UNIVERSITY OF NAIROBI

School of Computing and Informatics

DECISION AID MODEL FOR DISASTER MANAGEMENT & RESOURCE ALLOCATION

By

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ABSTRACT

Governments and humanitarian organizations are taxed with complex disaster responses with little or no forecasts let alone reliable field information. Decision support systems come in handy when faced with the task of response of such complex tasks. The planning and management process of a disaster is quite complex with many decision makers involved and limited resources being required immediately, decision makers and victims (indirectly) can benefit from decision support tools. The current decision aid models are not dynamic such that they only focus on one type of disaster and do not take into consideration that one disaster can lead to other associated hazards. A decision process is displayed in this paper and the processes explained in brief. We came up with a prototype to illustrate how decision support would help humanitarian organizations and governments in multi-hazard disasters. The proposed solution included coming up with a model that assists humanitarian organizations and governments determine the need for opening a disaster recovery center in context of multi-hazards. The study allows significant efficiencies to be gained by taking a multi-hazards perspective during the planning process and furthermore, accounting for a risk package and not just a single type of risk but a more accurate risk assessment and finally aiding governments and humanitarian organizations in resource allocation during disasters**.**

Keywords: Multi-hazard events, long-term planning, decision support systems, disaster operations management, disaster recovery center.

DECLARATION

This research project is my original work and has not been presented for a degree or any other award in any other university.

Student Signature: .... **Date:** ....

Name: .... **Registration Number:**

This project report has been submitted as a partial fulfillment of the requirements for award of the degree of Master of Science in Distributed Computing Technology with my approval as the University supervisor

Supervisor Signature:....................... **Date:** ....

Name: Professor Okelo-Odongo

DEDICATION

This work is dedicated to my parents Samuel and Mary Lagat who's constant support, motivation and encouragement have enabled me to get this far. My siblings Jebet Lagat and Stephen Kimeli who have been a driving force to ensure I set a right pace for them. To my grandmother, Leah Kabon who believes so much in me, she believed that I could accomplish and become the best and no obstacle is too high for me to go over. My friends Grace Waiharo, Mercy Murugi and Karanja Mwangi who supported me when family, work and education overwhelming. They made me believe in myself even when giving up seemed like a better option.

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For the panel Members, Dr Miriti, Dr Chepken, Mr. Mburu and Prof. Okelo Odongo, this work would not have been completed were it not for your constructive criticism during and after defence. This provided useful inputs which were incorporated in improving and polishing up the research work.

Lastly, special thanks to my family and friends for their belief that it was indeed possible to finish the project. I could not have gotten this far without the above mentioned people and for that I am truly grateful.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The number and impact of disasters has been on the rise in the last decades, there is therefore need for the best management of consequences that accompany such disasters. This has become a topic of high relevance and a lot of research is being done in this field to avoid more than necessary loss of lives of damage to property. A disaster as defined by oxford dictionary as “A sudden accident or a natural catastrophe that causes great damage or loss of life”. They are characterized by a number of victims who requests for resources that overwhelm the available. In the recent past for instance, Kenya has experienced a number of disasters, for instance a recurrent wave of terrorist attacks, collapsing buildings, mudslides but to mention a few that have led to mass casualties (Panapress, 2014) incidents such as the Westgate in Nairobi terrorist attack where 62 civilians from thirteen countries died (Okari, 2014), recent Garissa terrorist attack killing 147 students (Justice, 2015). According to a report from World Bank (World Bank 2010), the number of disasters experienced in sub-Saharan Africa alone have been more than a thousand needless to mention the number of lives lost. This has been attributed to the vulnerability of its population, their economy and their often low capacities to cope with natural hazards. A report by UNISDR states that “In Africa alone, from 1990 to 2012, an average of 152 disasters was recorded per year, the majority triggered by floods and storms. In 2014, over 6.8 million Africans were affected directly by a total of 114 recorded disasters” (Anon n.d.). In other parts of the world for instance, Japan’s earthquake and subsequent tsunami that occurred in 2010 killed more than 15,000 people, floods in Thailand claimed more than 800 people and is said to have been the costliest disaster in the recent past not forgetting the devastating earthquakes in Haiti and Chile (GlobalPost 2011). The common characteristic in the above scenarios is the large number of victims and additional hazards that impact the affected areas. There are also incidences where the theft or competition of remaining available resources occurs hence which posses as an additional hazard. There are also cases of disease outbreaks and in some gas or oil leaks (ABS-CBN News, 2013).

The intensity and frequency of such disasters bring about the need to have better decision support systems to help manage the complexity and cost of response to such disasters given resource constraints. These systems can come a long way in providing value by (i) help provide support in order to aid in helping save lives and reduce suffering (ii) helping in management of scarce resource efficiently, and (iii) cater for multi-hazard disasters more efficiently.

Various decision support systems have been introduced in the disaster management field due to the need of management of few resources but large demand for the same. Most of these do not consider the fact a disaster can cause various related hazards. Decision support system should not be interested only in solving only one type of event as this is rarely the case. By following the multi-hazard context, resource allocation can be made more efficient bringing about a significant help in recovery process Selva et al., 2013; Marzocchi et al., 2012;).

The objective of this research paper therefore is to come up with a decision support system, with a resource-allocation model in its model base that focuses on multi-hazards scenario.

1.2 Problem Statement

It is both difficult and prepare and respond to disasters for govenments and Humanitarian organizations when disaster strikes decision making is far more difficult. Governments and humanitarian organizations are taxed with complex disaster responses with little or no forecastso let alone reliable field information. Decision support systems come in handy when faced with the task of response of such complex tasks. Governments and humanitarian organizations can benefit from decision aid models by improving forecasts by facilitating data collection and helping in resource allocation during disaster preparedness and response. They can also facilitate information sharing and disbursement between concerned parties which is very important in such cases when disaster strikes.

There have been a number of decision support models within the disaster management field, however most of them focus only on single risk in mind without providing decision support system that help the govenement or humanitarian organizations manage the available resources. There are various decision support systems that have been developed for disaster management most of these developed with a single risk in mind (Papamichail et al., 2005). Not takind in to consideration that an intial impact of disaster can trickle other associated hazards. Therefore by taking a multi-hazard viewpoint, resource allocation can be done more efficiently thereby saving many lives and property.

By taking multihazard point of view significant efficiencies can be gained providing a more accurate risk assesment (Selva et al., 2013; Marzocchi et al., 2012; Cox, 2009). This research solves this problem by introducing a model that aids governments and humanitarian organizations make decisions efficiently given the available recources at the same time considering multiple interelated hazards.

1.3 Objectives

1. Identify gaps in previous research and present model for decision aid models.
2. Develop a decision aid model for disaster management and resource allocation
3. Implement a prototype to illustrate resource allocation

1.4 Research Questions

This research paper addresses the following research questions:

1. How can disaster response situations be modeled for multi-hazard scenarios?
2. How can resource allocation in disaster management be solved efficiently for governments and humanitarian organizations?
3. To what extent can solutions obtained by proposed methods improve current best practice behavior?

1.5 Justification

The time required to fully understand an unfamiliar situation would take quite some time. This research focuses mainly on a methodology to fully utilize available resources and given multi hazard scenarios. This will therefore be very important in the recovery phase which is the final stage in emergency management. This will be done by analyzing the dynamics that occur during a multi hazard scenario hence providing more efficient disaster relief operations

1.6 Scope

The main research problem that this research project tried to solve was lack of a decision support tool to be used by governements and humanitarian organizations to aid in resource allocation in multi-hazard scenarios. Any other factor apart from this factor will not be monitored in the architecture.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

The difference in economic losses from disasters in the period 1950 – 1959 and 1990-1999 have steadily increased from €150 billionto about €375 (Munich RE, 2000). There is also ample evidence that there have been loss of lives, livelihoods ans daily lives interruption all this affecting people directly and indirectly hence deepening poverty and making lives more difficult (Arnald et al., 2006; Daniell et al., 2011; Hoyois and Guha-Sapir, 2003; World Bank, 2010). Most regions of the world are affected by multiple hazards leading to damage to infrastructure, business interuptions and loss of lives.

Intergration of large volumes of data and sophisticated analysis together with risk quantification are the existing risk assesment methods. The key question is why our scientific knowledge on multi-risk is increasing, could it mean that are losses from natural and man-made disasters continuing to grow (White et al., 2001)? There are many reasons one of them being the fact that the value of assets and resources spent on them are exposed to risk, there is therefore need to understand the various causes as this will help in reduction of losses in the future.

To be able to understand this question, there is need to examine also the frameworks employed in the field of risk management, as well as the interactions between science and practice in terms of knowledge transfer and the applicability of results (Kappes et al. (2011). In order to accomplish disaster risk reduction, there is need to communicate appropriately and trasfer knowledge on risk to various stakeholders and anyone involved in the decision making process. Decision support and multi-risk assessment tools can come along way in helping decision makers and provide them with information on mitigation measures. These will help decsion makers have a better perspective in terms of the probabilities of hazards and their impacts.

Disaster mangement is complex and challenging, this has brought about a lot of literature in disaster and emergency management. Given that limited resources that always accompany disasters there is need for decision making support tools in allocating resources in order to come out with the best outcome in this case when in comes to multi-hazard disasters.

2.2 Hazards and disasters

"A hazard is a threatening event or probability of occurrence of a potentially damaging phenomenon within a given time period and area". It can be both natural or human-made.

- Natural: naturally occurring physical phenomena caused either by rapid or slow onset events which can be geophysical, hydrological, climatological, meteorological or biological (earthquakes, landslides, tsunamis, volcanic activity, avalanches, floods, extreme temperatures, droughts, wildfires, cyclones, storm/wave surges, disease epidemics, animal plagues, etc.).
- Human-made or technological: events caused by humans and which occur in (or close to) human settlements, such as complex emergencies/conflicts, famine, displaced populations, industrial accidents (toxic dumps or radioactive escapes), catastrophic transport accidents, etc.

An ***emergency*** is a situation that poses an immediate risk to health, life, property or environment. A disaster as defined by oxford dictionary as "A sudden accident or a natural catastrophe that causes great damage or loss of life". They are characterized by a number of victims who requests for resources that overwhelm the available.

2.3 Disaster management and humanitarian logistics

The process of disaster response involves many stakeholders with severe time contraints and very high uncertainity. Various agencies have to collaborate in order to mitigate, prepare, respond, and recover from hazards to society.

The various agents involved in disaster response can be classified into:

- **Local level**: the first response level, which is usually addressed by local agencies, civil society organizations and civil protection. This level of emergency is not declared as a disaster.
- **National level**: when an emergency is declared a disaster the army and national civil protection, governmental organizations and NGOs are usually involved.
- **International level**: this level is arrived at when the national country is not able to respond to the disaster due to lack of enough capacity to act on the disaster this brings

foreign governments and inter-governmental organizations, international NGOs for disaster response and the United Nations Agencies.

The multiple players involved in the decision making process make it extremely difficult to manage disasters due to the complexity of tasks involved.. Humanitarian logistics are differentiated from business logistics in terms of as defined in the Humanitarian Logistics Conference, 2004 (Fritz Institute):

- Unpredictable demand in terms of timing, geographic location, type and quantity of commodity.
- Short lead time and suddenness of demand for large amounts of a wide variety of products and services.
- Lack of initial resources in terms of supply, human resources, technology, capacity and funding. Balcik and Beamon et al (2009).
- Presence of multiple decision makers that can be sometimes difficult to identify.

2.4 Phases, tasks and decisions of the disaster management cycle

A lot happens in before and after the disaster event when it comes to the actual decision making process. The decisions that need to be made immediately a terrorist attack occurs is not the same as decisions that will need to be made after or a week later.

There are three successive phases in the management of emergencies and disasters with respect to the disaster event (INAMPUDI 2011):

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.

