A REAL TIME WEB BASED ELECTRONIC TRIAGE, RESOURCE ALLOCATION AND HOSPITAL DISPATCH SYSTEM FOR EMERGENCY RESPONSE

A Thesis Presented

by

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ABSTRACT

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Disasters are characterized by large numbers of victims and required resources, overwhelming the available resources. Disaster response involves various entities like Incident Commanders, dispatch centers, emergency operations centers, area command and hospitals. An effective emergency response system should facilitate coordination between these various entities. Victim triage, emergency resource allocation and victim dispatch to hospitals form an important part of an emergency response system. In this present research effort, an emergency response system with the aforementioned components is developed.

Triage is the process of prioritizing mass casualty victims based on severity of injuries; thereby requiring a rapid and efficient first-response. Triaging of patients ensures that critically injured victims are made a top priority for reception of medical attention and treatment. Consolidation of victim triage information is time consuming with existing paper triage systems. The system presented in this thesis is a low-cost victim triage system that replaces paper triage-tags with RFID tags that aggregate all

victim information within a database. It will allow first responders' movements to be tracked using GPS.

A web-based real time resource allocation tool that can assist the Incident Commanders in resource allocation and transportation for multiple simultaneous incidents has been developed. This tool generates an optimal transportation plan such that emergency sites with highest priorities for a resource are assigned the resources in the least amount of time. This web-based tool also computes the patient dispatch schedule from each disaster site to each hospital. An algorithm is developed to dispatch critically injured patients to the nearest hospital that has the medical facilities to treat the patient. It is assumed that a database of emergency resource depots and the available beds in hospitals is known. The web-based emergency resource allocation and patient dispatch system complements emergency response systems by providing decision-making capabilities.

This tool can also assist resource managers in emergency resource planning by computing the time taken to receive required resources from the nearest depots using Google Maps. This resource planning tool will be helpful in analyzing how additional new resources in the depots can affect the response time at a potential disaster site.

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CHAPTER 1

INTRODUCTION

A natural or man-made disaster is a life threatening event with an impact on a large number of people. They are rare, overwhelming and unforeseen events creating a chaotic environment for the people managing them. The Red Cross defines disasters as "exceptional events which suddenly kill or injure large numbers of people". They are also defined as events occurring on a scale which require external assistance. Hence, disasters are characterized by a large number of victims and requests for resources which overwhelm those that are available. In this way, disasters are different from daily emergencies which involve a small number of victims and can be handled with available resources.

In the case of emergencies, people from police departments, fire departments and medical services are first to arrive on the scene. Coordination between these different entities is important to achieve. Generally, fire personnel act as Incident Commanders, paramedics are responsible for triage and police perform perimeter control.

A disaster cycle, as defined by FEMA, is shown in Figure.1.1. It consists of Response, Recovery (rehabilitation/reconstruction), Mitigation and Preparedness phases. Some of the phases in an emergency response happen simultaneously.

RESPONSE: After a disaster occurs, response activities are started. If a warning system predicts an upcoming disaster, then response starts right away. This includes victim triage, evacuation, requests for emergency resources containing the incident, and the dispatch of the victims to hospitals. Response involves minimizing the property damage and saving lives.

RECOVERY: The Recovery stage involves bringing the community back to normalcy. It involves reconstructing and repairing the damaged infrastructure.

MITIGATION: This phase involves the steps to be taken to prevent the occurrence of the disaster in the future.

PREPAREDNESS: This phase involves getting prepared to respond to this type of emergency in case it occurs again.

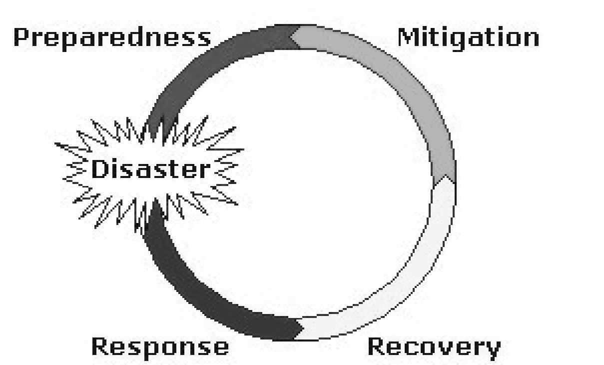

Figure 1.1 – Emergency management cycle

1.1 Motivation

Triage is the process of prioritizing mass casualty victims based on their criticality. Hence rapid and efficient triaging is an important part of emergency response in mass casualty incidents. Triaging of patients will ensure that critical victims are served with the scarce medical resources. A triage tag should have the following properties to be effective: Low cost due to the number of casualties in mass casualty incidents, should be compact and easy to carry/use by the first responders, and should help in consolidation of the victim information. It is also important to track the location of first responders [19] to account for the number of first responders. Tracking will aid in directing the search and rescue efforts, if the first responders are trapped.

Optimal deployment of emergency resources in multiple mass casualty incidents is a challenging task due to the competition for the limited available crucial resources. The IS-703 course [27] (National Incident Management System-NIMS resource management) offered by the FEMA Emergency Management Institute, mentions that in case of complex incidents, "*It may become necessary to move from a first-come-first-served protocol to an incident and/or resource prioritization system, requiring additional policy and technical assistance*". Hence it is important to develop an emergency resource deployment system with decision support capabilities.

In the case of mass casualty incidents, a large number of victims with varied medical needs will be present at the emergency sites. It is very important to move them to the hospitals according to their medical needs and acuity levels. Recommendations for a National Mass Patient and Evacuee Movement, Regulating, and Tracking System [18] mentions that "*an ideal national regulating system could offer decision support in the process of matching vehicles to patients and hospitals*". Hence a victim dispatch system with recommendations mentioned in [18] should be developed.

Resource planning forms an important part of resource management. Homeland Security Presidential directive-8 mentions that a national preparedness system to "*strengthen the preparedness of the United States to prevent and respond to threatened or actual domestic terrorist attacks, major disasters, and other emergencies*" be initiated. Requesting additional resources, moving resource depots and rearranging the available resources during the preparedness phase of the emergency response cycle will make the resources readily available for deployment in less time during the emergency.

1.2 Overview

The overall architecture of the emergency response system is shown in Figure 1.2. A first responder tracking engine, emergency resource allocation module and patient dispatch module form important parts of the system. The first responder tracking engine uses GPS technology to track victims. The emergency resource allocation module and the patient dispatch system are used as decision support tools in allocating resources to the emergency sites and victims to the hospitals. Each module is explained briefly below.

