



A System Dynamics & Emergency Logistics Model for Post-disaster Relief Operations

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Abstract

Emergency teams' efficiency in responding to disasters is critical in saving lives, reducing suffering, and for damage control. Quality standards for emergency response systems are based on government policies, resources, training, and team readiness and flexibility. This research investigates these matters in regards to Saudi emergency responses to floods in Jeddah in 2009 and again in 2011.

The study is relevant to countries who are building emergency response capacity for their populations: analysing the effects of the disaster, communications and data flows for stakeholders, achieving and securing access, finding and rescuing victims, setting up field triage sites, evacuation, and refuges. The research problem in this case was to develop a dynamic systems model capable of managing real time data to allow a team or a decision-maker to optimise their particular response within a rapidly changing situation. The Emergency Logistics Centre capability model responds to this problem by providing a set of nodes relevant to each responsibility centre (Civil Defence, regional/local authority including rescue teams, police and clean-up teams, Red Crescent). These nodes facilitate information on resource use and replenishment, and barriers such as access and weather can be controlled for in the model. The dynamic systems approach builds model capacity and transparency, allowing emergency response decision-makers access to updated instructions and decisions that may affect their capacities. After the event, coordinators and researchers can review data and actions for policy change, resource control, training and communications. In this way, knowledge from the experiences of members of the network is not lost for future position occupants in the emergency response network.

The conclusion for this research is that the Saudi emergency response framework is now sufficiently robust to respond to a large scale crisis, such as may occur during the hajj with its three million pilgrims. Researchers are recommended to test their emergency response systems using the Emergency Logistics Centre model, if only to encourage rethinking and flexibility of perhaps stale or formulaic responses from staff. This may lead to benefits in identification of policy change, training, or more appropriate pathways for response teams.

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Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously in whole or in part to qualify for any other academic award; the content of the thesis is the result of work that has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and ethics procedures and guidelines have been followed.

Shougi Suliman Abosuliman

Dedication

This thesis is dedicated to those who supported and inspired me emotionally in pursuing my PhD degree especially my mother Khadeja Mahmood Algarni and my father, the late Suliman Hassan Abosuliman. The thesis is also dedicated to my dear wife, Amani Omar Bakarman, who has fully supported my postgraduate studies in Australia, and for which I am forever grateful. I also dedicate this study to my daughters Sofana and Solaf and my unborn baby Mohammad; and to my uncle Mohammad Mahmood Algarni. I acknowledge the assistance and support of my uncle Mohammad Mahmood Algarni, my brothers and sisters Mohammad Suliman Abosuliman, Mostafa Suliman Abosuliman, Khaireya Suliman Abosuliman, Samera Suliman Abosuliman, Asmaa Suliman Abosuliman and Asia Suliman Abosuliman.

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Publications

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Chapter 1 Introduction

This study investigates the factors that contributed to the loss of life and damage to property caused by successive floods in Jeddah, Kingdom of Saudi Arabia in 2009 and 2011. These factors include structural and procedural matters such as town planning, flood mitigation, infrastructure maintenance, readiness of emergency response teams and civil agencies responsible for immediate and long-term amelioration from flooding. The research seeks to identify and understand the Kingdom's disaster management policies in a comparison with similarly scaled Brisbane (Australia) floods of 2011 and the Christchurch (New Zealand) earthquakes in 2010 and 2011. The Japanese tsunami 2011 is also included for issues of scale on emergency recovery.

Several times over the last decade, Jeddah was subjected to inundation. Although situated on the western coastline of the Kingdom of Saudi Arabia, one of the driest places on Earth, the city lies on a flood plain along the Red Sea, and is periodically subjected to downpours as the tropical lows rise to clear the Hijaz range to the east. Whilst this phenomenon is well-known, by 2009 there had been years of respite, and lax planning allowed buildings and infrastructure to interfere with the wadi system (dry creek beds) that usually dispersed the flash floods across the plain to the sea. There were intense lows in November 2009 (123 deaths, 90mm downpour) and a larger 111mm event occurred with 10 deaths in February 2011 (Murphy, 2010; Swiss Reinsurance, 2012; Wagner, 2011). After the first catastrophe, response teams were widely criticised, as were government officials for their inability to lead during the crisis. This first chapter sets out the background to the Jeddah events, then introduces the research problem, research questions, contribution to knowledge, literature review, methodology and the flow of the thesis,

1.1 Context of investigation

Natural disasters were long considered as 'acts of God' and accepted as random events, usually to punish perceived misdeeds (Paradise, 2005). Eventually, as in the case of frequently flooded land, people learned to avoid areas that were subject to inundation. The communities began to limit the extent of the damage by digging out channels, erecting dams and bridges to avoid danger. This was the first approach, engineering, which began in the Arab region. Mays (2010) related that the Saad-el-Kafara (dam of the pagans), 30km south of Cairo, was constructed about 2650BC as the first large-scale dam for flood mitigation, although smaller dams in Jordan and

Mesopotamia preceded it. The Saad-el-Kafara failed during construction due to flooding, as there was no diversion channel, and was not replaced for another eight centuries. The second attempt resulted in a dam 14m high and 113m in crest length with a capacity of 500 megalitres (Mays 2010).

Controlling the Nile's seasonal floods protected the delta and provided for the country's agriculture. However, the Tigris and Euphrates, draining a large basin, produced floods that were unpredictable and destructive. Altinbilek (2004) described flood protection and drainage for the region as complex and of the utmost importance; nevertheless, despite the 13th century Mongol invasion which destroyed a large part of the canal system, this was not restored until the 19th century (Altinbilek, 2004).

Whilst all countries use dams and waterways for flood control and irrigation, the next step in flood control perspectives was social or behavioural. Burton, Kates, and White (1968) noted that authorities traditionally reacted to floods through technology or engineering: they built more dams, and widened and cleaned waterways. Burton et al. advocated for a social response of better planning of land use in flood-prone areas, terming this 'human ecology' to describe the human-environment relationship. Nevertheless, Paradise (2005) contended that the engineering solution remained dominant throughout the 20th century: more dams, better use of monitoring instruments and statistics, and improving the bureaucratic response to disaster planning and emergencies. This paradigm was derived from technology and capitalism (capital works and insurance to ameliorate disasters) and was not open to either large-scale human vulnerability or environmental effects from projects.

The third step was the developmental paradigm. This argument contended that poor economies cannot afford the massive engineering responses of developed nations and that disasters are caused largely by political and social systems which rank equally with natural events (Blaikie, Cannon, Davis, & Wisner, 2004). In this view, societies that are vulnerable to trade flows from poor to rich countries are forced to overuse their land and other resources. As well, rural over-population results in unplanned urban accommodation. According to Paradise (2005) the developmental paradigm was useful in producing a more balanced interpretation of disasters through mapping human vulnerability and socioeconomic conditions alongside geophysical risks when planning for disaster reduction.

1.1.1 The Jeddah events

Jeddah lies for about 50 km north-south along the narrow, low-lying Tihama coastal plain between the sea and the northern escarpment of the Red Sea Rift, the Jabal al-Hijaz, which reaches

1,000 metres. There are 11 significant wadis that cross the city and which are prone to flooding during the summer storms that occur between November and January. On 25 November, 2009 90mm of rain, twice the city's yearly average, fell in just four hours. By noon, the main Haramain expressway between King Abdulaziz International Airport and Makkah was closed, flooding underground road tunnels and stranding the pilgrims attending the hajj. The floods affected the southern poorer neighbourhoods of Jeddah and the areas around the Haramain expressway, including the King Abdulaziz University.

Saudi Arabia is an absolute monarchy, directed from Riyadh in the north-centre of the country and with offices in the main centres of the 13 Saudi provinces. Respondents to the disaster who had representation in Jeddah and could provide policy and financial support included Ministries of Civil Defence, Interior, Transport, Communications, Water and Electricity, and Health. The Regional Committee for Civil Defence was the coordinator for the emergency response for the 2009 floods, with the Municipality of Jeddah's traffic department, police, emergency services, communications and relief centres, and hospitals. Medical evacuations were provided by Red Crescent.

Jeddah is divided into administrative districts, each responsible for maintaining civic services including flood mitigation. Wagner (2011) reported that in the north of the city, the districts were well maintained and escaped the worst of the flooding, whilst in central Jeddah, Al-Azziyah, with low-income expatriate workers was badly maintained and affected by flooding. Wagner (2011) reported that 10,785 buildings were damaged and more than 10,000 vehicles lost. Momani and Fadil (2010) mentioned inadequacy with the disaster warning system and that Civil Defence was ill-prepared for the task. Besides the blocked stormwater drains, civic damage included electricity supplies and road and footpath construction. With evidence of sub-standard governance and *wasta* (nepotism), King Abdullah called for the prosecution of city officials and contractors (Murphy, 2010). However, in 2013, Alshehri, Rezgui, and Li (2013) reported low awareness and fatalism from the Saudi population, despite media coverage of the perpetrators, who were generally unnamed to protect their families.

In defence of allegations, the Director-General of Saudi Civil Defence stated that the organisation responded to the events appropriately, given that the bulk of their resources were concentrated in Makkah and Al-Madinah and in support of the army in the south of the country (Al-Harithy, 2010). Further, a news blackout was in place to stop public panic on the effects of flooding for the first few days of the disaster. Al-Saggaf (2012) said this was circumvented through social

media, which for the first time in the Kingdom was used to post pictures, including bodies in the flood, to report local events, and to call for action from volunteers.

On 26 January 2011, Jeddah received another rain event, 111mm, again with heavy flooding in east Jeddah; ten lives lost and significant damage to homes and infrastructure (United Press International, 2011). This time there was a prompt response from Civil Defence (Agence France-Press, 2011).

1.2 Research objective

The issue with rejuvenating emergency response organisations after a disaster is the effect of time. Catastrophic events, as described by Paradise (2005), produce public outrage, official enquiries, and organisational and administrative responses that may or may not be capable of addressing subsequent events. In the Saudi example, the time interval was another two years, May 2013, when the General Directorate of Civil Defence again responded to widespread flooding across the country that killed 16 people. Five people died in Riyadh (Asharq Al Awsat, 2013).

Better preparation for such events by the responsible authority depends on emergency response coordinators learning from each experience and incorporating that information into a model that can be applied by successive decision makers. The objective of this research is to develop a dynamic systems model as the appropriate vehicle to manage real time data, given the number of responsibilities (stakeholders) and organisations involved, and the unknown location and size of each disaster.

1.3 Research questions

The research question is: What is the existing disaster response system in Saudi Arabia and what is the optimum approach for the country? Jeddah floods are used as an example. This thesis is intended to provide a framework for many urban areas around the world at a similar stage in emergency preparation. Sub-questions are therefore:

1. What were the responsibilities of the various Saudi organisations during the 2009 and 2011 Jeddah floods, and how did they coordinate their activities?
2. What is the optimum national emergency relief framework?
3. What are the optimum operational strategies for emergency relief?
4. How can the effects of a disaster be mitigated efficiently and effectively?

1.4 Contribution to research and statement of significance

The contribution to research of this thesis lies in the use of a dynamic systems model to incorporate responses from government and non-government organisations. The model is intended to provide real time data from the various national and local teams and to use these to direct resources to repair infrastructure, gain access to victims, and evacuate. The model is considered more advanced than previous regional and discipline-related theoretical constructs by incorporating access and weather variables and giving it greater capacity for data and systems flows (cf. Alshehri, Rezgui, & Li, 2013; Besiou, Stapleton, & Van Wassenhove, 2011; Gonçalves, 2008; Keller & Al-Madhari, 1996; Momani & Fadil, 2010). This model is intended to be used by other researchers to explore further variables and incorporate these into organisation systems to improve its function.

The significance of this research is that it allows the General Directorate of Civil Defence more effective decision making through real time data from more response teams. Whilst a number of ministries are involved together with municipalities and non-government organisations, a comprehensive systems model allows input from several localised teams to allow them an overview of events and the actions of others that affect the immediate situation in their sub-system. This information, together with the local responses from several sub-systems, informs organisational response and ultimately, coordination at the executive level to inform the media and to arrange distribution of bulk resources. Currently, such potential data sources exist on several different systems within organisations, and would be physically transmitted and incorporated into the executive overview for Civil Defence. A dynamic systems model such as envisaged in this research allows faster data flows and greater accuracy for decision making. The model is also dispersed through its sub-systems and not subject to loss if the disaster also includes administration.

1.5 Research framework and theoretical bases

This introduction to the literature review considers emergency response, systems models and notes the available literature on Saudi disaster responses. Due to issues with statistical veracity in the GCC countries¹, the media is the preferred channel for government announcements. Therefore some commentary is included.

¹ Gulf Cooperation Council countries: Saudi Arabia, Kuwait, Bahrain, Qatar, United Arab Emirates and Oman

1.5.1 Emergency response approaches

Each country has an emergency response structure to coordinate local, regional, national or international responses. A large part of the United Nations' work includes response to international disasters, especially for emerging nations that are overwhelmed by the scale of the disaster such as the 2004 Aceh tsunami disaster. The responsible entity is the Office for the Coordination of Humanitarian Affairs (OCHA, 2013/2014), led by the United Nations Emergency Relief Coordinator. This organisation calls on member countries, including Saudi Arabia, to respond.

At a national level, Saudi Arabia has a coordinator for emergency response, the General Directorate for Civil Defence. Researchers investigated the response of the Directorate to the disaster, citing human error and a lack of clear public policy to respond to the suddenness and severity of the emergency (Momani & Fadii, 2010). Alamri (2011) stated that floods are a regular occurrence in Jeddah, due to its flood plain location; however there was little official response to prepare for such events, for example a dedicated emergency centre to call. Alamri (2011) and Alshehri et al. (2013), as noted, also pointed to Islamic fatalism as a leading factor in an absence of planning, where disasters are seen as inevitable or punishment for some wrongdoing. Qari, Jomoah, and Mambretti (2014), acknowledged this attitude, calling for effective flood risk management that included upgrading rainfall analysis, spatial identification of flood prone areas, and priority placed on safety and property. Other researchers investigated factors they saw at risk, often providing computer modelling: roadwork awareness (Ibrahim, Albatati, Batweel, Shilli, Bakeer, & Al Laban, 2013); road flood impediments for emergency crew access (Dawod, Mirza, & Al-Ghamdi, 2012); or new dams (Alnaheet, 2012). Further review shows that in the GCC, formal national emergency management systems were studied only in Oman (Al-Shaqsi, 2012).

1.5.2 Emergency response systems

Late last century, Tufekci and Wallace (1998) posited that emergency response measures required a holistic response. They introduced the concept of a 'systems view of emergency management that took account of both pre-existing policies and systems, and a post-event analysis of the unfolding operations and how they were managed by the various organisations. The authors advocated for increased use of technology and advanced communication protocols for the efficient use of data for decision making, and to lead to better performance for the next event through improving resource allocation, systems and team practices (Tufekci & Wallace 1998).

The call for further research on disaster response planning and its equivalents was taken up to the extent that Altay and Green (2006) surveyed over 100 papers in the field. They found that jurisdictional borders and autonomy issues of nations, states, regions and cities impacted adoption of superior response systems due to perceived risk and resources, among other factors. Even when fully implemented, policy formation and working practices remain suboptimal. It appeared that those policies that were least disruptive of existing operational routines were most successfully in being implemented. In systems modelling Altay and Green stated that design should incorporate space and time for significant disruption at the commencement of an event to communicate its nature to key operators and decision makers, wherever they may be. Next, whilst emergency response organisations respond to all disasters, the nature of each disaster has a specific pattern and involves member organisations differently. They allude to a traditional response to a mass casualty event such as the aftermath of a flood where the response teams move in; unlike an earthquake where risk of after-shocks where concentrations of response teams place them in further jeopardy. Teams may be dispersed to ensure their survival, and this disrupts resource delivery, routing, communications and evacuations (Altay & Green, 2006).

1.5.3 Dynamic systems modelling

Systems planning for emergency response incorporates many fields: logistics, communications and administration (Smith, 2013). Smith acknowledges the technological advances made in emergency response policies and practices over the years, but supports Altay and Green's (2006) observation regarding the human element and the eroding of commitment until the next event occurs. Gonçalves (2008) also advocated using dynamic systems modelling to include analysis of the emergency crews' response and later operations which could be used to enhance the capability of the coordinator. It was also a permanent program that could counter the effects of personnel changes and changes to organisational responsibilities.

As computer capacity grew, system dynamics methodology was applied to sub-systems of a dynamic system model envisaged in this research for a national disaster response coordinator. In resourcing national and international sites that could be expected to be at risk, Rawls and Turnquist (2010) developed a resources and transport network model that considers uncertainty in demand; Zhang and Xu (2010) established an adaptable forecast demand model, and Li, Ru, and Xu (2010) modelled reorder points for consumables. Franke, Charoy, and Ulmer (2010) and Besiou, Stapleton, and Van Wassenhove (2011) used dynamic systems models to analyse field vehicle fleet variables in humanitarian operations. Recently, Nourjou, Hatayama, Smith, Sadeghi, and Szekely (2013)

designed a Geographic (local) Incident Coordinator that integrated site information with artificial intelligence capability for a spatial intelligent coordinator system for emergency relief coordinators to improve decision making capacity and efficiency. Similarly, Magariño and Gutiérrez (2013) analysed case studies of coordination of messages during disaster responses, building a multi-agent-based approach to message networking. Realising the risk for inaccurate or biased entries into such data banks, Smari, Clemente, and Lalande (2014) incorporated a guarantee for privacy of attributes into a collaborative graphic tool that assists decision making in emergency response management. As computer capacity increases, the models researchers are building appear to become more comprehensive and interactive.

Dynamic network models prove effective for evacuation planning. Saadatseresht, Mansourian, and Taleai (2009) used models to plot evacuation routes in Iran, and Kongsomsaksakul, Yang, and Chen (2005) produced a model to determine the location of shelters along evacuation routes. Zhang, Liu, Zhang, and Wang (2010) posited that people could evacuate by foot or car to intermediate assembly points, a system widely in use in Australia for bushfire risk. In all, many researchers of diverse nationalities adopted systems modelling to analyse many aspects of emergency relief operations; however, as noted there is little investigation of the coordinating national organisations, or the use of modelling to develop their ongoing capacity and knowledge built up from experience of such events. It is the objective of this research to gather sufficient data from the literature, the government, the media and primary investigation to develop such a model.

1.5.4 Research response to Saudi floods

Flash flooding is a feature of desert terrain, and is the subject of investigation in several fields. In hydrology, Subyani (2011) studied flood risk in the terrain around Makkah, mapping areas of potential risk, especially during the hajj (pilgrimage). Investigating various aspects of the Jeddah floods, Al-Saud (2010) used satellite imaging to identify locations at risk of flooding and this was confirmed by Rose (2011) as Wadi Qous as the primary at-risk area, near the university and a major hospital. Al Saud (2011) questioned the siting of the flood abatement measures. Meteorological modelling for Jeddah's weather events was the focus of other research, including Alamri (2011) and Deng et al. (2013). Several other researchers mapped flood risk areas in the Kingdom, including Dawod et al. (2013) in Makkah; Bajabaa, Masoud, and Al-Amri (2014) for Wadi Al Lith, south of Jeddah; Al-Momani and Shawaqfah (2013) for Tabuk in the north of the country.

Major event warnings for the population were the subject of investigations by Alshehri et al. (2013), Momani and Salmi (2012) and Aljohani, Alahmari and Aseere (2011). Kumar (2013)

recently called for a comprehensive regional disaster management and prevention policy for the Gulf countries. Cultural impediments to evacuation, such as gender separation, were studied by Almejmaj, Meacham, and Skorinko (2014).

In all, Saudi researchers are exploring many elements of organisation, resource allocation, efficient evacuation, and prediction initiated by the Jeddah flood sequences. The current study adds to the literature in this regard.

1.6 Methodology

This research follows Jahre, Jensen, and Listou's (2009) call for theory development in emergency relief to understand logistics needs in different stages of a crisis through a mixed-method approach. It comprises a literature review and primary and secondary data collection to develop a system dynamics model for emergency response to answer the research problem (Badiee, Wang, & Creswell 2012). Systems planning included models to isolate elements of the disaster response (Özdamar & Demir, 2012; Sheu, 2009; Yi & Kumar, 200; Yuan & Wang, 2009). Gonçalves (2008), who suggested a multi-level systems dynamics model for national disaster relief, was of interest in the research design, in collecting qualitative data from the decision makers to understand the processes involved in the emergency response. In effect, Gonçalves' suggested model incorporated first the emergency response: the number of people requiring relief, the number receiving relief, and the shortfall in real time (as a process). As part of the model, the second system described the effectiveness of the coordinating agency in its capacity to provide relief (organisational capability), to replenish resources for operators to continue providing relief, or to regroup quickly after the disaster in preparation for future calls. This model was therefore selected as it tracks the relief effort across staff and volunteers, resource logistics, and rescues, showing locations, supplies and the need for replenishment.

The sample comprised the population: that is, those involved in disaster relief operations in Jeddah and its provincial capital of Makkah, in the province of Makkah. A decision was made to collect data by survey, as it was obviously difficult to identify key individuals over the years who actually responded to the events; individual public servants were not identifiable; those in Red Crescent and similar organisations were similarly difficult to identify. Yet there was a description for each responsible position in a given organisation, and the individuals occupying those positions were selected for their competence and knowledge. The questions on the survey were guided by

Bharosa, Lee, and Janssen (2010); Aitken, Leggat, Harley, Speare, and Leclercq (2012); and Hammad, Arbon, and Gebbie (2011).

Descriptive analysis was used for demographics to categorise the functions of the decision makers and the operators. A systems dynamics framework is constructed from causal loop diagrams (Simonović, 2011), stock and flow diagram (Sterman, 2001) and these are adapted to produce a national policy model planning for disaster relief (Deegan, 2005). Flow equations were informed by Georgiadis and Vlachos (2003) and Sterman (2001). In the quantitative analysis phase, control theory techniques (Jagacinski & Flach, 2011) were employed together with the statistical analysis, as noted (Altay & Green, 2006). Validation followed Bagheri, Darijani, Asgary and Morid (2010) and Bossel (2001). The systems model is developed through this methodology

1.7 Organisation of the thesis

This thesis comprises seven chapters. This chapter introduces the thesis, describing the context, research problem and the subsequent questions, and shows the contribution to the research and its significance in the literature. This is followed by a preview of the literature, the methodology and the setting for the thesis. The next chapter, 2, is the literature review, beginning with a discussion of systems planning for emergency response planning, and aspects of such response, including inventories, supply chains and other aspects of modelling a range of natural disasters. The various iterations of the vehicle routing problem, multi-commodity flows and communications and information sharing are described.

Chapter 3 moves to the United Nation's policy and operational capacity in international disasters, and its guidance for national disaster plans. The main non-government aid organisations are discussed, predominantly Red Crescent and Red Cross. This is followed by three case studies of the times: Japan's Tōhoku earthquake and tsunami; New Zealand's Christchurch earthquakes, and Queensland's Brisbane floods. The Saudi disaster management framework is described, coordinated by the General Directorate for Civil Defence, and the chapter is completed by the descriptions of the Jeddah floods. Chapter 4, methodology is described above. Chapter 5 comprises the results: the demographics, descriptive analysis, the quality of response (dependent variables) and quality of preparation (independent variables). The development of the dynamic systems model based on Gonçalves (2008) is presented. In chapter 6, the Emergency Logistics Centre capability model is tested with a range of iterations (scenarios) and a case study discussion using the Jeddah flood

sequences. Chapter seven answers the four research questions and discusses the outcomes of the model.

This concludes the introduction. The next chapter moves into the research, beginning with the literature review.

Chapter 2 Literature Review

Catastrophes occur frequently, with earthquakes in China, New Zealand, and Haiti; tsunami in Japan and Indonesia; fires in Australia, Europe and the United States; and devastating floods around the world. Some 500 natural disasters each year kill approximately 70,000 people and affect more than 200 million people worldwide and the cost of response and rehabilitation is incalculable (Duran, Gutierrez, & Keskinocak, 2011). Researchers and media reports show that in the majority of occurrences, emergencies on a large scale expose flaws in institutional response and collective behaviour, highlighting the social processes that characterise such events.

The scale of such disasters now prompts a global response, and governments and international organisations such as Red Cross, Red Crescent and Oxfam respond quickly to a catastrophe, bringing in emergency supplies and human resources. Researchers have also responded to the humanitarian crises, examining the preparation and execution of relief efforts. However, the new field of ‘humanitarian logistics’ is in its infancy, described by Overstreet, Hall, Hanna, and Rainer (2011) as emerging from logistics research, theory of constraint, and management information systems.

This chapter, which addresses the second research question (What is the optimum national emergency relief framework?) examines the literature for trends in the following dimensions of humanitarian logistics: planning and modelling, various models pertaining to the vehicle routing problem, other heuristic models relevant to humanitarian logistics, and finally the multi-commodity flow problem.

2.1 Literature search strategy

The literature review explored the systems planning processes for emergency crisis response centre functions. Keywords were humanitarian and logistics, supply and chains, emergency* and response, disaster and response, evacuation, path and selection, and path and deployment. Databases selected were EngnetBase, ProQuest, IEEE Xplore, SAE Digital, Google Scholar, databases. The parameters were 2000 to 2012. However, earlier references were included to explain antecedent, and after the literature search earlier in the research, continuous development in the field added post-2012 material when appropriate. Non-literature sources (secondary sources) included several government organisations, including the Saudi government, United Nations, international disaster response organisations, and news media.

Articles that focused on specific localised incidences, specific theoretical studies, and emergency response articles were excluded if the response teams' procedures differed, such as volcano, earthquake or fire. Sea flood (tsunami) or land floods were selected when possible, together with floods in economies which were aligned to Saudi Arabia, that is, undeveloped economies without emergency response centres were deleted. The counts from the various stages of the literature search are not included as the figures are not indicative of the final reference list (305 from all sources). Table 2.1 explains the initial working plan.

Table 2.1
Literature search criteria and results

Authors	Commercial logistics		Humanitarian and emergency logistics				
	Minimum operational cost	Penalty or weighting factors	Uncertain demands	Variable priority	Variable needs urgency	Multiple decision makers	Systems dynamic model
Toregas, Swain, ReVelle, & Bergman, 1971	x						
Haghani & Oh, 1996	x						
Tufekci & Wallace, 1998	x		x				
Fiedrich, Gehbauer, & Rickers, 2000		x	x	x			
Bryson, Millar, Joseph, & Mobolurin, 2002		x			x		x
Kasapoğlu & Ecevit, 2003	x					x	
Özdamar, Ekinci, & Küçükayazici, 2004			x				
Barbarosoğlu & Arda 2004			x				
Yi & Özdamar, 2007		x		x			
Yi & Kumar, 2007		x	x				
Chang & Hsueh, 2007	x	x	x			x	
Chiu & Zheng, 2007	x						x
Sheu, 2007	x	x	x		x		
Li & Tang, 2008	x			x			
Gonçalves 2008			x	x	x		x
Saadatseresht Mansourian, & Taleai, 2009		x			x		
Yuan & Wang, 2009	x			x			
Aslanzadeh, Rostami, & Kardar 2009	x	x	x				x
Besiou, Stapleton, & Van Wassenhove, 2009	x		x				x

Table 2.1 shows researchers' interests in emergency logistics as they developed the field in humanitarian recovery systems. Context is shown by 'x', 'minimum operational cost' refers to focus of the paper, and 'penalty or weighting factors' concerned the analytic procedure. The humanitarian and emergency logistics headings refer to the research variables or focus. This research follows the directions shown by Gonçalves (2008) and Besiou et al. (2009) in developing models for immediate response and long term maintenance of competence and capacity.