It is important to understand the whole disaster process independent of the each other as each stage requires a different focus. The outcome of the whole process will depend on the decsion made in each stage, the preparedness phase relies critically on the prediction systems set up in the mitigation phase and the urgent decision-making of the former phase would be impossible without the previous vulnerability analysis and emergency plans developed in the latter phase.

The allocation of resources for first response operations must be taken into account when designing the mitigation policy.

Thus, the disaster management process is a continous cycle (see Fig. 2.1, as in Tomasini and vanWassenhove et al (1987),

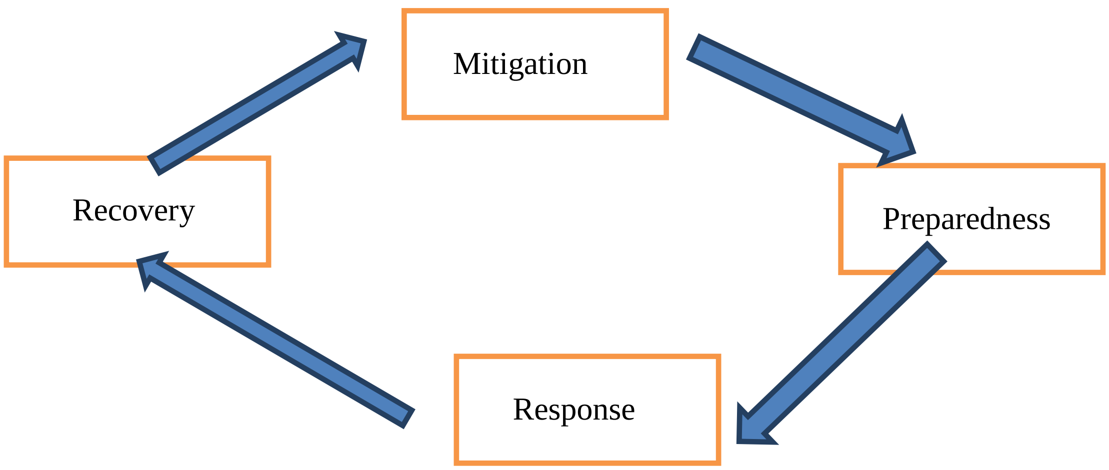

Fig. 2.1 *Phases of the disaster management cycle*

2.5 Definitions of multi-risk assessment

Risk assessment includes hazard assessment, followed by estimations of the vulnerability and values of the elements at risk (or exposure), all leading to the computation of risk as a function of hazard, vulnerability and exposure (Varnes, 1984). The term "natural hazard" refers to the "natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage" (UNISDR, 2009).

Risk is defined as "expected losses of lives, persons injured, property damages and economic activities disrupted due to a particular hazard for a given area and reference period" (WMO, 1999). Another definition of risk is "the combination of the probability of an event and its negative consequences" (UNISDR, 2009). In any case, a definition of risk must also include the interaction of hazards and the vulnerability of the affected area, especially the built environment. Definitions developed by the European Commission extend the previous definitions by incorporating the terms "exposure" and "vulnerability" (COM, 2010a). This foresees that an event of the same magnitude can have a different impact, dependent upon the vulnerability and exposure of a given population and the associated elements, thus also involving the need to take into consideration preparedness and preventive measures.

The definition of risk is also closely connected with the definition of uncertainty, as the term “probability” itself implies uncertainties. Risk can also be understood as “the effects of uncertainty on objectives” which appear as a “combination of the consequences of an event and the associated likelihood of occurrence” (ISO Guide 73:2009). It is therefore important to understand such uncertainties when it comes to the development of decision-making models and tools for the purposes of civil protection.The purpose of multi-risk assessment is therefore to establish a ranking of different types of risk, taking into account possible conjoint and cascade effects. Multi-risk assessment is a relatively new field, until now developed only partially by experts with different backgrounds such as engineering, statistics or various fields of geosciences. Currently, there is no clear definition of “multi-risk”, neither in science, nor in practice (COM, 2010a; Kappes et al., 2012). The only definition that exists concerns the requirements for multi-risk, which needs to consider multiple hazards and multiple vulnerabilities (Carpignano et al.; Di Mauro et al., 2006; Marzocchi et al., 2012; Selva, 2013).

There are essentially two ways to approach multi-risk. The first considers the different types of hazards and vulnerabilities of a region and combines the results of various single risk layers into a multi-risk concept (Grünthal et al., 2006). This approach provides an overview of multiple risks, but neglects the interactions between the hazards and vulnerability. The second one considers the risk arising from multiple hazardous sources and multiple vulnerable elements coinciding in time and space (Di Mauro et al., 2006). In these cases, we speak here about conjoint and cascading events. Conjoint events are when a series of parallel adverse events are generated by different sources, for example a windstorm occurring at the same time as an earthquake (Di Mauro et al., 2006). Cascading events on the other hand are when an initial event (located inside or outside an area) triggers a subsequent event or series of events, for example an earthquake that then triggers landslides or tsunamis (Marzocchi et al., 2012).

2.6 Related Work

Currently, various decision models for multi-hazard and multi-risk assessment are being developed, but to be useful in disaster management, these models must respond to the requirements and expectations of disaster and emergency humanitarian logistics, thus helping in the decision aid processes appearing when trying to respond to the consequences. The principle aim of such models should be to provide stakeholders with a set of scenarios or alternatives to help them make or select the most appropriate decision or action with availababe resources. In risk assessment, decision models display different risks with respect to their probability and frequency, as well as to their possible outcomes.

Even though the majority of decision models were developed to assess-single types of risks and hazards, some models are available for multi-risk mapping of natural hazards and their impact assessment. The review presented below in this work to uncertainty in decision aid models for disaster management and resource allocation show the extent of these efforts.

2.6.1 Belardo et al (1984) Model

Belardo et al (1984), deals with the problem of locating oil spill response equipment with a partial set covering model, including both assessments of the relative probability of occurrence and the impact after occurrence of various spill types by means of a multiple objective approach. The purpose is to attain the best overall protection with existing re-sources while minimizing the risk of being unprepared for politically and environmentally sensitive events.

Limitations of Belardo et at (1984) Model

Belardo et at (1984) model which relates to locating oil spill response aims at attaining the best overall protection with existing resources while minimizing the risk of being unprepared for politically and environmentally sensitive events. However the framework does not incorporate an approach for extending the model to consider multiple interrelated hazards hence unsuitable for scenarios that require multi-hazard viewpoint with respect to disaster response and recovery.

2.6.2 Huang and Fan (2007) Model

Huang and Fan et al (2007), compare different modeling approaches for the problem of allocating multiple emergency service resources to protect critical transportation infrastructures. The objective of the paper is to test various risk preferences in decision making under uncertain service availability and accessibility in case of disaster. A stochastic and a robust formulation for the maximum coverage problem are proposed. The models are tested on realistic data, and a sensitivity analysis is conducted to show the robustness of the solutions found to changes in the models' parameters. An extension of this work can be found in Huang and Fan (2011). the model is reformulated as a parametric linear programming model. Finally, the devised methodology is tested on real data collected from NATO-EADRCC reports (publicly available).

Limitations of Huang and Fan et al (2007)Model

Huang and Fan et al (2007), model provides a solution where various risk preferences in decision making under uncertain service availability and accessibility in case of disaster are tested. Although the model provides an approach for the problem of allocating multiple emergency service resources to protect critical transportation infrastructures hence assisting in scarce resource allocation, it only has a single view point of disaster and thus not suitable for multi-hazard viewpoint with respect to disaster response and recovery.

2.6.3 Sheu et at (2010) Model

Sheu et at (2010), presents a dynamic relief-demand management model in large-scale natural disasters. Uncertainty is driven by the number of disaster affected people due to im-perfect information. In fact, the relief demander is usually not the same as the information provider. Also, information sources are diverse and hard to be promptly verified. Therefore, the required information for logistics management in large scale events is desired to be aggregated in urban areas. The methodology proposed is divided in three steps: data aggregation in urban areas, area severity classification according to the expected number of fatalities, and multi-criteria decision making to rank the order of priority.

The time frame considered is the 72 hours after the disaster. During this phase the most critical activities are search and rescue of entrapped civilians. The case study replicates the massive Chichi earthquake (7.3 on the Richter scale), which occurred in central Taiwan on 1999 (2455 deaths in total, more than 8000 injured, and the destruction of 38,935 homes). The results where compared with the real severity level of 13 urban areas through the consideration of 9 possible scenarios. A previous and less sophisticated version of this work can be found in Sheu (2007).

Limitations of Sheu et at (2010)Model

Sheu et al (2010)**,** model presents a dynamic relief-demand management model in large-scale natural disasters where uncertainty is driven by the number of disaster affected people due to imperfect information. The model is good in proving a mechanism for scarce resource allocation for large scale natural disaster but does not provide a mechanism that allows management of disasters not caused by natural event. Thus the model is not useful for multi-hazard viewpoint with respect to disaster response and recovery.

2.6.4 Rodriguez et al (2010) Model

Rodriguez et al (2010), design a Decision Support System (DSS) for aiding humanitarian organizations based on fuzzy logic. Such DSS, called SEDD, focuses on providing an estimation of the effects of a disaster right after a disaster strikes; i.e., when there is a lack of reliable knowledge on the real magnitude of the emergency. Given a disaster-type and the affected area, SEDD makes use of the data stored in the EM-DAT [1] database to predict the number of casualties, injured, homeless, affected, and the total damage value (in US Dollars). The little data, technological, and infrastructure requirements make SEDD particularly useful and accessible to NGOs.

In a subsequent paper, Rodriguez et al (2012), the interpretability of the results provided by SEDD is improved by including three kinds of output; i.e., numerical, interval, and class predictions. Next, in Rodriguez et al (2011), the authors compare the fuzzy DSS with classical statistical analysis tools, such as multiple linear regression, linear discriminant analysis, classification trees, and support vector machines. The conclusion of this work is that SEDD outperforms the methods above in the task of simultaneously providing an accurate and interpretable inference tool for the evaluation of the consequences of disasters.

Limitations of Rodriguez et al (2010))Model

Rodriguez et al (2010) model provides a post-disaster estimation and projection in terms of impact in relation to cost and number of people affected for optimum resource allocation. The model has the advantage of providing sufficient data for disaster aftermath for decision makers. However the model does not provide an approach for extending it to consider multiple interrelated hazards hence unsuitable for scenarios that require multi-hazard viewpoint with respect to disaster response and recovery.

2.6.5 Abkowitz et al (2012) Model

Abkowitz et al. (2012), model assessed risks from intentional attacks and natural hazards, computing a dollar value to social and economic costs, where the cost provides weighting information when making resource prioritization decisions both at the hazard and location level.

Limitations of Abkowitz et al. (2012) Model

Abkowitz et al. (2012), model which relates dollar value to social and economic costs aims at assessing risks from intentional attacks and natural hazards by cos weighting. However the model does not have significant efficiencies that are gained by taking a multi-hazards perspective during the planning process hence the model is not suitable in providing a more accurate risk assessment (Selva et al., 2013; Marzocchi et al., 2012; Cox, 2009).

2.6.6 Canto-Perello et al (2013) Model

Canto-Perello et al (2013), along developed an expert system along the same lines as Abkowitz et al. (2012) to assess risks from both intentional attacks and natural hazards on underground utilities.

Canto-Perello et al (2013), model aims at assessing risks from both intentional attacks and natural hazards on underground utilities based on an expert system.

Limitations of Canto-Perello et al. (2013) Model

The most effective resource allocation is not described by the risk ranking which is focused by the Canto-Perello model since this discourages resource allocation towards assets that may be characterized by lower risk.

2.7 Unresolved Issues In Decision Aid Model For Disaster Management and Resource Allocation

The development of a comprehensive multi-risk framework is limited by three main requirements, namely the large amount of input data required, cross-disciplinary expertise and innovative risk assessment methods. The first two points are generally solved in dedicated multi-risk projects at the national, international or private sector levels. The third point remains to be solved. As indicated by Kappes et al. (2012), "despite growing awareness of relations between hazards, still neither a uniform conceptual approach nor a generally used terminology is applied".