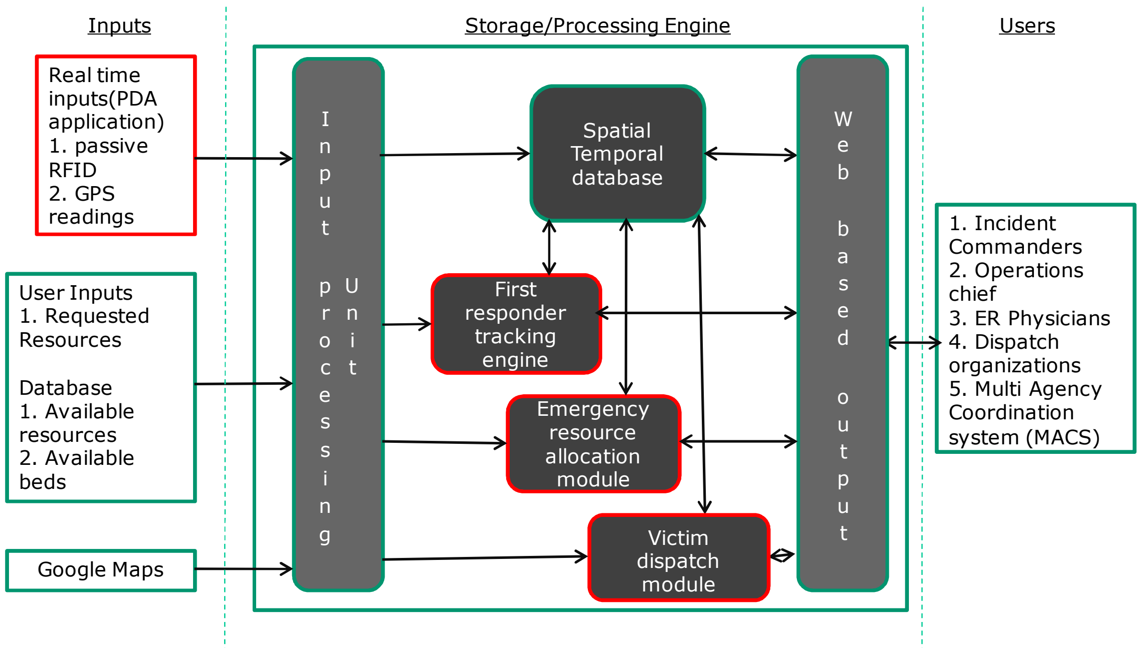

Figure 1.2. Overall architecture

A mass casualty victim triage system that uses rewriteable passive RFID tags, replacing paper triage tags, is proposed and implemented as part of this thesis. This system can track the first responders and consolidate the victim information. The first responders carry a windows mobile based PDA with a triage application that can read and write triage information to RFID tags using a passive RFID reader/writer. This client application sends this information and continually updates the GPS location of the first responder in the database server. Tracking of first responders helps in rescuing trapped or injured first responders. A scene overview with victim triage information and the path taken by the first responder is displayed on a web page using Google Maps. Victim triage information includes symptoms, treatment administered, vital signs and triage color indicating the criticality of the victim.

A web-based emergency resource allocation tool (optimization problem formulation and implementation done by Mr. Russell Kondaveti [1] [2]) that can assist Incident Commanders and resource managers in the complex task of resource allocation and transportation is developed. This system takes real time inputs, like location of emergency sites, and generates an optimal transportation plan so that the emergency sites with the highest resource priorities are assigned resources in the least amount of time. This system informs the Incident Commander on the arrival times of resources to the emergency sites.

A transportation problem (similar to emergency resource allocation [1] [2]) is formulated which minimizes the dispatch time for critical victims to emergency shelters and hospitals while considering: 1. The demand at each site in terms of medical facilities required by the victims and the associated priorities, 2. Location of emergency sites and hospitals, and 3. Available hospital resources like available beds at each hospital. The optimal transportation plan is presented graphically using Google Maps. This system also computes the patient dispatch schedule from each emergency site to each hospital. The hospital dispatch system is designed in such a way that it can work with other emergency response systems like DIORAMA [3].

A web-based emergency resource planning system is also proposed [28]. It is assumed that a database of emergency resource depots is available. Database entries like location of resource depots and available number of resources can be changed from the web interface. Potential emergency sites can be marked on Google Maps and the response times at each emergency site will be calculated such that requested resources at the emergency site are allocated from the nearest resource depots. This tool can assist resource managers when new resources have to be allocated to depots based on the response times across a region.

In Chapter 2, e-triage system is discussed. Chapter 3 details resource allocation system. Chapter 4 discusses victim dispatch system and Chapter 5 describes emergency resource planning tool. Conclusions are presented in the Chapter 6.

CHAPTER 2

E-TRIAGE SYSTEM

2.1 Literature Review

A number of triage tag systems for disaster management [4-7] were proposed. It was proposed in [4] that passive RFID tags be used replacing existing paper triage tags. Passive RFID tags were used to transport, classify injured victims and understand the scale of the incident. Special bar-coded bracelets were used as tags in [5]. Location information of first responders was not considered in [4] and [5]. A low power electronic triage was used to track the location of the patients in [6] and [7]. Triage tags in [6] and [7] include CodeBlue motes and sensors like pulse oximeter and accelerometer to detect vital signs and motion activity. Overall cost of triage tags used in [6] and [7] is more than \$252[1,2]. An emergency response triage system employed in a mass casualty system should satisfy the following criteria 1. Facilitate the coordination of various diverse entities like Incident Commanders, area command, resource managers and hospital authorities 2. Generate and store location information of first responders. It was mentioned in [8] that about 80% of information required for emergency decision making has a location component. None of papers [4-7] satisfy all criteria of an effective triage system.

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[1] Cost of sensors used in triage tags is as follows: BCI medical micro power oximeter board (from smiths-medical) - \$170, ST microelectronics LIS3LO2AQ accelerometer - \$40, Analog ADXRS300 single axis gyroscope - \$42. Information on prices is obtained from manufacturing companies. Overall price of tag may decrease if produced in bulk.

[2] Price of CodeBlue mote is not included.

2.2. Architecture

In mass casualty incidents, current victim triage and evacuation processes are done as follows:

1. Emergency personnel arrive at the incident site and establish a treatment area that is safe and close to the incident site.
2. First responders arriving on the scene will triage the victims on the incident site based on the injury levels. Victims are triaged into Red (immediate), Yellow (delayed), Green (minor) and Black (dead) categories. First responders attach a triage tag shown in Figure 2.1 to the victims
3. Injured victims are evacuated from the incident area to the treatment area based on their severity levels (Red followed by Yellow, Green). Green victims who are able to move go directly to the treatment area.
4. In the treatment area, victims are re-triaged and additional information such as name, age and address are updated on the triage tag.
5. Resource manager requests emergency resources.
6. A transportation officer allocates the victims to the hospitals. As soon as the ambulances arrive at the incident site, victims are transported to the corresponding hospitals.

Some of the steps mentioned above occur simultaneously

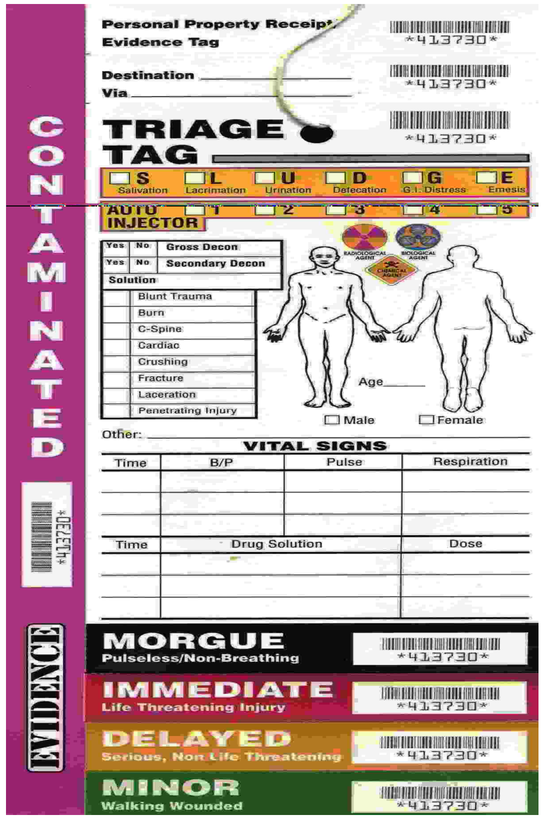

Figure 2.1 Paper triage tag

The proposed system architecture is shown in Figure 2.2. Similar to the paper triage process, the following steps will be followed in the e-triage system:

1. First responders carry a PDA equipped with input triage application, GPS and a passive RFID tag reader/writer. They also carry color-coded passive RFID triage tags.
2. In the first phase of triage, first responders pick a color-coded RFID triage tag (Red, Yellow, Green and Black) appropriate to the victim and attach it.
3. The RFID reader on the PDA will scan the tag and write the triage tag ID to the server through a cellular network.
4. The GPS location of the first responder is updated to the server every 1 second.
5. In the treatment area, the second stage of triage is done. More triage information

is written to the tag by the PDA and updated on the server.

6. Information stored on the server can be accessed through a web page. Incident commanders can use this data to estimate the intensity of the incident. Hospitals can search the triage information of the incoming victims.