2.2 Systems planning

Systems planning precedes a response to a humanitarian crisis, and several researchers have offered logistics, management, communications and complex modelling systems to overcome the issues of resources, chaos, and aid (Beamon & Balcik, 2008; Aslanzadeh, Rostami, & Kardar, 2009). However, Beresford and Pettit (2009) use the Thai tsunami response to question the traditional approach of preparedness, response and recovery, noting that the Thai government was under-prepared and the scale of the disaster quickly overwhelmed supply routes and communications. The Thai government now uses a less rigorous model, based on local communication networks, early warning systems, and danger mitigation rather than placement of large scale emergency resource stocks. A summary of recent areas of research interest is presented in this section.

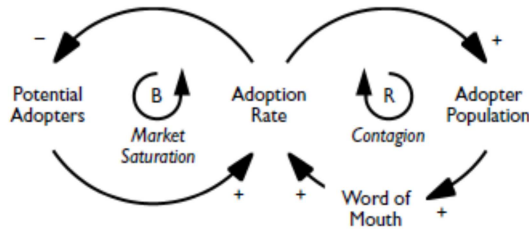
2.2.1 Humanitarian management

Whilst disaster relief of human and physical resources can be globally sourced, especially in emerging economies, the management of response activities at intra-and inter-organisational levels is generally the responsibility of the government of the host country. Franke et al. (2010) interviewed end users and found that such management is complex and further complicated by the dynamics of the unfolding events. The researchers proposed an activity centric pathway system for managing crisis response activities. Using agency theory, Li and Tang (2008) and Nikbakhsh and Farahani (2011) described behaviours in an emergency logistics system, developing a planning model towards achieving reasonable outcomes. Their framework included six dimensions, pollution, transport, epidemiology, weather, medical and rescue, and geology, integrating these functions into a core system to aid in managing humanitarian response.

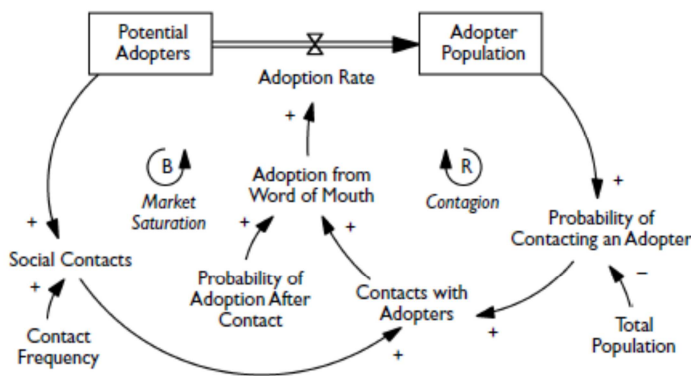
There are several theoretical approaches to facilitating humanitarian response scenarios. A system dynamics methodology was employed by Besiou et al. (2011) for humanitarian field management, which they note is characterised by multiple actors, uncertainty, time pressures and

resource constraints. According to the commentators, systems dynamics can accurately represent the dynamic complexity of these operations. Sterman (2001) described the process of systems modelling, using adoption rates, at figure 2.1 below.

1. Causal loop diagram



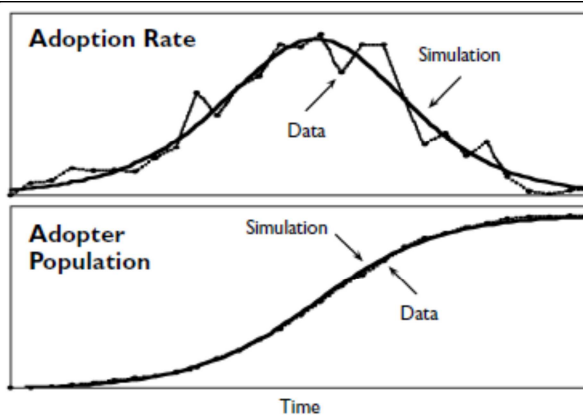
2. Causal diagram showing stock and flow structure



3. Model equations

$$\begin{aligned} \text{Adoption Rate} &= \text{Adoption from Word of Mouth} [+ \text{Adoption from Other Sources}] \\ \text{Adoption from Word of Mouth} &= \text{Contacts with Adopters} \times \text{Probability of Adoption After Contact} \\ \text{Contacts with Adopters} &= \text{Social Contacts} \times \text{Probability of Contacting an Adopter} \\ \text{Probability of Contacting an Adopter} &= \text{Adopters} \div \text{Total Population} \\ \text{Social Contacts} &= \text{Potential Adopters} \times \text{Contact Frequency} \end{aligned}$$

4. Simulation



Source Sterman 2001 pp.18-19.

Figure 2.1 Systems modelling

Figure 2.1 depicts a simplified systems modelling for adoption rates of a service or a good; however the flow and stock principles shown in the figure are valid for developing an emergency

response model. The causal loop in the first part of the model shows just two feedback systems, although there could be many more reinforcing and balancing systems such as a learning curve and economies of scale. If the feedback of the product is sufficiently attractive, word of mouth will stimulate further adoption through positive feedback. In an emergency situation, reports of extent of damage from the disaster site will generate a response from field quarters and thus headquarters, either lessening aid flow or increasing it (+ or -). The loop is self-reinforcing and has a loop polarity rate (R) and depicts the contagion rate for word of mouth. When the product is saturated (or the emergency response is optimal) the rate of increase slows, hence the positive polarity on the link from potential adopters to the adoption rate. The balance of feedback is thus denoted as B.

To develop the simulation model, part 2 of figure 2.1 augments the causal diagram by potential and actual adopters, or in an emergency model, potential and actual supplies. The flow indicator moves the stocks from the potential adopter population (potential supplies) into the adopter population (actual supplies consumed or used). Part 2 also widens the scope of word of mouth in the feedback loops. Equations are shown at part 3, and a simulation for a new computer model is presented as part 4 (Sterman, 2001).

Systems modelling was used by Donnelly, Lyons, and Flassak (2009) to detect air quality changes which occur during volcanic eruptions. Banomyong and Sopadang (2010) found the use of simulation modelling can help enhance the reliability and validity of emergency response models, whilst Altay and Green (2006) showed the potential for operations research in disaster operation management. In an empirical approach, Chou, Zahedi, and Zhao (2011) noted the value of the internet and websites for communication, data entry, information, and guidance in dealing with natural disasters. However, there is little known regarding contents and structures of internet information systems for natural disaster management. The authors used a grounded-theory approach and selected 100 disaster management websites containing 2094 elements to allow easy online access. Chang and Hsueh (2007) developed a geographic information system for flood emergency logistics planning. They utilised GIS for flood emergency planning by first collecting data and formulating the map and then obtaining information about predicted flooding locations, volume of flood water and quantity of rescue equipment, and finally calculating the shortest pathway for transport. To examine the feasibility of the proposed model, they applied it to Taipei City.

Of particular interest in this research, Gonçalves (2008) advocated for the use of systems modelling as an aid for successive managers of humanitarian relief organisations to estimate resources and flows in a dynamic environment. The dynamic systems model developed for the purpose, according to Gonçalves, allows for different values to be inserted at different nodes so that

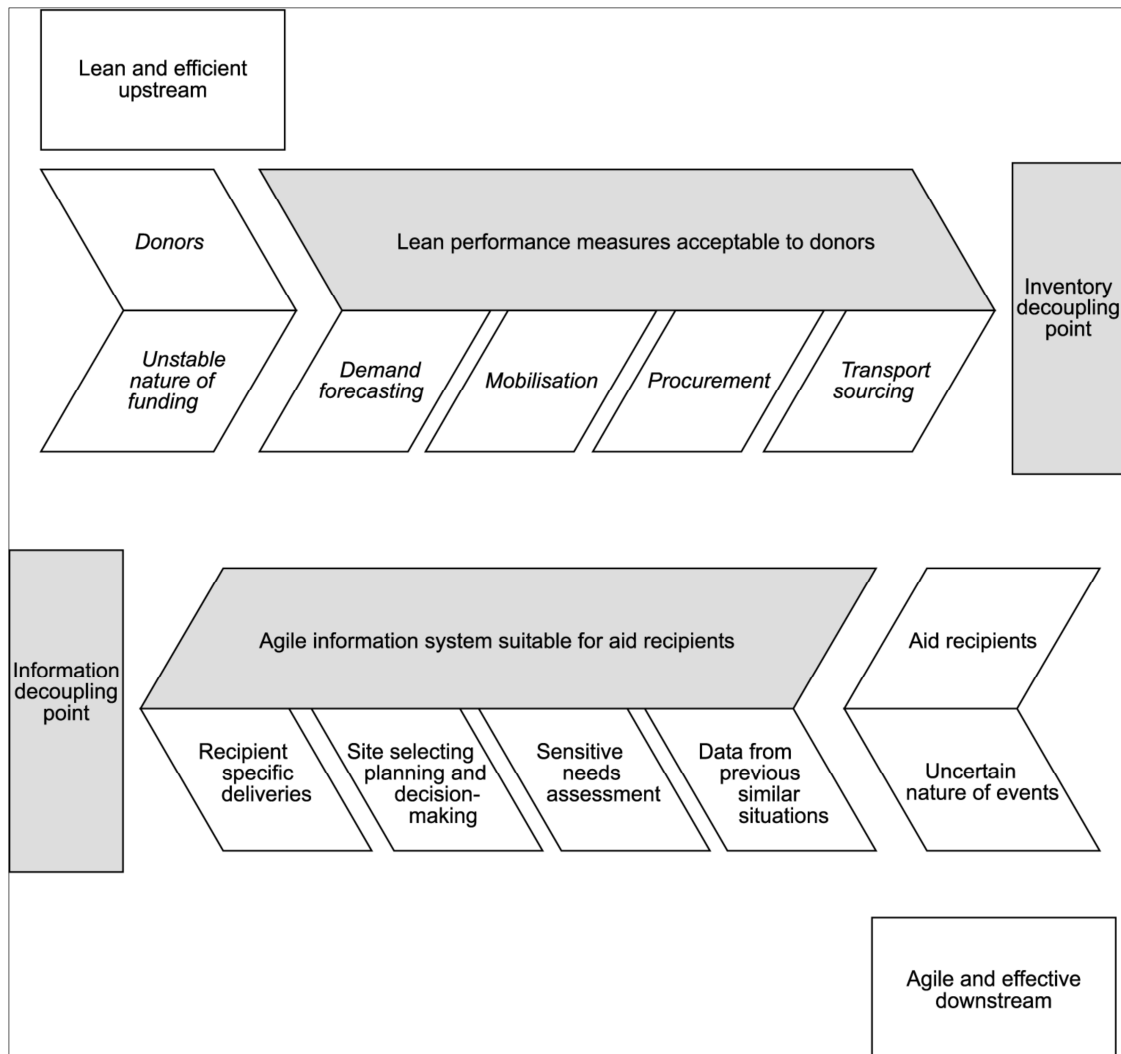
their effects on the model as a whole may be described. Whilst such models generally describe the capability of the organisation or the effects of the crisis event, Gonçalves combined the effects of the emergency response on the capability of the organisation itself, particularly its ability to replenish its resources and planning and decision making for future events.

Several authors developed models or programs specific to localised resources and networks. In an empirical study grounded in the United States' hurricane disaster zone, Tovia (2007) reviewed the existing operation policies to examine the efficiencies of the various responsible authorities and developed an emergency response model to suit the existing hierarchy. Meanwhile, new models on disaster management planning are emerging.

2.2.2 Supply chains

Humanitarian logistics, according to Maon et al. (2009), is too frequently based on a theoretical, two-part model based on the focus of the various disaster relief organisations: prevention and planning, then response and recovery. The authors investigated the aims of these community and public organisations as disaster relief supply chains and compared these with commercial practices, advocating for coordination between the two sectors to facilitate learning, strategy and coordination for the public and community sector in their supply chain management. Further, they considered that corporations should take the initiative in sharing supply chain and logistics expertise, technology, and infrastructure with relief agencies to demonstrate their good corporate citizenship. This followed earlier work by Van Wassenhove (2005), who stated that private sector logistics can improve the performance of disaster logistics; however, the core capabilities of humanitarian logistics differ from the traditional model. There are mutual learning opportunities for both sectors and the aspect of corporate social responsibility to consider: better preparedness for the humanitarian sector, and the need for supply chains to be agile, adaptable and aligned for the corporations' competitive edge.

'Agile' supply chains were selected by Oloruntoba and Gray (2006) as a solution to satisfying customer demand, the customer in this case representing donors. Humanitarian organisations must raise large amounts of funds at short notice to respond. Therefore, agility in the context of donor governments and organisations demand that the aid is specific to short term direct relief and distribution, rather than long term investment in infrastructure and systems. Oloruntoba and Gray conceptualise an agile humanitarian chain at figure 2.2 below.



Source: Oloruntoba & Gray 2006, p.117.

Figure 2.2 *An agile supply chain for humanitarian aid*

The shaded areas are areas where researchers can add knowledge to the model (Oloruntoba & Gray, 2006). The decoupling points are where a product in the supply chain ceases to be planned and becomes a customer (donor organisation) order. The first, inventory-based decoupling point is as far downstream in the chain as possible to meet the principle of postponement, and the information decoupling point should be moved as far upstream as possible. They ‘propose that the proper location of decoupling points for material and information flows can produce a hybrid supply chain that combines a lean and efficient supply upstream and an agile and effective supply downstream’ (Oloruntoba & Gray, 2006, p.117).

Recently, disaster planning supply chain management research has broadened its parameters, and taken a different approach. For example, Dash, Mishra and Mishra (2013) proposed

a disaster supply chain model that incorporates legal, structural, and administrative (that is, political-social-economic) factors as a model applicable to Asian disasters. There are instances of supply chains being treated as a series of problems. For example, Kumar and Havey (2013) developed their model by isolating different stages in the supply chain and, using fault tree analysis, applied variable risk levels to each stage before entering it into the model. In developing their fuzzy logic for transport in disaster planning in China, Zheng and Ling (2013) also divided their transport supply chain problem into three: air, land and water. They thus produced subcomponents which they solved simultaneously, bringing the results together as the model which is scalable, robust and effective. Melnyk, Narasimhan, and DeCampos (2014) used this approach to separate aspects of a supply chain, proposing influential factors, design decision makers, and the resources, or building blocks. They explained that supply chain designers understand these dependent levels. First they must analyse the influencers: the higher decision echelon such as government policy or the corporate business model; the public sector strategy or the business model employed; the organisations' projected (desired) outcomes; and the life cycle of the supply chain. The physical/structural design elements, social and behavioural decisions comprise the supply chain. Building blocks, or elements of a supply chain include transport systems, inventory, technology, and content capacity (Melnyk et al., 2014).

A social welfare chain model for a nongovernmental organisation was developed by Adivar, Atan, Oflaç, and Örtten (2010) that consolidates the non-integrated style of logistics functions with a cost minimising approach. The optimal solution resulted in significant cost reduction and distribution efficiency, incorporating using temporary distribution centres at no extra cost. Following Adivar et al. (2010), Bhattacharya, Hasija, and Van Wassenhove (2012) note that humanitarian logistics-based supply chains operate under funding constraints and restricted funds flows. They approached this problem as two independent aid programs where investments are of two types: a primary resource that provides the aid, and infrastructural investments that improve the aid operation. They established that a centralised procurement system with decentralised infrastructure investments perform with the same efficiency as a completely centralised system containing both elements. Bhattacharya, Hasija, and Van Wassenhove (2014) expanded on this model recently to provide policy recommendations, noting that by allowing resource providers flexibility in aid allocation, efficiency is improved. The model can be enhanced by establishing an administrator to buy from one resource provider and sell to another within the humanitarian system. Bhattacharya et al (2014) argued that this maintains decision making autonomy by the providers relative to the disaster at hand. This results in a centralised financial system within the aid event, yet

maintains the integrity of each organisation. The researchers maintained that this model is as effective as the supply chain for a single centralised system.

2.2.3 Emergency logistics inventory

Preparation for disasters, according to Rawls and Turnquist (2010), includes stockpiled resources at hand. To determine the location and quantities of various types of emergency supplies, the authors present a two-stage stochastic mixed integer program (SMIP) that provides for hurricanes or other disaster threats. The program is a robust model that considers uncertainty in demand for resources and the transport network availability after an event. Whybark (2007) studied inventories for disaster relief, finding little research on management, from acquisition through storage and distribution.

Using multiple linear regression analysis on historical case data and various emergency supplies, Zhang and Xu (2010) identified demand for various types of materials, then normalised it through the Euclidean algorithm. This established a model to forecast demand for various types of emergency materials in a given situation. A simulation example of the model verified it as valid. Li et al. (2010) used a similar model to determine the reorder point and reorder quantity for materials, also validating their model.

In a case study, Duran et al., 2011 examined CARE International's disaster response: its agility in mobilising supplies and effectiveness in distributing them. The researchers collaborated with CARE to provide a model to pre-position relief items to reduce the average relief-aid response time. The model assisted CARE managers to determine a desired configuration for the pre-positioning network, changing three sites around the world.

2.2.4 Evacuations

Dynamic network models prove effective for a range of logistic planning problems, with the quickest flow problem, with multiple sources and a single sink, commonly used to model the evacuation problem (cf. Hoppe & Tardos 2000). Evacuation planning is determined for a range of applications, from disaster emergency management to civil defence. In recent times, modelling extended to the evacuation of buildings, and this type of problem can be addressed as the network flow model or traffic assignment-simulation approach. As macroscopic models, network flow models do not consider individual differences and evacuees are treated as groups with common characteristics. Chalmet, Francis and Saunders (1982) earlier used a dynamic model on building evacuation, whilst in the same issue, Jarvis and Ratliff (1982) noted solutions for variables such as

arcs that plot room evacuation over time. In evacuation response, Hamacher and Tufekci (1987) focussed on minimising the total evacuation time; avoiding cyclic movements and priority evacuation were treated as lexicographical minimum cost flow problems. Choi, Hamacher and Tufekci (1988) extended the Chalmet et al. (1982) model by considering flow dependent capacities on arcs, whilst Hoppe and Tardos (1994) gave a polynomial time algorithm for the evacuation problem with a fixed number of sources and sinks. Lovas (1998) discussed network components, including population characteristics affecting evacuation performance.

Evacuation processes remain of interest to researchers. In Iran, Saadatseresht et al. (2009) determined the routes of evacuees to safe areas, using multi-objective evolutionary algorithms and the geographical information system. The researchers used a spatial multi-objective optimisation problem and identified two objective functions in solving the problem. Using a case study, the model was successfully tested. Galindo and Batta (2013) found that most articles dealt with the response phase of evacuation, followed by the preparedness and mitigation stages, while Altay and Green (2006) earlier found that mitigation was the most investigated.

In a similar action, Kongsomsaksakul et al. (2005) produced a location-allocation model for flood or storm evacuation to determine the optimum location of shelters; however, the evacuees can choose the shelter and the route they take. The problem uses bi-level programming, where first the locations are determined, then a combined distribution and assignment model was used to include the evacuees' decisions and pathways. Zhou, Liu, and Wang (2010) established the most effective siting of emergency shelters in the Tianjin city earthquake shelter location planning. Six earthquake shelters accommodate the population and minimise total distance. The results showed that the model can satisfy the planning requirement of urban shelter management.

In an interesting study on evacuation preparedness, Zhang et al. (2010) note that an urban traffic system can be employed in a no-notice evacuation events. Without flood or hurricane warnings, where urban or rural people can use their cars to evacuate, earthquake or terrorism events require urban people to leave the area by foot, then arrive at the evacuation shelter by public transit system. The authors used a two-phase optimisation model to solve this problem: evacuation by foot, then collection by public transit vehicles, including buses, taxis or cars and proved the efficiency of the solution through simulation.

2.2.5 No-notice events modelling

Large-scale evacuations from major cities occasioned by sudden events such as earthquakes have an impact outside the directly affected area. This includes emergency evacuation traffic and

accommodation and assistance for those affected. Auld, Sokolov, Fontes, and Bautista (2012) state that compared to events with advance notice, such as evacuations based on an approaching hurricane or a distant tsunami, the response to no-notice events relies on planning and general regional emergency preparedness. The authors used empirical data on individuals' responses to no-notice evacuation to construct an evacuee behaviour model for such planning. Again as an emergency response in no-notice events, Chiu and Zheng (2007) modelled for simultaneous mobilisation destination, traffic assignment, and departure schedule for multi-priority groups for a real time emergency response.

2.2.6 Path selection/optimal deployment

A large proportion of research is devoted to optimal deployment of resources in an emergency, more so than studies on evacuation pathways. In support of this statement, Yuan and Wang (2009) used two mathematical models for path selection to incorporate a greater number of variables into a program. The first model minimises total travel time on each arc, where the speed on each arc is continuously decreased. The second model is based on the first and introduces congestion, thus using a multi-objective path selection model to minimise the total travel time along a path and to minimise the path complexity. Özdamar and Demir (2012) used a hierarchical cluster and route procedure for coordinating vehicle routing in large-scale post-disaster distribution and evacuation. Their model is a multi-level clustering algorithm that groups demand nodes into smaller clusters at each planning level, enabling the optimal solution of cluster routing problems. The model preserved the consistency among parent and child cluster solutions obtained at consecutive levels; was assessed using large scale scenarios and found satisfactory.

Similarly, Yi and Kumar (2007) explored pathways for distribution and evacuation, using ant colony optimisation to plot stochastic vehicle paths and a network flow-based procedure to assign the different types of vehicle flows and the resource capacities. Sheu (2009) proposed a relief demand management model for emergency logistics operations for Cyclone Nargis in Burma (Myanmar) and the Sichuan earthquake in 2008, with relief demand management inadequate due to lack of reliable information. Later, Sheu (2010) produced a dynamic relief-demand management model under imperfect information conditions for emergency logistics operations in large-scale natural disasters. The procedure consisted of data fusion to forecast demand from different areas, fuzzy clustering to classify groups in the area affected, and multi-criteria decisions to allocate priorities among the groups. Tests resulted in overall forecast errors of less than 10 per cent,

inferring the model's capacity for dynamic relief-demand forecasting and allocation with imperfect information.

2.2.7 Disaster management systems

Manufacturing processes in the form of workflow management systems are an emerging interest for disaster workforce planners. Hofmann, Sackmann and Betke (2013) advocate the use of elements of workflow management systems in the dynamic environment of disaster response management to address challenges of rapidly changing resources and actions, and their condition, location and time. Hofmann et al. refer to adaptive workflow management systems, which they propose provide flexibility and improved management, for example, designing the system to incorporate geographic imaging systems and real time analysis of situational resource flows.

Real time information is the subject of many other models. For example, Preece, Shaw, and Hayashi, (2013) developed a viable system response model to order information processing to improve the quality of the information which is affected by merging data flows from systems into the primary disaster model. Crooks and Wise (2013) used crowdsourced data from social media to identify those most in need of assistance and to understand the nature and extent of the devastation to assist the disaster response managers. Similarly, Peters-Guarin, McCall, and van Westen (2012) used local knowledge of flood hazards, forecasting models and risk scenarios embedded into geographic information systems.

In India, Phalkey et al. (2012) studied the early detection of flooding and the capacity of the rural healthcare system to cope with casualties. A flood in 2008 overwhelmed the primary healthcare services in Jagatsinghpur, Orissa state and this was used for the study. The researchers found that despite the regularity of flooding, there was no preparation of disaster planning at the 29 healthcare centres, no clear lines of command, and no access to contingency funds for use in local emergency response. Phalkey et al. also advocated for contractual arrangements to be put in place to aid emergency supplies of living needs such as feed and supplies for domestic animals. Strong primary healthcare systems, as the authors state, provide an important centre for services and distribution to the affected population.

2.2.8 Predictive systems

In Europe, Alferi et al. (2012) studied preparedness for potential flood zones. They noted that nations were moving towards risk abatement strategies to minimise the impact of catastrophic events on their populations through the use of early warning systems. Graded weather predictions are instrumental in triggering flood-related warning systems in many countries, allowing progressive alerts for communities and disaster response managers to commence primary

preparations for their operations. The systems assessed by Alferi et al. from the European Commission included slowly spreading water, fast flooding and debris detectors; then landslips and mudflows caused by heavy rain events. This regular evaluation, they noted, was instrumental in promotion of innovative system enhancements, detection of possible system failure, and using new material into training courses to improve crew skills and team coordination.

Predictive systems include primary healthcare systems, which provide valuable individual data regarding casualties and survivors of a disaster. These systems could be strengthened, according to Aung and Whittaker (2013), as a source of data for disaster response management. Aung and Whittaker pointed out that costs of system enhancements could be distributed amongst agencies that shared the data and end-user functions. This notion was adopted on an international scale by Kussel, et al. (2012), as a pilot project, that integrated data management and support systems for monitoring floods in Namibia, using computation clouds, sensorwebs, and grids. The scale of this system is such that it crosses international borders, following the path of the potential flood across the southern African continent. The system may also be used for disease control, leading to risk maps on flood and disease.

In urban areas, lack of disaster preparedness leads to devastating consequences in terms of communities, livelihoods, and infrastructure. Interestingly, in a Ekurhuleni, South African case study, Fatti and Patel (2013) argue that residents' perceptions of local government capability and lack of robust governance, whilst the officials, cite a number of issues: resources and interlinking responsibilities with other agencies. Thus there is potential for the regional government and the population to seek a more productive environment to plan and work together in addressing future catastrophic events.

Studying another emerging economy, Vietnam, Schad et al. (2012) sought information regarding the repetitive nature of some disasters for the local population, and persistent refusal to prepare for the next. Evidence suggests that individual farmers believe that water management failure (the government) and the unpredictability of occasional flood events curbs their flood mitigation intentions. Their own land management and that of their neighbours did not enter into their beliefs. Thus national governments should support local governments in promoting soil conservation through the interactions of land use and hydrology as part of flood mitigation policy.

2.2.9 Hazard assessment systems

Commenting for the United Kingdom's Royal Society, Vörösmarty et al. (2013) stated that although rural populations in flood-prone areas confront a greater risk than urban populations, there

is increasing risk to urban areas through rapid urbanisation. The notion of climate change or global warming concerned many researchers, such as Scheid et al. (2013) mapping risk areas in Hamburg, Germany. In Nanjing, China, Wu et al. (2013) developed a sediment analysis system for a flood hazard assessment model based on a variable fuzzy recognition model for the lower Yangtze River. The result was that flood hazard assessment based on the variable fuzzy recognition model although consistent with the results calculated by the projection pursuit model, was simpler and visual. Thus the Wu model should be capable of greater analytical use of flood sediment, thereby improving the scope and results for determining current, old and ancient flood risk areas.

The effects of rapid urbanisation across flood plains concerned Wright (2014). Wright explained that flood risk is derived from complex conditions concerning rain events, topography, and drainage networks. The intensity of floods is compounded in urban locations as compared with that occurring in less populated areas. However, as Fatti and Patel (2013) state, this may be affected by the country's level of disaster planning. Wright studied decades of weather events at Charlotte, North Carolina and Atlanta, Georgia using high-resolution rainfall data and analysis to identify flood risk validated through rain gauges and cross-referencing this with stream flows and topology. Wright found that the effects of rainfall events changed at both sites and were affected more by water channelling 'rather than changes in the properties of extreme rainfall' (Wright, 2014, Abstract). However, the timeframes and the nature of the urbanisation (houses with gardens, higher density flats, paved roads and gutters) remained a challenge. Extreme rainfall events over Charlotte were used to construct 'storm catalogues' used to estimate local storm area reduction factors from the conventional area reduction factors. It was found that conventional reduction factors cannot identify the properties of extreme rainfall and this finding has implications for assessing flood risk. Applications of a stochastic storm transposition and the gridded surface subsurface hydrologic analysis models found issues with existing analyses of several predictive models, including expected rainfall duration and intensity. Wright developed a simple storm classification system to describe the rainfall events at Charlotte. When extrapolating the data into these models, the researcher concluded that model uncertainty, climate trends using relatively short simulation periods and natural climate variability remain issues in predicting catastrophic storm events.