The recognition of this need has led to a number of different decision support systems being developed within the disaster management arena as discussed in the literature review. Most of these, however, have been developed with a single risk in mind, for example: nuclear emergencies (Papamichail et al., 2005), epidemics (Arora et al., 2010), and terrorist attacks. They do not take into consideration that the initial impact of a disaster can lead to a variety of associated hazards. By taking a multi-hazard viewpoint with respect to disaster response and recovery, there is an opportunity to allocate limited resources more effectively, particularly in the context of long-term planning for community sustainability.

Therefore significant efficiencies can be gained by taking a multi-hazards perspective during the planning process (Pollet, 2009); furthermore, accounting for a risk package and not just a single type of risk, provides a more accurate risk assessment (Selva et al., 2013; Marzocchi et al., 2012; Cox, 2009). With this in mind, there is need for an approach for extending decision aid models for disaster management & resource allocation to consider multiple interrelated hazard with innovative risk assessment methods.

2.8 Proposed Solution

Multi-risk is not systematically addressed among many countries for all hazards, and is only singularly integrated into risk assessment approaches. Therefore taking a multi-hazards approach to disaster management, also termed in some literature as 'All-Hazards,' is an approach to disaster management which was initially set upto:

(i) to prepare communities to be ready for one of many likely hazards (Waugh, 2005). Over time, this approach has been extended

(ii) to prepare communities for multiple simultaneous hazards, i.e., the occurrence of multiple hazards at the same time (Selva et al., 2013; Marzocchi et al., 2012); and

(iii) to prepare communities for multiple sequential hazards, or the spawning of multiple hazards by a single initial hazard (Selva et al., 2013; Marzocchi et al., 2012).

The proposed approach for extending decision aid models for disaster management & resource allocation to consider multiple interrelated hazard with innovative risk assessment methods to determine econimical distribution of resources through opening of DRCs on a need to have basis based on the available resources.

2.9 Conceptual Framework

Generally, in major disasters, various resources, conditions and activities are involved; identifying and utilizing such resources, conditions and activities at a detailed level should be the goal of a disaster management model. Incorporating this level of activities and conditions affecting disasters, into existing models, would provide the basis for an effective, useful and practical disaster management model; one which would expand the attention to the full range of concerns about preparedness, mitigation, response and recovery focusing on multi-hazard risks. I shall use the Moline (Moline, 2014) formulation but will tailor it to fit the multi-hazard concept in this paper (Moline et al. 2015).

2.10 Methodology for the usage of the conceptual model

Analysis 1: Does Expected Demand Justify Opening a DRC?

One has to decide whether demand justifies opening a DRC? These questions include:

i. The expected demand,

ii. The threshold above which demand justifies opening a DRC.

Types of questions required to determine threshold

- What is the minimum expected visit per week is required to determine opening of a DRC?
- What quantity of resources should be available in evaluating the opening of a DRC?
- What are the specific decisions we must make in terms of numbers/visits?
- What information do we need and what information is available to make those decisions?
- What information do we need and what information is available to refine those decisions overtime?

In order to determine whether demand would justify opening a DRC, there is need to find the expected maximum or peak demand in each disaster/incident. This is obtained from registration module for visits on disaster management.

I used the following empirical formula for average daily registrations and DRC visits as follows borrowed from (Moline et al. 2015):

$$d\text{pm} = \sum_{x=0}^{n} \text{n}/\text{m}$$

Where dpm = expected peak weekly DRC visits calculated on day m and x= average daily registrations through day m.

(Table 2.1) shows a sample distribution of visits to a DRC:

m	visits
1	50
2	30
3	30

Table 2.1**:** Regression Coefficients for Peak DRC Visitor Forecasting Model

Dpm= (50+30+30)/3

Average expected demand per day for the week (dm) =36.6

Expected peak weekly= (m) * days of the week

dp=(36.6*5)= 109.8

In order to determine the minimum visitor threshold, it was necessary to determine the minimum operating capacity of small, medium, and large DRCs. The operating capacity, in number of visitors served, is the product of the number of employees working, the number of operational hours, and the throughput capacity (visitors per employee-hour).

Moline (Moline et al. 2015) determined minimum, target, and maximum number of employees and operating hours based on DRC standard operating procedures (Table 2.2).

	Employees			Hours		
	Small	Medium	Large	Small	Medium	Large
Minimum	3	3	3	60	60	60
Target	5	10	15	57	57	57
Maximum	8	15	23	84	84	84

Table 2.2: Staffing and Operating Hours for Small, Medium, and Large DRCs

To find target throughput capacity in Kenya, I took records from Red Cross Kenya during the Westgate Shopping Mall attack in Kenya in September 2014 (Emergency plan of action, 2016) an estimated 175 people visited the DRC by Red Cross. The average DRC visit duration is 45 minutes, i.e. will require 0.75 staff-hours. The goal is to have the exact number of staff required to meet demand, so the target throughput capacity is 1.33 visitors per person-hour.

Moline calculated standard operating capacities by combining Table 2.1 and Table 2.2, shown in Table 2.3. To determine whether to open a DRC, I determined whether the expected peak weekly DRC visits equal or exceed 96.

	Employees		
	Small	Medium	Large
Minimum	96	96	96
Target	380	760	1140
Maximum	1431	2684	4115

Table 2.3: Standard Operating Capacities for Small, Medium, and Large DRCs

Distribution Ratio: (3:7:11)

Hence:

Small=expected visits * ratio

Target= expected visits * ratio

Maximum = expected visits * ratio

Analysis 2: Determine the Number and Types of DRCs Required in each Region

The question of how many DRCs should be opened to serve peak demand arises. The goals being:

i. To serve all expected visitors and
ii. To minimize cost.

Costs (Table 2.4) included the fixed cost of opening DRCs as well as variable costs of operating DRCs and are based on previous efforts conducted within Disaster scenarios in Kenya for instance (Bomb Attacks and terror attack).

	Cost
Small	Kshs 1,000,000
Medium	Kshs 3,000.000
Large	Kshs 5.000,000

Table 2.4**:** Cost Assumptions for Small, Medium, and Large DRCs

A simple linear program optimized the number of small, medium, and large DRCs required to meet expected demand. The objective function is as follows:

Minimize CsNs + CmNm + ClNl

Where C is cost (Table 5) and n is the number of DRCs, and where S, M, and L denote small, medium, and large DRCs. The objective function is subject to the following constraints:

- The total number of DRCs (ns + nM + nL) must be greater than or equal to 1
- The total combined capacity of all DRCs must be greater than or equal to the expected number of visitors, where the operating capacity is the target capacity.

In addition, each n must be an integer greater than or equal to 0.

Analysis 3: Determine the Resources Required at each DRC.

In order to receive resource assistance, individuals must be registered on the Decision support system (DSS) portal with a model I came up with as visitors stating the kind of resources required e.g. Food, shelter, beds, ambulances etc. In Moline's case (Moline et al. 2015) they determined at least 36 visitors register on a daily basis. Therefore, the total required resource is a simple calculation based upon the above assumptions and the expected peak visitors. The resource required is equal to distribution of available resources to the expected peak visits to meet at least 25% of visitors' resource needs.

Analysis 4: Determine Staffing and Hours for each DRC

Next is to determine how to staff DRCs. First, expected visitors are distributed across the DRCs in each county proportionally according to DRC size using the following mathematical description.

$\text{Sm}=\sum_{k=0}^{n} \text{k}/\text{dr}$

Where

K=expected visits

Dr=Available DRC sites

The number of employees is determined and operational hours required in each DRC. For each type of DRC (small, medium, and large), they took target values from Table 2.2. They first determined the minimum number of staff required based on the assumption that it is more expensive to add staff than to have existing staff work longer hours. The minimum number of staff at each DRC is taken to be the maximum of three and the required number of staff to meet demand. The required number of staff is calculated by dividing expected visitors by the target throughput capacity and multiplying by the maximum weekly operating hours. Given the staffing, they calculated the minimum operating hours as the maximum of 60 hours per week and the required number of hours to meet demand. The required number of hours is calculated by dividing expected visitors by the target throughput capacity and multiplying by the required staff calculated above.

Analysis 6: Other Factors

The decision process includes two exit points: the decision not to open DRCs, and the decision to close DRCs for proper, economical distribution of resources.

2.11 Conclusion

This paper provides a comparison of mono-hazard and multi-hazard approaches to disaster management in order to highlight features unique to multi-hazard ones, particularly in resource allocation models. In doing so, the paper borrows from both the multi-hazard and the resource-allocation literature. The paper argues for the need for advances in analytical formulations as encapsulated in the model base for an appropriate disaster management decision support system, and provides preliminary suggestions for how the modeling might be adjusted to move from a single-hazard to a multi-hazard context. The model advanced here can then be simulated over many replications to examine different policies and a strategy to see which best achieves the community's prescribed values over the long run in the face of multiple hazards and threats.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Introduction

This chapter starts by outlining the research strategy that will be used, the sources of data and their relevance, tools that will be used to collect that data and also their justification. After this, it briefly touches on how the testing will be done, and how this testing will answer the research questions.

3.2 Research Strategy

This research project will be an applied computing research. It will start by investigating all the set requirements of a proper triaging procedure. This review of requirements will be important as these requirements will be part of the data that will be required for the portal to be developed. The research intends to come up with a resource allocation for use in emergency situations. This is important as it is the research main question.

3.3 System development methodology

This architecture most importantly being based on developing a web based tool to help in emergency resource allocation. I will use the agile system development to come up with a prototype. Agile development is the process of continuously cycling through the whole software development process to incrementally, quickly and visible develop a working software (Anon n.d.). This is the most appropriate system development methodology since its main objective is to reduce the amount of project risk (Centers for Medicare & Medicaid Services 2008). This is also due to the fact that it will enable me to write a documentation which will be necessary in the field of research as I add to the body of knowledge. It will also help to mitigate integration and architectural risks earlier in the project. The steps will include:

- ❖ A series of mini-waterfall where all the phases of the waterfall model are completed for a section of the system. The waterfall model consists of (Anon n.d.):
    - Requirement gathering and analysis where all possible requirements of the system to be developed are gathered
    - System Design: this is where the system is specified and overall system architecture is defined.

- Implementation: each unit of the system is developed and tested for its functionality
- Integration and testing: this is where all units are integrated into a system and tested

❖ Iterative prototyping is then implemented.

3.4 Evaluation

Evaluation will be done through simulation experiments. Agency resource availability will also be simulated and the results integrated into the resource allocation module. That testing will be driving at answering the research questions. Proper tests will be done to show that the prototype could be used in real life scenarios.

3.5 Implementation Software Tools

The system that has both a front-end and back-end applications was built. The front-end application is a web based system built using the PHP language and Codeigniter Framework. Dreamweaver CS5 IDE was used in the development of the application. The system's database on the other hand, was implemented using open source SQL Server Database management system. The system database was designed using Toad data modeler; a database design tool that allows users to visually create, maintains, and document new and existing database systems.

3.6 Sources of data and their relevance

This project will derive its data from three main sources: Technical Users (Paramedics and Red Cross staff), Non-Technical sources (casualties) and researchers.

The technical users will provide data on how a triaging process and resource allocation takes place. One of the non-technical users will be a patient’s vital signs.

3.7 Tools methods for data collection and their justification

Data collection will be done by documents analysis, literature review and interviews. Documents analysis and Literature review will be used in collecting technical information effective the current emergency resource allocation is. To understand all these different ways of operation the research will need to use documents analysis and literature review to collect all that data. Those two tools were also be used to collect data from previous researchers. Interviews will also be done on both the technical and non-technical data sources in order to get a better understanding of what exactly happens in reality

3.8 Limitation of methodology and its possible solution

The main limitation in this methodology is Self-reported data for the technical and non-technical users. To overcome this, the project will try and accommodate as much possible outliers as possible.