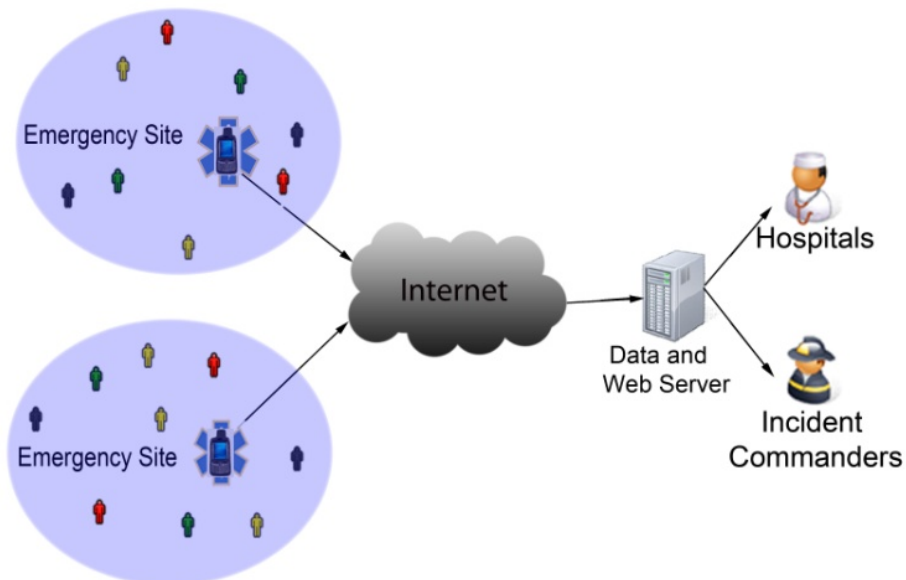

Figure 2.2 E-triage system architecture

Figure 2.3 shows the input output block diagram of the e-triage system. This system takes the input triage information of victims like triage color, treatment administered, name, age and address. The GPS information from the GPS receiver attached to the first responder is updated to the database every 2 seconds. The output of the system is the number of victims in the emergency site and their triage information. When combined with an effective patient dispatch system, this model can inform hospitals about arriving patients.

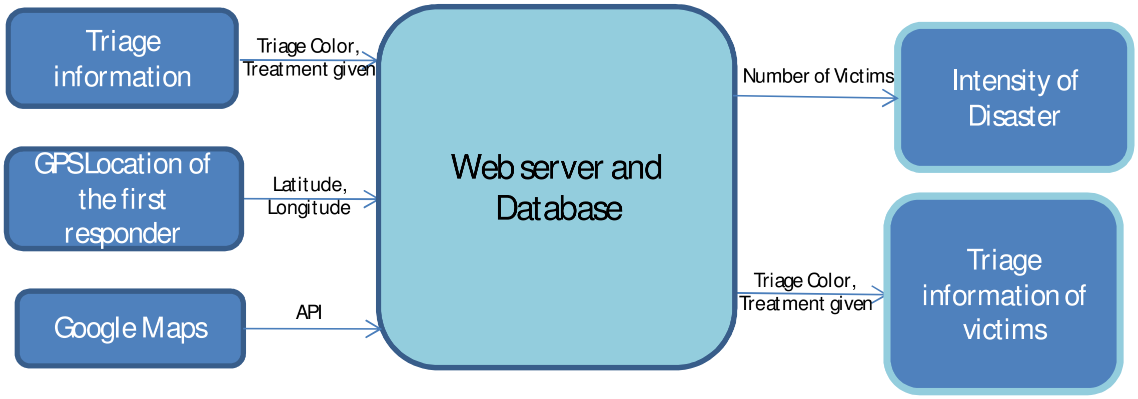

Figure 2.3 E-triage system block diagram

2.3. Implementation

The PDA application (client) and web server are implemented as part of this thesis. Implementation details of the server in the e-triage system are shown in Figure 2.4.

1. User Interface (UI): The web UI periodically reads the triage database and renders output on Google Maps. Queries about arrival of victims to hospitals are also served by the UI. Web pages are designed using HTML and JavaScript.
2. PHP Hypertext Preprocessor (PHP) server: A PHP/Apache web server is used to interface with (MySQL) database of the server using AJAX.
3. MySQL database: MySQL databases are used to store/modify details about victim information and location information of the first responders. In addition to this, color coding of each triage tag is also stored in the database.

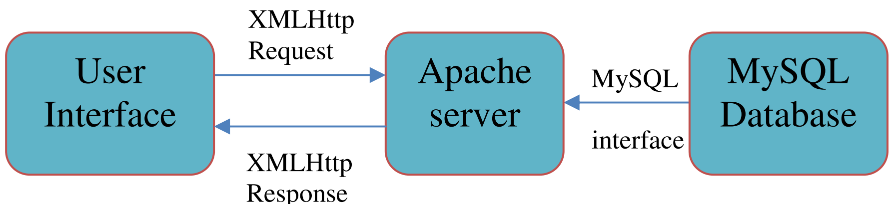

Figure 2.4 E-triage server

The PDA application developed for this thesis has the UI as shown in Figure 2.5. It has all the entries similar to the paper triage tag. The PDA is windows mobile based and the application is based on .NET compact framework. The PDA application interfaces with GPS device carried by the first responder using Bluetooth. The PDA used is Motorola MC35.

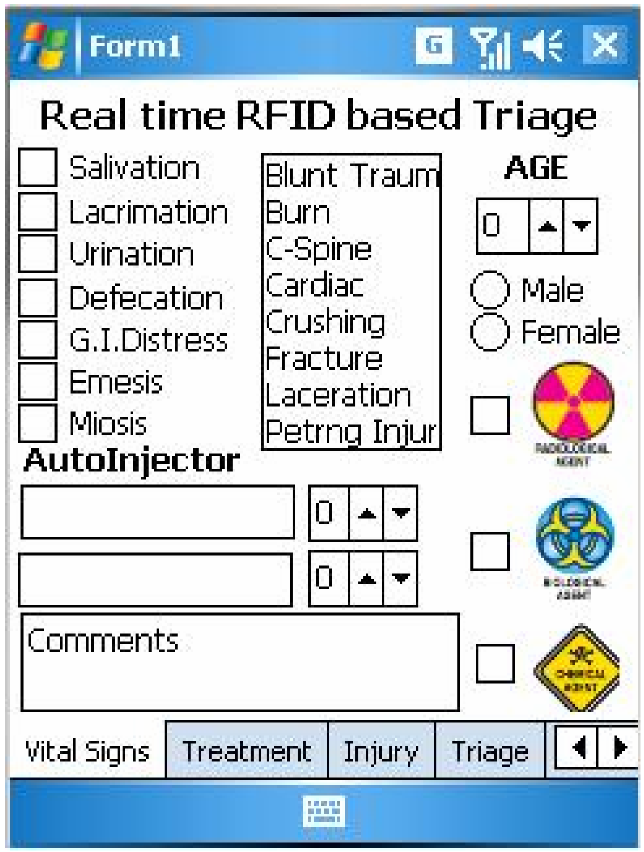

Figure 2.5 PDA application (client)

2.4. Hypothetical Disaster Scenario

In this section, a hypothetical disaster scenario experiment performed at the quadrangle of ECE department at UMASS is described. The usefulness of the system is demonstrated by this experiment with hypothetical victims. 14 victims represented by colored cones (marked in red circles) were placed in a quadrangle as shown in

Figure.2.6. In the first triage, one first responder (carrying PDA and RFID tags) moves from one victim to another. Depending on the triage condition of the victim, paramedic will pick an appropriate color coded tag, scan it with PDA and attach it to the victim. The PDA will send the RFID tag ID and GPS location to the server. Depending on the triage tag ID, a database lookup will reveal the color of the tag. This information is presented on a web page using Google Maps.

Figure 2.6 Hypothetical disaster scenario with cones

The output of first phase of triage is shown in Figure 2.7. The server calculates the number of victims based on the RFID tag IDs received. The path taken by the first responder is also displayed on Google maps.