In Egypt, with relatively similar desert conditions to the Arabian Peninsula, Ghoneim, and Foody (2013) noted that flash floods occurred with relative frequency in the wadi El-Alam basin in the Eastern Desert. Ghoneim and Foody (2013) also used hydrological modelling to predict the occurrence of flash flooding. They found that a flood peak at the primary outlet required at least 40 mm rainfall. Other factors concerned the location of rainstorm, as the nature of the topography

created more dangerous flows in the higher reaches of the basin than the same effect of rain in the less elevated terrain. The permeability of the surface, rock, vegetation or urban development also affected the nature of the flooding. The model developed by Ghoneim and Foody (2013) is applicable to similar rapid assessment of such hazards in mountainous desert such as the Hijaz mountains.

2.2.10 Section summary

Crises do not fit into a pattern, and disaster relief is no exception. There are several approaches to humanitarian logistics and these can be characterised as type and size of the disaster, its location, and preparedness and response of the accountable entities. These points are widely recognised in the broad literature on systems planning. This study is concerned with a specific type of organisational response to floods in Jeddah, so that the problem has alignment within the broad field of humanitarian logistics. For example, location and size of the disaster can be estimated for flood relief, as the flood inevitably follows a severe rain event in a catchment. Further, whilst breakdowns in communications occur due to the disaster, Saudi Arabia has a robust emergency response system and direct command chains and responsibilities are clearly defined. Yet these matters are post-disaster; people die or are hurt in a few seconds, whereas the work of placing resources effectively to secure the area and manage the catastrophe takes considerable time.

Systems planning discussed in this section are the theoretical responses of researchers to isolate elements of the disaster, resources and routes into the area, and the removal of people through evacuation. The east Asian researchers in their largely no-warning zones of disaster (earthquakes, tsunamis) advocate that victims can leave. This is problematic; one would expect that able-bodied survivors would attempt to rescue those less fortunate and those hurt would be unable to flee. However, there are elements of path selection relevant to this research, as the catchment areas above Jeddah or along the coast can be ascertained and various extreme events modelled from these. It is then a matter of selecting the best fit of the many models that researchers trialled for Jeddah's emergency response organisations.

For this study within the discipline of transport and logistics research, the literature review therefore focuses on the vehicle routing problem (VRP) in both static and dynamic versions, the multi-commodity network flow problem, and dynamic networks. Studies using exact and heuristic solution approaches to these problems are also discussed as they are relevant to this thesis. These aspects of disaster management are discussed in turn.

2.3 Vehicle routing problem

The vehicle routing problem (VRP) was first introduced by Dantzig and Ramser (1959) in the 1950s. The problem concerned the ‘optimum routing of a fleet of gasoline delivery trucks between a bulk terminal and a large number of service stations supplied by the terminal’ (Dantzig & Ramser, 1959, p.80). The authors were seeking the means of delivering one or more products to each service station, and the problem was to assign stations to trucks to satisfy demand and minimise travel. Dantzig and Ramser (1958, p.80) used linear programming to be ‘performed by hand or by an automatic digital computing machine’. Developing the Dantzig-Ramser approach, Clarke and Wright (1964) published an algorithm based on the savings concept, termed the classical vehicle routing problem. Following the two seminal papers, the field opened up through the introduction of logistics and many models and exact and heuristic algorithms were proposed for the optimal and approximate solution to different versions of the VRP. These are discussed below.

2.3.1 Problem formulations

There are three disparate basic VRP modelling approaches in the literature. The most frequently mentioned is the vehicle flow formulation, which uses $O(n^2)$ binary variables associated with all arc in the single vehicle version, and $O(Kn^2)$ in the multi-vehicle version. The next, commodity flow models, were first introduced by Garvin, Crandall, John, and Spellman (1957) for the oil delivery problem and later extended by Gavish and Graves (1982) to variants of TSP (the travelling salesman problem) and VRP. These formulations require a set of continuous variables associated with commodity flows in addition to those used by the vehicle flow formulations. The last modelling approach is the set-partitioning problem that uses an exponential number of binary variables, each of which is associated with a different feasible circuit of network. This was originally proposed by Balinski and Quandt (1964).

Researchers present several variants of the basic version of the VRP that are based on these formulations. The restrictive assumptions of the problem are often relaxed to accommodate more realistic settings: VRP with pickup and delivery (VRPPD) and VRP with split delivery (VRPSD) are most relevant to the emergency logistics problem. In VRPPD, vehicles are not only required to deliver goods to customers; they also pick up return loads for recycling at customer locations. Simultaneous pickup and deliveries are common in the emergency logistics setting, where some goods are delivered to affected areas from depots and injured people are picked up and transported back to medical centres. The standard definition of VRPPD necessitates that the customer is only

visited once. The problem was solved by Min (1989) using clustering followed by TSP solutions. Gendreau, Guertin, Potvin, and Taillard (1999) solved the TSP first and then ordered the pickups and deliveries. Nagy and Salhi (2005) established a weak solution first that includes total load delivered or backhaul (pickup), not vehicle capacity, and then removed infeasible variables. Multi-depot extension was also introduced to this problem by the authors. A close variation of simultaneous pickup-delivery is the mixed pickup-delivery problem (Golden, Baker, Alfaro, & Schaffer, 1985; Kontoravdis & Bard, 1995, Salhi & Nagy, 1999). Similar to the simultaneous pickup-delivery problem, maintaining the feasibility of vehicle capacity is difficult in this problem since available capacity fluctuates on the tour. The solution approach improved in Nagy and Salhi (2005) for simultaneous pickup-delivery problem also applies in this instance. Shin (2009) noted that research on VRPPD increased due to pickup demands for packaging and used product returns from customer locations due to new environmental regulations, and that integrating pickups with deliveries maximises vehicle capacity. This limitation for the planning problem increases travel distances or the number of vehicles, through deliveries made first which then allowed space on the truck for pickups, mixed pickups and deliveries, and simultaneous pickup and deliveries. Trucks are now side-and back-loaded so that rearranging delivery loads onboard is no longer a requirement, allowing for mixed pickups and deliveries model in which deliveries and pickups may occur in any sequence on a vehicle route. A VRPPD solution is feasible only if the following conditions are satisfied: delivery-feasibility and pickup-feasibility which means that the balance of freight does not exceed the maximum capacity of the vehicle; and load-feasibility, which means that the maximum capacity of the vehicle is not exceeded at any point on the route. Ropke and Pisinger (2006) transformed all backhaul (pickup) problems into a given generic form and proposed a unified heuristic based on insertion and removal moves, and large neighbourhood search with probabilistic move acceptance scheme. Hyytiä, Häme, Penttinen, and Sulonen (2010) used the VRPPD problem based on a separate vehicle allocated immediately upon the arrival of the request. The use of dynamic policies that define how each customer is managed with a fleet of vehicles required extensive simulations. The authors developed a model for studying the performance of a large scale system with different policies under given trip requests. Their problem reflects the use of ambulances as calls are received from rescuers.

A special case of the simultaneous pickup-delivery problem (VRPSDP) occurs where the customers are either delivery (linehaul) or pickup (backhaul) nodes and linehaul customers are accommodated first (Deif & Bodin, 1984; Goetschalckx & Jacobs-Blecha, 1989; Osman & Wassan, 2002; Toth & Vigo, 1997; Yano, Chan, Richter, Cutler, Murty, & McGettigan, 1987). Proposed

solution approaches include saving methods, set covering, VRP plus insertion, clustering and routing, and tabu search. Lu, Dessouky, and Leachman (2004) proposed a branch and cut based algorithm for the multiple vehicle version of this problem. With the goal of minimising number of routes and total travel costs, Bent and van Henterynck (2006) proposed a simulated annealing approach for assigning customers to vehicles first and then construct feasible tours by large neighbourhood search. Karaoglan, Altıparmak, Kara, and Dengiz (2012) proposed a simultaneous pickup and delivery approach to solve a small-scale and a large-scale problem. They found that a flow-based formulation performed better than a node-based formulation in terms of solution quality on small-size problems, although the reverse was true for larger scale problems. Kanthavel, Prasad, and Vignesh (2012) similarly attempted to solve VRPSDP by developing an algorithm of a nested particle swarm optimisation as master and slave particle swarm optimisation (SPSO) to solve the problem. The algorithm generated a feasible candidate list and developed an optimum set for the vehicle route. To solve a generalised vehicle routing problem for minimising the total cost of a flexible sized fleet, Afsar, Prins, and Santos (2014) recently used an exact method for column generation. In this problem, each cluster is visited once, and the total load is delivered to one node. Afsar et al. state that using column generation provides adequate upper and lower bounds. Similarly, Battarra, Erdogan, and Vigo (2014) used an exact algorithm for the capacitated vehicle routing problem; again with grouped clusters. This problem concerned an integer programming formulation with an exponential time preprocessing scheme.

Finally, a survey on such dynamic routing problems as on-line requests for picking up and depositing customers and maintaining capacity on cyclical trips (dial-a-ride) was undertaken by Gendreau and Potvin (1998). Of the solutions proposed are branch and price (Savelsbergh & Sol, 1998), clustering (Ioachim, Desrosiers, Dumas, & Solomon, 1995), insertion heuristics (Madsen, Ravn, & Rygaard, 1995; Diana & Dessouky 2004.), local search (Healy & Moll, 1995), simulated annealing (Hart, 1996), and tabu search (Gendreau, Laporte, Musaraganyi, & Taillard, 1999; Cordeau & Laporte 2003). Whilst the concern of the dial-a-ride problem is cost, Paquette, Cordeau and Laporte (2009) considered quality of the ride for the disabled. However, these iterations assume constant vehicle availability, which is incorrect in an emergency, hence split delivery limitations regarding vehicles and loads are valid in the ELP.

In split delivery, a customer can have repeat visits if demand exceeds vehicle load capacities. Dror and Trudeau (1989) showed split deliveries could result in significant savings in distance and vehicle number, whilst Dror, Laporte, and Trudeau (1994) developed an exact constraint relaxation branch and bound algorithm for the VRP split delivery. Frizzell and Giffin

(1995) included multiple time windows and grid network distances. Ho and Haugland (2004) proposed a tabu search based heuristic where the split delivery options are decided by a pool of solutions. Several studies have shown the benefit of split loads as applied to the split delivery vehicle routing problem and the pickup and delivery problem with split loads using heuristic methods; however, Nowak, Hewitt, and White (2012) applied an exact solution method on a constrained version. In this problem, all origins to be visited must be served before any destination on each route. The authors developed a dynamic programming formulation of the pickup and delivery with split load.

Specific emergency applications for VRP include communications. Zhou, Li, and Roy (2011) used a single cell 'pigeon' network to manage continuous traffic in lieu of discrete calls, broadcast ability instead of one-to-one, and dual role of a node as both source and destination of messages. The aim was to minimise the average delay of messages, which was achieved through sectoral region partitioning. Milburn and Wardell (2012) followed this with model for evaluating imperfect information when routing supplies for disaster relief. They used two constraints: maximising the population numbers and minimising response time in the use of social media streams to inform routing and resource allocation decisions immediately after a disaster. Berkoune, Renaud, Rekik, and Ruiz (2012) recently developed an efficient genetic algorithm to deal with realistic situations that is sufficiently fast to be used to provide high-quality transport plans to emergency managers. Similarly, Afshar and Haghani (2012) proposed a model that combined vehicle routing and pick up or delivery schedules, and also finding optimal locations for temporary facilities. The model included constraints for each facility and the transportation system as a centralised operations plan. In a complex system, Uddin, Ahmadi, Abdelzaher, & Kravets (2013) developed a protocol for disruption-tolerant networks to minimise the energy required for mobile communications in disaster-response applications. Power and infrastructure were assumed to be intermittent or absent. Uddin et al. envisaged a system that exploits naturally occurring contact patterns formed by survivors, and rescue workers and volunteers, and their transport to attain adequate deliveries to disaster scenes. Their routing protocol identifies relatively reliable routes and estimates delays and through this, forwards the goods and curtails myriad messages across the network on progress of the deliveries.

2.3.2 Heuristic solutions

The importance of combinatorial optimisation (CO) problems has attracted research solutions, classified either as exact or approximate algorithms. Exact algorithms find an optimal

solution for every finite size instance of a CO problem in bounded time, yet, for CO problems that are NP-hard (Non-deterministic Polynomial-time hard), no such polynomial time algorithm exists. Further, the VRP has been shown by Lenstra and Rinnooy Kan (1981) to be NP-hard. The largest VRP instances that can be solved so far contain about 50 nodes; larger instances can only be solved to optimality in particular cases (Toth & Vigo, 2002). Several families of approximate methods for the VRP have been proposed over the last decades: basic approximate methods and metaheuristics. For basic approximate methods, researchers generally use either fast constructive algorithms which build toward new solutions by adding components to an initially empty partial solution until a solution is complete; or local search algorithms which start from an initial solution and define the environment of a solution. Local search algorithms perform a limited exploration of the search space and can be extended to incorporate real life situations efficiently (Golden & Assad 1988, Toth & Vigo 2002).

Another form of approximation is metaheuristics (Glover 1986) and this includes ant colony optimisation, genetic algorithms, simulated annealing and tabu search. Blum and Roli (2003) opined that simulated annealing and tabu search are ‘intelligent’ extensions of local search algorithms. The purpose of these algorithms is to move beyond local minima to explore the search space for other locations for minima. Ant colony optimisation and genetic algorithms implicitly or explicitly try to find correlations between decision variables to identify higher quality areas in the search space; this type of metaheuristics essentially performs a biased sampling of the search space. Metaheuristic forms focus on deep exploration of promising regions within the solution space. In this way, they achieve solutions of higher quality than obtained by classic heuristic algorithms; however, they require greater computer resources, defined parameters and are usually context dependent (Renaud, Laporte, & Boctor 1996). After a review of extant research, Taillard, Gambardella, Gendreau, and Potvin (2001) demonstrated that metaheuristics with memory evolved towards a unified problem-solving approach from which they proposed a unified view, termed adaptive memory programming.

Among the metaheuristics applied to the VRP, tabu search was of early interest (Osman, 1993; Taillard, 1993; Gendreau, Hertz, & Laporte, 1994; Rego & Roucairol 1996). Taillard (1993) obtained benchmark results and introduced a decomposition method for the main problem, suited for parallel implementation. Further, Osman (1993) showed tabu search superior to simulated annealing. Genetic algorithms used by Baker and Ayechev (2003) and Prins (2004) were competitive with tabu search and simulated annealing, with the latter implementation better for large-scale instances generated by Golden, Wasil, Kelly, and Chao (1998).

The ant colony optimisation, a metaheuristic algorithm was developed by Dorigo, Maniezzo and Coloni (1996) for the travelling salesman problem. The ant colony is a multi-objective function problem, and the method coordinates the activities of ants in a colony, each of which is optimising a different objective. The ants use independent pheromone trails and collaborate to exchange information. The approach by Dorigo et al. (1996) was more effective than Rochat and Taillard's (1995) tabu search, the large neighbourhood search of Shaw (1998), and the genetic algorithm of Potvin and Bengio (1996). The rank-based version of the ant system was applied successfully to the vehicle routing problem by Bullnheimer, Hartl, and Strauss (1999) using various standard heuristics to improve the quality of VRP solutions, including modification of the tabu list, including constraints on the maximum distance and capacity of the vehicle. Bell and McMullen (2004) and Gambardella, Taillard & Dorigo (1999) also applied the ant colony optimisation to a more realistic logistic VRP with time windows. Ant colony optimisation was also successfully applied to other problems, including the quadratic assignment problem (Gambardella et al., 1999; Maniezzo & Carbonara, 2001) and the scheduling problem (Merkle & Middendorf, 2002). With the travelling salesman problem, Kaji (2001) and Tsai and Tsai (2002) used hybrid variants with tabu search; however, with large TSP instances, they used genetics evolution and nearest neighbour search. Wassan et al. (2013) noted the lack of research on backhaul with the mixed vehicle routing, and they utilised an ant system heuristic to solve their problem. This has application in a disaster with the issues of evacuation and moving materials from node to node. Wassan et al. focussed on placement of their vehicles and the nodes, visibility forward, and strategies for updating immediate and global trails, successfully using the model to test benchmark data sets.

This analysis shows that the search space in the ELP is more relaxed than commercial routing models, and the number of alternatives in a local neighbourhood increases significantly. Thus local search based methods may not be the most effective in this problem. Instead, the population-based metaheuristics seem more promising due to their highly effective exploration scheme of large search space. Moreover, as an extension of traditional construction heuristics, the ant colony optimisation (ACO) solution framework is readily available for both the diversification on vehicle paths building and the efficiency of commodity dispatch to deal with the complexities of the ELP.

2.4 Multi-commodity flow problem

Of interest to researchers, network flow problems are an area of combinatorial optimisation. Kennington and Helgason (1980) state that specialised network simplex algorithms can solve

minimum cost linear programming problems with pure network structure with greater efficiency and speed than the general linear programming algorithm. Because of the efficacy of the network model, researchers accept that under conditions of large instances methods based on the embedded network structure are more efficient than the standard linear programming algorithm (Aderohunmu & Arosen 1993). Multi-commodity networks arise in practice when more than one type of commodity must share arc capacities in a network. In some applications, the flow variables in the model can be fractional; in other contexts, however, the variables must be integers. In integer multi-commodity network flow problems, integer variables are an area of research. Since the linear programming model may be a good approximation of the integer programming model, or the model may be used as a linear programming relaxation of the integer program and embedded within branch-and-bound or some other type of enumeration approach, the literature on linear multi-commodity flow problems is discussed below, with its integer counterparts following.

Direct approaches to the multi-commodity flow problem consist of exploiting the special block-network structure of the constraint matrix. The solver can be either simplex-based or use interior point methodology; the other popular approach is based on decomposition, that is, Lagrangian relaxation approach, and column generation scheme. Other solution methods proposed for the model include primal-dual heuristics (Barnhart & Sheffi, 1993) and approximation algorithms (Goldberg, Korb & Deb 1998; Bienstock, 1999). In addition, the solvability of the linear multi-commodity flow problem has been largely developed (Castro, 2003).

Simplex-based methods have special structures and primal partitioning techniques (Ahuja, Magnanti & Orlin 1993) and include the more efficient code EMNET (McBride 1998, Mamer & McBride 2000) and PPRN (Castro & Nabona, 1996). EMNET includes superior tuning of pricing and heuristic for obtaining an initial feasible point. Mamer and McBride (ibid.) also demonstrated an efficient pricing strategy where a new decomposition based pricing procedure results in enhanced performance. Use of interior point methods for solving large multi-commodity flow problems was studied by Kamath, Karmarkar, Ramakrishnan, and Resende (1993), Resende and Veiga (1993), Resende, Pardalos, and Li (1996), and Castro (2000, 2003). However, results are inconclusive among interior point algorithm and simplex-based solvers.

Decomposition approaches on both linear and integer multi-commodity flow problems were addressed by Ahuja et al. (1993), Chardaire and Lissner (2002), and Larsson and Yuan (2004). Lagrangian decomposition methods are widely applied, where Lagrangian multipliers (or price) are used so that the resulting problem decomposes into a separate minimum cost flow problem for each commodity (Holmberg & Yuan 1996). Frangioni and Gallo (1999) also successfully used a cost

decomposition approach to the problem, providing similar performance to the bundle-methods-based algorithm. However, Larsson and Yuan (2004) found the comparison among the simplex-based solvers and decomposition methods depended on implementation and the problem sets. Babonneau, du Merle and Vial (2006) applied the analytic centre cutting-plane method to solve the Lagrangian dual problem, resulting in acceleration on the large problem instance in comparison with the augmented Lagrangian algorithm proposed in Larsson and Yuan (2004).

Solutions for large linear multi-commodity flow problems are used in commercial applications, such as fleet management problems (Cheung & Powell 1996, Powell & Carvalho 1997), network design problems (Lamar, Sheffi & Powell 1990; Holmberg & Yuan, 2000), and capacity expansion (Chang & Gavish, 1995). In Holmberg and Hellstrand (1994), an efficient solution method based on Lagrangian heuristics and branch and bound was developed for solving the uncapacitated network design problem formulated in integer multi-commodity flow problem, and Holmberg and Yuan (ibid.) adopted a similar approach was adapted to the capacitated version of the same problem. Gendron and Crainic (1994) studied different relaxation schemes with heuristics for multi-commodity network design problems. Applied to an integer program, Dantzig-Wolfe decomposition is a reformulation of problem to provide a tighter linear programming relaxation bound and is another approach for finding the correct price for multi-commodity flow structures (Desrosiers, Dumas, Solomon, & Soumis, 1995; Desaulniers, Desrosiers, Dumas, Solomon, & Soumis, 1997; Barnhart, Johnson, Nemhauser, Savelsbergh, & Vance, 1998; Vanderbeck & Savelsbergh, 2006). Jones, Lustig, Farvolden, & Powell (1993) investigated the Dantzig-Wolfe decomposition and showed that the path-based formulations by decomposition outperform the equivalent tree-based formulation. Barnhart, Hane, and Vance (2000) presented a column-generation model and branch-and-price-and-cut algorithm for origin-destination integer multi-commodity flow problems. Holmberg and Yuan (2003) extended the basic multi-commodity flow model to include side constraints on paths in telecommunication applications, and a column generation method was efficient in solving the model for large networks.

A third form, the resource-directive decomposition method, allocates mutual capacity among the commodities and then re-allocates the capacity to improve the overall system cost (Kennington & Shalaby, 1977). Applying computational comparisons of Ali, Helgason, Kennington, and Lall (1980) to these three methods, resource-directive decomposition is less efficient than the other two.

2.4.1 Dynamic network flows

The need for dynamic network models leads to the development of dynamic network flow in this section, where time is included to accommodate travel through each arc. This is the case in the emergency logistics problem, where the objective is to minimise delay of services. Ford and Fulkerson (1958) introduced time to the maximum flow problem, using binary search. Burkard, Daskin, and Klinz (1993) showed that the quickest flow problem is related to the maximum dynamic flow problem and to linear fractional programming problems. The generalisation of the quickest flow problem as the quickest transshipment flow was proposed by Hoppe and Tardos (2000) as a dynamic network with several sources and sinks; each source with a certain supply and each sink with a specified demand. A polynomial algorithm for this problem was posited to solve the problem in the minimum overall time.

The literature on general dynamic flow problems includes a survey to 1985 by Aronson (1989) that concentrated on the maximum flow and transshipment problems in discrete time. Powell, Jaillet, and Odoni (1995) focused on dynamic modelling issues with discrete time settings and stochastic parameters, whilst Kotnyek (2003) gave an overview of dynamic flow problems and solution techniques. To study evacuation plans, Hamacher, Heller, and Rupp (2013) used location analysis and dynamic network flows, using exact algorithms to solve the single facility version. They described their model as nodes which were rooms or cross-streets in a building or a region to be evacuated, and edges as doors or street, proposing a heuristic for q-FlowLoc and a mixed integer program. Location analysis was introduced as a new technique in evacuation modelling, as it is important to identify the optimum site for vehicles or facilities for efficiency and time minimising (Hamacher et al. 2013).

2.4.2 Comparison of discrete and continuous modelling

Time modelling in dynamic network flow research considers discrete time steps and continuously monitored time. Discrete research typically uses the time-expanded network, either explicitly in algorithms or implicitly in proofs to produce theoretically or practically efficient algorithms (Ford & Fulkerson, 1962). Research on the continuous approach considers networks with time-varying capacities and costs for optimal solutions whilst generalising the model (Fleischer & Tardos, 1998; Hall, Hippler & Skutella, 2003). Whilst there are practical solutions for discrete time problems, theoretical results occur for continuous time problems which are reduce to discrete time (Kotnyek 2003). Hence, this research focuses on the discrete time model for dynamic emergency logistical planning.

2.4.3 Systems modelling post-disaster

There is little research interest in post-disaster modelling, and this has consequences for disaster response organisations who require financial and physical resources and competency training maintained at a high level for an optimum response. Of those who have investigated disaster response from a systems modelling approach, Ramezankhani and Najafiyazdi (2008) studied a location-specific earthquake zone in Iran, where the city of Bam was largely destroyed in 2003. Their approach was to build up a dynamic system to simulate the disaster response teams' activities in the zone after a subsequent earthquake within the relevant fault lines. They developed a series of models specific for search and rescue teams, medical teams, food supplies, transport, and building debris removal, which were incorporated into a general systems model. However, this model was specific also to the response teams, not to recovery or maintaining response capacity after a disaster.

In a contemporary paper, Gonçalves (2008) as noted, proposed that disaster relief organisations could use system dynamics modelling to assist planning and maintain response capacity. Because of the nature of disaster responses as complex systems with substantial dynamic inputs, long time delays, multiple feedback effects, and nonlinear responses to decisions; simulation modelling can assist with relationships among variables, time-dependent results from decisions, and allow the exploration of new strategies. Models may be constructed with many variables, such as Ramezankhani and Najafiyazdi (2008) used, but on an organisational level rather than a response level.

Other disaster relief models at a national level were developed by Pettit and Beresford (2005) in regards to military-non-military response, and Helbing (2012). Helbing noted the cascading effects of large-scale disasters, which occur through non-linear and/or network interactions. The effects of the disaster spread in many different fields, such as disease, and the collapse of trust and civil order in the face of overwhelming adversity. Systems modelling can be used to identify sources and drivers of systemic risks post-disaster and these show that linear, intuitive, or experience-based approaches may not capture the functioning of social and economic systems. An inability to react to external factors in decision making can lead to under-control and failure to establish a strong response, leading to unwanted side effects, and sudden paradoxical shifts. Using a dynamic systems approach allows anticipation of events, avoidance, or for decision-makers to mitigate systemic risks and certain disasters resulting from them.

2.5 Communications and information sharing

In all emergencies, communications are vital to managers and operations. Data flows are critical to rescue operations and telecommunications are among the first systems to fail in an emergency. There are several categories where communications failure may occur, and this section reviews the literature in this regard.

2.5.1 Communication issues

In a review of the literature, Bharosa et al. (2010) found that despite the progress in disaster management over the years, information sharing and coordination remain barriers to effective operations. Their assessment is shown at table 2.2.

Table 2.2
Overview of information sharing and coordination problems

Coordination level	Perspective being adopted	Typical problems
1. Community	Institutionalisation and political power between actors, Inter-organisational interdependencies and collaboration procedures	Organisational silos, no incentives for horizontal information sharing, conflicting role structures, mismatch between goals, independent projects, lack of meetings, standardisation/interoperability, heterogeneous systems
2. Agency	Organisational procedures, division of roles, tasks and responsibilities, standards, values and rules	Reliance on protocols, focus on vertical information sharing, allocation of responsibilities, contact persons, privacy, security and authentication
3. Individual	Human cognition/perception of uncertainty and time pressure, Personal propensity to adopt innovations	Information overload, inability to determine what should be shared, misinterpretation of information, bounded rationality, prioritisation of own problems, information quality, system quality, access limit

Source: adapted from Bharosa et al. (2010). p. 52.