CHAPTER FOUR

4.0 DESIGN AND IMPLEMENTATION

4.1 Introduction

Decision aid models can help governments and humanitarian organizations by improving their forecasts during disaster preparedness and by facilitating data collection during field assessments in disaster response. They can also facilitate collaboration and coordination between different parties involved in disaster management. The recognition of this need has led to a number of different decision support models being developed within the disaster management arena. Most of these, however, have been developed with a single risk in mind. They do not take into consideration that the initial impact of a disaster can lead to a variety of associated hazards. By taking a multi-hazard viewpoint with respect to disaster response and recovery, there is an opportunity to allocate limited resources more effectively, particularly in the context of long-term planning for community sustainability.

The importance of decision aid model for disaster management and resource allocation with regards to multi hazard perspective was made evident through literature review. This formed the basis for conducting a survey, in order to determine if literature was consistent with industry practice. The findings of the survey were consistent with published literature, as it was established that the methods used by practitioners in resource allocation for disaster management with regards to multi-hazard assessment were not effective—as they were largely subjective. Therefore, this section presents a comprehensive model for disaster management with improvements over existing models.

4.2 Framework Implementation

One of the objectives of this study was to build a prototype of a disaster management and resource allocation system in order to determine the whether there is need of opening a disaster recovery center based on available resources and demand —based on the decision aid model that is presented in the preceding subsections of this chapter. This section presents the design and development process of the initial version of the system.

4.3 System Design and Development

4.3.1 Requirements Analysis

This section begins by describing the different users of the system and their roles, and subsequently presents system requirements—(both functional and non-functional), based on user needs and roles.

4.3.2 System Users and Their Roles

a) **Administrator**: This is a user who has administrative rights of the system. The roles of the administrator include:

- Creating user accounts. This includes setting system privileges to users.
- Managing user accounts (editing and deleting user accounts).

b) **System Manager:** This is a user who is involved in the day to day activities of the system in relation to disaster and resource allocation. The specific functions of the system manager include:

- Managing resources of the organization such as relief foods and assets.
- Developing and reviewing incidents of a disaster including impact and required resources to mitigate the disaster.
- Inspecting completed quality control checklists, forms and other documents for conformance to prescribed standards.
- Reviewing and resolving resource allocation issues in regards to organizational assets.

4.4 System Requirements

The functional and the nonfunctional requirements for the reusability assessment system are summarized in tables 4.1 and 4.2 respectively.

a) Functional requirements

Table 4.1: Functional requirements of the disaster management system

ID	Requirement
FR-1	System should be accessible everywhere i.e. should be web based.
FR-2	**Incident Management**: Ability to manage hazards/incidents as they occur, logging and making them visible to users
FR-3	**Resource Management:** ability to manage Day-to-day logging of community resources such as relief goods and facility assets.
FR-4	**Reporting Capacity:** Capacity to generate program, agency, community, and, if applicable, collaborative level reports for the various incidents/hazards.
FR-5	System should have ability to capture various information needed to undertake a project e.g. undertaking firms, resources required
FR-6	**System Security**: system should have Integrated technical safeguards to ensure a high level of privacy and security, including, data encryption and transmission, Administrator controlled user name and password access, Automatic timeout/log-off, Administrator controlled user level read, write, edit and delete capabilities, Administrator controlled user level module and sub-module access

b) Nonfunctional requirements

Table 4.2: Nonfunctional requirements of the reusability assessment system

ID	Requirement
NFR-1	The system should guard against accidental deletion and erroneous update of stored data.
NFR-2	The system should provide for user authentication.
NFR-3	The system should check and verify that entered data is in the appropriate format
NFR-4	The system should have adequate understandability, testability, maintainability, and reusability.

4.5 Use Cases for Disaster Management and Resource Allocation System

The disaster management system and resource allocation for multi-hazard scenario will be used by both Systems Managers (normal users). Managers will use the system in determining efficient mechanisms for managing a disaster and related resource allocation. The system will have a system administrator, who will have the overall administrative rights of the system. The roles of the two system users are depicted in the system-level use-case diagram shown in figure 4.1.

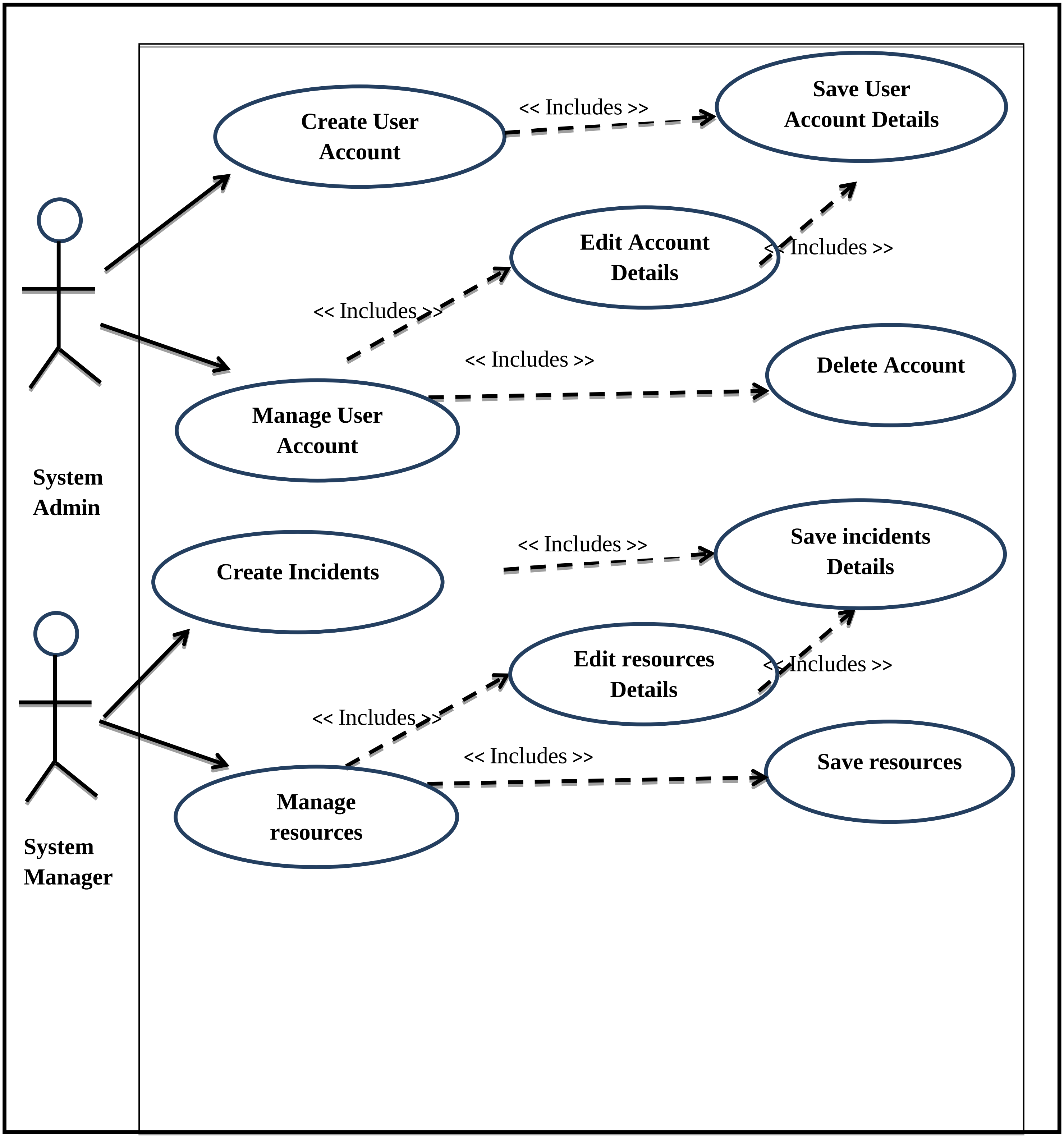
Create User Account
<< Includes >>
Save User Account Details
Edit Account Details
<< Includes >>
<< Includes >>
<< Includes >>
Delete Account
Manage User Account
System Admin
Create Incidents
<< Includes >>
Save incidents Details
Edit resources Details
<< Includes >>
<< Includes >>
<< Includes >>
Save resources
Manage resources
System Manager

Figure 4.1: System level use-case diagram for the disaster management system

4.6 Database Design

A database for storing disaster incidents and related assessments as well as user accounts was built using MYSQL—which is a relational database management system. The identified entities and attributes for the database are shown in figure 4.2.

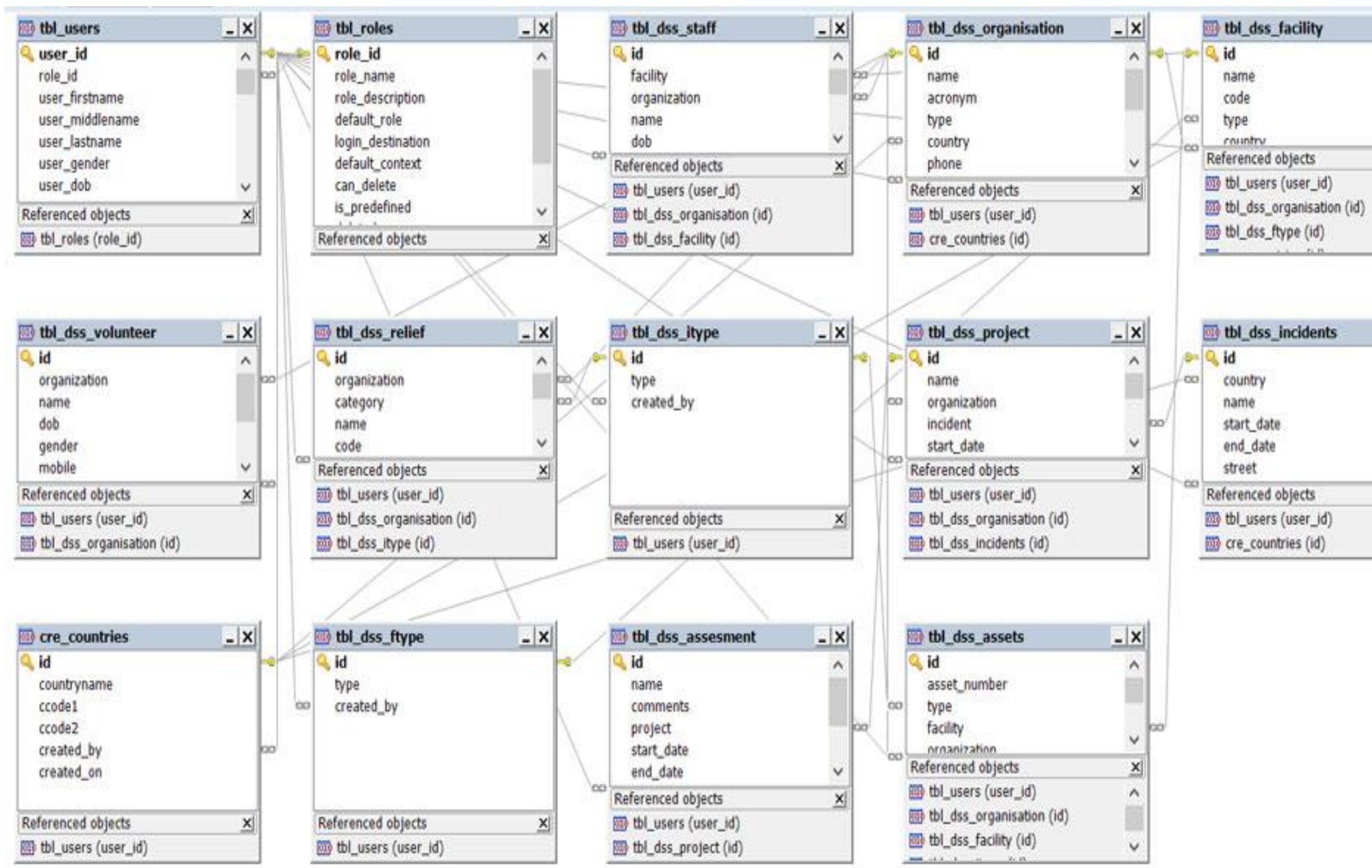

Figure 4.2: Database design for the disaster management & Resource Allocation system

4.7 Class Design

4.7.1 The Data Tier Class Design

The data layer for the application is comprised of two public classes, i.e. Database, Auth_model, Auth_lib, and form_validation. The inheritance hierarchy for the data layer classes is shown in figure 4.3.