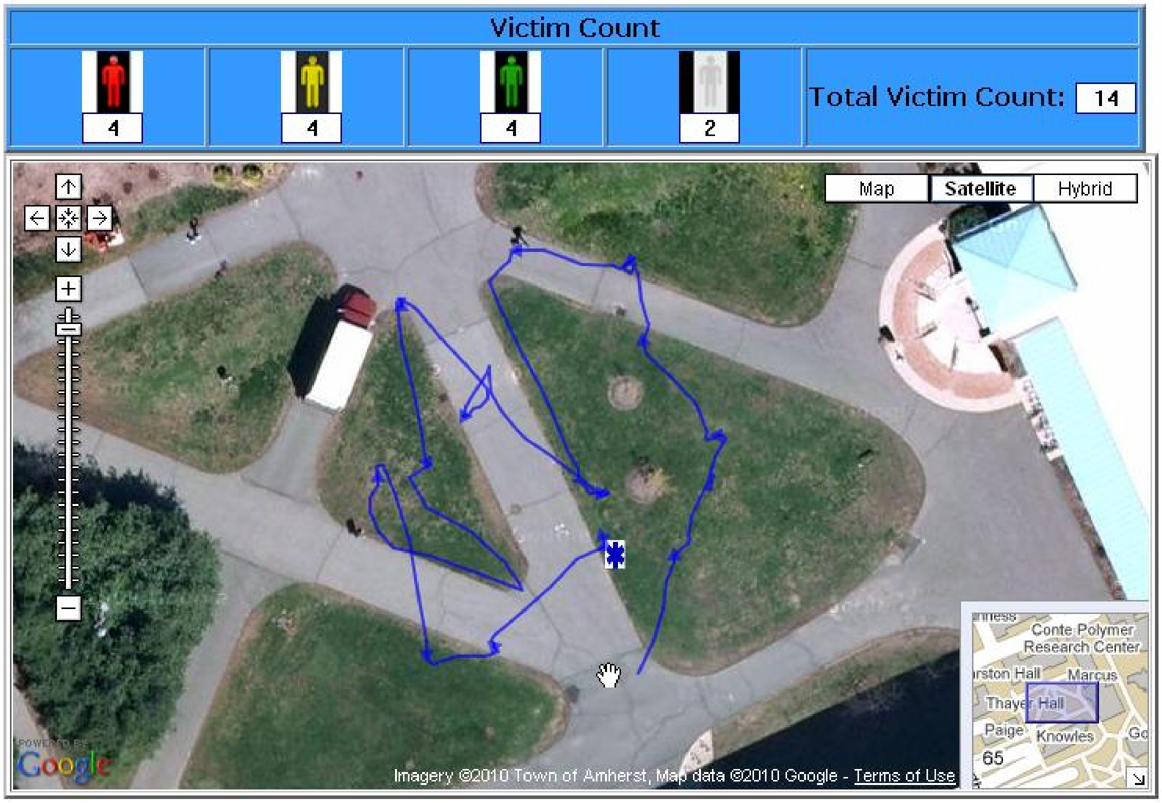

Figure 2.7 Web server output

CHAPTER 3

EMERGENCY RESOURCE ALLOCATION SYSTEM

3.1. Literature Review

A decision support system that performs resource allocation should meet the following requirements [27]: 1. Consider multiple emergency sites in close geographical proximity and multiple resource depots, 2. Consider the resource requirements and their priorities at each emergency site, 3. Consider real time inputs that can affect the resource allocation 4. Easy to use web based user interface that can be viewed from any location.

A number of research papers describe various decision support systems for disaster management [20-26]. Although all of these papers use similar optimization techniques to frame the resource allocation problem, none of these papers meets all the requirements 1-4 mentioned above. A summary of the differences of other papers with respect with criteria 1-4 is given in the Table.3.1 below:

	Criteria-1	Criteria-2	Criteria-3	Criteria-4	Notes
[20]	✓	×	✓	×	Assumes resource depot has infinite capacity
[21]	✓	×	✓	×	Minimizes monetary cost
[22]	×	×	✓	×	Minimizes monetary cost
[23]	×	×	×	×	-
[24]	×	×	×	×	-
[25]	×	×	×	×	-
[26]	×	×	×	✓	Tool for Loss Estimation during Earthquakes
Emergency resource allocation	✓	✓	✓	✓	Minimizes the time taken for resources to arrive at emergency sites based on priorities

Table 3.1 Literature survey

3.2. Architecture

The architecture of the emergency resource allocation tool that is implemented is shown in Figure 3.1. Inputs to this system include disaster location, requested resources and the available resources database. Requested resources along with the priorities will be given by the Incident Commander. It is assumed that a database of available emergency response resources is known. The optimization problem (Appendix B from [1]) is solved using the Matlab optimization toolbox. The solution includes the number and kind of resources allocated from each resource depot to the disaster site as well as the deployment route.

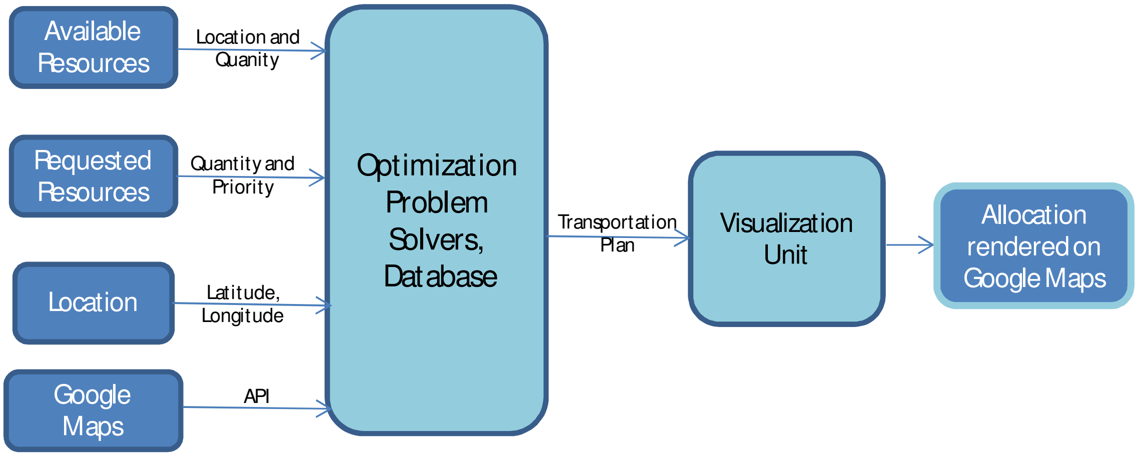

Figure 3.1 Emergency resource allocation architecture

3.3. Implementation

A block diagram showing implementation details is shown in Figure 3.2. Development of web user interface and design of MySQL database is done as part of this thesis. Mr. Russell Kondaveti has formulated and implemented the optimization problem discussed in Appendix B.1

1. User Interface (UI): The UI takes input from the Incident Commanders and renders output on Google Maps. The UI also enables to add and delete resource depots. It is designed using HTML pages with JavaScript.
2. PHP Hypertext Preprocessor (PHP) server: A server implemented in PHP is used to interface with (MySQL) database and MATLAB optimization solver.
3. MySQL database: MySQL databases are used to store details about resource depots, and available number of resources at each depot.
4. MATLAB optimization solver: MATLAB optimization solver is used to solve the optimization problem in Appendix B.1.