Table 2.2 provides three levels for communications and data sharing, community (government agency or crisis centre), agency, and individual. For the government/community level, collaboration is constrained by the various organisations and their disparate goals in responding to the crisis and possibly the lines of communication that require one responsible person to respond to the crisis centre, rather than lateral responses between the disciplines of each contributing organisation. Further, each agency is restricted to its protocols and its individual responsibilities, that is, according to various tasks to certain groups or individuals. Finally, communication failures

among individuals and an attempt to gain information rather than passing it along constrains communication flows (Bharosa et al. 2010).

2.5.2 Alerting stakeholders

In the health field, Goodwin (2013) noted that, in an emergency, alerting and summoning responsible people for decision making is critical. In the United States, Goodwin assessed response times for state health agencies' emergency preparedness finding that in 7 per cent of recorded events critical time targets were not met, and that the majority of jurisdictions recorded at least one event where timelines failed. These failures occurred due to issues of organisation structures, communication channels and staff. Whilst the organisation and communications issues were reduced, staff issues increased as they had their mobile phones turned off against instructions to have them on at all times.

In Saudi Arabia, Azim and El-Semary (2012) assessed the vulnerability of the Saudi National Fibre Network against regional failures caused by a disaster. The researchers used simulations which found that the Fibre Network is at risk from large events, especially Riyadh and Al Madinah which can be isolated even for events such as an earthquake that has a small shock radius. They recommend that support communications be put in place to reduce the risk, especially with the main centre connections.

2.6 Chapter summary

In planning for disaster response, the magnitude of each event appears to defeat the efficacy of aid distribution to those who most need it. Despite national foreknowledge of the effects of disasters, maximum preparation, and the prompt response of physical and human resources to a site, seemingly these actions are still inadequate in mitigating the effects of overwhelming and chaotic situations. There are several logistical reasons for this: the country's disaster response framework, the preparedness of the emergency teams, the geophysical conditions and proportions of the disaster, the unpredictability of the course of events, and the vulnerability and numbers of people involved. Grounded in specific places and times, data collection from the disparate and unfolding events could allow predictions of the path of destruction, more effective communications and targeting of aid, including routes open for delivery from distribution centres. System modelling takes this a stage further, allowing robust models to be developed that can respond on a sectional basis and to real time data flows.

In this research, a range of theoretical and practical approaches were considered to find pathways or models which best address the problem of responses to Jeddah's emergency agencies to floods or catastrophic events. It was found that due to the relatively quantifiable nature of natural disasters, which on the Arabian Peninsula desert are unlikely to be fire or earthquake, then flood paths and human disasters such as aircraft crashes or terrorism remain the most likely sources of disaster. In this case the continuous approach to the multi-commodity flow problem will be addressed through the use of the discrete time model for dynamic emergency logistical planning.

The systems models assessed in this literature review concern researchers' models to address perceived gaps in governments' responses to disasters, such as Beresford and Pettit's (2009) analysis of the Thai tsunami, or theoretical models, such as agency theory (Li & Tang, 2008; Nikbakhsh & Farahani, 2011) to describe behaviours in an emergency logistics system. However, system modelling can explain the dynamic complexity of these operations (Sterman, 2001). Other researchers used systems modelling for a variety of purposes; Donnelly et al. (2009) for events relating to volcanic eruptions; Altay and Green (2006) and Banomyong and Sopadang (2010) for emergency response models. Gonçalves (2008) further developed model theory to take into account the management of humanitarian relief organisations to allow values to be inserted at different nodes to estimate their effects on the whole model.

Other models for partial explanation of the dynamics of emergency planning and execution use supply chains (Oloruntoba & Gray 2006) and Dash et al.'s (2013) extension of supply chain logistics into policy and administration. Kongsomsaksakul et al. (2005) and Zhou et al. (2010) used systems models for evacuation planning. Other approaches include no-notice planning Auld et al. (2012) and path selection/optimal deployment (Özdamar & Demir, 2012). Disaster management systems were developed by Hofmann et al. (2013), Preece et al. (2013) and Crooks and Wise (2013) for social media communications. Predictive systems model for risk, such as Alferi et al.'s (2012) potential flood zones and Fatti and Patel's (2013) country readiness in disaster planning. Model selection and explanation are presented in chapter 4.

Chapter 3 National Emergency Response Plans

Situated on a coastal plain backed by a mountain range, Jeddah was flooded after heavy rain on 25 November 2009. As the desert city extends across numerous wadis off the escarpment, it is prone to flooding after exceptional storms; however at twice the city's yearly average, 90mm of rain fell in just four hours on that day. By noon, torrents struck many parts of the city, especially the poorer southern neighbourhoods where thousands of vehicles were caught in a traffic jam trying to escape. The death toll was variously reported at 123 and 161, with damage to 8,000 homes and over 7,000 vehicles. The consequences of the floods drew criticism for wastewater management, flood mitigation and emergency response from the various responsible Saudi government organisations (Assaf, 2010).

This, the contextual chapter, discusses the Kingdom's disaster management policies prior to the 2009 floods and this is undertaken in comparison with countries also prepared and capable of emergency response. In this discussion, the Jeddah emergency structures and their responses in the 2009 and 2011 floods are taken in context to the 2011 Brisbane (Australia) floods, and the Tōhoku (Japan) tsunami, whilst the other possible natural cause of disaster in Jeddah could be earthquake, which also meets the Tōhoku criteria, and that of the disaster that befell Christchurch in New Zealand in 2010 and 2011, where the ground was liquefied. Once the various response structures are presented, the outcomes from the four disasters, although not comparable in magnitude, can be explained. First, the international response system is examined, with the hierarchy that commences with the United Nations, and then the global aid agencies are briefly surveyed to establish their position in a Kingdom of Saudi Arabia event. Four case studies are presented to compare responses with that of the Kingdom, and therefore the governance structures of each are presented, as this explains the various national approaches. This is followed by the Japanese, New Zealand, and Queensland emergency administration structures and their responses to the 2011 and 2012 emergencies. Saudi Arabia's structure and the events pertaining to the floods are presented.

3.1 International response system

The international response system to a disaster includes neighbouring countries, altruistic countries, specialised regional and international organisations such as Red Cross and Red Crescent, Islamic Relief Worldwide, Médecins Sans Frontières, Oxfam, Catholic Relief Services and Care. These primary organisations are presented below.

3.1.1 United Nations

The United Nations Disaster Assessment and Coordination (UNDAC) is part of the Office for the Coordination of Human Affairs (OCHA), an international sudden-emergency response system that was established in 1993 to coordinate international relief at the national level and possibly at the site of the emergency. The UNDAC system comprises four components: experienced staff from donor countries; defined coordination structures for facilitating assessments and information management; deployment of UNDAC teams that can be deployed within a matter of hours and are provided on request free of charge to the disaster-affected country; and equipment for self-sufficiency in the field (OCHA 2013). In this model, the United Nations is emulating a national response from a developed economy, or an international response to a large-scale disaster or from a country with ineffective response systems.

The organisation itself also provides an effective model for continuous improvement for international and national agencies. It has a strategic framework comprising three goals:

A more enabling environment for humanitarian action, where the organisation seeks partnerships with United Nations members in support of humanitarian action; strengthened operational relationships; improved communications with these organisations; and a research and learning environment.

A more effective humanitarian coordination system to manage and support accountable coordination leaders; to respond quickly with clear triggers for establishing, phasing and drawing down operations; systematic coordination of the program cycle (needs assessment and analysis, joint planning, fundraising and resource allocation and monitoring and evaluation); improved predictive and scalable suite of response services

Strengthened organisational management and administration: effective financial, budgetary and resource management and reporting; improved recruitment, deployment and retention of qualified and diverse staff (OCHA 2013).

The OCHA responsibility structure is of interest in its approach. Its Humanitarian Reform of 2005 introduced improved capacity, predictability, accountability, leadership and partnership using a cluster approach. A cluster is developed when there is clear humanitarian needs, very many organisations are involved working in shelter and health, and when national authorities need coordination support.

Clusters provide a clear point of contact and are accountable for adequate and appropriate humanitarian assistance. Clusters create partnerships between international humanitarian actors, national and local authorities, and civil society (OCHA 2013 Cluster coordination).

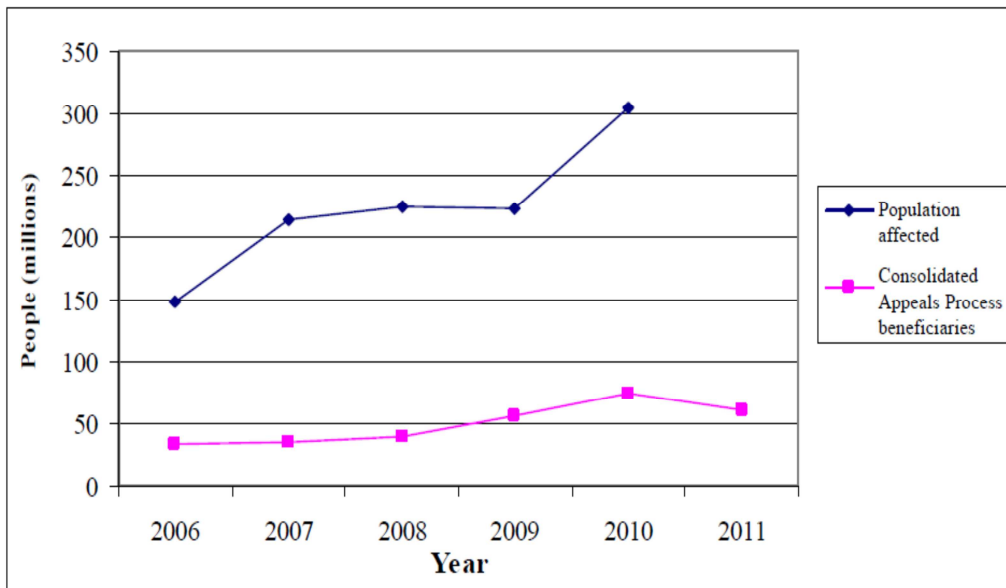
The United Nations' own cluster system is depicted in figure 3.1.



Source OCHA 2013 Cluster coordination

Figure 3.1 *Disaster management approach: clustering*

The Office’s operational structure comprises several elements. The first response is a ‘surge’: a swift deployment administrator who manages the establishment or expansion of facilities for the Disaster and Coordination teams following. This is then supported by an Onsite Cooperation and Coordinator Centre that performs the national-international communications and coordination linkages. Further there is an international framework of organisations experienced in urban and rural search and rescue systems, and planning and preparation functions for OCHA (OCHA 2013). Figure 3.2 indicates the extent of OCHA’s responsibilities.



Source: United Nations Economic and Social Council, 2013

Figure 3.2 *Humanitarian needs arising from natural disasters, 2006-2011*

There are regional organisations which use the resources of the UN in this regard. Relevant to this comparative study, the Asia Disaster Reduction Centre is a consortium of 29 countries from Yemen to Japan, established in 1998 to build capacity across Asia in the event of disasters. Advised by the United Nations and assisted by the United States, France, Australia and New Zealand, it maintains a database for disaster mitigation structures and procedures, providing a forum, skills, training and support in times of crisis (Asia Disaster Reduction Centre 2012).

Of interest to this study, OCHA developed a partnership structure for needs assessment after an emergency. Coordinated needs assessments are planned and carried out in partnership by specialist organisations that document the impact of a particular crisis and identify the needs of affected populations. Credible and accurate assessments assist strategic planning and system-wide monitoring. A Multi-cluster/sector Initial Rapid Assessment (MIRA) Manual was developed that outlines a joint multi-sector assessment from the earliest days of a crisis and guides subsequent in-depth sectoral assessments. This is supported by a Humanitarian Dashboard that facilitates a consolidation of needs assessment and response information, provides a structured format for the collection of data, and presents a shared analysis of a humanitarian situation. This is being implemented by non-government organisations, UN agencies and governments, with broad academic and technical input into the assessment framework.

The United Nations system is important to Saudi Arabia as it is providing guidelines and structures for intra-national emergency response systems as well as of interest in meeting the

Kingdom's humanitarian obligations in the region and internationally as a member of the United Nations. The United Nations was originally focussed on a coordinating role between international aid and the national government where it would be expected that public sector systems would be breaking down under the strain of the disaster. However, over the last decades it has taken a hands-on role in providing aid and resources, and is now returning to its coordinating and communications role in producing manuals and recording devices for the donor countries to facilitate rebuilding the site of the disaster and restoring livelihoods. This is a perennial issue for victims of tragedies; that people whose lives are affected by disaster cannot easily return (Fritz et al., 2012).

3.1.2 Red Cross and Red Crescent

An international medical conference initiated by Henry Davison, an American Red Cross member, resulted in the League of Red Cross Societies in Paris in 1919 after World War I, when millions of volunteers in the various countries had built a large body of expertise. In 1983 it was joined by Red Crescent and in 1991 the organisation became the International Federation of Red Cross and Red Crescent Societies (IFRC). The first goals were 'to strengthen and unite, for health activities, already-existing Red Cross Societies and to promote the creation of new Societies' (International Federation of Red Cross and Red Crescent Societies (IFRC) (n.d.)). The International Red Cross and Red Crescent Movement is now the world's largest humanitarian network, neutral and impartial, and providing assistance to people affected by disasters and conflicts. It has 97 million volunteers, supporters and staff in 186 countries, responding to catastrophes around the world. Its relief operations are combined with disaster preparedness, health and care activities, and the promotion of humanitarian values. Its goals include the reduction of the number of deaths, injuries and impact from disasters.

The scale of the IFRC's work was made evident two years on from the 2011 Fukushima earthquake and tsunami. In immediate response to the disaster, Japanese Red Cross medical teams deployed across the country, treating nearly 90,000 people. Since then, the Red Cross is assisting 135,000 displaced families resettled into temporary homes, rebuilding damaged health infrastructure and building temporary medical facilities. Five hospitals and medical centres were constructed with Red Cross support, 300 vehicles donated to support transport needs for welfare institutions, and nearly 1,000 special beds for the elderly. However, at March 2013, more than 300,000 remain displaced (IFRC 2013, 11 March).

International organisations and governments support the Federation as well as their national societies. The European Commission's humanitarian aid department is a major donor to the IFRC's

Disaster Relief Emergency Fund, contributing 3 million euros for grants to national societies for small-scale disasters and health emergencies globally. In 2012, the Fund allocated EUR 14.2 million to assist 12 million people subject to small-scale disasters (IFRC 2013, 6 March).

Red Crescent is also active in Saudi Arabia, and has a significant presence during the annual hajj (pilgrimage), where the society provides support at Makkah and Al Madinah, supplying 1000 paramedics, 500 ambulances, an air ambulance fleet, and 154 seasonal medical centres (IFRC 2012, 29 October).

3.1.3 Other international aid agencies

There are several international humanitarian aid organisations. This section presents Care, Islamic Relief Worldwide, Médecins Sans Frontières, Catholic Relief Services, Save the Children Foundation and Oxfam.

CARE is a large private humanitarian organisation, headquartered in Atlanta, GA, with an international confederation of 12 member organisations (including Australia) committed to helping communities in the developing world. CARE began as an aid organisation, delivering food packages to Europe after World War 2, now continuing emergency aid to survivors of war and natural disasters. The Emergency and Humanitarian Assistance Unit works to ensure those in distress receive food, water, shelter, healthcare and other emergency relief supplies and assists communities recover and rebuild after disaster strikes. In all, the organisation assisted 22 million people worldwide in 2011, spending \$626 million, 26 per cent on emergency relief and rehabilitation. Private contributions were 49.5 per cent of that amount (CARE 2013).

The United States-based Catholic Relief Services was also part of the World War 2 relief effort, and now forms an emergency response organisation that in 2011 provided \$US835m for aid, 35 per cent of which went to emergency response funds, including Japan and Haiti (earthquake) Pakistan and the Sudan. The Catholic Relief Services do not have a network of affiliates, so that their funds are raised in the United States and distributed in donor countries. They have a low administration rate of 5 per cent.

Islamic Relief Worldwide was founded in 1984, is based in Birmingham, England, headquarters for 12 organisations, including a branch in Australia. It has seasonal tasks such as distributing food to the poor during Ramadan, and it also assists people affected by war or natural disasters, regardless of religion, ethnicity or gender. The organisation provides training manuals for disaster response preparedness, mobilising resources for relief, protection and recovery, building

partnerships, and develop local capacity in 30 countries. Islamic Relief raised £86m (\$AU125.4m) in 2011, about half to disaster relief. Areas of operations were Arab Spring countries, Pakistani floods, Haiti earthquake, Iraq (war), food security and water in East Africa, and continuing flood relief in Sri Lanka and Bangladesh (Islamic Relief Worldwide 2013).

Médecins Sans Frontières claims to be the leading independent organisation for medical humanitarian aid, as it 'limits' the amount of funding accepted from governments. More than 80 per cent of the organisation's budget internationally is from private donations; in Australia, for example, it is 100 per cent from private sources. Médecins Sans Frontières provides relief after natural disasters such as floods or earthquakes, amongst other medical aid. The organisation is also involved in training local medical staff and providing safe drinking water and sanitation facilities. The organisation was established by French doctors in 1970 in response to humanitarian crises in Africa. The Australian organisation has a strong presence, raising some \$AU54 million for projects around the world in 2011, generally in Africa (Médecins Sans Frontières, 2013).

Oxfam, established in 1992, is also an international confederation of 17 organisations networked together in more than 90 countries responding to ongoing humanitarian aid, including emergencies. The Oxford Committee for Famine Relief was established in 1942 to respond to European starvation emergencies. Oxfam is now a world leader in emergency relief, and delivering long-term development programs in vulnerable communities. They join with other international humanitarian organisations in advocating the end of unfair trade rules and demanding better health and education services for all. In 2010-2011, the Australian Oxfam attended 30 emergencies around the world, and assisted 7.15 million people in 29 countries. They had 761 employees in 12 countries (Oxfam International 2013, Oxfam Australia 2013).

Save the Children is another international organisation where an affiliation of 30 member organisations (including Australia) works to deliver change to children in 120 countries. In 2011, the international budget was \$US1.6billion, thus it is double the size of the next comparable aid organisation, although fundraising and administration is high at 19 per cent. The group has extracted (then) future funding from the United Nations of \$US4 billion. Income is derived primarily from governments, foundations and individuals and in 2011, Save the Children primarily delivered food and support in drought-prone East Africa and for Afghanistan. The group responded to 53 crises in 2011, including Japan, the Philippines, Cambodia and Ethiopia (Save the Children 2013).

3.1.4 Summary of aid agencies

The United Nations organisations coordinate international relief, and in the last decade have developed a sophisticated system to bring world aid efficiently to the site of a catastrophe. As this requires the permission of the government, such as Pakistan's with their second flood in 2011, the United Nations system is also of value in preventing unnecessary mobilisation where a government does not request assistance, and in coordinating the various government and non-government organisations when assistance is required.

The extensive aid agencies were largely developed from war situations in Europe and have grown in the ensuing sixty years into the world's disaster support system, bringing knowledge and resources to where it is needed and providing support over time for reconstruction, generally to developing nations. In the case of governments that can manage a disaster, such as Japan's Tōhoku earthquake and tsunami, aid is generally in the form of expert assistance: humanitarian such as international search and rescue teams, and scientific advice regarding the Fukushima nuclear plant melt-down. Further, aid in the form of cash and resources can be delivered to individuals and families by international organisations with a presence in the country, such as Red Cross, Catholic Relief Services, and Save the Children in Japan. In this manner, international advice and contractual assistance was used by Jeddah Municipality in responding to the 2009 and 2011 floods as risks were reassessed and flood plain as planning regulations and flood control infrastructure were established.

3.2 National disaster response plans

Each nation has a framework of emergency response plans. With federations, such as United States of America and Australia, this task is devolved to a regional level so that the federal government has a guiding role and each autonomous regional (state) government devises a plan and implements it (Sahin, Kapucu, & Unlu, 2008). This is effectively what happened with the Queensland floods, where the Queensland government had full responsibility (Queensland Floods Commission of Enquiry 2012). On the other hand, Japan has a unitary form of government, where the central government has control over its regions, rather than the federation style. There is thus a high level of organisational and policy standardisation among the 47 local prefectures (Japan-guide.com 2013). Similarly, New Zealand has a centralised form of government, with 16 regional councils that are largely directed from Wellington (New Zealand Parliament.com). The Kingdom of Saudi Arabia is also a unitary form of government, with total control over its 13 provinces (figure 3.3).



Source Royal Embassy of Saudi Arabia 2013

Figure 3.3 Map of Saudi provinces

Within the context of the differing jurisdictions, each country is discussed in relation to its emergency plans and structures in effect at the time, the context of the disaster, and the result.

3.2.1 Japan: Tōhoku earthquake and tsunami

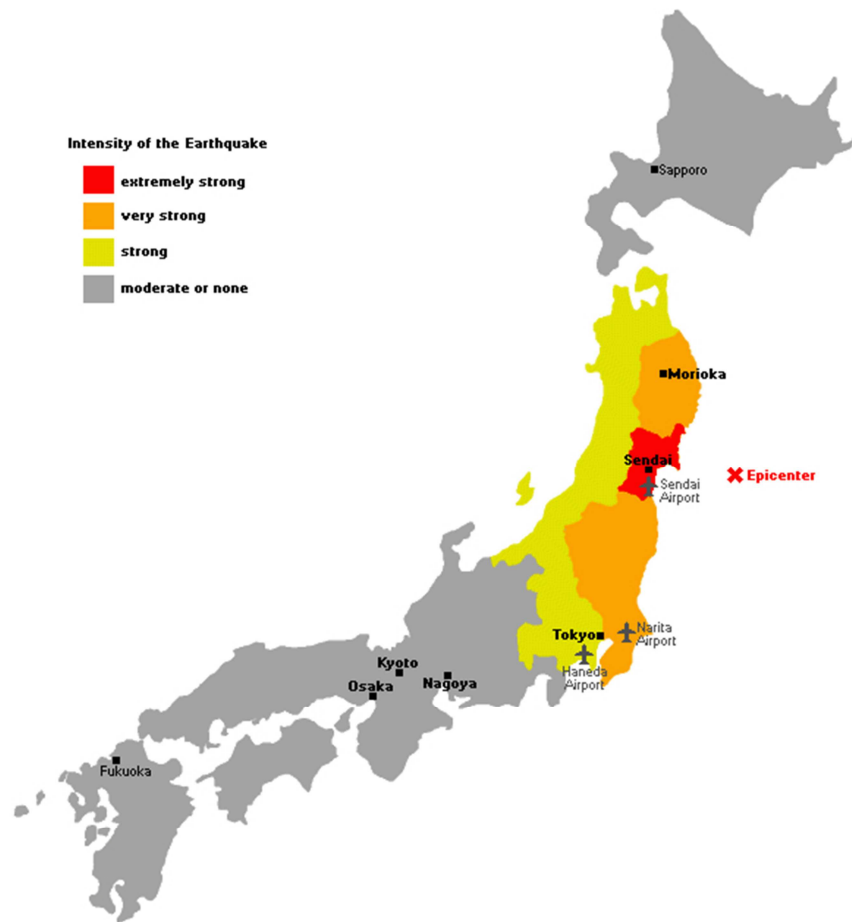
Japan enacted its *Disaster Countermeasures Basic Act* in 1961. The Act sets out the responsibilities of the national government and the prefectures; the coordinating organisations for disaster management, the disaster mitigation plan, and the procedures to be enacted by the various parties at the various stages: prevention/preparedness, emergency response, and recovery/rehabilitation. There is an annual report to the government on these measures. The *Basic Act* is supported by further legislation enacted over the years, covering large scale disasters and building community capacity to respond to disaster. In 2001 after the Kobe earthquake in 1995, the *Disaster Countermeasures Basic Act* established the position of Minister for Disaster Management and formed the Central Disaster Management Council to facilitate multi-ministerial and multi-sectoral coordination in the event of a large scale disaster. The Council is chaired by the Prime Minister, and its members include all Ministers and chief officers of essential services including media, telecommunications, the Bank of Japan and the Japanese Red Cross Society. The Council formulates the Disaster Management Basic Plan and other policies, strategies and guidelines. All government organisations and designated private sector organisations then formulate local plans in accordance with these regulations and guides. Disaster reduction measures are also incorporated into national and regional development plans (Asia Disaster Reduction Centre, 2012). In 2005, the

Hyogo framework for action was developed to modernise the strategy, and address changes in priorities, organisations and technology:

1. Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation
2. Identify, assess and monitor disaster risks and enhance early warning systems
3. Use knowledge, innovation and education to build a culture of safety and resilience at all levels
4. Reduce the underlying risk factors by promoting rebuilding and retrofitting of old houses and buildings vulnerable to earthquakes
5. Strengthen disaster preparedness for effective response at all levels by formulating emergency contingency planning in response to possible large-scale earthquakes (Asia Disaster Reduction Centre, 2012).

As a nation Japan has satisfactory governance, according to Kaufmann and Penciakova (2011), and this can assist preparation for, and mitigation of, the effects of natural disasters. In 1995 there was a 7.9 magnitude earthquake in Kobe and this focussed the government's attention on collapsing structures, the main cause of the 6000 deaths at the time. This focus over 15 years on strengthening the fabric of buildings and infrastructure was supported by the government's actions in educating and drilling the population on emergency practices associated with such disasters.

With these matters in place, Japan was better prepared for a massive earthquake of 9.0 on the Richter scale that occurred at 2.46pm local time on 11 March 2011. The epicentre was some 130km off the east coast of Honshu. Casualties and damage were concentrated across the three north eastern prefectures of Iwate, Miyagi and Fukushima, and caused mainly by the force of a tsunami that reached 40m in run-up height and engulfed the low-lying parts of the prefectures. Under the directions of the Central Disaster Management Council, the Japanese Society of Legal Medicine established the first Disaster Response Headquarters in Iwate (Kubo 2012). The National Police Agency of Japan (2013) reported the deaths of 15,881 persons, with 2668 missing and 6,142 injured. There were 128,801 homes demolished and over three-quarters of a million residences sustained damage. Significantly, the Fukushima nuclear reactor experienced melt-down and some leakage of radioactive material, thus causing a triple disaster: earthquake, tsunami and radioactivity release.



Source: Willey, 2011

Figure 3.4 *Japanese earthquake zones*

During the initial response, Japan's Meteorological Agency issued earthquake and tsunami warnings; the tsunami arrived within 15 minutes of the earthquake. An earthquake early warning system was also installed and in Tokyo, over a minute before the quake hit, alerts were sent to millions of mobile phones, trains were halted and media provided warnings. Mobiles then went dead to preserve bandwidth for emergency services, the internet continued to function for news and communication, and the Bank of Japan released \$US700 billion to stabilise the economy. However, the planned response did not include the third part of the disaster, that concerning the Fukushima reactor. Kaufmann and Penciakova (2011) were critical of the maintenance schedule of the operator of the reactor, the Tokyo Electric Power Company, and the responses of the regulator, Nuclear and Industrial Safety Agency, and the government. Further, global organisations such as the International Atomic Energy Agency seemed unable to assist.