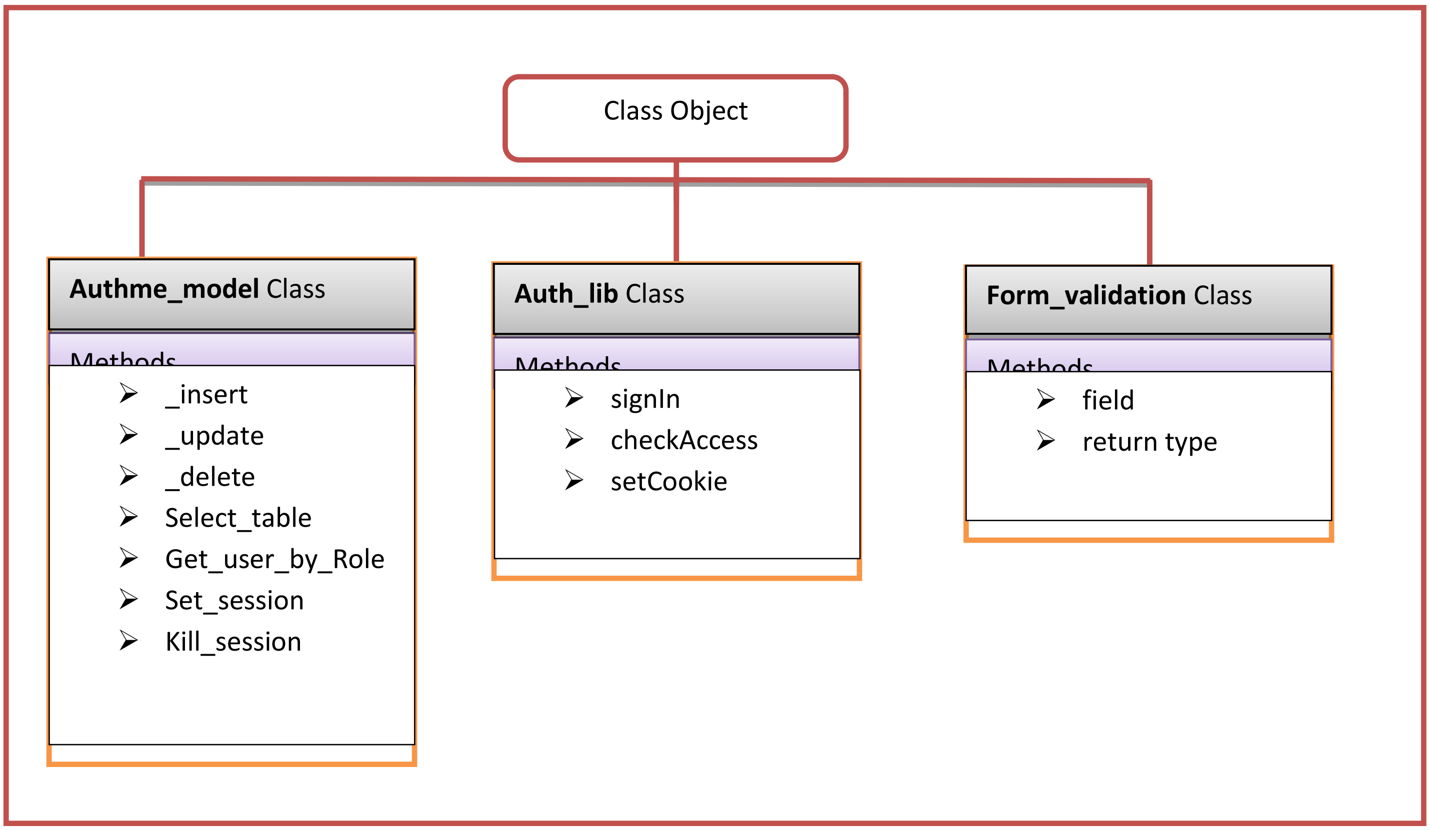

Figure 4.3: Data Layer Classes

i. **Public Class Authme_model:** this class performs database connection and Database objects creation i.e. tables and views.

ii. **Public Class form_validation:** comprises of methods that ensures that all user input is provided as required. That is, it validates if all required fields are provided.

iii. **Public Class auth_lib:** comprises of methods that performs password encryption and decryption in addition to session's management.

4.7.2 The Business Tier Class Design

The Business layer (Layer 2) for the application encapsulates business logic for data manipulation and transformation of the data into information. It is also responsible for processing the data retrieved from the database and sends it to the presentation layer. The business Layer for the system has one class, namely dss, which inherits from class, Authme_model. The business layer class and its members are shown in the figure 4.4 below.

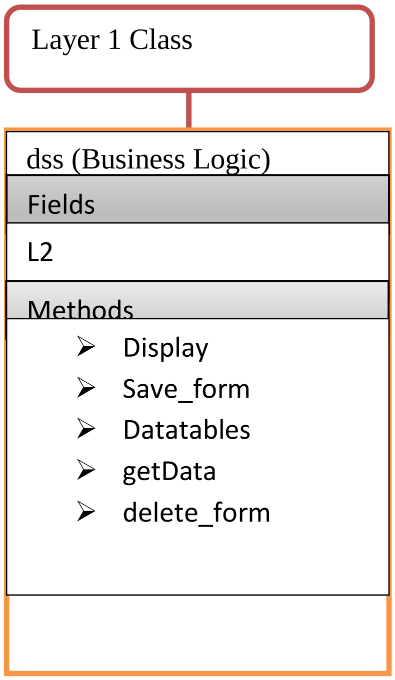

Figure 4.4: The business tier classes for the disaster management & Resource Allocation system

4.7.3 The presentation Tier Class Design

This layer comprises of components that are responsible for presenting system data to the user/user interface. It also presents user input to the business layer. The major presentation tier(Layer 3) classes for system are:

i. Class frmUser: This Layer 3 component handles the creation and management of user accounts. It includes methods for displaying user account information that exists in the system database, as well as methods that enable the user to create new user accounts.
ii. Class frm_organisations: This Class consists of methods that display organizations information that exist in the system database, as well as methods that enable a user to enter and edit new organization.
iii. Class frm_facility: This class includes methods that enable a user to add new facility for an existing organization (i.e. all facilities that an organization has such as hospital or fire station) into the system.
iv. Class frm_assets: This class includes methods that enables the user to supply asset information for a given organization e.g. vehicles, furniture etc.
v. Class frm_staff: This class includes methods that enable the user to enter all staff members in an organization and assignment to their various facilities.
vi. Class frm_volunteers: This class includes methods that enable the user to enter all volunteers in an organization and their roles.
vii. Class frm_rgoods: This class includes methods that enable the user to enter all relief goods an organization has in stock.
viii. Class frm_incidents: This class includes methods that enable the user to enter incidents that have happened in a disaster e.g. bomb threat and casualty.
ix. Class frm_project: This class includes methods that enables the user to register a project based on an incident or incidents and organization that’s implementing the project.
x. Class frm_assesment: This class includes methods that enable the user to assess the disaster and advice on resources required.

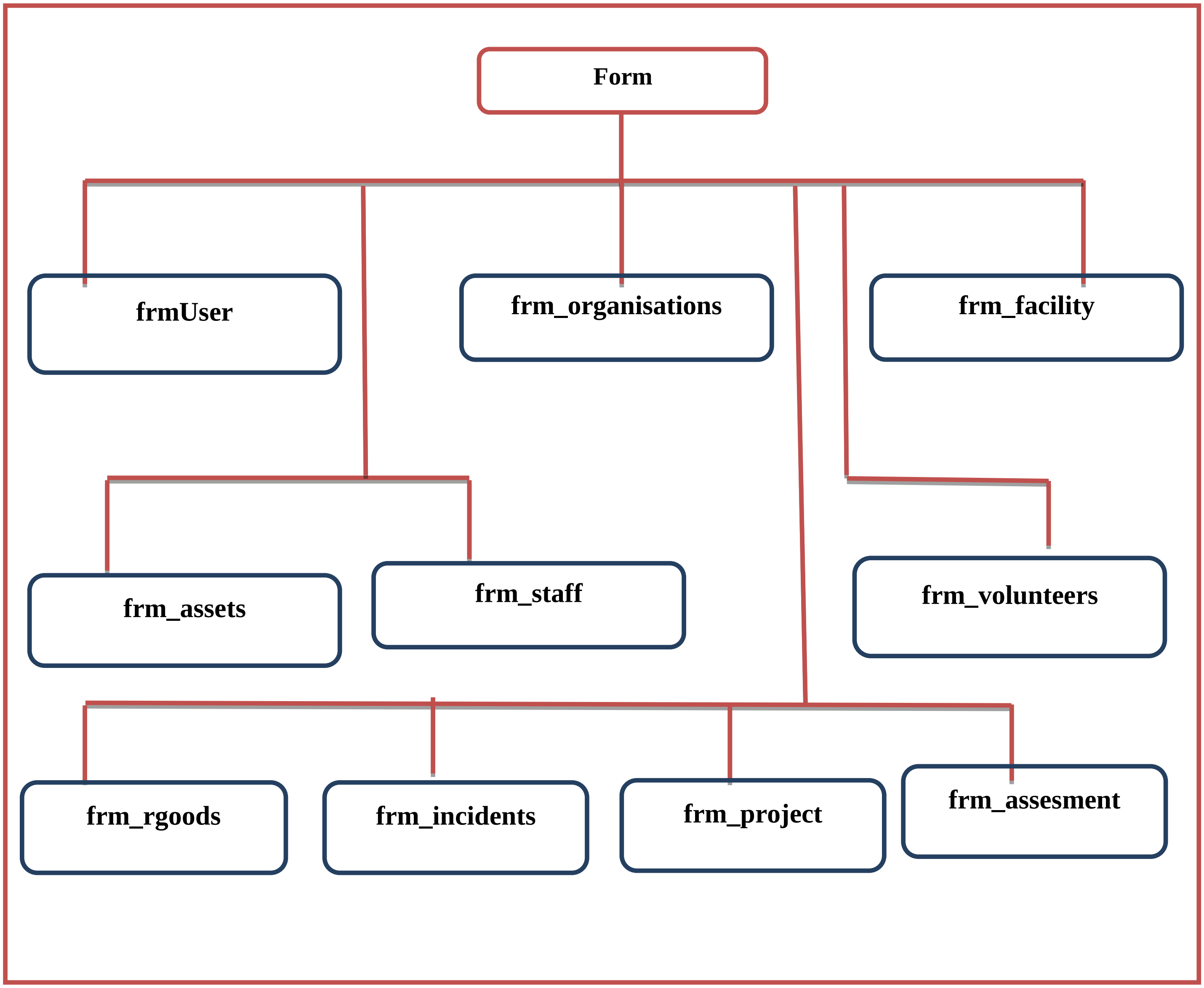

Figure 4.5: Presentation layer classes for the disaster management & Resource Allocation system

4.8 Major User Interfaces for the Reusability Assessment System

4.8.1 The Login Module

This module enables users to gain access to the system. For a user to gain access to the system, he must supply the correct user name and password. The user name and password are then matched with the account details (user information) stored in the system‘s database. The user gains access to the system if there is a match—otherwise, the user is notified that the supplied information is invalid. The screenshot for the login interface is displayed below.