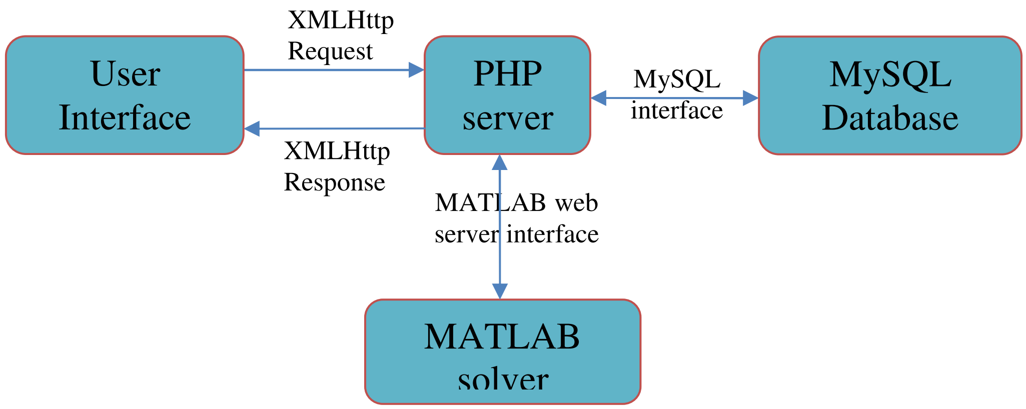

Figure 3.2. Implementation of emergency resource allocation system

3.4 Hypothetical Disaster Scenario

In this section, a hypothetical disaster scenario is described and the emergency resource allocation model is applied to the system. Assume that there are three emergency sites and three EMS depots. For simplicity, let us assume that all emergency sites require Type 1 Advanced Life Support (ALS), leading to competition for this resource.

Table 3.2 represents the estimated time taken to travel from EMS locations to emergency sites. This information is obtained by finding the time taken to travel between the location of emergency sites and EMS locations using Google Maps.

Resource Depot	Emergency site 1	Emergency site 2	Emergency site 3
EMS 1	10	15	10
EMS 2	5	9	8
EMS 3	12	10	6

Table 3.2 Transport time matrix

Table 3.3 represents the available resource matrix at each EMS location. This information is obtained from the available resources database. Table 3.4 represents the demand matrix. This matrix is obtained from the Incident Commander at each emergency site or from the resource managers. Table 3.5 represents the output allocation of resources to various emergency sites from EMS centers. It represents how much of a resource should be moved from each EMS center to emergency sites. MATLAB's optimization toolbox is used to solve the problem.

Resource Depot	Available number of ALS-Type1 ambulances
EMS 1	15
EMS 2	10
EMS 3	8

Table 3.3 Resource matrix

	Resource Demand	Resource Priority
Emergency site 1	15	5
Emergency site 2	5	7
Emergency site 3	13	6

Table 3.4 Demand matrix

Resource Depot	Emergency site 1	Emergency site 2	Emergency site 3
EMS 1	5	0	10
EMS 2	10	0	0
EMS 3	0	5	3

Table 3.5 Resource allocation matrix

Incident commanders can override the values in the resource allocation matrix and recompute the resource allocation matrix. During re-computation, overridden values are considered as additional constraints to the existing optimization problem. As part of this scenario, assume that three decision variables in the resource allocation matrix are overridden one after another by the Incident Commander as given below:

1. Allocate 2 ambulances from EMS-3 to Emergency Site 1.

2. Allocate 3 ambulances from EMS-1 to Emergency Site 2.

3. Allocate 3 ambulances from EMS-2 to Emergency Site 3

Table 3.6 shows the resource allocation matrix that is recomputed after all the three decision variables are overridden.

Resource Depot	Emergency site 1	Emergency site 2	Emergency site 3
EMS 1	6	3	6
EMS 2	7	0	3
EMS 3	2	2	4

Table 3.6 Resource allocation matrix with constraints

Table 3.7 shows the value of objective function in optimization problem as values are overridden and constraints are added. Value of objective function is obtained from the log file created by MATLAB when the optimization problem is solved.

Number of Constraints	Value of Objective function $Min\left(\sum_{i\in S}\sum_{j\in D} p_j t_{ij}\delta_{ij}(x_{ij})\right)$
0	2108
1	2196
2	2244
3	2358

Table 3.7 Values of objective function with constraints

Table 3.8 shows the time taken[3] by MATLAB optimization toolbox to execute the optimization problem (Appendix B.1) for different combinations of depots and emergency sites. Table 3.8 shows that time taken to obtain optimal allocation of resources increases as the number of decision variables increase.

[3] Time taken to execute the optimization problem is calculated using ‘tic’ and ‘toc’ functions of MATLB.

Number of Depots	Number of Emergency Sites	Number of Decision variables	Time taken (in secs)
3	3	9	2.1
7	3	21	2.5
7	7	49	7.6
9	8	72	16.8
10	10	100	98.7

Table 3.8 Time taken to execute optimization problem

CHAPTER 4

PATIENT DISPATCH SYSTEM

4.1 Literature Review

The AHRQ Hospital surge model [9] estimates the medical resources that will be required to serve a given number of victims for ten different types of mass destruction attacks (e.g. nuclear, biological, chemical and radiological), and calculates the arrival patterns of patients at the hospitals. This model assumes that each hospital has an infinite capacity. Our system deals with the allocation of victims to various hospitals based on the availability of medical resources in the hospitals.

AHRQ's mass evacuation transportation model [10] estimates the time taken by the transportation resources to move patients/victims from one facility to another before a mass casualty incident. It takes the transportation resource types like ambulances, percentage of patients who have to be transported in a given transportation resource and capacities of evacuating and receiving facilities as inputs. It estimates the total time taken to evacuate all the patients and the number of round trips taken per vehicle. The mass evacuation model calculates total evacuation time of all facilities per vehicle type whereas in our proposed model we calculate the number of patients and the estimated arrival time at each facility. Victim evacuation is not based on priority needs in the mass evacuation model.

The Department of Defense (DoD) uses a system called TRAC2ES [11] to track and regulate patients. It notifies Federal Coordinating Centers (FCC) about arriving patients. Allocation of patients is done by regulators at FCCs who determine who should be moved to where. There is no decision support in TRAC2ES although the hospital dispatch system can efficiently allocate patients to hospitals.

To meet the guidelines specified in [18], the following requirements should be met by a patient dispatch system: 1. prioritize victim evacuation based on the medical needs, 2. include and integrate multiple emergency locations with patients into the system, 3. easy-to-use web-based user interface that can be viewed from any location for better coordination. A transportation problem (similar to emergency resource allocation [1] [2]) is formulated as given in Appendix B.2, which minimizes the dispatch time for critical victims to emergency shelters and hospitals while considering the following: 1. The demand at each site in terms of medical facilities required by the victims and the associated priorities, 2. Location of emergency sites and hospitals, 3. Available hospital resources like available beds at each hospital.

4.2 Architecture

The architecture for the patient dispatch system is shown in Figure.4.1

a. Real Time Inputs: Inputs include the disaster location, the number of victims and acuity level of each victim. Inputs like location can be given directly on the map. Inputs about victims and their acuity level are obtained from systems like e-triage or DIORAMA.

b. Available Resources Database: A resource database is a database of hospital resources like available free beds. This information can be known from CMED (Centralized Medical Emergency Director) or from the HAvBED (National Hospital Available Beds for Emergencies). A database similar to these systems is assumed to be available. Users can also update the database through a web interface.

c. Decision Support System Optimization Formulation and Solvers: MATLAB optimization toolbox has been used to solve the optimization problem as an integer programming problem. The output of the solver is a transportation plan that includes the number and kind of patients allocated from each emergency site to the hospital.