Search and rescue teams arrived within hours to support survivors of families combing through the wreckage, and national and international teams continued for months (Goss & Teagarden, 2011). They evacuated between 300,000 and 350,000 people during the crisis, and national and international response teams coped with issues regarding transport for evacuations, finding shelter in the sub-freezing conditions and then supplying consumables for displaced people, many ill. The Japanese Red Cross dispatched 62 response teams of 400 professionals within 24 hours, primarily for medical relief. Japan received offers of assistance from 116 countries and 28 international organisations, requesting specific assistance from the US, UK, Australia, and New Zealand (Goss & Teagarden, 2011).

Upon invitation from the Japanese Institute for Social Safety Science, a social response team including the World Bank visited the affected regions in the following June to assess the response. Chang et al. (2011) reported that whilst the population had high levels of earthquake and tsunami awareness and pre-disaster mitigation (residences and infrastructure), authorities assumed a maximum size event based on once in a 100-years probability rather than the once in a 1000-years probability event that occurred, and this overwhelmed communities' risk reduction preparations.

In many communities, the tsunami killed community leaders and destroyed government buildings, emergency centers, designated emergency shelters, hospitals, and other emergency facilities and resources; therefore, it was extremely difficult for local jurisdictions to respond quickly and effectively (Chang et al. 2011, p.1).

The inability of local staff to respond according to the disaster planning delayed responses from the prefecture and the national level of government. Chang et al. (2011) reported that the disaster at the Fukushima reactor necessitated a mass evacuation that at the time competed with resources dedicated to the tsunami. Apart from aftershocks, the main earthquake lasted four minutes, whilst the cycle of surge and retreat of the tsunami lasted several hours, limiting search and rescue team activity until after nightfall. Radio, landline telephone and mobile communications were disrupted, there was very limited access to satellite and communication issues prevented early reporting of damage and response needs. Highways and railways along the coast were destroyed and access from the major highways to the west was blocked by road damage and landslips. Sea access was blocked by continuing tsunami action, then by damaged dock facilities and debris. Fuel was in short supply through loss of power and damaged refineries. However, the following responses were recorded

- 27,373 teams and 103,600 staff from the Disaster Management Agency
- 193 teams from the Disaster Medical Centre

- 4,143 boats, 1,564 aircraft and 1510 search and rescue teams from the Japan Coast Guard
- 307,500 National Police Agency staff, whose mission was not specified in the disaster planning
- 107,000 soldiers from the Ministry of Defence
- 28 countries provided search and rescue teams, including 16,000 people, 15 ships and 104 aircraft from the US, who later provided landing resources for heavy duty machinery.

In a World Bank paper, Osa, Sagara, and Ishiwatari (2012) reported that the emergency teams reported loss of communication and lack of fuel as major constraints to their operational capacity, and these resources were strengthened. The medical teams found that, due to the scale of the disaster and the loss of local facilities, they were treating chronic illnesses in mobile units and their work extended well beyond the expected 48 hours after the event. The Technical Emergency Control Force assists disaster-affected municipalities to quickly assess damages and provide technical assistance for emergency response activities. The Force used satellite communication vehicles to connect to public lines and establish communications, and these could be deployed further (Osa et al. 2012). A report to the Central Disaster Management Council contained a recommendation to provide for the largest tsunami that could be expected, and to rely on evacuation more so than shoreline protection (Chang et al. 2011).

Non-government organisations comprised international relief operations located generally in Tokyo, termed the Japan Platform, and Japanese-based organisations that usually address domestic needs. The Japan Platform mobilised relief operations within 3 hours after the earthquake. Seven organisations conducted an initial needs assessment using JPY15m in funding, five provided support to education (JPY450m), two organisations provided health care and hygiene promotion (JPY210m), and eight organisations engaged in rehabilitation and 12 provided food and practical support (JPY3.12 billion). Experienced in providing emergency humanitarian aid overseas, these organisations supplied international standards and expertise and had a pivotal role in mobilising experts in specialised fields. Osa et al. (2012) further noted that there was no functional coordination mechanism operating in Japan such as the UN cluster system, which they advocated should be established, possibly using the Japan (finance) Platform.

3.2.2 New Zealand (Christchurch) earthquakes, 2010 and 2011

Given its propensity for earthquakes, New Zealand has a Ministry dedicated to Civil Defence and Emergency Management. This supports a National Crisis Management Centre for government crisis management and offers inter-agency and scalable operability to deal with any

type of event or crisis. In effect, this addresses the Japanese issue of underestimating the severity of an emergency situation. When activated for an emergency response the Centre is staffed by Ministry personnel and liaison officers from other government and support agencies. The Centre's responsibilities are to:

- monitor and assess local and regional emergencies
- collect, analyse and disseminate information on events/emergencies
- action requests for operational and logistical support from local level requests
- accommodate, inform and guide meetings of central government on response requirements
- during a national emergency, manage and control the entire response to the event (New Zealand Ministry of Civil Defence and Emergency Management, 2013).

The Ministry of Civil Defence and Emergency Management administers the 2005 National Civil Defence Emergency Management Plan that together with a Guide became operational in July 2006. The Plan was subject to wide consultation and provided for hazards and risks at the national level and support for the management of local emergencies. It thus supports the management of emergency responses and the subsequent recovery from events in the community and provides the framework for that support from the national level, to the regional level and again to the local level. Section 5 of the Plan sets out the responsibilities of the Civil Defence Management Groups, the police, fire and health services, lifeline utilities, and clusters at a national regional and local level, and for cluster coordinators (non-government organisations). According to the Plan, clusters determine their own membership; however at all levels they must have a coordinator and a secretariat to facilitate communications with other teams and government (New Zealand Ministry of Civil Defence and Emergency Management, 2013).

At 4.35am local time on 4 September 2010 a magnitude 7.1 earthquake on the Richter scale occurred on a fault, previously unknown, 35 kilometres west of New Zealand's second largest city, Christchurch. With its location and timing, there were injuries and damage to a large proportion of the 160,000 buildings (500 demolished) but no deaths. However, a magnitude 6.3 aftershock struck at 12.51pm local time on 22 February 2011 nearer the city (at Lyttleton) at shallow depth and in susceptible ground conditions. The unprecedented intensity of ground shaking in the centre and east of the city was well in excess of engineering design criteria and resulted in extensive damage to buildings including collapse of three reinforced concrete multi-storey buildings, destruction of unreinforced masonry buildings, and major damage to other buildings. The intense shaking caused extensive liquefaction in the soft soils of the eastern part of the city, resulting in building and infrastructure collapse, flooding and silt inundation (Mamula-Seadon, Selway, & Paton, 2012).

Flooding was restricted to subterranean water pressure destabilising soil structures, particularly around the River Avon, and allowing sink holes and rifts to develop. During the earthquake, fine sand, silt and water moved up under pressure through cracks and other weak areas to erupt onto the ground surface. Near the river, the ground moved sideways into the river channel (Christchurch earthquake response 2011).

A comparison of the effects of the Christchurch and Tokhoku earthquakes is presented at table 3.1.

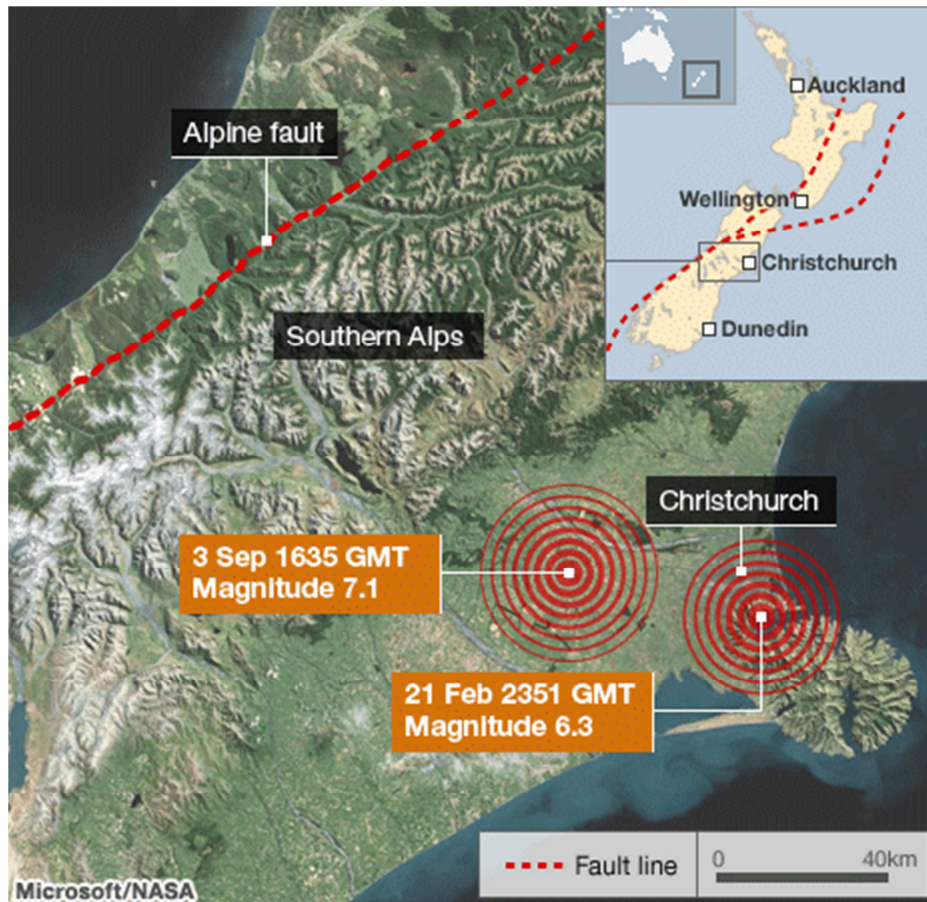
Table 3.1
Comparison of Christchurch and Tokhoku earthquakes

Parameter	Christchurch, NZ	Tohoku, Japan
Magnitude	6.343Ml	9.0Mw
Depth (km)	5, onshore	24, offshore
Max. intensity	Modified Mercalli 9 event	Modified Mercalli 9 event
Flooding	Yes (liquefaction)	Tsunami
Largest aftershock (Mw)	n/a, aftershock	7.7-7.9
Total damaged buildings	140,000 (30,000 seriously)	1,038,854 (127,185 destroyed)
Fatalities	185 dead	15,844 dead, 3451 missing
Injuries	7,171	5,950
Homeless	Approx. 40,000	Approx. 450,000
Economic losses (USD) incl. \$16bn (\$15bn-\$20bn) direct nuclear disasters		\$594.5bn (\$479bn-\$710bn) total \$334.5bn (\$295bn-\$374bn) direct
Unemployment increase after 962 (17.88% increase) event		70,000 in 3 most affected regions (75% increase)

Sources: McLean, Oughton, Ellis, Wakelin, Rubin, 2012, Parker & Steenkamp, 2012; Vervaeck & Daniell, 2012

Unlike the Tokhoku tsunami, building failures in Christchurch caused the majority of deaths, 175 of the 185 deaths, with the CTV building collapse responsible for 115.

Following the major Christchurch earthquake, emergency services responded and citizens initiated rescues. Although communications were reduced, the National Crisis Management Centre provided national coordination from Wellington in the North Island by 3pm NZ time on 22 February and a regional operations command established in Christchurch, according to the guidelines. A National Emergency was declared next day, triggering satellite coverage to monitor the extent of the disaster (McLean, Oughton, Ellis, Wakelin, Rubin, 2012).



Source BBC News, 2011

Figure 3.5 *Christchurch earthquakes, 2010-2011*

The New Zealand Fire Service coordinated search and rescue operations using urban search and rescue teams from Australia, UK and the USA, and nations affected by the collapse of an international school also assisted with urban search and rescue and disaster victim identification teams. Christchurch police were supplemented by Australian police to support search and rescue teams, organise evacuations, provide security cordons, and provide ancillary services to citizens, media and politicians. The New Zealand Defence Force provided logistics and resources for the evacuations, including equipment, surveys of the damage to the port and to Lyttleton, which was isolated from Christchurch for a time. The army also operated desalination plants to provide water to the eastern suburbs. Over 1400 Defence forces personnel were involved, supplemented by 116 soldiers from the Singapore Army, in Christchurch for a training exercise (McLean et al., 2012).

The official report, Review of the Civil Defence Emergency Management response to the 22 February Christchurch earthquake (Mclean et al. 2012) makes 108 recommendations regarding coordination between central and local government agencies, including training, review of

guidelines, and other matters pertaining to the recovery phase. There is full acknowledgement of non-government organisations such as St John Ambulance, Red Cross and the Salvation Army that were contracted to provide services; however this is in the context of the highly organised Civil Defence structure and designated roles for recovery (New Zealand Ministry of Civil Defence and Emergency Management, 2013). Yet the report continually relates to local groups who had formed under strong leaders after the September 2010 earthquakes and sought recognition for these:

This Section concentrates on other groups that are usually described as spontaneous volunteers. In a New Zealand setting these are normally associated with local churches, marae, and other local/community based groups. They are well organised and led, and exist for another purpose and they do not usually have contact with CDEM (Ministry) apart from in emergencies. In addition organisations like the Farmy Army (Federated Farmers) and the Student Army spring up under strong leaders, and are able to play a significant role. CDEM culture appears to lump such valuable organised resources into the category of 'spontaneous volunteers' along with the quite different class of well-meaning individuals with limited skills who walk in off the street and have less to offer the Response (McLean et al., 2012, p. 181).

This area of recognition of community capacity, apart from that of the skilled volunteers in the emergency services, appears to be an authoritarian mindset that does not recognise social change. McLean et al. (2012) were highly critical of the National Crisis Management Centre's approach to coordination with skilled volunteers and called for high level communications and the cluster approach recommended by the UN to facilitate search and rescue operations during a disaster.

3.2.3 Queensland: 2010-2011 Brisbane floods

As a relatively autonomous state of the Commonwealth of Australia, Queensland legislates and administers its disaster response. This was promulgated as the *Disaster Management Act 2003* which established a disaster management hierarchy for the state, then districts, and local government. As local government is better placed to assess its needs in an emergency, it can call on the district for assistance, which in turn can access state-wide resources and the state can then gain further relief from the Commonwealth (Queensland Floods Commission of Enquiry, 2011).

The state disaster management group comprises chief executive officers of all government departments, the principal officer of Emergency Management Queensland and chief executive of the Local Government Association. It develops and reviews the disaster management strategic policy framework and the state disaster management plan. The state group coordinates the disaster response and recovery activities across all government agencies and liaises with Commonwealth agencies, in particular the Australian Defence Force, and non-government organisations that

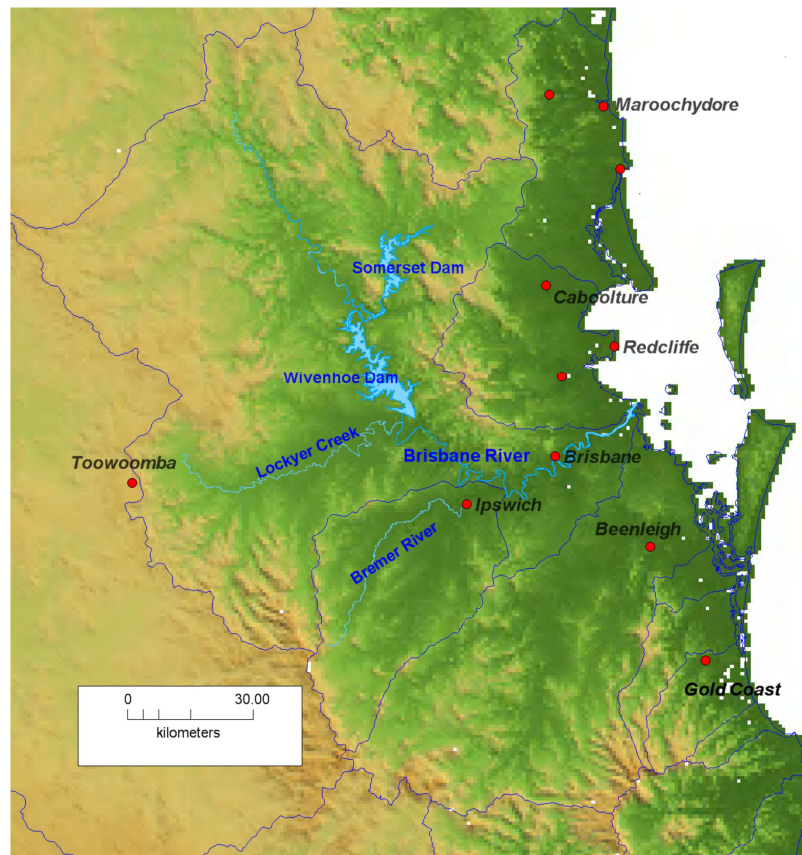
respond to emergency relief. There are two persons appointed in an emergency, a state disaster co-ordinator and state recovery co-ordinator (Queensland Floods Commission of Enquiry, 2011).

Emergency Management Queensland leads the co-ordination of disaster prevention, preparedness, and recovery activities in Queensland; however, the Queensland Police Service is responsible for coordinating the emergency response. Emergency Management Queensland provides training and advice, monitors the performance of disaster management groups and provides support resources, particularly for remote regions. The Police Service provides management for the emergency response by appointing district disaster co-ordinators. Emergency response is provided by the largely volunteer State Emergency Services who work with local government as Queensland's primary agency for storm and flood emergencies. The Fire and Rescue Service provides response and rescue services for all hazards, including floods and swift water rescue. The Queensland Ambulance coordinates land and air medical services during an emergency (Queensland Floods Commission of Enquiry, 2011).

In 2008, the government reviewed its disaster management legislation, policies, guidelines and plans, including the role of the State Emergency Service. There were several amendments to the 2003 Act, including the change in responsibility to the Queensland Police Service for the coordination of the disaster response phase. The current state plan was approved in December 2010, during the Queensland floods and until then, the 2008 version was applicable. The 2008 state plan was based on four principles, that of the disaster management phases of prevention, preparedness, response and recovery; that plans should be able to respond to all forms of hazard and disaster risks; responsibility for disaster management is shared among various agencies at all levels of the disaster management hierarchy; and communities should be knowledgeable of risk and their response. The 2010 version added another principle, that of local level response as central to Queensland's disaster management arrangements (Queensland Floods Commission of Enquiry, 2011).

At 309 km, the Brisbane River is the longest river in south-east Queensland, rising in the Brisbane Ranges about 120 km north-west of Queensland's capital city, Brisbane. From there it runs south to the Stanley River, just downstream of Somerset Dam, then into Lake Wivenhoe, the main water supply for Brisbane. The Wivenhoe dam was completed in 1984, with the principal aim of protecting Brisbane from future floods such as those that occurred in 1974. Downstream from the Wivenhoe dam the river flows eastwards, meeting the Bremer River near Ipswich and then flowing through Brisbane to the ocean. The Brisbane River is bounded by the Great Dividing Range to the west and minor ranges to the north and southeast producing a catchment area of 13,570 km².

including major metropolitan areas of Brisbane and Ipswich and a number of smaller townships (figure 3.6) (van den Honert & McAneney, 2011).



Source: van den Honert & McAneney 2011

Figure 3.6 *Map of the Brisbane River catchment*

Record-breaking rains occurred in Australia from July to December 2010 and Queensland had its wettest December in that year. In ordinary rainfall conditions, incoming flows into small reservoirs in the Brisbane River catchment area must be released at the same rate to protect the dam structures; the larger reservoirs Somerset and Wivenhoe were designed to provide significant flood attenuation, including measured flow releases from their flood compartments. However, once the system is filled and flowing at its maximum design rate, the pivotal Wivenhoe has no moderating influence on downstream flooding (van den Honert & McAneney, 2011).

Given an extremely wet spring and record December rains, in the 3 month period to the end of January 2011, all weather stations in the catchment area recorded rainfall of at least 600mm and which in some cases exceeded 1,200 mm. From the 10th to the 12th January, direct rainfall into Wivenhoe and Somerset Dams was very heavy, with totals of 480 mm and 370 mm respectively

and on the 12th, the Brisbane River flood gauge in the city exceeded its major flood level. Electricity was switched off for substantial sections of Brisbane's central business district. By the 13th January there was major flooding throughout the Brisbane River catchment, most severely in its major tributaries of Lockyer Creek and Bremer River where record flood heights were experienced. The flooding caused the loss of 23 lives in the Lockyer Valley and one in the capital of Brisbane, and an estimated 18,000 properties were inundated in the Brisbane River Valley (Queensland Floods Commission of Enquiry, 2011; van den Honert & McAneney, 2011).

The Queensland Floods Commission of Enquiry (2011) found that local councils differed in their ability to warn the public and prepare emergency centres. Toowoomba Regional Council received little warning of the catastrophic flash flooding of 10th January, and in Ipswich, predictions of expected flood levels of the Bremer River rose dramatically the day before the Bremer River peaked on 12th January 2011. Events in the Lockyer Valley were equally sudden and overwhelming and the Commission noted that the less-resourced Lockyer Valley and Somerset (Ipswich) councils, both less well-resourced councils, found events rapidly overtook their means to cope with the disaster. The emergency procedures failed through the size of the event, the absence of key figures due to isolation, and lack of communications in the rural communities. However, the Commission saw no need to change the emergency response procedures based on local government control, recommending that resourcing, training and deputy responsibility positions would suffice (Queensland Floods Commission of Enquiry, 2012).

Other matters recoded by the Commission included installation of an All Hazards Information Management System to track requests for assistance for local disaster management groups informed of progress. The report questioned the management response of the Fire and Rescue Service Queensland, given that there was insufficient resources and training for swift water rescues, despite the frequency of floods in the region. The role of the Australian Red Cross was not widely understood by local government and communications broke down regarding emergency centres. Despite the central role of the Police Service, there were minor recommendations regarding training on communications. Other recommendations concerned evacuation plans for commercial premises; establishing command structures between the various parties at various levels (these could be viewed as the UN's clustering of stakeholders). Community organisations from isolated districts that formed as self-help groups as a result of previous floods were supported in the Commission's final report, recommending similar status for their actions and initiatives as the local government commanded (Queensland Floods Commission of Enquiry, 2012).

The Commission's report was challenged in at least two studies. McGowan (2012) stated that the Commission 'remained trapped in a reactive, inquisitorial mindset that led the commissioners to produce prescriptive recommendations aimed at increased regulation and modelling' (McGowan, 2012, p.355). McGowan advocated for greater recognition for the Australian community resilience policy approach and to redirect funds to securing preparedness, prevention and mitigation matters. In support of this stance, Bird, Ling, and Haynes (2012) recorded the role of social media (Facebook) during the Queensland emergency, where administrators sourced and edited local news and conditions from official sites, and added near-real time information from the general public to assist residents under threat. Travellers driving through the area posted and received up-to-date information on road closures and flooding. The results from their study during the events indicated that most respondents began using community information and 'almost all found the medium useful and an effective means of communicating with family or friends' (Bird. et al., 2012, p. 27).

3.2.4 Summary

There were three themes that emerged from the Japanese, New Zealand and Queensland emergency responses: that the size of the event overwhelmed and negated part or all of the emergency response planning and procedures; that the breakdown in communications as a contributory factor cost lives in each case; and that community actions, or those of non-government organisations, tend to be ignored as viable resources during the emergencies.

Whether the country has centralised control such as Japan and New Zealand's national governments, or distributed control such as Queensland's local government, the size of the event overwhelmed the response processes in each case through the inability of the nominated persons to carry out their duties and the failure of the authorities to get aid to where it was needed. This was due to the event itself, and this should be an obvious point in any emergency response planning. Whilst modelling acknowledges difficulties in reaching and evacuating a site, it tends to ignore impossibility through the size of the event, whether fire, flood or earthquake. Secondly, emergency communications are always centralised, controlled by the government organisation in charge, and not accessible outside the command structure. Thus in the case of systemic failure, as in the case of Japan where news was handwritten and taped to walls, or partial failure as occurred in New Zealand and Queensland, vital information cannot be transmitted or, alternatively, received. Information on procedures, process and requests should be networked across the available media to enable the flow of information into and from the region in a very short time (Bird et al. 2012). This relates to the

policy recognition of community resilience; if the local government in Queensland is the first line of response, then that occurs *after* the community is very much involved (McGowan, 2012). In all disasters the ability of neighbours to respond, rescue and assist the wounded is the criterion of a lower casualty rate. As such, this aspect of search and rescue is equally important to the efforts of official resources and their procedures that follow and take over. Passers-by and neighbours cannot be trained in every eventuality; however, they are the rescuers.

This summary outlines the limitations inherent in every national or regional emergency response policy: that planning can at most model and mitigate a disaster's effects and the size and complexity of the event determines whether the response model is workable. If the system is overwhelmed, the emergency response plan must be structured as staged responses as access becomes available. Thus this section partially answers research question 3 (What are the optimum operational strategies for emergency relief?).

3.3 Saudi disaster response plans

This section addresses the first research question: What were the responsibilities of the various Saudi organisations during the 2009 and 2011 Jeddah floods, and how did they coordinate their activities?

As noted, the Kingdom of Saudi Arabia is an absolute monarchy, so that the structure of government comprises a national government in Riyadh that has Ministerial and department representation in each of the provinces shown in figure 2.2. Part of this ministerial function directs the provincial governments and for Jeddah, this tier of government is located in Makkah, some 80km to the south-east. The Municipality of Jeddah has the responsibility for their part of the official disaster planning. These are discussed in relation to the situation in place during the 2010-2011 Jeddah floods and the subsequent changes.

3.3.1 Saudi disaster management planning

The first emergency response team, a fire brigade, was established in Makkah in 1926 and was absorbed as a presidency into the General Security Service. Jeddah received a fire brigade in 1963, along with Riyadh and Al Madinah. In 1960 the fire brigade presidency became the General Directorate of fire fighting within the Ministry of the Interior and in 1986 had a name change to General Directorate of Civil Defence. The General Directorate has a very broad responsibility for planning, resourcing, managing and executing all emergency response measures concerning

(the protection of) citizens, public and private properties from fire hazards, disasters, wars and different accidents plus helping devastated people, providing the safety of transportations, communications, and the best organizing in public utilities in addition to the protection of national wealth during the times of war, peace, and emergency situations (Ministry of the Interior 2013, p.1).

Civil Defence in Saudi Arabia has a structure comprising the Civil Defence Council, chaired by the Minister of the Interior, and comprising nine Ministry heads and seven other voting public service organisations. The Council develops civil defence policy and establishes plans and projects to support that policy. It identifies the roles and responsibilities of all government and non-government agencies, and releases regulations and procedures for the Kingdom's civil defence system. The Council is supported by a Civil Defence Administration Committee, chaired by a General Director, and comprising eight civil, military, financial, safety and technical members. At a regional level, the Civil Defence Committees are responsible for implementation of the Council's directives. They are chaired by the emir (in this case for Makkah) and comprise:

Regional Director of police services

Regional Commander of the National Guard

Regional Director of roads and transport

Branch Manager of the Electrical and Industrial Ministry

Branch Manager of Municipal Affairs and Rural Areas Ministry

Regional Director for civil defence

Commander of the military zone

Branch Director of the Ministry of Finance (Ministry of Interior, 2013).

As noted, these responsibilities, both civil and military security, are extremely comprehensive and are shown at appendix 1.

In the event of a natural disaster, the Regional Committee for Civil Defence implements the Council's direction in regards to fire fighters, search and rescue, and ambulance. Regional Civil Defence has broad powers to instruct civil and military organisations and to take over resources as required. The regional organisation prepares local emergency response plans, directs all response teams, and communicates with all government and non-government organisations, thus it leads a coordinated response. To meet its commitments, the Regional Council is also responsible for sourcing and training teams. Further, it implements regulations for occupational health and safety and enforces its directives through an inspectorate (Ministry of Interior, 2013).

