEROUTE EVA42 FSTOP TSTOP SYMBOL

&REM Remove routes and stops.
&SETVAR 20 1
&LABEL REMOVEROUTE6
SELECTROUTE %20
REMOVEROUTE
&CALCVAR 20 %20 + 1
&GOBACK REMOVEROUTE6 &IF &NE %20 4
REMOVESTOP ALL
&GOTO END

&LABEL END
&RETURN
```