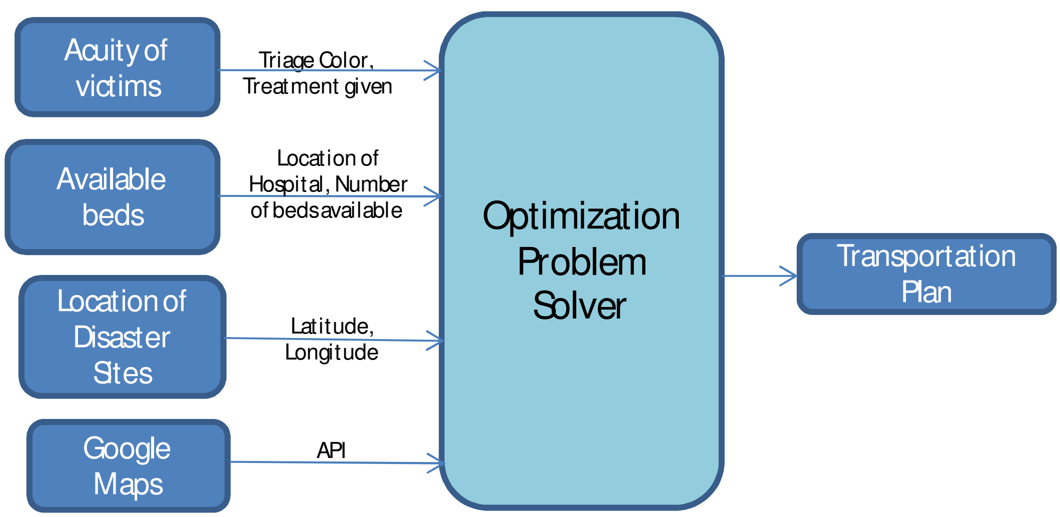

Figure 4.1 Patient dispatch system

4.3 Implementation

Implementation of the patient dispatch system is similar to the implementation of emergency resource allocation (Section 3.3). Web server user interface, MySQL database design, optimization problem formulation (discussed in Appendix B.2) and implementation (in MATLAB) are done as part of this thesis. The difference lies in the following two components.

1. User Interface (UI) takes input from the Incident Commanders and renders output on Google Maps. The UI also allows users to add, and delete hospitals, along with being able to modify the available number of beds at each hospital. It is designed using HTML pages with JavaScript.
2. MySQL database is used to store details about location of hospitals and available number of beds at each hospital.

4.4 Hypothetical Disaster Scenario

In this section, a hypothetical disaster scenario is described and the patient dispatch model is applied. Assume that there are three emergency sites and six hospitals in Western Massachusetts area. Table 4.1 represents the estimated time taken to travel from hospitals to emergency sites. This information is obtained by finding the time taken to travel between the location of emergency sites and hospitals using Google Maps.

Hospital	Emergency site 1	Emergency site 2	Emergency site 3
Hospital-1	29	6	34
Hospital-2	31	13	28
Hospital-3	21	27	33
Hospital-4	26	28	9
Hospital-5	22	27	34
Hospital-6	37	35	28

Table 4.1 Transport time matrix (in mins)

Table 4.2 represents the available beds at each hospital for each acuity level. This information is obtained from the available beds database. Table 4.3 represents the victims with different acuity levels at each emergency site. This matrix is obtained from systems like E-triage system described in Section 2. Table 4.4 represents the output allocation of victims from emergency sites to hospitals. MATLAB's optimization toolbox is used to solve the problem described in Appendix B.2.

Hospital	Red	Yellow	Green
Hospital 1	4	5	6
Hospital 2	5	4	2
Hospital 3	5	4	5
Hospital 4	6	3	4
Hospital 5	4	3	4
Hospital 6	4	2	8

Table 4.2 Available bed matrix

	Red Victims	Yellow Victims	Green Victims
Emergency site 1	8	7	9
Emergency site 2	9	6	8
Emergency site 3	8	5	11

Table 4.3 Victims at each emergency site

Hospital	Emergency site 1			Emergency site 2			Emergency site 3		
	Red	Yellow	Green	Red	Yellow	Green	Red	Yellow	Green
Hospital 1	0	0	0	4	5	6	0	0	0
Hospital 2	0	0	0	5	1	2	0	2	0
Hospital 3	5	4	5	0	0	0	0	0	0
Hospital 4	0	0	0	0	0	0	6	3	4
Hospital 5	3	3	4	0	0	0	0	0	0
Hospital 6	0	0	0	0	0	0	2	0	7

Table 4.4 Victim allocation matrix

CHAPTER 5

EMERGENCY RESOURCE PLANNING TOOL

5.1 Literature Review

A highway emergency dispatch system [12] is modeled considering response time as the decision making variable. An optimization problem is formulated considering travel times, weights and delay in response time. References [13] – [16] provide various decision support system frameworks for emergency resource allocation. They are models proposed to implement a decision support system for emergencies. The severity of traffic incidents on a highway is decided by traffic flows pattern in [17]. A resource planning tool should give an idea about how the additional resources or moving depots from one location to another change the response times of the emergencies in a region. Our web-based tool allows resource managers to know how the allocation of new resources will change the response times over a region for a particular scale of incident.

5.2 Architecture

The web-based planning tool takes inputs like location of the emergency, demand at the location and a database with available resources at each depot. A block diagram of the resource planning tool is shown in Figure 5.1. The web-based tool is designed such that the inputs (resources required at an emergency site) and database entries (available resources at each depot, adding a new depot, removing a depot) can be changed. This will help the resource managers to analyze how the response times vary in the following example scenarios:

1. Adding a new resource depot
2. Moving resources from one depot to another

3. Adding new resources at a depot
4. Moving a depot from one location to another
5. Removing a depot
6. Removing resources from a depot

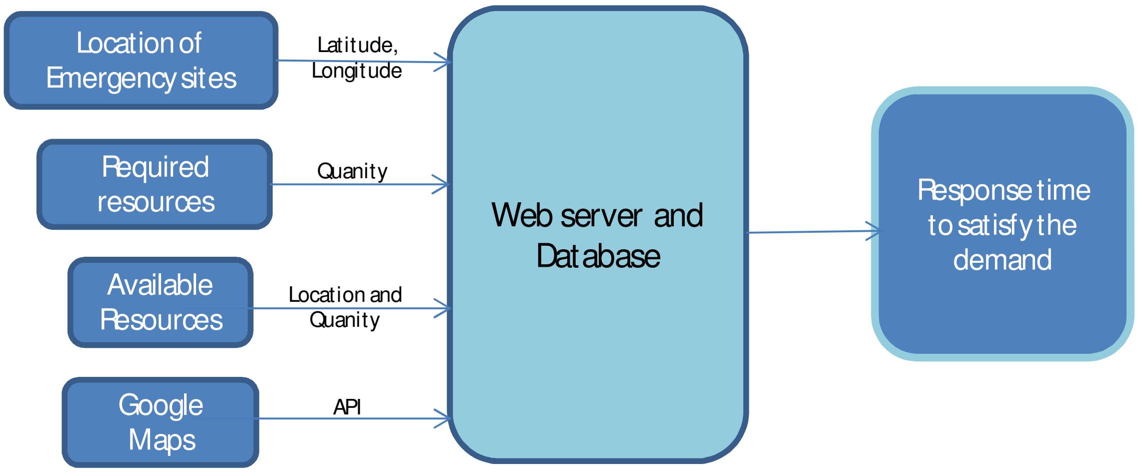

Figure 5.1 Resource planning tool

The web-based tool developed can also suggest an optimal distribution of the new resources, to resource depots to obtain minimum average response time across a selected region. This is done by executing the tool with an automated search space of resources. For example, consider that 100 new resources are available to be deployed across 3 depots. Possible allocations could be [(25,25,50), (50,25,25), (33,33,34) ..Etc]. For each possible allocation, the resource allocation tool calculates the average response time across a selected region for a given demand. The allocation with minimum average response time will be suggested as the optimal allocation of new resources to the depots.

5.3 Implementation

Software implementation details of the resource planning system are same as discussed in Section 2.3 with changes in following components. Web server user interface, implementation of optimization problem discussed in Appendix B.3 and database design are done as part of this thesis.

1. The web User Interface (UI) provides an interface to modify the number of resources at a depot, to remove depot and to add new resource depots. It also allows selection of the locations of potential emergency sites. Web pages are designed using HTML, JavaScript and Google Maps API.
2. MySQL database is used to store details about resource depot information like number of available resources and location of each depot.

5.4 Hypothetical Scenario

Emergency planning tool can be applied to a section of a road or a selected region. Response times are calculated at equally spaced points along the selected region given the demand at each point, available resources at each resource depot and the location of each depot. In this hypothetical scenario, ambulances are considered as resources. Available number of ambulances at each depot is given in Table 5.1.