This is the extent of publicly available documentation to inform this study. The remainder are English translations from documentation that was sourced from the various organisations.

3.4 Jeddah: Emergency planning and response

The duties of government agencies in Jeddah regarding waterways and flooding were requested from the various agencies. The following notes signify the responsibilities the various public offices, and the Saudi Electricity Company.

As shown, the Regional Committee for Civil Defence is the lead agency, and in the preparation stage for emergency response, its role is:

- to provide optional evacuation and accommodation plans to manage different emergencies
- with Ministry of Finance - Social Affairs, provide plans for accommodation and life necessities at emergency centres
- with Ministry of Finance and National Economy, plan for optional relief supplies and plan to delegate emergency operation control if necessary
- coordinate communications and actions across municipality and regional borders if necessary (evacuation centres, emergency resources)
- maintain situation information records for further research; gather and maintain all statistics of injuries, death, causes and structural damage to homes and businesses.

Upon declaration of an emergency, Civil Defence assumes control of the operations:

- (Field Operations Command) Manage coordination and communications with all parties during the emergency
- open emergency operations centre and deploy teams to set up emergency evacuation centres; the emergency operations centre is attended by a representative from each of the organisations in this sub-section; engage all utility firms
- evacuate areas with the potential for flooding
- conduct search and rescue operations on water and in buildings
- transport displaced persons to designated emergency shelters and provision them until they can return home (coordinating with the Ministry of Finance)
- mobilise fire fighters in the case of gas or electrical fire
- maintain continuous situation information regarding the emergency and alert agencies where resources are required
- maintain continuous contact with news media to prevent citizens entering potentially dangerous areas or returning home prematurely
- determine the extent of damage; identify actions to be taken and immediate solutions; determine the amount of resources required and location during the emergency.

The Presidency of Meteorology and Environment is the first agency to issue an alert, based on annual data relating to humidity and storm action. Meteorology and Environment has the following duties:

- provide Civil Defence and Jeddah Municipality with quarterly climate reports and rain predictions
- maintain weather watch through weather alerts and warnings to allow sufficient time for preparation, and continue with updates
- declare an emergency (red alert) when rainfall from the weather event is predicted to exceed 30mm.

The Municipality of Jeddah has the prime responsibility for infrastructure relating to flood mitigation. In the preparation stage for disaster control, the Municipality provides for planning and maintenance:

- implement an infrastructure program to reduce flood risk across the Municipality.
- maintain drainage infrastructure, including inlet gates, and ensure drains and potential stormwater routes are kept clear
- Municipality maintenance teams perform small and short-duration waterway repairs, also rapid response for smaller emergencies.

Upon issue of a red alert for potential flooding by Meteorology and Environment, the Municipal authorities:

- allocate Municipality teams to protect life and property and to contain flooding through removal of debris along flood path, sandbagging, protecting and repairing levees
- mobilise contractors to aid damage control and to assist in protection of life and property; provide civil defence teams with resources
- at clean-up, the Municipality attends to fatalities by providing mortuary resources, removes debris, and funds restoration and can exceed that if required; in event of death can provide quantities of body bags
- repair and replace Municipality infrastructure damage (including pavements)
- provide hygienic measures such as waste water, and spraying remaining wetlands with pesticides.

Information and alerts regarding storm events and warnings to evacuate are issued by the Makkah office of the Ministry of Culture and Information. The Ministry's responsibilities are to:

- undertake awareness campaigns before the flood season on inundation dangers and preparedness measures
- coordinate with Civil Defence with warnings of flood danger
- provide alerts and evacuation instructions as required.

The Jeddah office of the Ministry of Water, Operations and Emergency Management, has the prime responsibility for assessing potential flood zones and providing the infrastructure to abate such floods. It should be noted that there is no natural permanent surface water on the Arabian Peninsula, so that measures aimed at flood mitigation are modelled on past events.

- annual review of emergency equipment, personnel resources and logistics to maintain supplies of water and sanitation
- ensure stormwater pumping stations and wastewater facilities are open and functional when rain is forecast
- upon alerts, provide quantities of drinking water at district centres and increase as required
- provide rationed water for residents' use at district centres.

The role of Jeddah Police is to support the emergency response agencies:

- upon alert, deploy security patrols and support resources
- assist Civil Defence in removing stalled or damaged cars from water
- provide security at Civil Defence sites when Defence security not available
- deploy security patrols where evacuations may be required

The Jeddah office of the Ministry of Transport has the responsibility for evacuation routes and access to the flooded areas for emergency teams:

- prepare optional traffic plans to account for scenarios of floods caused by rainfall of 30mm or more
- on alert, close off affected streets, and position heavy haulage equipment (trucks, cranes) where traffic blockages may occur.

The Jeddah division of the Saudi Electricity Company (Jeddah) has the following duties by law:

- prepare emergency plans for closing down districts where Civil Defence reports dangerous levels of water or storm damage, implement when required
- prepare plans for rerouting of electricity to Civil Defence evacuation sites
- provide emergency teams to repair electricity infrastructure caused by storm damage or flooding
- maintain operational generators for lighting at electricity grid locations

The Jeddah division of Ministry of Agriculture (Jeddah) has the responsibility for monitoring flood level and measuring flows during the emergency:

- provide current hydrological studies relating to rain catchment areas and routes of surface water through Jeddah
- install and maintain monitoring equipment throughout water catchment areas, dams and waterways; notify Civil Defence and agencies of water levels and flow rates

Roads and Transport Management in Makkah attends to flood infrastructure operation and providing transport for evacuations:

- open drain collectors if roads begin to flood, clear debris from inlets during flood event
- support emergency crews regarding stalled cars and clearing debris for emergency response vehicles
- place buses at a central location to maintain adequate response for evacuees

The duties of the Coast Guard, also headquartered in Makkah, relate to water search and rescue:

- support Civil Defence with divers to participate in search and rescue operations as required
- provide and maintain water transport and rescue support for evacuations

The Makkah division of the Ministry of Finance provides and tracks the resources for the activities of all agencies:

- provide resources for emergency operations centre by contract with the Municipality and other agencies
- provide resource funding for Civil Defence stores and equipment to be maintained at the old airport
- provide estimates for emergency shelters, food and personal items, and cash for displaced persons according to their legal rights
- participate in inventory of losses and provide for relief proposals according to regulations.

This section, 3.4, and that preceding, 3.3, therefore addressed the first research question stated at the beginning of section 3.3.

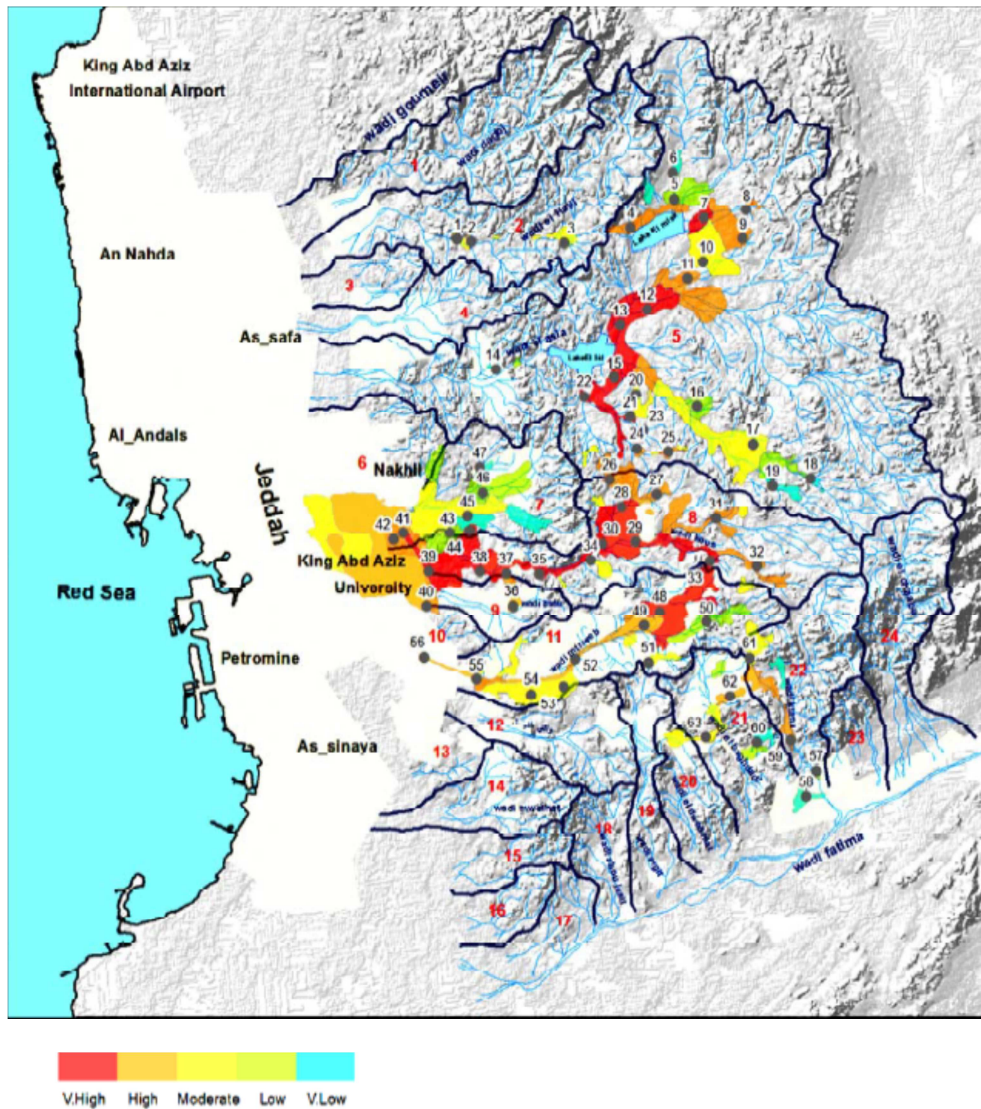
3.5 Jeddah's floods

Saudi Arabia is a desert country taking up the greater part of the Arabian Peninsula. Its maritime borders are the Red Sea with 1840 km of coastline, and a 560 km presence on the Arabian Gulf to the east (Royal Embassy of Saudi Arabia, 2013). The capital, Riyadh, has 4.7 million people, and the second largest city, Jeddah, 3.2 million. These, the holy cities of Makkah (1.5m) and Al Madinah (1.1m), and the eastern city of Dammam (0.9 m), comprise the main centres of

Saudi Arabia's population of 27 million. However, foreign workers form a proportion of the population (5.5 million) and provide nearly 80 per cent of the private sector labour force, critical in an emergency (World Factbook, 2013). It should be noted that demographics and economic data are notoriously difficult to access and these figures are indicative only.

Jeddah, situated midway down the western side of the Arabian Peninsula, is the culmination of a number of settlements reaching back perhaps 3000 years. Jeddah is the gateway to the two holy cities of Makkah and Al Madinah, and the once walled city in the mid-20th century has since grown to a large modern city, dedicated to hosting 3 million *hajj* pilgrims each year, effectively doubling the population for weeks (Aljazeera, 2012; Royal Embassy of Saudi Arabia, 2013). Jeddah claims some 80km of the Red Sea coast, and extends five to ten kilometres inland on the Tihama plain to the base of the Hijaz mountains, some 200m high at that point, which run along the length of the Arabian Peninsula (Al Saud, 2010). However, the Municipality administers some 5460 km². The city has a hot desert climate, with average daily temperatures of 39°C from May to October during the summer and humidity peaking at 89 per cent in early October. The winters are warm, with a maximum below 30° although humidity remains relatively high. Whilst rain is rare, it frequently falls as thunderstorms, with an average of 63 per cent of 56mm annual precipitation in this form, generally around November-January (Municipality of Jeddah, 2013; Weatherspark, 2013).

Jeddah received two severe thunderstorm events on 25th November 2009 and 26th January 2011, causing catastrophic flooding and 123 deaths from a 90mm downpour in 2009 and a further 10 with a larger 111mm event in 2011 (Murphy, 2010; Swiss Reinsurance, 2012; Wagner, 2011).



Source: Al Saud 2010

Figure 3.7 *Jeddah, 2009: watersheds and flooding*

Figure 3.7 shows the 24 watersheds above Jeddah and depicts the initial path of the 2009 flash floods into the city (Al Saud, 2010). The colours represent the severity of the water flows and the initial impact of the 25th November event, which saw 90 mm rainfall in four hours, 1.6 times the city's average annual rainfall. Further, 25th November was the first day of the annual hajj, and several thousand pilgrims were still arriving at King Abdulaziz International Airport. They were therefore obliged to make their way through the floods across the hills to Makkah, 80km to the south-east of Jeddah (Al Arabiya News, 2009).

The city's residential areas were built on wadis, especially in the foothills of the Hijaz, which originally served their purpose as flood channels (Al Saud, 2010). However, Jeddah is

divided into administrative districts, each of which is allocated annual funds to pay for services, and maintenance and new construction, including flood mitigation (Wagner, 2011). Wagner reported that in the north of the city, the Al-Arawdah, Al-Shati and Al-Azahra districts were well maintained and escaped the worst of the flooding, whilst in central Jeddah, Al-Azziyah which housed low-income expatriate workers was badly maintained and affected by flooding. As it received its full allocation each year, this was evidence of sub-standard governance and *wasta* (nepotism) by the city officials (Momani & Fadil, 2010). Further, drainage tunnels, where constructed, were inadequate for the deluge (Al Saud, 2010). Wagner (2011) reported that 10,785 buildings were damaged and more than 10,000 vehicles lost in the 2009 floods. Adding to the flood-related damage were Jeddah's infrastructure problems of crumbling footpaths and street pavement and the dangerous condition of its electricity supply. Thus the effects of the entirely foreseeable floods were a symptom of shoddy construction practices, and King Abdullah recognised this when he called for the prosecution of city officials and contractors (Murphy, 2010). After the 2009 floods, a deputy mayor said a third of the city had a drainage system which could handle just 25mm of rain, and the Municipality planned that Jeddah would be flood-free by 2014 (Momani & Fadil, 2010).

The following is an account of the unfolding disaster summarised from Momani and Fadil (2010).

Table 3.2
Events relating to 2009 Jeddah floods

Date	Actions
25 November	Rain inundated Jeddah from 8am until noon, with initial reports of 10 deaths and more than 100 rescued
26 November	Saudi civil defence reported the death toll had reached 48 people with 900 rescued from flooded properties; it was using inflatable boats
27 November	Jeddah's Director of Health Affairs warned parents to keep away from water due to pollution from sewerage; rescue operations continued
28 November	Death toll at 122. A lawyer, Waleed Abu Al Khair, declared he would sue Jeddah Municipality on behalf of the families of victims of the floods regarding the failure of the sewerage system
30 November	Floods stranded hajj pilgrims trying to return home. People still reported missing from the floods, which were receding King Abdullah announced a commission led by the governor of the province of Makkah to investigate the disaster. He authorised a payment of one million SAR (\$US267,000) to each victim's family and provided accommodation for those that could not return home
1 December	A commission was set up to provide emergency assistance for flood-affected people. An investigation was set up for 'Lake Musk', a sewerage treatment site in the foothills, to ensure its security during rainfall
2 December	The search for the missing continued in the 9 th day, and the names of 108 of the dead announced
3 December	The high level disaster committee held its first meeting and nominated sub-committees to pay victims' families and monitor the emergency responses
5 December	The disaster committee called for citizens and residents to provide information on the floods. The Municipality cancelled leave for engineers and experts to help in investigations
9 December	Civil Defence announced 133 deaths, 39 missing, with 7167 accommodated by the authorities, whilst 221 families were sheltering 784 additional individuals
10 December	Death toll rises to 138
23 December	Electricity cut in Yanbu due to further rain, businesses and schools closed
25 December	King Abdullah called for an investigation on the Jeddah disaster and for those responsible for sewer failures to be held to account. He "will not compromise with any remiss in this respect"
30 December	25 employees of Jeddah Municipality taken into custody
20 February 2010	Ministry of Transport investigated actions by contractors which restricted the disaster management plan's operations, and set up safeguards for future occurrences.

Source: Momani and Fadil, 2011

Given the sudden downpour, Momani and Fadil (2011) found that there was no comprehensive disaster warning system in place, and that Civil Defence was ill-prepared for the task, including retrieval of human remains and the inadequate and ill-maintained drainage system. In the absence of official reports, they advocated for a system of emergency response measures including meteorology reports and alerts, civil defence coordination between authorities and aid agencies, and preparedness through maintenance and public awareness campaigns. Yet in 2013, Alshehri et al. (2013) found that the Saudi population remained fatalistic and had low awareness of

their risk and preparedness for a future emergency. Alshehri et al. advocated for resilience training of the population as the United Nations advises.

The Director-General of Saudi Civil Defence denies accusations of inadequate response, and stated that the organisation responded to the events with ‘the utmost professionalism’, claiming that the *Human Rights Commission* had supported this stance (Al-Harithy, 2010). However, this researcher could find no reference to Civil Defence in the UN Human Rights Commission documentation, where the latest report on the Kingdom at the time of writing (April 2013) was prior to the 2009 floods. The Director-General noted that the Jeddah flood occurred at a time when Civil Defence officials

had stationed equipment and personnel at the holy sites (Makkah and Al Madinah) to provide the best possible services to pilgrims, while at the same time the aggression occurred against Saudi territory in the south which required backing for the Armed Forces and Civil Defense evacuation plans for the displaced (Al-Harithy, 2010, p.1).

In the first few days of the 2009 floods, Saudi authorities issued a news blackout and blamed victims for panicking, according to Al-Saggaf (2012). However, there was a civil response to the 2009 disaster. In a country with an absolute monarchy, criticism of authority is forbidden. There are no political parties in Saudi Arabia and street protests are banned; however, technology has changed the nature of protests (Spitzberg, Tsou, An, Gupta, & Gawron, 2012). Howard and Hussain (2010) earlier investigated diffusion of media in Islamic countries. They stated that Saudi Arabia is the largest Islamist monarchy, Indonesia is the largest Muslim democracy, and Egypt at the time was the largest secular authoritarian regime. These countries were prominent in having

the highest diffusion rates of digital media in the developing world; they are all countries in which digital media has been a means of building a transnational, Muslim political identity; they are all countries in which the protection of religious and cultural norms has been used to justify levels of censorship and surveillance not tolerated in other parts of the world’ (Howard & Hussain, 2010, p.1).

Using the 2009 Jeddah floods as the focus, Al-Saggaf (2012) studied the phenomena of social media among young Muslims, and found it was used to express feelings and emotions about the loss of lives, to call for action, or to organise themselves as volunteers. The images of bodies floating in the street led to outrage and demands of accountability. The impact of social media was such that for the first time in Saudi Arabia the ruler stated that negligent behaviour by administrators would not be tolerated. In May 2010, King Abdullah ordered the prosecution of some 50 Municipality administrators and private individuals on corruption charges stemming from land use and construction projects (Wagner, 2010). Murphy (2010) reported that, apparently in an

effort to halt *wasta*, the decree also ordered that ‘crimes of financial and administrative corruption’ (p.1) be classified among crimes ineligible for royal pardon. In the past, corruption and malfeasance was usually ‘fined, asked to resign and in a polite way made an outcast’ (ibid.).

There was widespread criticism in all media regarding the lack of planning oversight by the Municipality which led to building in flood-prone zones, and lack of response from the emergency teams when the flooding occurred. There were claims of corruption in the Municipality when contracting for flood alleviation measures and lack of maintenance of the existing drainage system. There was a focus on new greenfields projects instead of the implementation of a comprehensive integrated master plan for the city. These matters continued over the 2011 floods, although debris clearance, prompt response, and adequate evacuation minimised death and property damage (Al Saggaf, 2012; Al Saud, 2012; Howard & Hussein, 2010; Murphy, 2010; Spitzberg et al., 2012; Wagner, 2012). In a report to the Arab Forum for Environment and Development, Assaf (2010) stated that the impact of flooding would have been negligible had the drainage network been properly designed and constructed and the development of the flooded area properly regulated. Maghrabi (2011) advised that post-traumatic counselling should be available for victims of disasters.

Jeddah’s floods, which occur intermittently on a minor scale, returned in force when a 111mm downpour on 26 January 2011 resulted in heavy flooding in east Jeddah, with ten lives lost and significant damage to homes and infrastructure (United Press International, 2011). However, in this instance there was a prompt response from Civil Defence, which limited loss of life and damage (Agence France-Press, 2011). By March 2011, Al-Dhibyani (2011) reported that the Governor of Makkah Province had approval for a Centre of Crisis Management as the coordinator for security and service authorities’ response. Emergency plans included an early warning system linking civil defence, National Guard, Jeddah Municipality and the Department of Meteorology, and public and private hospitals. The King’s approval also included restructuring and resourcing Jeddah Mayoralty, the policy makers for the Municipality. The corruption cases are proceeding slowly, with Al-Sibyani (2013) reporting that 23 people, including a deputy mayor, have been fined and gaoled, and 15 cleared of charges. A hundred cases were still before the courts. No identities have been published to protect the families of the felons, and this is widely condemned on the social media.

The Arab News Editorial (2012) said that although the physical infrastructure was under construction, the authorities have yet to demonstrate clearly that they have a well-prepared and regularly practised disaster relief plan, including for flooding. Whilst individuals within the

emergency services in 2009 acted with considerable bravery and initiative, overall coordination and clear command lines were conspicuously lacking, and this was not resolved when the next floods arrived in January 2011, 14 months later. There is evidence in the news media that Jeddah’s Directorate of Civil Defence is addressing structural issues, as it is installing sirens, upgrading the city’s mapping system, and refusing to certify fire safety provisions for some 800 schools located in rented buildings (Al Awai, 2012). Further, in the gender-segregated country, women in Al Madinah were setting up their own Civil Defence contingent to teach in women-only working environments, demonstrating evacuation and fire equipment use (Arab News 2012).

For future meteorological forecasts, Haggag and El-Badry (2013) developed a predictive model from the 2009 event that may aid the recognition of similar circumstances to provide longer warning periods. They reported that, at the time, there were warm Red Sea surface temperatures and the low levels of the troposphere held high humidity. An anticyclone system was stationary over the southeast of the Arabian Peninsula, and this concentrated the water vapour flow over Jeddah. Haggag and El-Badry found that these conditions suggest a deep low system developing, which with a wind storm induced by the Al Hijaz escarpment, provided low-level convergence and upper level atmospheric instability. This caused rainfall up to 400mm in some parts of the city.

A comparison of the Jeddah floods and the 2011 Brisbane event is presented at table 3.3

Table 3.3
Comparative analysis Brisbane and Jeddah flood events

Factor	Jeddah 2009/2010	Brisbane 2011
Population	3,200,000	2,100,000
Sited	Coastal plain (between Hijaz escarpment and sea)	Coastal plain (Between Great Dividing Range and sea)
Average annual rainfall	53.5mm over 8 days	1200mm over 124 days
Rainfall event	2009: 90mm over 4 hrs 2011: 111 mm over 3 hrs	3 mths to Jan 2011 from 600-1200mm 480mm on catchment 10-12 Jan 2011.
Flooding	Through 11 wadis transversing city, inadequate drainage, overbuilding	Over Lockyer Ck and Brisbane River valleys, inadequate warning, use of social media
Fatalities	2009 - 123 2010 - 10	24
Buildings damaged/ insurance	2009 -10785 buildings damaged 2010 - 1500 buildings damaged	Over 7000 buildings, \$AU2.5b insurance

Sources: References as cited, Mason, Phillips, Okada & O’Brien, 2013.

3.6 Chapter summary

This chapter presented the crisis management protocols attributed to the United Nations, and the national structures for the three countries, Japan, New Zealand and Australia (Queensland). There were two points to be made at this level: the first was that the emergency response structures and procedures in all cases broadly followed international (UN) practice; second, that the scale of the event was in all cases beyond the control of the ad hoc organisations formed. Viable and efficient emergency response plans must be immediately executed. Volunteer and international groups can assist; however they are at the direction of the national or regional authorities who are in control.

In a rigid bureaucratic structure such as Saudi Arabia, decision making is slow and the chain of command is so long it lacks cohesion and breaks down quickly when under pressure. Thus emergency organisations in the 2009 Jeddah floods lacked coordination and a credible response; whether this was due to the Yemen incursion and the unfortunate coincidence of the hajj, or whether there was simple inadequate leadership to take charge, the results were that death and destruction were maximised. This was exacerbated by the reported refusal of the authorities to communicate or engage with the population (Al-Saggaf, 2012). Whilst the authorities, including Civil Defence, do not acknowledge criticism or explain their actions, they are responsible under Saudi law for security of the entire country, not just where they happen to be positioned.

In the next Jeddah deluge, social media had graphically exposed the issues and changed the government's attitude, and the response was far better. King Abdullah demanded retribution, wasta was exposed and arrests made, although it appears to be minimal public sector employees, and many private developers and their retinue. Whilst the infrastructure was still under construction during the 2011 floods, the crews were trained; the various security, health and emergency organisations were in communication; and the death toll was a fraction of 2009, despite greater rainfall. Heavy rainfall since has had little adverse effect. Social media can assist in changing government policy.

Chapter 4 Methodology

The research problem concerns the existing disaster response system in Saudi Arabia and exploring options for an optimum approach; Jeddah floods are used as an example. To this point, the research sets the context and the theoretical structure for the research, meanwhile using the secondary data collection to address the research questions:

1. What were the responsibilities of the various Saudi organisations during the 2009 and 2011 Jeddah floods, and how did they coordinate their activities?
2. What is the optimum national emergency relief framework?
3. What are the optimum operational strategies for emergency relief?
4. How can the effects of a disaster be mitigated efficiently and effectively?

The first research question regarding the Saudi emergency response structure was addressed in sections 3.3 and 3.4 of this thesis; question 2 was answered in chapter 2, which introduced theoretical constructs, and part of research question 3 resolved through emergency organisational structures and communications reports.

Research questions 3 and 4 are addressed in the primary research and introduced in this chapter. A system dynamics methodology is employed to develop an Emergency Logistics Centre model. The structure of the chapter is as follows: the first section explains options and selection for the research design. The second and subsequent sections explore the development of the research instrument to collect and analyse the data, the selection of the sample, ethics and administration, and the forms of analysis.

4.1 Research design

Whilst there is substantial literature on logistics, supply chain management, and coordination, the previous chapters point to particular issues in humanitarian logistics. 'There is a need for theory development within the field of humanitarian logistics to understand logistics needs in different stages of a crisis and how to meet these' (Jahre, Jensen, & Listou, 2009). Theoretical constructs in exploring humanitarian logistics were subsequently used: stakeholder theory in China by Feng, Yang, Li, Xiong, and Xie (2012); location theory, network flows and inventory management by Duran, Ergun, Keskinocak, and Swann (2013); and system dynamics modelling by Wang, Wang, and Chen (2012); among others. As this thesis takes Jahre et al.'s (2009) approach to encapsulate real time emergency response, a mixed-method approach to the research design was

adopted: a literature review; secondary data collection from the public and not-for-profit sectors; a qualitative primary data collection; and a system dynamics analysis to build a model for emergency response. This is a form of mixed methods design.

Once the research questions were established, the Saudi emergency response structure was ascertained through secondary data collection, and optimum systems models in emergency humanitarian response were largely developed within the literature review. This chapter, methodology, commences the primary research collection through a mixed methods design. This incorporates a questionnaire to establish emergency stakeholder experiences during past disasters, that is, Jeddah floods, to generalise results to a population, and then focuses, in a second phase, on a quantitative analysis of their answers to build a regional emergency response model. These are addressed below.