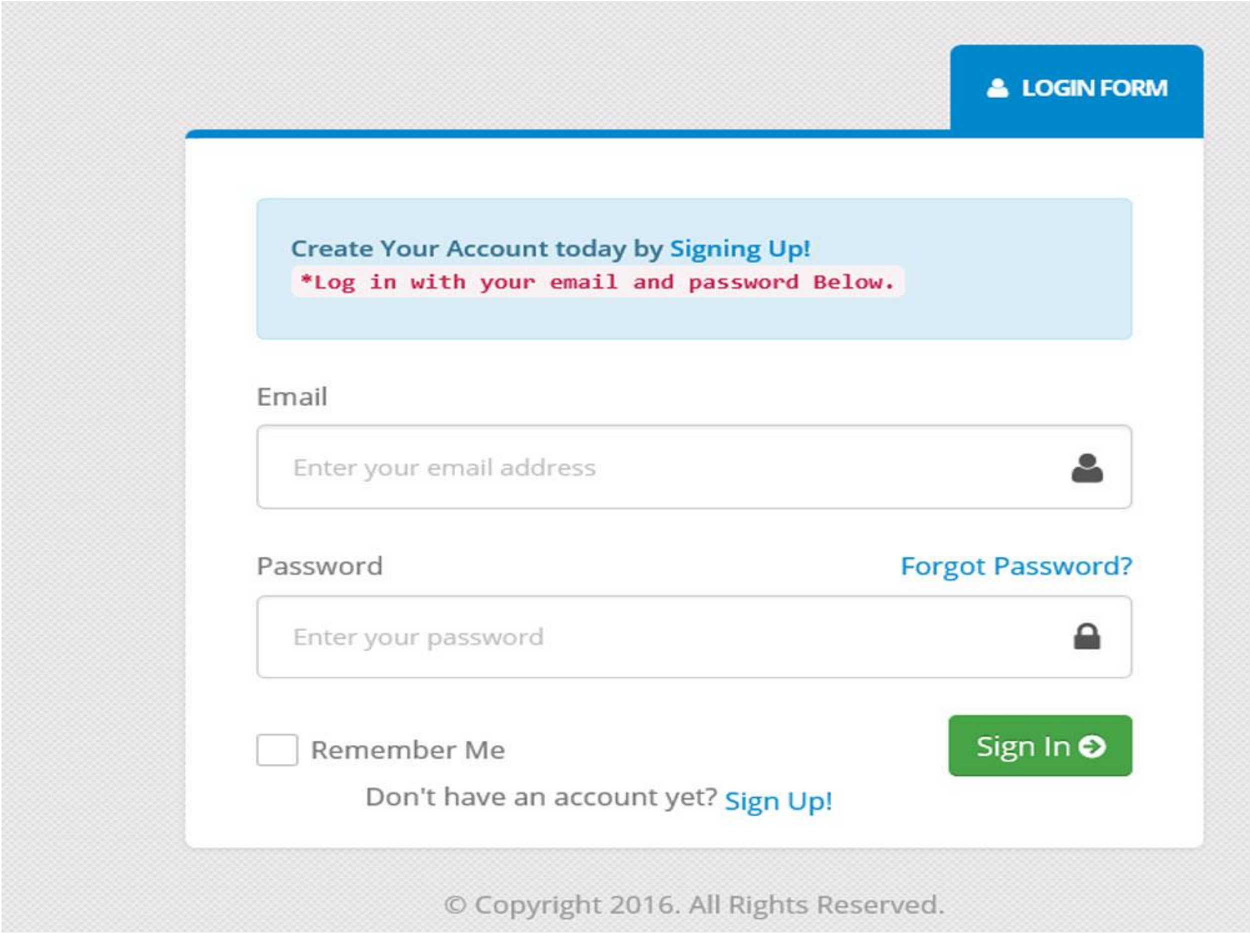

Figure 4.6: The Login Interface for the disaster management & Resource Allocation system

4.8.2 The System's Main Interface

After a user has successfully logged into the system, the main system user interface is displayed. This interface, displays the major tasks that the user can perform. The choice of a particular task displays the relevant corresponding sub-interface. The main user interface for system is displayed in figure 4.6.

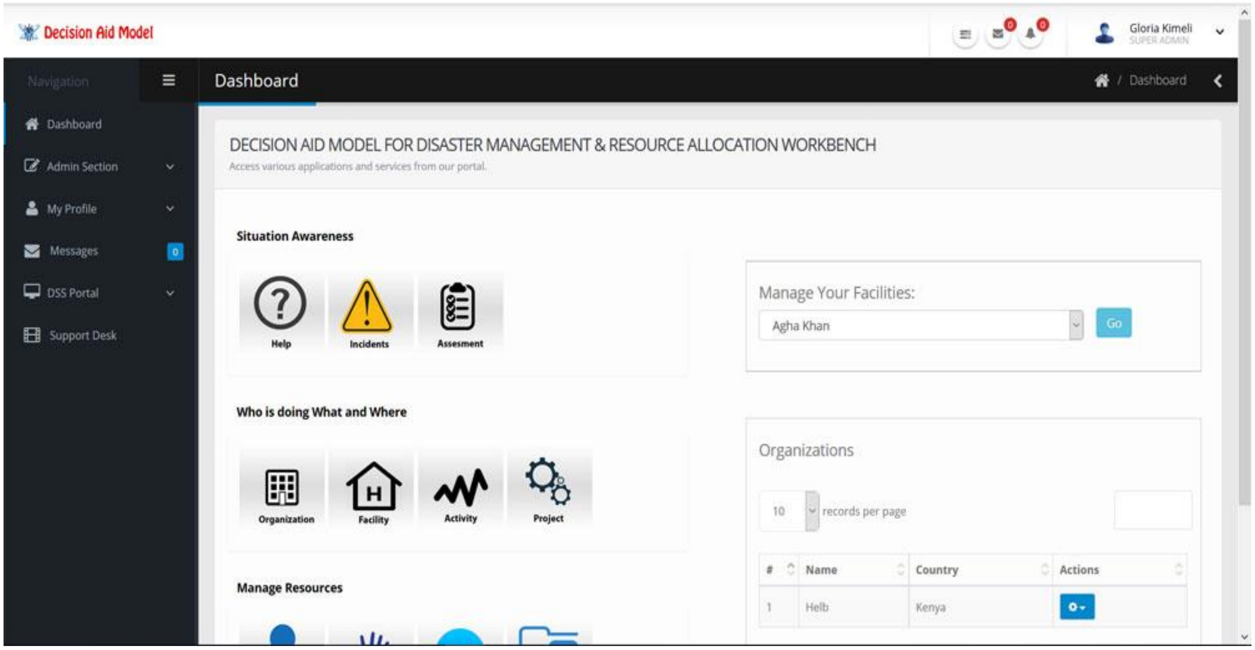

Figure 4.7: Main user interface for the disaster management & Resource Allocation system

4.8.3 Interface for Managing Users

When the user who is logged in as an administrator chooses the 'manage users task' from the main interface, an interface for managing users (shown in figure 4.9), is displayed. From this interface, the user can view and edit existing user accounts and user groups, as well as create new user accounts or user groups.

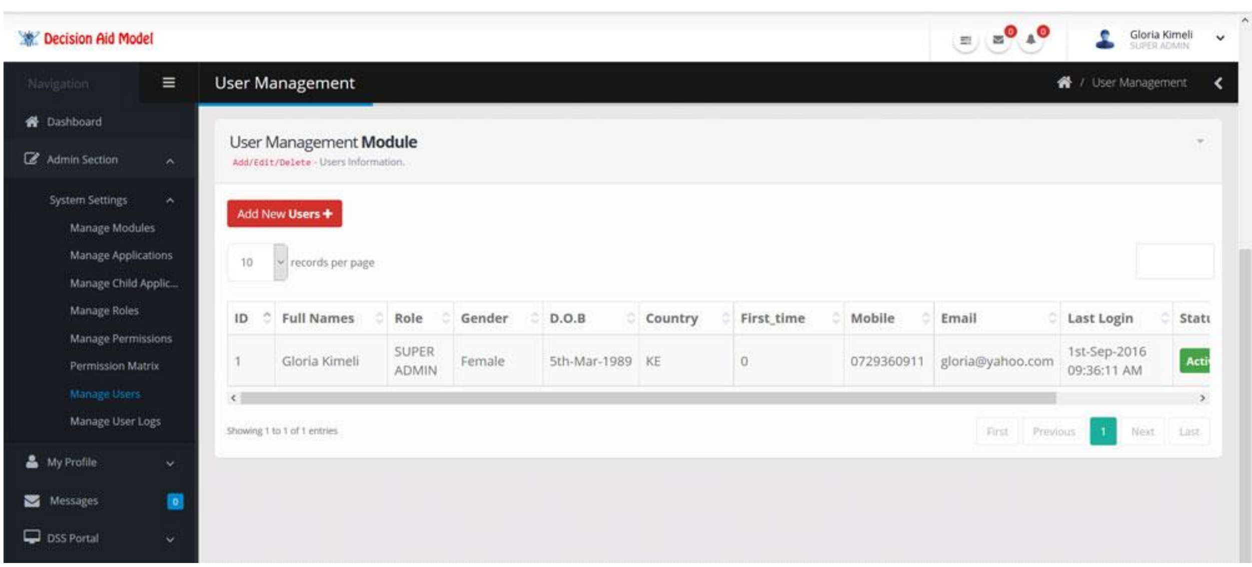

Figure 4.8: The disaster management & Resource Allocation system interface for managing users

4.8.4 Interface for Managing Organizations

The major tasks that can be performed from this interface include; viewing of created organization details by logged user that exists in the system‘s database and editing the same. Organization forms the entry point in the disaster management system and all other modules inherit from it. Figure 4.9, shows the screenshot of the said interface.

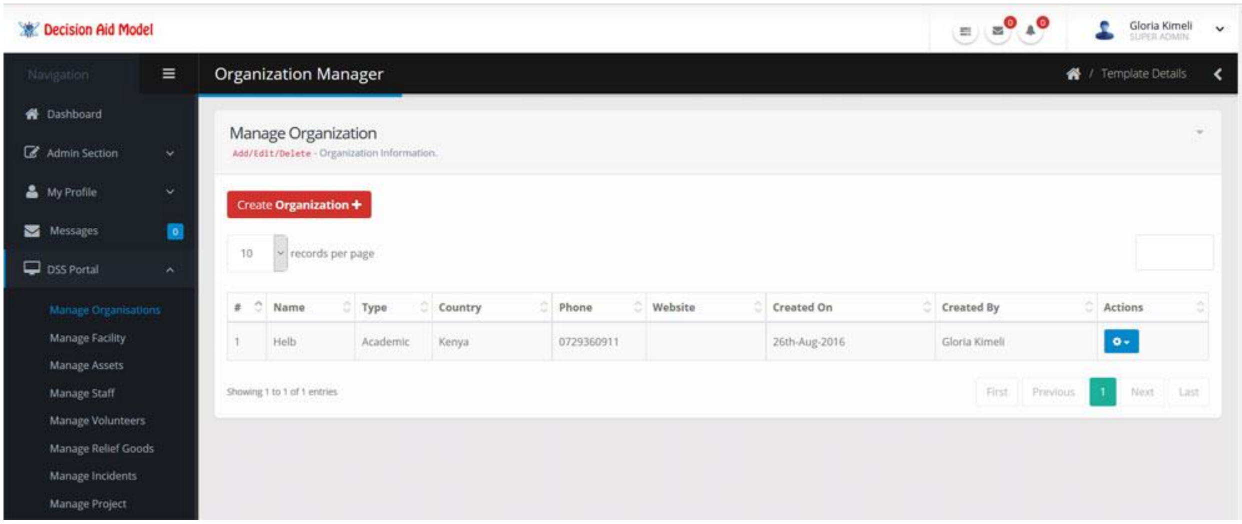

Figure 4.9: interface for managing Organizations for the disaster management system

4.8.5 Interface for Managing Facilities

The major tasks that can be performed from this interface include; viewing of created facilities for a particular organization and editing the same. A facility belongs to an organization. Figure 4.10, shows the screenshot of the said interface.