Ambulance Depot	Available Ambulances
Ambulance Depot-1	15
Ambulance Depot-2	10
Ambulance Depot-3	8
Ambulance Depot-4	10
Ambulance Depot-5	8
Ambulance Depot-6	8

Table 5.1 Available ambulances

The requested demand at each point along the path is 25 ambulances. A region is selected on Google maps and 15 equally spaced points are calculated in the selected region as shown in Figure 5.2. For each point, response times are calculated such that ambulances are allocated in least possible time as specified in Appendix. B.3. Response time to satisfy all the demand at each point is tabulated in Table 5.2

Point	Response Time (in mins)
1	29
2	27
3	26
4	22
5	22
6	28
7	27
8	25
9	24
10	23
11	29
12	26
13	27
14	23
15	23

Table 5.2 Response times

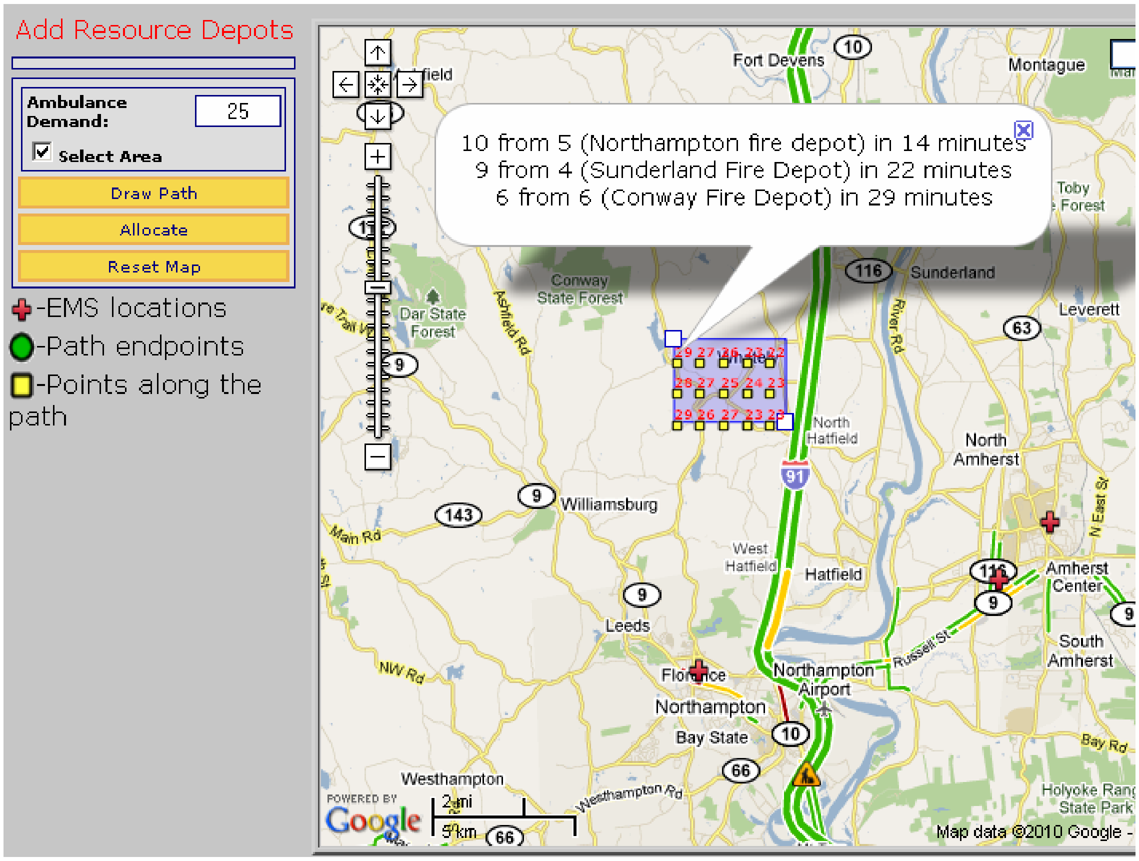

Figure 5.2 Sample output of resource planning tool

Consider that 25 new ambulances are available to be deployed across 6 depots. The resource allocation tool can suggest the optimal distribution of these new ambulances such that the unsatisfied demand over time is minimized for points in the selected region. This is done by trying different combinations of allocations. Table 5.3 shows several optimal allocation strategies for different numbers of combinations.

Ambulance Depot	Number of Combinations			
	100	200	500	1000
1	5	4	4	4
2	4	4	4	4
3	4	4	4	4
4	6	6	7	7
5	3	4	3	3
6	3	3	3	3

Table 5.3 Optimal distribution of ambulances

CHAPTER 6

CONCLUSIONS

The proposed e-triage system proves to be useful in mass casualty victim triage mainly because of scalability and low cost. This system also provides disaster scene overview to remote Incident Commanders. The scene overview includes the number of victims, their severity level and triage information. This information helps in requesting emergency resources. This system can also help in rescuing trapped first responders. The input throughput of this kind of system [4] is comparable with that of paper triage tags. This is the first hybrid system to include GPS and passive RFID for a mass casualty victim triage system. The disadvantages of this approach include: the location information from GPS may not be accurate in case the incident occurs near high-rise buildings, and this system cannot track first responders indoors.

The web-based resource allocation system allocates resources to the emergency sites and renders the output onto Google Maps. This model takes into account multiple emergency sites, multiple resource depot and the priorities of resources. This model also ensures that emergency resources are directed to emergency sites where they are needed the most. The information about the estimated arrival time of resources to emergency sites will be helpful to the Incident Commanders for better coordination of resources at emergency sites. Thus, this model can assist Incident Commanders in making decisions about allocating emergency resources like ambulances from multiple depots to multiple emergency sites.

The patient dispatch system assigns patients from multiple emergency sites to hospitals based on their acuity levels. This model ensures that the highest priority victims get to nearest hospitals with available medical facilities. Estimated arrival time of patients to hospitals helps hospitals to better prepare for incoming patients. Thus, this model assists Incident Commanders in decision making of patient allocation. Integration of e-triage system, emergency resource allocation system and patient dispatch system provides a comprehensive emergency response system with decision making capabilities in multiple complex emergency incidents.

The web based resource planning tool is designed such that the inputs (resources required at an emergency site and location of emergency sites) and database entries (available resources at each depot, adding new depot, removing a depot) can be changed. This allows resource managers to compare different scenarios. Analyzing response times of different scenarios will help communities in requesting additional resources. This tool can also suggest optimal allocation of new resources to depots based on selected criteria. As part of future work, this resource planning tool can be automated to provide guidance on reorganizing resources and suggest locations for new depots, based on criteria like minimizing average response time over a region with a minimum threshold limit on response times.

APPENDIX A

DIORAMA

DIORAMA is a distributed information system that collects information about the severity and location of the victims. The DIORAMA system supports real-time tracking of victims and emergency responders. This information can help Incident Commanders in requesting resources and understanding the scale of the incident. The DIORAMA system is built using GPRS, RFID and data mining technologies. A GPRS connection (using cradle point) will provide communication to the internet. RFID technology will provide the location information of the victims. The hospital dispatch model under development can be integrated with the DIORAMA system.

The DIORAMA system is shown in Figure A.1 with various components

1. D-tag: D-tags are color-coded active RFID tag. They are used to replace the existing paper triage tags.
2. D-track: D-tracks consist of active RFID readers positioned at the disaster site to track the patients with active RFID tags. RFID readers interface with Wi-Fi routers through Bluetooth. Signal strengths from the RFID tags are read by the readers and sent to the server through the routers.
3. D-gateway: A D-gateway consists of a cradle point which provides GPRS connections to D-tracks for internet connectivity.
4. Paramedic Device: A paramedic carries a helmet of passive RFID tags and a PDA is used to triage the victims.

5. Application Server: The application server acts an information collection, processing and storage unit. The information about the RSSI values from the tags is collected and processed by a tri-lateration algorithm at the server. The server also hosts a web-based application that shows victims on the Google maps.