4.1.1 Multi-methods design

The complex nature of the research questions calls for more than one approach to primary data collection and analysis. A multi-methods approach, according to Badiiee, Wang, and Creswell (2012) is a pragmatic approach; it is consequence-oriented, problem-centred, and pluralistic. Data are derived from various sources on the assumption that diverse data best provide an understanding of a research problem. A multi-methods design involves collecting data sequentially, in this case, through secondary and primary sources, and using focussed analysis to answer the research questions. To answer the research problem, a system dynamics model is presented and this also answers research questions 3 and 4 relating to optimum systems design for an Emergency Logistics Centre and its operations in the field.

4.1.2 System dynamics model

System planning was discussed in section 2.2, and this included models to isolate elements of the disaster including resources and routes into the area, and evacuation (Özdamar & Demir, 2012; Sheu, 2009; Yi & Kumar, 200; Yuan & Wang, 2009). Acknowledged by researchers, each model contained issues including communication, ability of local population to assist, and removal of people through evacuation. Thus a system dynamics approach was selected for the analysis in this multi-methods study as it can be constructed to represent the characteristics of the observed systems (Sterman, 2001).

System dynamics models contribute significantly to complex decision making, according to Ghaffarzadegan, Lyneis, and Richardson (2011), who argue that model characteristics include a

feedback approach; that they are aggregated; they present simulation runs; and they are also preliminary models. However, they have limitations inasmuch as they cannot contain all possible causal links, either observed or contemplated. Ghaffarzadegan et al. stated that clients may need perimeter elements separately represented, increasing the level of disaggregation. This is an important point for this research, as there are various government, non-government and private sector organisations involved, and a potential systems model requires feedback. Once the insights provided by a small model are well understood by the representatives, a more detailed model can be constructed to analyse further elements.

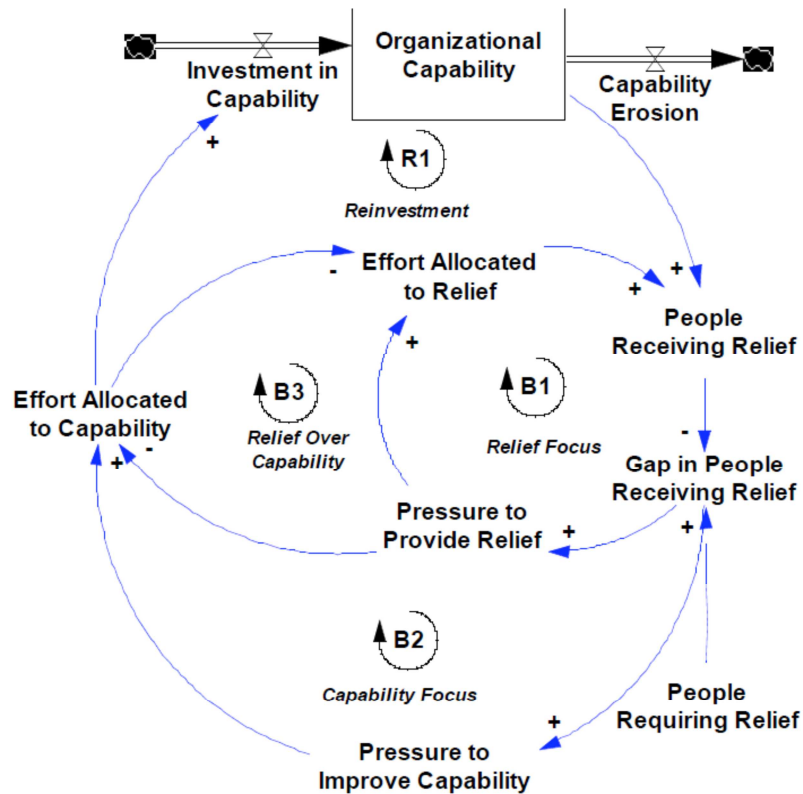
In particular, as discussed at section 2.4.3, Gonçalves (2008) suggested a multi-level systems dynamics model for national disaster relief that included the skills, capabilities and resources necessary for a substantial, if not catastrophic disaster. Disaggregating each model separately could assist decision making among the agencies, providing understanding of the gaps that could evolve under different scenarios, and the consequences of decisions and optional responses to a familiar problem. To run and validate the model, quantitative and qualitative data are required. Gonçalves suggested collecting qualitative data regarding resources from the decision makers to understand the resource decision making processes under different conditions; quantitative data could be attained through past data collections to target relief or capability improvement. Analysis of the results from this research would allow policymakers and operators to consider if the simulated dynamics reflected past experience.

A system dynamics methodology is employed to develop a logistics model for humanitarian disaster relief. Interdependence, mutual interaction, information feedback, and circular causality are contained in the logistics system under study (Sterman, 2000; Tovia, 2007). Mathematically, the basic structure of a formal system dynamics computer simulation model is a system of coupled, nonlinear, first-order differential (or integral) equations:

$$\frac{d}{dt} \mathbf{x}(t) = \mathbf{f}(\mathbf{x}, \mathbf{p}) \quad (4-1)$$

where \mathbf{x} is a vector of levels (stocks or state variables), \mathbf{p} is a set of parameters, and \mathbf{f} is a nonlinear vector-valued function (Richardson, 2008).

In this research, a systems model by Gonçalves (2008) was chosen as the basis for a logistics model for humanitarian relief (figure 4.1)



Source: Gonçalves, 2008, p.14

Figure 4.1 *Systems dynamics framework*

Figure 4.1 shows the model of a systems design with the following characteristics:

- people receiving relief, calculated as actual performance for the desired performance level:
- people requiring relief, which leads to
- the gap in people receiving relief, and action to close it through
- pressure to provide relief, by allocating more resources, people, equipment, consumables.

According to Gonçalves (2008), there are two factors that impinge on this outcome: effort allocated to relief and organisational capability. Effort allocated to relief impinges on organisational capability (better communications, wider coordination), to provide more resources to rescue more people.

4.2 Data collection

Data collection for this research comprised secondary and primary data, plus information on aspects of emergency relief operations such as media reports. For the primary data, a survey of stakeholders in disaster relief for Jeddah, province of Makkah, Kingdom of Saudi Arabia was obtained. The structure of the Kingdom results in all lines of control resting with the Council of Ministers and ultimately, King Abdullah. Thus there was at the time of the Jeddah floods, little consultation or communication between the various levels of the public services and each had separate information and both organisational and individual views.

Data gathering from agencies involved in disaster relief is primarily either written, through questionnaires, or verbal, through interviews. Cole, Zhuang, and Yates (2012) sought interviews from 18 local and international agencies regarding coordination and partnerships in the aftermath of the 2010 Haiti earthquake. Others used written surveys, such as Hu, Salazar, Zhang, Lu, and Zhang (2010) examining the impact of the 2008 Wenchuan earthquake disaster on the functioning of China's social protection system. Varvas and Mckenna (2013) used both forms of surveying to gather data on agencies' responses for the 2010 Haiti earthquake.

Interviewing as a means for data collection was difficult in Saudi Arabia due to identification of, and accessibility to, the key organisers at the time of the floods (2009, 2011). A written questionnaire could be drafted to accommodate experiences and views; as well, use of Likert scales aid quantitative analysis and this aspect was difficult to ascertain in an interview. Thus a questionnaire was considered the optimal method to answer research questions 3 and 4, and to confirm the literature and context findings for the other questions.

4.2.1 Questionnaire

The objective of the questionnaire was to gather respondents' experiences during the 2009/2011 Jeddah floods, and their views at the time and at the time of completing the questionnaire on disaster relief funding, human resources, operational training, and coordination between agencies (independent variables) and organisational performance (dependent variable) in terms of response time and duration of the allocated tasks and duties. Whilst the literature did not reveal survey questions that were relevant to the Jeddah floods, direction on the questionnaire framework followed Bharosa et al.'s (2010) survey on coordinating information during multi-agency disaster response; Aitken et al.'s (2012) survey of international emergency response

logistics; and Hammad et al.'s (2011) assessment of health professionals' training for disaster response.

The questionnaire was constructed in several sections: the emergency response framework, organisational characteristics, and the adequacy of the various entities' responses to the floods. The questions were adapted from data requirements on the website of the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), Gonçalves (2008), with some factors adapted from Oloruntoba and Grey (2006) and Bharose et al. (2010). The survey commenced with respondents' demographic details and position in the organisation. The second part of the questionnaire had a range of factual responses, from open or non-directed to closed, yes/no answers. It was constructed by section as follows:

- 1 Organisation profile (5 questions)
- 2 Risk assessment (6 questions)
- 3 Policy and planning (4 questions)
- 4 Operational training (4 questions)
- 5 Government structures (15 questions)
- 6 Non-government and Red Crescent input (12 questions)
- 7 Disaster relief resources (17 questions)
- 8 Funding (6 questions)
- 9 International assistance (10 questions)
- 10 Strengths and weaknesses of current disaster response plan (7 questions).

The third part of the questionnaire used a series of independent and dependent variables regarding respondents' views of factors regarding emergency response. These were based on a 5-point Likert scale, 1 (excellent) to 5 (poor). The dependent variables were:

- 11 Response time (3 questions)
- 12 Duration of response (3 questions)
- 13 Adequate emergency teams (3 questions)
- 14 Cost efficiency (3 questions)

The independent variables were:

- 15 Funding (3 questions)
- 16 Human resources (3 questions)
- 17 Training (3 questions)
- 18 Coordination between responsible organisations (4 questions)

Other questions:

19 Opportunities for improvement (19 questions).

4.2.2 Sample and data collection

This was a full population sample; a knowledgeable representative from all public entities and not-for-profit organisations who were involved in the management of disaster response in Jeddah, Makkah (approvals), or Riyadh (finance) during the 2009/2011 floods. There were 40 possible disaster management respondents in various agencies and organisations in Jeddah and, after initial contact to establish this researcher's credentials, the purpose and ethics of the study, these questions were sent to a central contact point in each organisation for answering by an organisational representative. Thus the research comprised a population of public entities, rather than a sample of respondents from each of the relevant organisations. This was considered acceptable, as the questions concerned public policy rather than respondents' views (Bryman, 2012). Of the 40 written surveys delivered in August 2012, 27 (79%) completed surveys were returned for analysis by October, 2012.

4.3 Data analysis

Descriptive analysis was used to identify the national and local government agencies and non-government assistance that could be called upon to act to lessen the impact of disasters, and the responsibilities each entity has in disaster mitigation (Gliner, Morgan, & Leech, 2009). After collection, data were entered into SPSS Statistical Package and analysed by part of the questionnaire; in the first part, demographics, the results were analysed by frequency; in the second part, the qualitative questions were analysed according to Badiee et al. (2012) using frequency of words and phrases to construct classifications of responses. From these categorisations, further analysis produces themes that can be used to answer the research questions. For the quantitative data analysis, Likert scale questions, frequencies, means and standard deviations were derived. The remaining analyses were performed using the system dynamics framework adapted from Georgiadis and Vlachos (2004).

4.3.1 Causal loop diagram

In the systems dynamics framework in figure 4.1, a causal loop diagram is used for interaction and feedback among elements in the system. Simonović (2011) describes a causal loop diagram as a link from element A to element B which is negative if A detracts from B, or A changes

so that there is a change in B in the opposite direction; that is, an increase in A tends to produce a decrease in B. A causal link from element A to element B is positive if either A adds to B or a change in A produces a change in B in the same direction; that is, an increase in A tends to produce an increase in B. Thus the polarity of a causal loop is the product of the polarity of its causal links, and a causal loop is positive if it contains an even number of causal links, and negative if it contains an odd number of causal links. Simonović (2011) uses a causal loop based on the attractiveness of volunteering (+), the effects of an increasing number of volunteers (+), thus decreasing rewards per volunteer (-). The polarity of the loop is therefore negative, although, as Simonović explains, it also determines that the loop describes a stabilising process whereupon individual rewards will determine the number of people volunteering.

4.3.2 Stock and flow diagram

The next part of the system dynamics model is a stock and flow diagram, used to depict the dynamics that emerge from the causal loop diagram. The stock and flow diagram has four basic objects: stock, flow, connector, and auxiliary. The stock represents the quantification of a variable at a given moment, and its numerical value is the net balance between inflows and outflows, that is, the sum of past activity results in the system. Flow represents the rate of change of stock variables, the numerical value is determined by the relationship between stock variables and auxiliary (control) variables; auxiliary variables represent the design of parameters or variables; the connector represents a transfer of relevant information among the variables. The stock and flow diagram is used in conjunction with causal feedback loop diagrams to present variable information flows (Chang, Teng, Yang, & Chang, n.d.). Sterman (2001) added the concept of cloud to signify the environment for the model.

A national policy model planning for disaster relief was developed by Deegan (2005) to distinguish between structural mitigation planning and structural mitigation capacity. In this stock and flow model there must be government commitment to emergency response plans, when it is challenging to deal with a low probability/high consequence problem. It is important to establish response plans that are no longer valid and the rate at which resources for planning are used efficiently. Further, implementation challenges outflow represents the cost of maintenance for structures such as dams, waterways and levees.

After building the stock and flow diagrams, mathematical equations describe the interactions among variables in the diagrams. The equation of a variable is a function of all variables and constants connected to the variable in the diagram. Moreover, the developed equation should be a

representative of its real world. The mathematical equations are categorised into state equations and flow equations. While the state equations define the accumulations within the system through the time integrals of the net flow rates, the flow equations define the flows among the stocks. Further, the flow equations are time functions of the stocks and other state variables and parameters (Georgiadis & Vlachos, 2003). Stocks can be formulated in three equivalent mathematical representations as following:

- Stocks accumulate or integrate their flows. Hence the structure corresponds exactly to the following integrate equation:

$$Stock(t) = \int_{t_0}^t [Inflow(s) - Outflow(s)] ds + Stock(t_0) \quad (4-2)$$

where inflow(s) represents the value of the inflow at any time s between the initial time t_0 and the current time t .

- The net flow into the stock is the rate of change of the stock. Equivalently, its derivative is the inflow less the outflow, defining the differential equation:

$$d(Stock)/dt = Inflow(t) - Outflow(t) \quad (4-3)$$

- The equation of stock can be represented by using the INTEGRAL() function:

$$Stock = INTEGRAL(Inflow - Outflow, Stock_{t_0}) \quad (4-4)$$

Thus the stock accumulates its inflows less its outflows.

Although the mathematical description of a system requires only the stocks and their rates of change, defining auxiliary variables assists clarity. Auxiliaries consist of functions of stocks (and constants or exogenous inputs). While constants are stocks changing too slowly to be modelled explicitly, exogenous variables are stocks outside the model boundary. The employment of auxiliary variables is critical to effective modelling. Ideally, one concept is represented by each equation in the models (Sterman, 2001).

4.3.3 Quantitative analysis

In the quantitative analysis phase control theory techniques and statistical techniques are employed, together with computer simulation. These are addressed in this section.

Control theory, according to Jagacinski and Flach (2011), describes the content and processes of a dynamic system that should be set to achieve a goal. Aspects of control theory

include classical control (feedback loop discussed in section 4.1.2) optimal control, fuzzy control, adaptive control, learning control, and perception and decision making in dynamic contexts. Techniques available to answer the research questions using control theory include a cost function of state and control variables; that is, a set of differential equations describing the paths of the control variables that minimise the cost function. Jagacinski and Flach describe fuzzy control as typically employing three stages: the subjective estimate of several different quantities; determining the positioning of each of these observations or measurements in a fuzzy set; together with ‘and-ing’ placing the elements in conjunction to obtain the best fit. Adaptive control refers to situational awareness, when a controller must have an underlying control and at another level, adapt the overt control law to adjust to a new situation; Jagacinski and Flach use the example of a pilot flying a plane and adjusting to the environment. Learning control relates to difficulty in learning and using a control system is influenced by increasing orders of control. ‘Position (zero-order) and velocity (first-order) controls are relatively easy to use. Acceleration (second-order) controls are more difficult. Third-order and higher order controls are very difficult and can lead to unstable performance’ (Jagacinski & Flach, 2011, p.96.) Action and perception are well suited to open systems and an environmental perspective, with action referring to a ‘force’ coupling and perception to information coupling between a human-machine system and its environment. The authors use this coupling analogy in the form of a feedback system, where forward loops (action) and feedback loops (information) represent the coupling between the human and the environment. Thus action and perception meet the needs of this system dynamics framework using scouting parties to assess the needs after a disaster and reporting back to start the feedback-action loops. This forms the decision making in a dynamic, real time context, whereby the ‘problem of decision making, as seen in this framework, is a matter of directing and maintaining the continuous flow of action towards some set goal’ ((Jagacinski & Flach, 2011, p. 314).

Statistical techniques in analysing the elements in disaster management are not widespread. In a somewhat dated meta-study, Altay and Green (2006) showed that mathematical programs were the most frequently utilised analytical method used by researchers in disaster management, followed by probability theory and statistics, although there was little use of statistics; simulation was third, and this was followed by decision theory and multi-attribute utility theory. Queuing theory was used with relative frequency, whilst system dynamics and constraint programming were underutilised. However, in a recent review of developments in disaster operations management, Galindo and Batta (2013) confirmed that little had changed since Altay and Green’s (2006) assessment. Thus the use of system dynamics in this study is confirmed in the literature.

The next analytical procedure in the systems dynamics framework adapted from Georgiadis and Vlachos (2004) was computer simulations. In this study, simulations were conducted to the emerging model under a number of certain system constants representing the application environment of the model. Independent or exogenous variables are often used to explore the dynamic characteristics of a model of a system (Groesser & Schaffernicht, 2012), who advocated for a more robust conceptual structure of a dynamic model to use this structure to operationally enhance the planning approach. Accordingly, scenarios are designed to evaluate the dynamic behaviour of the system against a certain number of factors or independent variables at different levels.

In this research, once the required equations were formulated, a system dynamics program is necessary to capture the stock and flow diagrams and the equations in the proposed system dynamics model. Two system dynamics models were developed by means of Vensim PLE for Windows version 6.00 Beta. All parameter values in each system were determined and entered into each model. Moreover, the values of each scenario were entered into each model before executions. The simulation results were utilised to study the behaviour of the proposed systems. A detailed description of the system dynamics simulations are presented in the following chapters.

4.3.4 Verification and validation

In examining post-disaster water crisis in Iran after the 2003 earthquake in Bam, Bagheri et al. (2010) used a system dynamics analysis of alternative policies to verify the optimum path. Bossel (2001) found that performance assessment in holistic approaches such as integrated system dynamics models such as disaster management include complex sets of interacting elements and agents, 'all pursuing their own "interests" while also contributing to the development of the total system' (Bossel 2001, 1). Performance criteria are necessary to verify and validate essential components together with the efficacy of their contributions to the viability and performance of other component systems and the total system under study. Verification and testing the system is required to eliminate known variation and bound known unknowns.

Validation of a systems dynamic model, according to Barlas (1996), primarily means validity of its internal structure and Barlas holds that this cannot be entirely objective, formal and quantitative. Barlas' verification process uses direct structure tests and structure-oriented behaviour tests. Direct structure tests assess the validity of the structure by comparing each element (quantitative or qualitative) with available knowledge about the real system, without using simulation. This can occur both empirically or theoretically, by comparing the model equations with

the literature. Of the tests, structure confirmation tests use verification and validation of computer models; conceptual confirmation occurs by identifying elements in the real system that correspond to the parameters of the model; and numerical confirmation consists of accuracy in estimating the numerical value of the parameters. Barlas' (1996) second category of structural tests indirectly assesses the validity of the structure, by applying behaviour tests on model-generated behaviour patterns using simulation of the entire model, and to sub-models to uncover potential structural flaws. These include stress testing (assigning extreme values to selected parameters and comparing the results to the observed behaviour of the real system); and behaviour sensitivity testing (identifying highly sensitive parameters). Modified behaviour prediction tests can also be applied to assess whether the model itself can reflect similar modified behaviour. In a subsequent paper on parameter search processes, Yücela and Barlas (2011) used a pattern identification algorithm based on qualitative features of a desired behaviour pattern, in the absence of a reference data series. The approach can be used in model calibration, sensitivity analysis, validation, and policy design stages in dynamic feedback models.

4.3.5 Dynamic analysis and What if analysis

The last aspects of the system dynamics model are analysis and 'what if' scenarios. The model analysis and its verification were discussed in this chapter; however, there are other aspects of this research that impact on the analysis of a post-disaster event. Deegan (2007) performed an extensive analysis on flooding and flood mitigation in the United States, taking both exogenous and endogenous perspectives. To analyse rising costs, the exogenous analysis arguably attributed this to more frequent floods or more severe floods, or both. Deegan argued for an endogenous view of flood damage, the influence of human activity in building on places vulnerable to flood damage. Elements in this model included the capacity of an area to withstand floods, development pressures, and incorrect decisions from policymakers. Thus analysis of the system dynamics in this study may just as accurately be directed on the policymaking processes and simulations of prior decisions as they are on the effects of the disaster once it has occurred. What if analysis is thus extended past the parameters of this thesis to explore other facets of the research problem.

4.4 Chapter summary

This chapter sets out the research questions and proposes a system dynamics framework that encompasses the primary and secondary data collection to answer the research questions. A multi-methods design with secondary and primary data collection was selected to answer the research

questions. The first two research questions were answered in the previous chapters, and this chapter proposed a system dynamics framework to address the data collection and analysis. Primary data collection comprised a survey of emergency relief stakeholders for Saudi Arabia and from Jeddah.

Descriptive analysis was used initially, followed by the discussions relating to the components of the model: a causal loop diagram, a stock and flow diagram, and the requisite equations. For the quantitative part of the framework, discussions included control theory techniques, statistics and computer simulation, followed by system validation, further analysis and what if analysis. The next chapters therefore present the results from the quantitative part of the systems dynamics model.

Chapter 5 Results

The previous chapter set out the methodology for this research, surveying representatives of the Saudi decision makers and administrators responsible for disaster control in Jeddah before, during and after flooding in 2009 and 2011. This chapter presents the results of the survey. First, demographics of the respondents are presented, and this is followed by quantitative analysis of their views and experiences regarding the Kingdom's readiness before and after each flood. This is shown as a series of dependent and independent variables. Following this is a list of respondents' priorities for disaster preparation in the Kingdom.

5.1 Demographics

This section includes the ages, qualifications, and work experiences of the participants. The age profile is shown in table 5.1.

Table 5.1
Age profile of study participants

Age level (years)	Frequency and percentage
< 30	2 (6%)
30-40	3 (10%)
41-50	20 (68%)
51>	2 (6%)
Not shown	3 (10%)
Total	30 (100%)

Given the youthful profile of the Kingdom (United Nations, 2014), it was surprising that 20 of the 30 respondents (68%) were aged from 40 to 49 years and this was reflected in the participants' years of experience, 16-20 years (table 5.2). Arguably, this is an indication that the offices were established during that period (1990s), as public servants have their jobs for life.

Table 5.2
Work experience of study participants

Years of work experience	Frequency and percentage
<10	2 (7%)
11-15	4 (13%)
16-20	19 (63%)
>21	2 (..7%)
Not shown	3 (10%)
Total	30 (100%)

The following table, 5.3, shows all that reported were university graduates and that a majority (47%) had Master's degrees. Further, seven (23%) of the respondents had further qualifications, either postgraduate studies in disaster management, or higher degrees.

Table 5.3
Qualifications of study participants

Qualifications	Frequency and percentage
Secondary school	0 (0%)
Bachelor's degree	6 (20%)
Master's	14 (47%)
Other qualifications	7 (23%)
Not shown	3 (10%)
Total	30 (100%)

5.2 Descriptive analysis

The Methodology chapter outlines the nature of the questions. This section presents the results of the questions using a 5-point Likert scale of 1= poor, 2 = fair, 3 = good, 4 = very good, and 5 = excellent. The results are compared and discussed in chapter 6.

5.2.1 Quality of response (dependent variables)

These questions asked for the participant's response in relation to the lead disaster response agency for the Kingdom, the General Directorate of Civil Defence. Each question required a response for 2009 and 2011. The results are presented at table 5.4

Table 5.4
Quality of response of General Directorate of Civil Defence

Year	Item	W.A. n=30	S.D.	Ranking
2009	Response time	2.778	1.500	1
	Efficiency	2.776	1.066	2
	Resources	1.949	1.000	4
	Cost structure	1.998	1.333	3
2011	Response time	2.001	1.100	3
	Efficiency	2.112	1.033	1
	Resources	1.991	1.333	4
	Cost structure	2.111	1.666	2
2009		2.375	1.224	
2011		2.530	1.283	

Table 5.4 shows four dependent variables depicting the study participants' views regarding the quality of the item relating to emergency responses from Civil Defence organisation to the Jeddah floods in 2009 and 2011. The participants were less satisfied with these responses for the 2009 episode, with weighted average at 2.375 and standard deviation 1.224, than the comparable 2010 weighted average, 2.530, and s.d. of 1.283. Other results for 2009 flood disaster showed that the variable *response time* was of primary interest to the participants (w.a. 2.778, s.d. 1.500), followed by *efficiency* (w.a. 2.776, s.d. 1.066), *cost structure* (w.a. 1.998, s.d. 1.333), and *resources available*, (w.a. 1.949, s.d. 1.000). The 2011 results, on the other hand, ranked variables *efficiency* (w.a. 2.112, s.d. 1.0333), *cost structure* (w.a. 2.111, s.d. 1.666), *response time* (w.a. 2.001, s.d. 1.100) and then *resources available* (w.a. 1.991, s.d. 1.333) as the least important factor.

The next organisation examined was the Red Crescent. It is the lead agency in administering medical aid for the Kingdom, working with the ambulance services and the hospitals. Each of these items asked for the participant's views on the quality of Red Crescent's response for 2009 and 2011. The results are presented at table 5.5.

Table 5.5
Quality of response of Red Crescent

Year	Item	W.A. n=30	S.D.	Ranking
2009	Response time	2.500	1.581	1
	Efficiency	1.889	1.666	4
	Resources	1.904	1.833	3
	Cost structure	2.000	1.003	2
2011	Response time	3.166	0.888	2
	Efficiency	3.500	0.667	1
	Resources	2.833	1.007	3
	Cost structure	2.333	1.223	4
2009		1.999	1.594	
2011		2.958	0.946	

Table 5.5 shows the analysis of participants' views of the Red Crescent and the quality of its response to the flood events of 2009 and 2011. The results show that participants were less satisfied with these responses for the 2009 flood, with the w.a. at 1.999 and s.d. 1.564, than the comparable 2010 w.a., 2.985, and s.d. 0.946. Other results for 2009 flood disaster show that the variable *response time* was ranked of interest (w.a. 2.500, s.d. 1.581); followed by *cost structure* (w.a. 2.000, s.d. 1.003), *resources available* (w.a. 1.903, s.d. 1.333); and of less interest, *efficiency* (w.a. 1.889, s.d. 1.666). For the 2011 flood event, the rankings were *efficiency* (w.a. 3.500, s.d. 0.667), followed by *response time* (w.a. 3.166, s.d. 0.888) *resources available* (w.a. 2.833, s.d. 1.007); and finally *cost structure* (w.a. 2.333, s.d. 1.223).

Local and national emergency response groups provide immediate relief in the event of an emergency in their neighbourhoods. The participants were asked for their views on the ad hoc groups' responses in 2009 and again in 2011 (table 5.6).