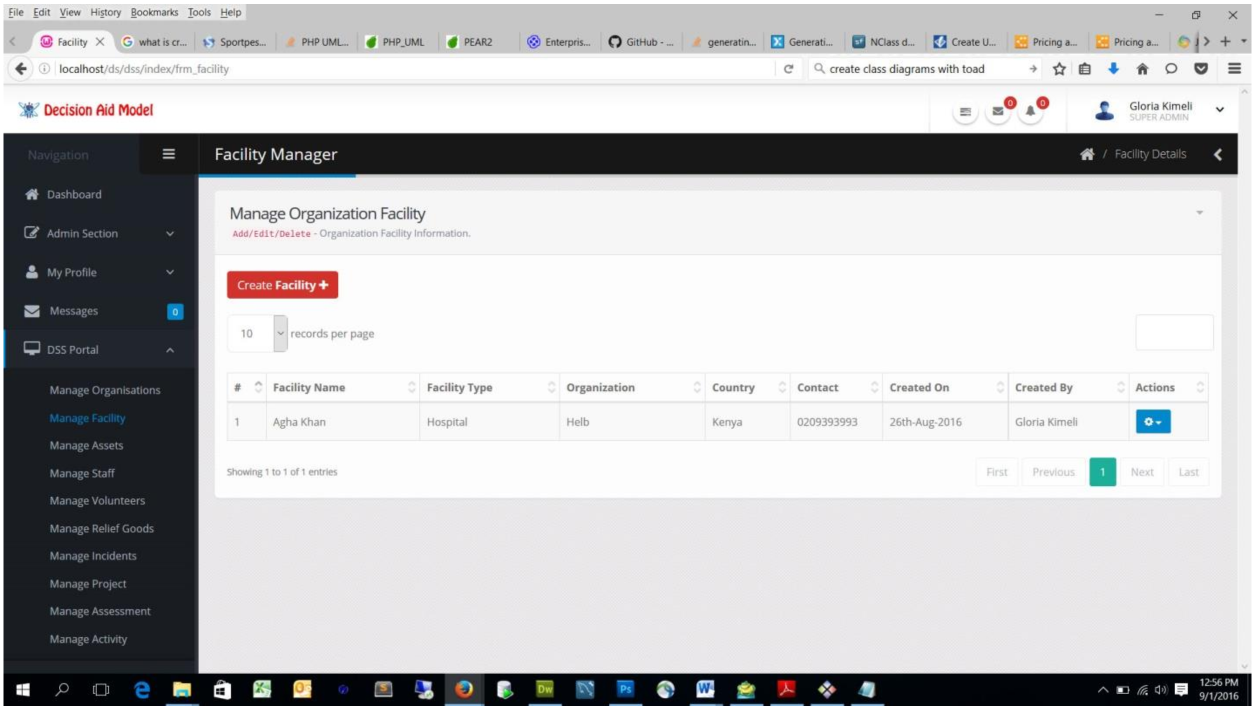

Figure 4.10: interface for managing facility for the disaster management system

4.8.6 Interface for Managing Assets

The major tasks that can be performed from this interface include; viewing of assets created in the existing database for a particular organization and editing the same. Assets include items like Furniture, motor vehicles etc. Figure 4.11, shows the screenshot of the said interface.

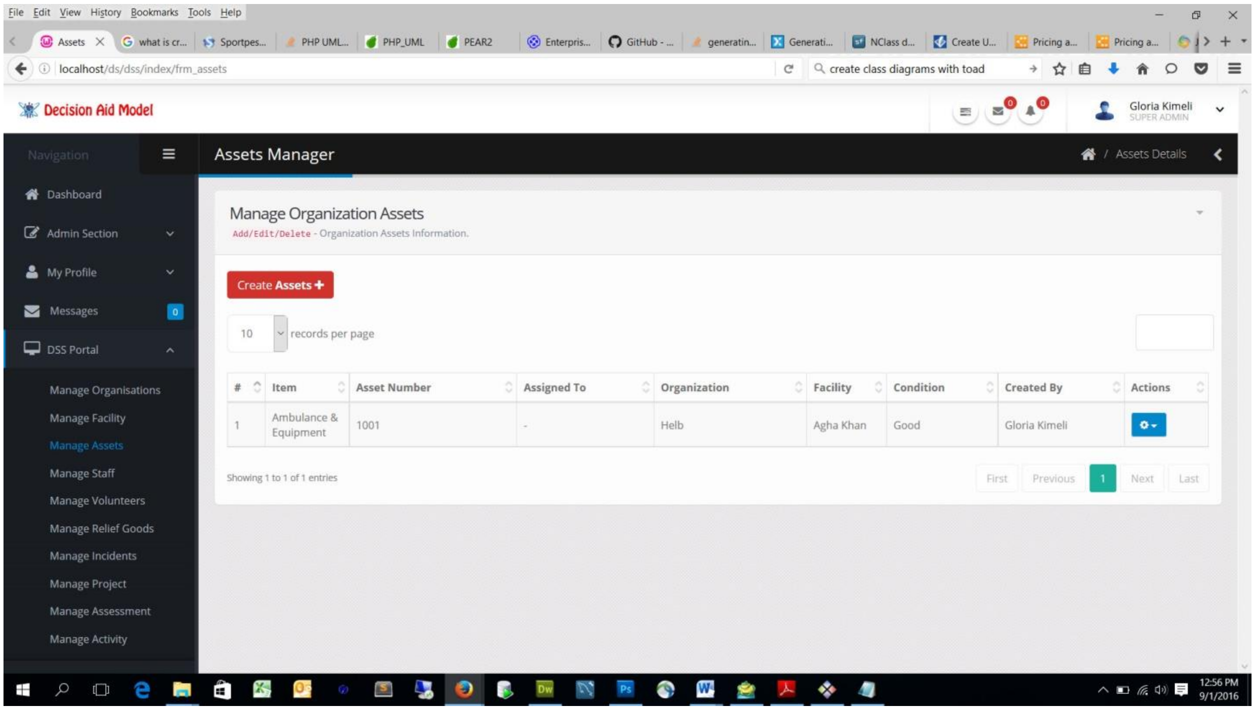

Figure 4.11: interface for managing organization assets for the disaster management system

4.8.7 Interface for Managing Staff Members

The major tasks that can be performed from this interface include; viewing of staff members created in the existing database for a particular organization and editing the same. Staffs are assigned specific roles. Figure 4.12, shows the screenshot of the said interface.

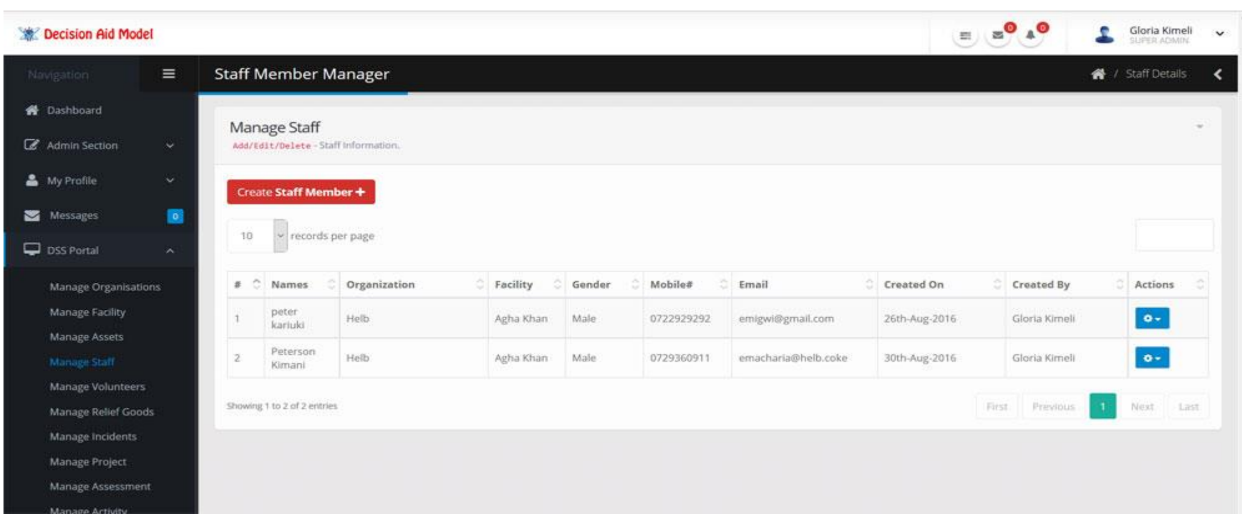

Figure 4.12: interface for managing staff members for the disaster management system

4.8.8 Interface for Relief Goods

The major tasks that can be performed from this interface include; viewing of resources such as relief goods created in the existing database for a particular organization and editing the same. Relief goods include items like food stuff etc. Figure 4.13, shows the screenshot of the said interface.

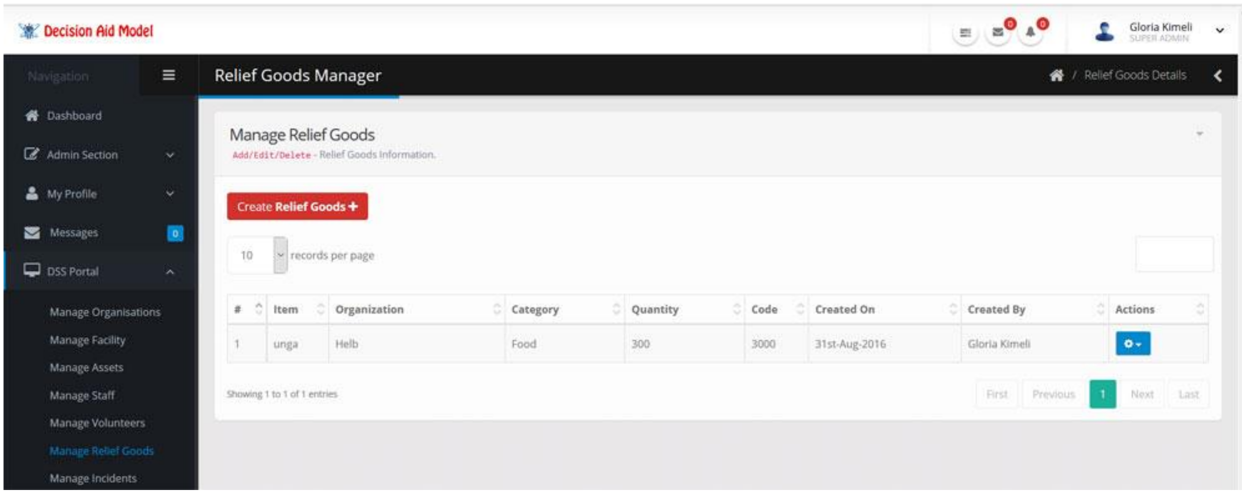

Figure 4.13: interface for managing staff members for the disaster management system

4.8.9 Interface for Incidents

The major tasks that can be performed from this interface include; viewing of incidents that have happened in a disaster and editing the same. Incidents include items like bomb threats, fire etc. Figure 4.14, shows the screenshot of the said interface.