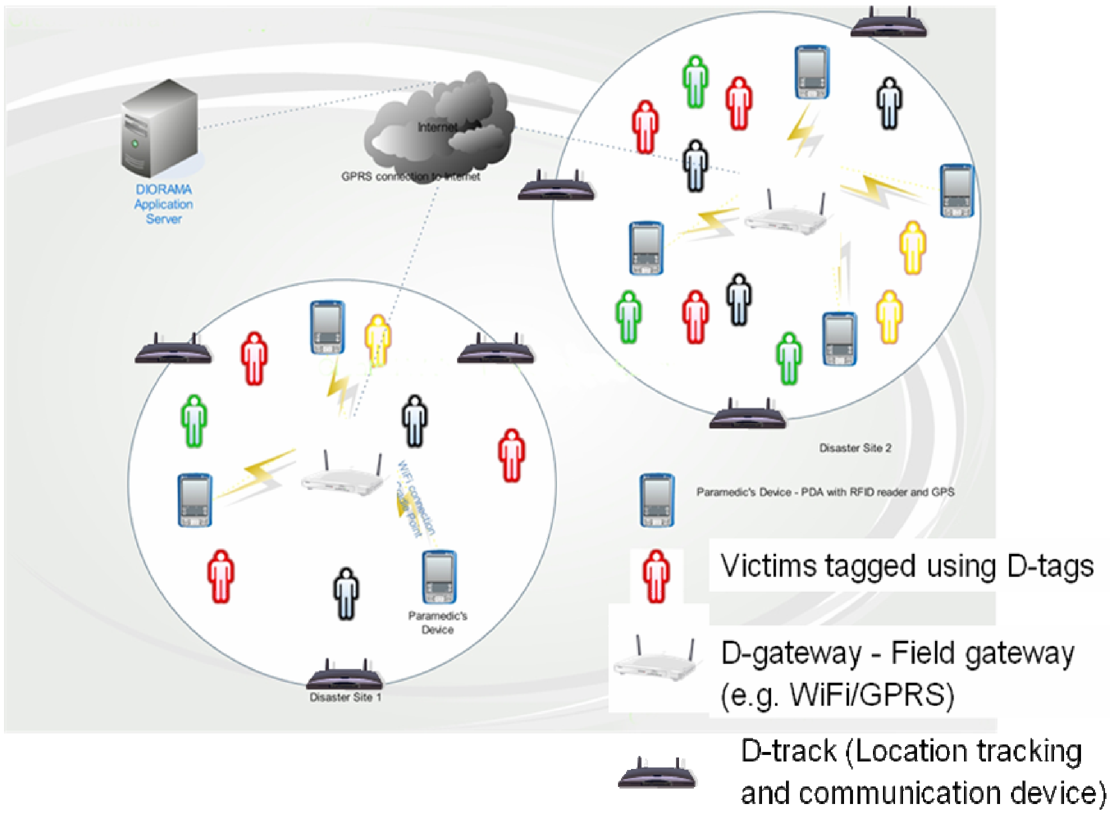

Figure A.1 – DIORAMA system architecture

APPENDIX B

OPTIMIZATION PROBLEM

In optimization problems mentioned below, objective functions are non-linear and constraints are linear. FMINCONSET library of MATLAB's optimization toolbox is used to solve these optimization problems.

B.1 Emergency Resource Allocation

This optimization problem is described in [1]. In the first phase of resource allocation, the number of emergency resources that can be allocated at each cluster is determined. Risk is the fraction of unsatisfied demands. The objective is to minimize the overall risk by allocating the constrained resources. The constraints in this problem are the available number of resources. Mathematically the problem can be formulated as,

$$Minimize : \sum_{\forall j} \sum_{\forall i} s_{ij}(1 - \frac{x_{ij}}{d_{ij}})$$

Subject to $\Sigma_j x_{ij} \leq r_i$ *for all i*

$x_{ij} \leq d_{ij}$ *for all i,j*

$x_{ij} \geq 0$ *for all i,j and Integer*

Where, *n: Number of Victims; c: Number of clusters; m: Number of resource types;*

$r_{i:}$ *Available level of Resource type I;*

x_{ij}*: Number of resources of type i allocated to emergency site j;*

s_{ij}*: Priority Index of the emergency site j with respect to resource of type I*

$d_{ij:}$ *Total number of resources of type i needed by emergency site j*

The output of this phase is the optimal resource allocation table which provides the optimal number of emergency response resources can be deployed at each emergency site.

In the second phase, the nearest resource depot that can cater to the demands of the emergency sites is found and resources are dispatched to that site. This is also an integer programming problem where the objective function is to minimize the cost over dispatching the resources. Mathematically, the dispatch problem can be formulated as,

$$Minimize : \sum_{\forall i} \sum_{\forall j} \sum_{\forall k} c_{ijk} * y_{ijk}$$

Subject to $\Sigma_k\, y_{ijk} = x_{ij}$ *for all i, j*

$\Sigma_j\, y_{ijk} \leq r_{ik}$ *for all i,k*

Where, n: Number of Victims; c: Number of emergency sites; m: Number of resource types; x_{ij}*: Number of resources of type i allocated to emergency site j;* r_{ik}*: Number of resources of type i located at warehouse k;w: number of resource depots;*

c_{ijk}*: cost associated with dispatching resources of type i to cluster j from resource location k;*

y_{ijk}*: Total number of resources of type i dispatched to cluster j from resource location k*

B.2 Patient Dispatch System

The patient dispatch system should allocate victims based on their acuity level to nearest hospitals with available beds. The optimization problem is solved per acuity level (Red, Yellow and Green). Notations used in the optimization problem for patient dispatch system is given below.

Decision Variable:

x_{ij} - Number of victims to be allocated from Emergency site *i* to Hospital *j*

Input Variables:

S = {S_1, S_2…} denotes the set of Hospitals;

D = {D_1, D_2…} denotes the set of Emergency Sites;

d_i - Number of victims of a particular acuity level at each Emergency Site *i*

a_j - Number of beds available at hospital *j*. We assume that there are sufficient beds at hospitals to serve victims at all emergency sites, i.e.

$$\sum_{j \in S} a_j \geq \sum_{i \in D} d_i$$

t_{ij} - Transfer time from emergency site *i* to hospital *j*

Objective Function: Minimize the total transfer time of victims to hospitals.

$$Min\left(\sum_{i \in D} \sum_{j \in S} t_{ij} \delta_{ij}(x_{ij})\right)$$

$$\delta(x) = \begin{cases} 1 & for \quad x > 0 \\ 0 & for \quad x = 0 \end{cases}$$

Constraints:

1. Victims allocated to hospitals should be a positive integer.

$$x_{ij} \geq 0 \qquad \forall i \in S, \forall j \in D$$

2. Allocate all victims at each emergency site to the hospitals

$$\sum_{i \in S} x_{ij} = d_j \qquad \forall j \in D$$

B.3 Emergency Resource Planning

Algorithm implemented for emergency resource planning is a heuristic to satisfy all demand at an emergency site from nearest resource depots. The optimization problem mentioned below is solved per emergency site. Notations used in optimization problem formulation are mentioned below:

D – Set of Resource depots

t_j *– Time taken to travel from emergency site to depot j*

d - Demand at emergency site

x_j *– Resources allocated from depot j to the emergency site*

a_j *– Available number of resources at depot j*

Objective Function: The objective function is to minimize the time taken to allocate resources to the emergency site.

$$Min \sum_j t_j * \delta(x_j) \qquad \forall j \in D$$

$$\delta(x_j) = \begin{cases} 1 \quad for \quad x_j > 0 \\ 0 \quad for \quad x_j = 0 \end{cases}$$

Constraints:

1. Resources allocated to a emergency site satisfy the demand at that emergency site

$$\sum_j x_j = d \quad \forall j \in D$$

2. Resources allocated from a depot are less than the available number of resources at that depot

$$x_j \le a_j \quad \forall j \in D$$

3. Resources allocated are non-negative

$$x_j \ge 0 \quad \forall j \in D$$

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