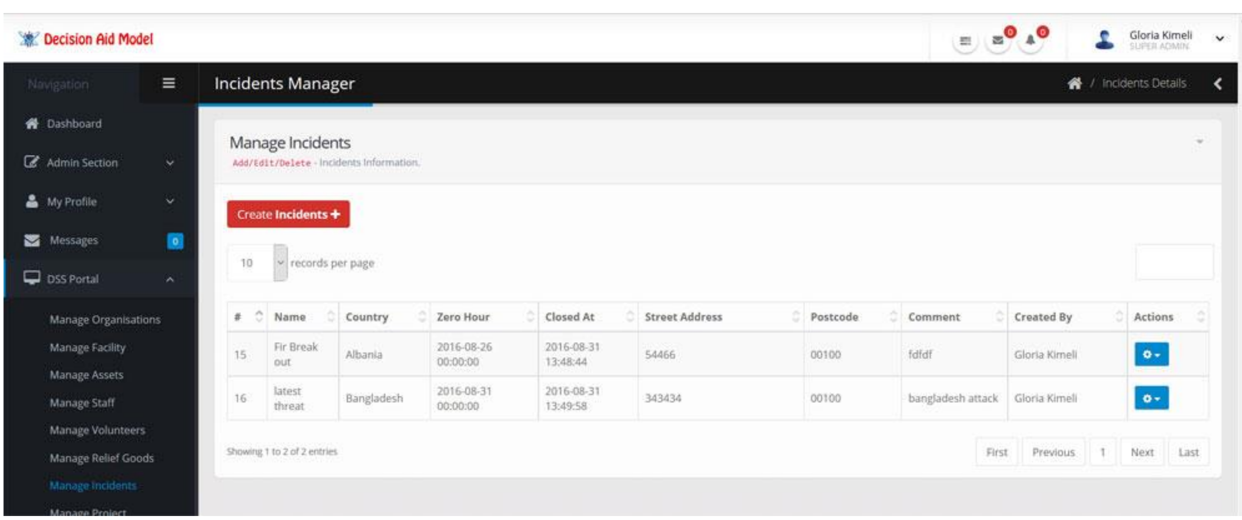

Figure 4.14: interface for managing incidents for the disaster management system

4.8.10 Interface for Project

The major tasks that can be performed from this interface include; viewing of projects based on an incident being undertaken by a particular organization that have happened in a disaster and editing the same. Figure 4.15, shows the screenshot of the said interface.

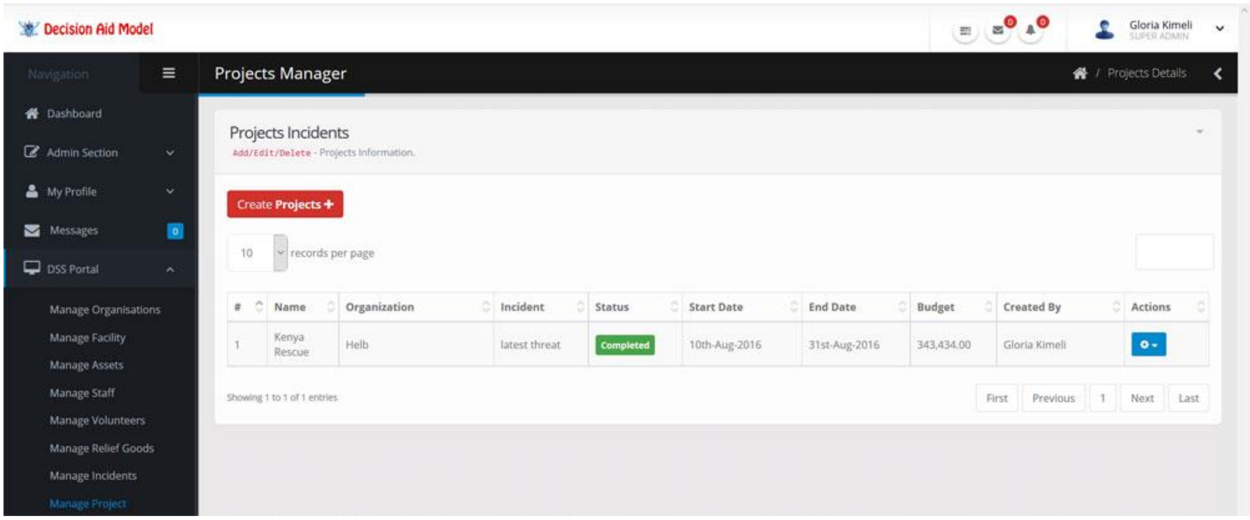

Figure 4.15: interface for managing projects for the disaster management system

4.8.11 Interface for Assessment

The major tasks that can be performed from this interface include; implementing the model to calculate and project resources required undertaking the disaster incident. Figure 4.16, shows the screenshot of the said interface.

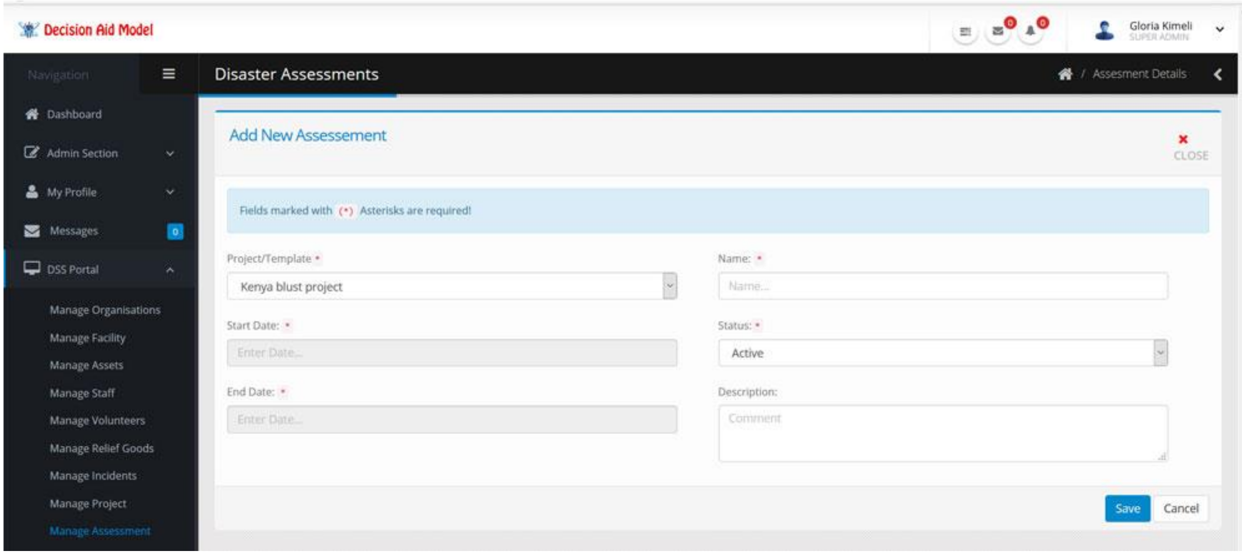

Figure 4.16: Interface for managing assessment for the disaster management system

4.9 Analysis

In order to evaluate this model, I revisited the decisions made during the Westgate attack in Kenya (Emergency plan of action, 2016) from the analysis; I found that the decision by this model would have been more effective given that the capacity reflected more accurately the demand. It was easier to determine resource allocation given that staff could be added or reduced given the demand. It was easier to determine whether to keep DRCs open or not for a given amount of time.

CHAPTER FIVE

5.0 CONCLUSIONS

5.1 Introduction

This chapter provides conclusion based on the work presented in the thesis. The main objective of this research is to outline a decision support system for disaster recovery centers, with a resource-allocation model in its model base, wherein the model includes multi-hazards scenario. The overriding goal of the research was to outline appropriate methodologies that can be used by decision aid makers in allocating limited resources more effectively with respect to disaster response and recovery, in the context of long-term planning for community sustainability. The main research findings and future works are described in following sections.

5.2 Summary

This literature review provides a comparison of mono-hazard and multi-hazard approaches to disaster management. In doing so, the study borrows from both the multi-hazard and the resource-allocation literature. The objective was to highlight features unique to multi-hazard ones, particularly in resource allocation models. This information played a key role in identifying limitations of the disaster management models that were found in literature, as well as in the development of a novel framework that is appropriate for the development of a disaster management decision support system.

The paper argues for the need for advances in analytical formulations as encapsulated in the model base for an appropriate disaster management decision support system, and provides preliminary suggestions for how the modeling might be adjusted to move from a single-hazard to a multi-hazard context. The model advanced here can then be simulated over many replications to examine different policies and strategies to see which best achieve the community's prescribed values over the long run in the face of multiple hazards and threats.

This research presented the background, data, and methodologies I used to develop a data-driven resource allocation decision process for decision support systems. In doing so, this research arrived at the following key conclusions specific to disaster management and resource allocation:

- The methodology developed and employed is generalizable to other disaster-specific resource allocation problems hence it can be used by others to tailor it to their specific needs in terms of resource allocation.
- Decisions can (and should) be separated from the decision-makers. The methodologies focus only on the decisions and their outcomes, not on the individuals and entities making the decisions. This is a critical point, as the individuals and entities change from disaster to disaster but the decisions themselves do not.
- The methodology in this research can be used to reduce uncertainty and improve information sharing after disasters. This approach enables the identification of what data is needed and what data is available, allowing decision makers to prioritize information and submit targeted, easily filled data requests.
- It is important for organizations to have clear decision making processes first before using the decision support tool in order to feed the system with the right requirements in order to assist in decision making with all requirements in place. There must be flexibility to account for other, disaster-specific factors in any decision process. A process such as this must be treated as a baseline for decision making; it must not be used to replace or supersede experience or common sense. Therefore it is critical to include a review of other factors, including political, cultural, and disaster-specific factors, in the final decision process.

5.3 Achievements

This section outlined the achievements attained in relation to the objectives of the study. Generally, the study was aimed at improving decision support systems so that decision making agency at strategic level can determine which intervention strategies provide the best outcome(s) in the face of multiple hazards and threats given limited resources. The first objective of the study was to identify and examine the strategies and methods that researchers use in coming up with decision support models. Through literature review; a number of methods were identified which however as described in the literature focus on single hazard events. As mentioned, however, none of these models adopts a multi-hazard viewpoint.

The second objective was focused on identifying the shortcomings of the decision aid models that are currently used. This objective was achieved by comparing methods that exist in industry with what literature describes as ideal disaster management and resource allocation techniques. It was established that the methods used in industry were highly subjective since they focus on single hazard events; hence unreliable to adopt a multi-hazard viewpoint.

The third and fourth objective was to implement and evaluate the working of the framework prototype for resource allocation in the face of a multi-hazard disaster. This objective was achieved through experimentation—where the prototype was used to illustrate resource allocation for multiple disasters and resource allocation for disaster recovery.

5.4 Impact of the Research

This research makes important contributions to the academia as well as humanity in terms of resource allocation in times of disaster which can go a long way in saving lives and the environment. This research provides a means for defining and experimentally validating the model in a precise and formal manner. The study allows significant efficiencies to be gained by taking a multi-hazards perspective during the planning process and furthermore, accounting for a risk package and not just a single type of risk but a more accurate risk assessment.

5.5 Limitations

The research identified specific limitations as listed below

- Issues such as legislation, welfare and policies were not considered in this research
- Not all physical resources were incorporated in to the system as there are is a wide variety of resources to be considered during resource allocation

5.6 Recommendations for Future Research

This research also identified several areas for further research and development.

- There is need for artificial intelligence and expert systems use in the system in order to represent human knowledge and in to provide tailor made decisions due to specific disasters so that resource allocation process is made faster.
- Geospatial analysis could add a lot to the decision making process as well as other decision processes by allowing for the incorporation of sensors data, location and route optimization, and more. This framework should be incorporated with Triaging frameworks in order to automatically get the number of visitors and get their category of help. Visitor tracking systems could provide for a richer understanding of visitor behavior and staff utilization. Linking staff allocation to staff skill sets could also provide for much

more efficient operations. This approach provides the necessary first steps for these efforts, and I look forward to additional advances in post-disaster resource allocation.

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