Table 5.6
Quality of response of local emergency groups

Year	Item	W.A. n=30	S.D.	Ranking
2009	Response time	1.833	1.353	3
	Efficiency	1.666	1.290	4
	Resources	1.966	1.402	2
	Cost structure	2.168	1.366	1
2011	Response time	3.833	0.957	1
	Efficiency	3.166	1.033	3
	Resources	3.300	1.002	2
	Cost structure	2.566	1.887	4
2009		1.707	1.553	
2011		3.216	1.219	

Table 5.6 depicts the respondents' views on the standards for local response groups to the Jeddah floods in 2009 and 2011. The participants were less satisfied with these responses for the 2009 event (w.a. 1.707, s.d. 1.553) compared to 2011 (w.a. 3.216, s.d. 1.219). Ranked results for the 2009 event show that the variable cost structure was of statistical interest (w.a. 2.168, s.d. 1.366); followed by resources available (w.a. 1.966, s.d. 1.402), response time (w.a. 1.833, s.d. 1.353), and efficiency (w.a. 1.666, s.d. 1.290). Other results for the 2011 flood disaster show that response time ranked first (w.a. 3.833, s.d. 0.957), then resources available (w.a. 3.300, s.d. 1.002) efficiency (w.a. 3.166, s.d. 1.033) and last, cost structure (w.a. 2.566, s.d. 1.887).

5.2.2 Quality of preparation (independent variables)

The independent variables, those factors available to address disaster response before the event, were funding, people, training and coordination. These were questions for the study participants to answer in regards of the two lead organisations, the General Directorate of Civil Defence and the Red Crescent, and also ad hoc emergency response groups. These questions were answered using a 5-point Likert scale of 1= poor, 2 = fair, 3 = good, 4 = very good, and 5 = excellent. The results are compared and discussed in chapter 6.

The first table in this section, 5.7, shows analysis of participants' responses to items critical to the country's preparation to respond to a crisis, and this is for the lead agency, General Directorate of Civil Defence.

Table 5.7
Preparation for disaster response by General Directorate of Civil Defence

Year	Item	W.A. n=30	S.D.	Ranking
2009	Funding	2.000	1.445	4
	People	4.000	0.305	3
	Training	5.000	0.101	1
	Coordination	5.000	0.112	2
2011	Funding	2.000	1.433	4
	People	5.000	0.110	1
	Training	5.000	0.117	2
	Coordination	5.000	0.201	3
2009		4.000	0.490	
2011		4.250	0.436	

Again there are four variables for the participants' response for this section of the analysis on the lead agency, General Directorate of Civil Defence, and again the respondents were found to be mildly less satisfied with preparations for the 2009 flood event (w.a. 4.000, s.d. 0.490) than 2011 (w.a. 4.250, s.d. 0.436), with more people being available in 2011. Other results for the 2009 flood disaster preparation show that the variables *training* (5.000, s.d. 0.101) and *coordination* (w.a. 5.000, s.d. 0.112) as significant, followed in ranking by *people availability* (w.a. 4.000, s.d. 0.305), and last, *funding* (w.a. 2.000, s.d. 1.445). Analysis of participants' views on preparations for 2011, with the exception of *funding*, were fairly uniform: *people* (w.a. 5.000, s.d. 0.110), *training* (w.a. 5.000, s.d. 0.117), and *coordination* (w.a. 5.000, s.d. 0.201). *Funding* in the disaster planning phase, as noted, was last (w.a. 2.000, s.d. 1.433).

The following table, 5.8, shows the analysis of these items for the Red Crescent.

Table 5.8
Preparation for disaster response by Red Crescent

Year	Item	W.A. n=30	S.D.	Ranking
2009	Funding	2.000	1.414	4
	People	4.000	0.998	3
	Training	5.000	0.301	2
	Coordination	5.000	0.112	1
2011	Funding	2.000	1.512	4
	People	5.000	0.222	2
	Training	5.000	0.189	1
	Coordination	5.000	0.300	3
2009		4.000	0.706	
2011		4.250	0.555	

As table 5.8 shows, there are four variables analysed to report study participants' views regarding emergency response by Red Crescent to the Jeddah floods in 2009 and 2011. The participants were somewhat less satisfied with Red Crescent's preparations before the 2009 floods (w.a. 4.000, s.d. 0.706) than compared to preparations for 2011 (w.a. 4.250, s.d. 0.555). Rankings for preparation reported by the study participants were similar for *coordination* (w.a. 5.000, s.d. 0.112) and *training* (w.a. 5.000, s.d. 0.301), followed by *people availability* (w.a. 4.000, s.d. 0.998) and last, *funding* (w.a. 2.000, s.d. 1.414). For preparation in the next year, the study participants viewed *training*, *people* and *coordination* similarly (w.a. 5.000; s.ds. 0.189, 0.222 and 0.300 respectively). However, funding preparation gained their disapproval yet again (w.a. 2.000, s.d. 1.512).

The last set of questions concerned local emergency response groups and their preparation. As ad hoc organisations (for example from neighbourhoods and social media responses) which formed when a response was necessary, respondents' views obviously reflected different groups. Nevertheless, their responses were an indicator of the community's risk awareness and capacity to respond (table 5.9).

Table 5.9
Preparation for disaster response by local groups

Year	Item	W.A. n=30	S.D.	Ranking
2009	Funding	4.966	0.344	4
	People	5.000	0.003	1
	Training	5.000	0.011	2
	Coordination	5.000	0.022	3
2011	Funding	4.633	0.422	4
	People	5.000	0.004	1
	Training	5.000	0.110	3
	Coordination	5.000	0.014	2
2009		4.991	0.095	
2011		4.908	0.137	

The responses from the participants were relatively unchanged between 2009 (w.a. 4.991, s.d. 0.095) and 2011 (w.a. 4.908, s.d. 0.137), although there was slightly less satisfaction for the 2010 preparation for the groups. Otherwise, the 2009 rankings for groups' preparation were people, training and coordination (w.a. 5.00 and s.ds respectively 0.003, 0.011 and 0.022) with funding obviously last (w.a. 4.966, s.d. 0.344), as ad hoc groups were volunteers. Similarly, 2011 group preparation was people, coordination and training (w.a. 5.00 and s.ds respectively 0.004, 0.014 and 0.110), signifying less training preparation.

5.2.3 Priorities for emergency response planning

The respondents were asked their views on elements for improving the country's emergency response. Again a 5-point Likert scale was used of 1 = disagree strongly, 2 = disagree, 3 = neutral, 4 = agree, and 5 = agree strongly. The results are shown at table 5.10 and discussed in chapter 6.

Table 5.10
Respondents' priorities on emergency response planning elements

Item	W.A. n=30	S.D.	Ranking
Existing plan unchanged	0	0	0
Organisational training	5	0.001	1
Inter-organisational responsibilities	5	0.012	2
Community preparedness	4.966	0.399	3
Coordinate all organisations	4.933	0.401	4
Public awareness	4.9	0.321	5
Communications	4.833	0.498	6
Experienced resources	4.5	0.603	7
Organisational preparedness	4.333	0.334	8
Public preparedness	4.333	0.311	9
Infrastructure	4.166	0.643	10
Policy making	4.066	0.723	11
Physical resources	4	0.643	12
Inter-organisational practices	4	0.664	13
Inter-organisational information sharing	3.933	0.712	14
Finance	3.866	0.767	15
Inter-organisational communications	3.766	0.822	16
International advice	3.3	0.987	17
Average	3.889	0.465	

Rankings shown in table 5.10 indicate that emergency response policy makers and administrators viewed training of response teams across all organisations (w.a. 5.000, s.d. 0.001) as vital for future preparedness of the country to respond to floods or other disasters. This was followed by defining the responsibilities of each group in the response system (w.a. 5.000, s.d. 0.012) to ensure they were allocating their resources to the greatest effect. Next was community preparedness (w.a. 4.966, s.d. 0.399), followed by coordination of all response organisations (w.a. 4.933, s.d. 0.401) communications (w.a. 4.833, s.d. 0.498), and at priority 5, public awareness (w.a. 4.900, s.d. 0.321). Of least interest was to leave the system as it was, which attracted no answers, and to increase international advice and input w.a. 3.300, s.d. 0.987). Due to the number of choices, the average agreement to all the items was low (w.a. 3.889, s.d. 0.465).

5.2.4 Section summary

In the first analysis of participants' views, which was on the 2009 disaster relief operation, General Directorate of Civil Defence's response time and efficiency were ranked highest, as fair to good. For the organisation's response to the 2011 floods, efficiency and cost structures were ranked highest, as fair. The Red Crescent is charged with medical duties during a crisis, and its response performance during the 2009 floods was selected by the respondents as fair to good, followed by its cost effectiveness which was fair. For the 2011 event, the respondents reported that Red Crescent's efficiency was good to very good, and its response time was also good. For local response groups, which were all volunteers, their performance during the first 2009 floods was described as poor; however, a year later, the study respondents said that both the volunteers' response time and their resources were good to very good.

The second set of questions involved planning and preparation for a disaster, and the respondents surprisingly gave an excellent verdict to coordination and training for the General Directorate of Civil Defence before the 2009 floods, and this was supported in the following year before the 2011 floods by excellence of the people who worked in the organisation. Given the low opinion of the group to the emergency response, it would be expected that they would also have a low opinion of the organisation's preparation and planning. A similar report was made for Red Crescent, duplicating the excellence rankings both for 2009 and 2011, although this was again more enthusiastic than the respondents' view of their response either in 2009 or 2011. Finally, preparation and planning for the volunteer groups was also given uniformly vigorous support in 2009 and 2011, despite poor opinion of their 2009 responses. The similarity of the responses for preparation may reflect indifference by the study participants to the questions, or a desire to praise the people involved.

The participants were overwhelmingly in agreement on the top areas for future attention: training of response teams, identification and coordination of the organisational responsibilities, community awareness and preparedness.

5.3 Modelling

Modelling the agencies' responses in specific situations allows better understanding of their capabilities and could indicate policies to improve performance. The objective of modelling dynamic systems supports decision making at a national, regional and individual organisation level. Each responsible agency can add data to their section of the integrated systems model and use this to see the relationships that develop with organisations integrated into the overall system. Feedback from these entities allows the agency to adjust their response to meet a simulation, such as a return of flooding to Jeddah (Gonçalves, 2008). This section presents the results from the systems dynamics modelling explained in section 4.3.2.

5.3.1 Causal-loop diagram

The variables for the causal-loop of the proposed emergency logistics system for a natural disaster situation in Saudi Arabia were derived from the literature, the contextual elements of the study, and the relative importance of each variable (weighting) was obtained by means of the qualitative component of the research as suggested by Gonçalves (2008). In this study, analysis of stakeholder participants' responses was used. The first strategic diagram is presented as figure 5.1.

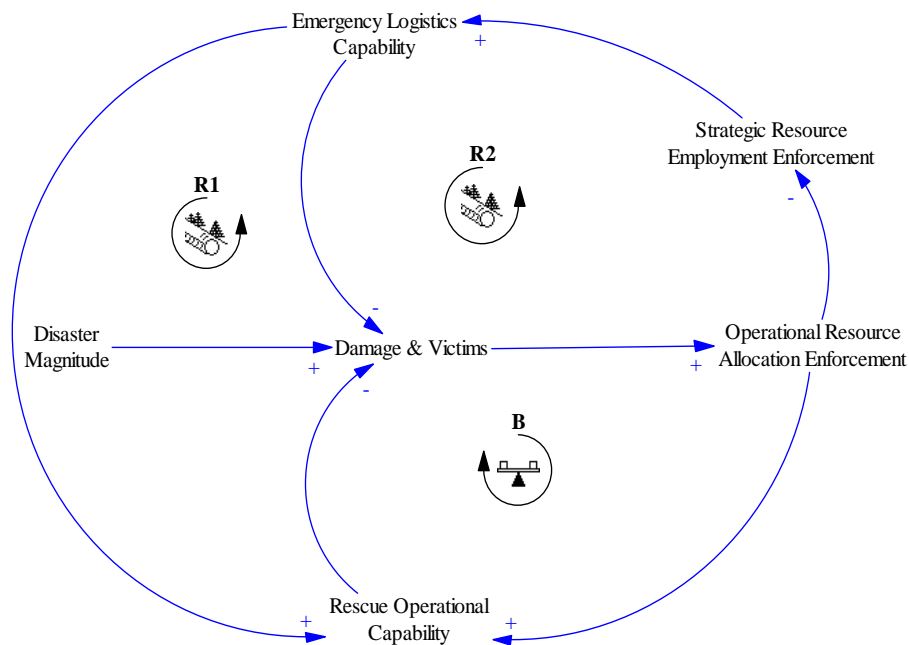


Figure 5.1 Results: Causal-loop model

Figure 5.1 shows the variables in the system that impact on a disaster response. The system's resources are termed emergency logistics capability, and this determines the rescue operations capability. Given the disaster magnitude, both the emergency logistics and the rescue operations capabilities engage with the effects of the disaster (damage and victims) and that results in the proportion of the people in the disaster that can be assisted over time (operational resource action/enforcement). The feedback from the causal loop (strategic resource deployment/enforcement) thereby results in change to the emergency logistics capability in the long run, and the rescue operational capability in the short run.

The dynamics in the system are illustrated by two types of feedback loops, positive (or self-reinforcing) and negative (or self-correcting) loops. While the positive loops tend to reinforce or amplify whatever occurs in the system, the negative loops counteract and oppose change (Sterman 2001). Figure 5.1 has two reinforcing loops, R1 and R2, the details of which are shown in table 5.11.

Table 5.11
Causal-loop: Self-reinforcing attributes

Loop	Variables	Sign
R1	Emergency logistics capability	+
	Rescue operation capability	-
	Damage and victims	+
	Operational rescue action/enforcement	-
	Strategic rescue deployment	+
R2	Emergency logistics capability	-
	Damage and victims	+
	Operational rescue action/enforcement	-
	Strategic rescue deployment	+

The first reinforcing loop in figure 5.11 has five variables: emergency logistics capability, rescue operation capability, damage and victims, operational rescue allocation enforcement and strategic rescue employment enforcement. The increase in value of a variable will also raise the value of interacting variables. Similar behaviour occurs in the second reinforcing loop: emergency logistics capability, damage and victims, operational rescue allocation enforcement, and strategic resource employment enforcement.

There is one balancing loop, B, in figure 5.1 and its details are presented in table 5.12.

Table 5.12
Causal-loop: Self-correcting attributes

Loop	Variables	Signs
B	Damage and victims	+
	Operational rescue action/enforcement	+
	Rescue operational capability	-

The balancing loop, B, is formed by three variables: damage and victims, operational rescue action/enforcement, and rescue operational capability. There is just one negative arrow in the balancing loop, that from rescue operational capability to damage and victims.

5.3.2 Derived dynamic systems model

In this study, the system dynamics software Vensim PLE for Windows version 6.00 Beta. was used to develop a stock-and flow diagram from the causal-loop diagram depicted in figure 5.11. Vensim was developed at Harvard University and is widely used in disaster management modelling (Gonçalves, 2008). Further, Kunz, Reiner, and Gold (2013) recently used the program to model training for response personnel in more efficient usage of pre-positioned physical resources. The resulting stock-and flow diagram is shown at figure 5.2.

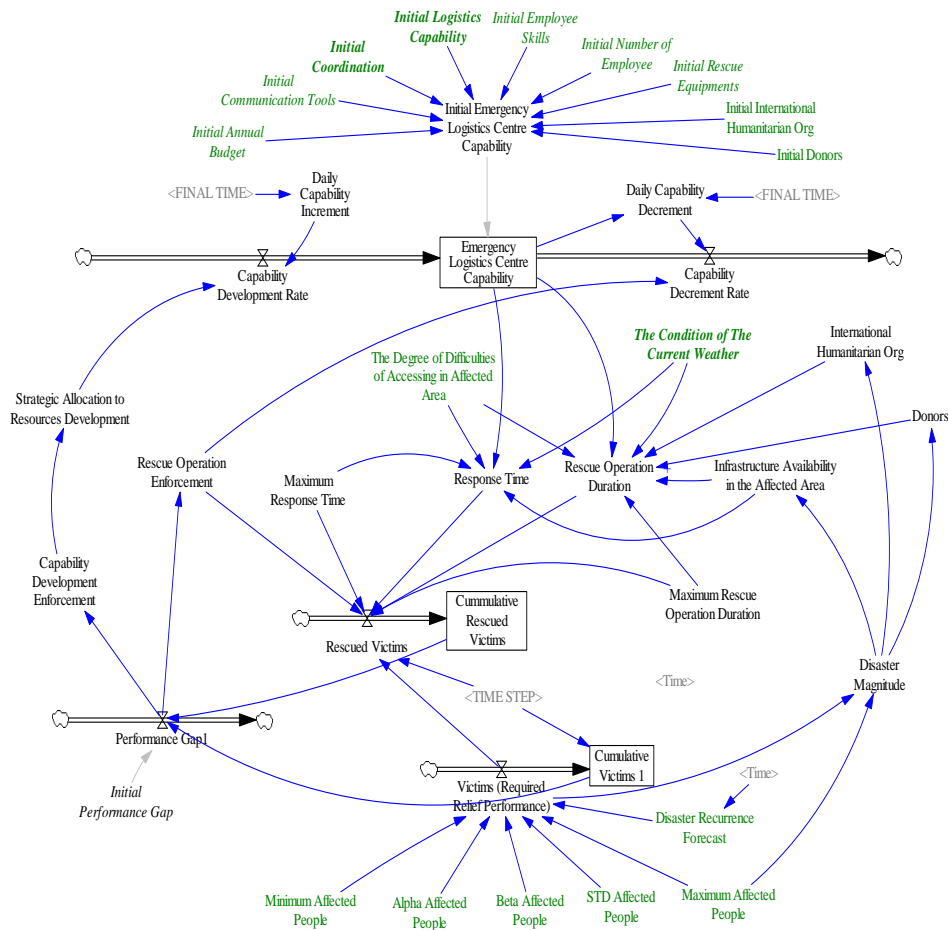


Figure 5.2 *Emergency Logistics Centre capability model*

As shown in figure 5.2, the stock-and-flow diagram models a dynamic system comprising stocks, flows, valves, and clouds. Stocks of variables, shown in rectangles, describe accumulations in the system. Flows can be inflows, represented by a pipe (arrow) pointing towards, or adding to stock, or outflows, pipes pointing out, thereby subtracting from stock; whilst valves represent flow controls. Clouds represent the sources and sinks for the flows. A source is external to the model and can replenish resources for use in the model, whilst a sink shows the site of resources leaving the model. Sources and sinks are assumed to be infinite and thus do not constrain the dynamics of the model (Sterman 2000). The variables used in this model include the following:

- Emergency Logistics Centre capability
- Capability development rate
- Capability decrement rate
- Final time*
- Daily capability increment

Initial annual budget
Initial communication tools
Initial coordination
Initial logistics capability
Initial employee skills
Initial number of employees
Initial rescue equipment
Daily capability decrement
Final time
International humanitarian organisations
Donors
Strategic allocation of resources development
Current weather
Difficulty of access to the affected area
Deterioration parameter
Capability development enforcement
Rescue operation enforcement
Maximum response time
Response time
Rescue operation duration
Infrastructure availability in the affected area
Rescued victims
Cumulative rescued victims
Maximum rescue operation duration
Time
Disaster magnitude
Minimum magnitude
Maximum magnitude
Mean magnitude
Standard deviation magnitude
Disaster occurrence forecasting
Performance gap1
Victims 1 (required relief performance)
Cumulative victims 1
Initial population in the affected area

Population in the affected area
Fatality rate
Initial performance gap
Victims 1 (required relief performance)
Rescued victims.

5.3.3. Emergency Logistics Centre capability model

The Emergency Logistics Centre capability model constitutes the first detailed physical structure of the factors that impinge on the disaster management framework for Saudi Arabia. It is different from previous studies such as Keller and Al-Madhari (1996) and Momani and Fadil (2010) on risk management in Saudi disasters, Bello and Aina (2014) on satellite imagery in disaster management, or public perception of disaster risk in the country (Alshehri et al., 2013).

As a model, the simulation differs from those of Gonçalves (2008) and Besiou et al. (2011) in complexity, depicting such variables as weather conditions and level of difficulty in access to the stricken area. Whilst intended for a disaster in urban and other areas of large populations, the model was tested for flood and earthquake; however, other natural disasters could be simulated in the model.

5.4 Chapter summary

This section explains the outcomes from the multi-methods approach to the research problem, which was to explore efficiencies in disaster management organisations in Saudi Arabia. To achieve this, a series of research questions resulted in identification of the civil defence framework which has since evolved to meet the international standards in this regard. The next issue was to find optimum response strategies for seek and recovery teams (short-term) and to mitigate the disaster scene and restore infrastructure and function in the longer term. In this task, system modelling was selected as an appropriate research approach and this was informed by querying officials in their experiences and perceptions of satisfactory response standards. Whilst the study participants were critical of the organisational structures, they were not critical of the officeholders' responses, a situation deemed to be cultural.

However, given the data available from the literature and from media and international reports, there was sufficient evidence to weigh the variables to construct a dynamic systems model, the Emergency Logistics Centre capability model, for testing. The testing is presented as a case study for Saudi Arabia in the next chapter.

Chapter 6 Case studies for the Emergency Logistics Centre capability model

The previous chapters presented the research necessary to construct a dynamic systems model to simulate the emergency response teams' behaviours during floods in Jeddah in 2009 and 2011. Whilst the generic model was influenced by weighting by stakeholders of the importance of the various organisations and the variables that must be addressed in a disaster, it is necessary to test the model to prove its efficacy.

This chapter commences with the results of the scenarios testing conditions of weather and access levels that relate to a Saudi Emergency Logistics Centre. By setting simulated conditions for the general model, testing can identify valid conditions for the Centre's performance over time. The Saudi Arabia model therefore is the result of testing the general Centre model for weather and access, as these were found to be crucial to Civil defence's response to the 2009 and 2011 Jeddah floods. The Australian model follows as a comparison for the 2011 Brisbane floods. A comparative discussion follows.

6.1 Testing model

This section comprises the test of the Emergency Logistics Centre capability model using various scenarios. This includes a discussion of the outcomes from the tests.

6.1.1 Scenario characteristics

The equations relating to the Saudi Arabia case study in the Emergency Logistics Centre capability model were derived using Vensim PLE software. The steps used in this task are:

Loading Vensim software

In developing the mathematical formulation, functions were developed as shown:

ACTIVE INITIAL (A,N): Defines an auxiliary with distinct active and initial values

FINAL TIME: The time at which the simulation will end

IF THEN ELSE (cond,X,Y): Returns X if condition is non-zero, otherwise Y

INITIAL TIME: The time at which the simulation will begin

INTEG (R,N): Performs numerical integration of R starting at N (defines a Level)

INTEGER(X): Returns the integer part of X

RANDOM NORMAL(m,x,h,r,s): Returns random variable with the common arguments m - minimum, x - maximum, h - shift relative to the referenced distribution, r stretch relative to reference, s-seed

SAVEPER Frequency with which simulation results are saved. Making SAVEPER bigger decreases the size of simulation files and increases the speed of simulations

TIME STEP The time interval for the simulation.

Principal equations to describe performance measurements in the proposed emergency logistics system are provided below:

1. Emergency Logistics Centre capability = IF THEN ELSE (Emergency Logistics Centre capability >= 1, 1, capability development rate - capability decrement rate)
2. Capability development rate = strategic allocation to resources development * daily capability increment
3. Capability decrement rate = daily capability decrement * rescue operation enforcement
4. FINAL TIME = (10 * 365) = 3650 days
5. Daily capability increment = 1 / FINAL TIME
6. Initial annual budget = 0.4
7. Initial communication tools = 0.4
8. Initial coordination = 0.4
9. Initial logistics capability = 0.4
10. Initial employee skills = 0.4
11. Initial number of employee = 0.4
12. Initial rescue equipments = 0.4
13. Daily capability decrement = IF THEN ELSE (Emergency Logistics Centre Capability = 0, 0, 1 / FINAL TIME)
14. International humanitarian organisation = 1 - disaster magnitude
15. Donors = 1 - disaster magnitude
16. Strategic allocation to resources development = capability development enforcement
17. Current weather = 0.8
18. Difficulty in accessing affected area = 0.8
19. Capability development enforcement = 1 - performance gap1
20. Rescue operation enforcement = performance gap1
21. Maximum response time = 0.5

22. Response time=(1-[current weather*0.3+ difficulty in accessing in affected area*0.2+infrastructure availability in the affected area*0.1+Emergency Logistics Centre capability*0.4])*maximum response time
23. IF THEN ELSE (Infrastructure availability in the affected area=1, 0 , (1-(the condition of the current weather*0.3+the degree of difficulties of accessing in affected area*0.2+infrastructure availability in the affected area*0.1+Emergency Logistics Centre capability*0.2+international humanitarian org*0.1+donors*0.1))*maximum rescue operation duration)
24. Infrastructure availability in the affected area=1-disaster magnitude
25. IF THEN ELSE ("Victims (required relief performance)"=0, 0 , ((rescue operation enforcement+((maximum response time-response time)/maximum response time)+((maximum rescue operation duration-rescue operation duration)/maximum rescue operation duration))/3*"victims (required relief performance)"/TIME STEP)
26. Cumulative rescued victims=rescued victims
27. Maximum rescue operation duration=7 days
28. Time= 1
29. Disaster magnitude="victims (required relief performance)"/maximum affected people
30. Minimum affected people=29
31. Maximum affected people=13000
32. Beta affected people =631.07
33. Standard affected people=5619
34. Performance gap1=IF THEN ELSE (cumulative victims 1=0, 0 , (cumulative victims 1-cumulative rescued victims)/cumulative victims 1)
35. Victims 1 (required relief performance)= IF THEN ELSE(disaster recurrence forecast=0, 0, RANDOM WEIBULL(minimum affected people , maximum affected people, alpha affected people, beta affected people , std affected people, 1997))
36. Cumulative victims 1="victims (required relief performance)"/TIME STEP
37. Initial population in the affected area=
38. Initial performance gap=0

Of the factors that emergency teams experience that cannot be controlled, difficulty in accessing the disaster area and the effects of the weather may have a significant effect on performance. To test the model, four scenarios were constructed containing three values: A for local

variables, B for difficulty in accessing the disaster zone, and C for the weather variables. Local variables (A) are:

1. Emergency Logistics Centre capability
2. Capability decrement rate
3. Capability development rate
4. Emergency team response times
5. Victims rescued from disaster
6. Accumulation rate of rescued victims
7. Duration of rescue operation
8. Constraint in allocation of emergency resources
9. Performance gap between optimum and minimal rescue conditions

For all scenarios depicting each of the above variables:

- rating is 0 to 1, with 0 as very poor and 1 as excellent
- value A (local variables), is 0.4 as the Saudi Arabian rescue system efficiency level was found to be 0.4 (below average)
- values B and C are alternated between 0.4 and 0.8 for the four iterations:

S1= (A=0.4, B=0.4, C=0.4)

S2= (A=0.4, B=0.4, C=0.8)

S3= (A=0.4, B=0.8, C=0.4)

S4= (A=0.4, B=0.8, C=0.8).

6.2 Testing Saudi case data

This section considers first four simulations using the Jeddah variables. The variables weather and access of the emergency crews on to the field were the tested.

6.2.1 Testing data for the Jeddah events

The four scenarios using the ten local variables for Jeddah were entered into the Emergency Logistics Centre capability model for estimations over a 10-year period. The first run concerned

local variable 1, the capability of the Emergency Logistics Centre. The model was tested through four scenarios over a period of ten years (figure 6.1)

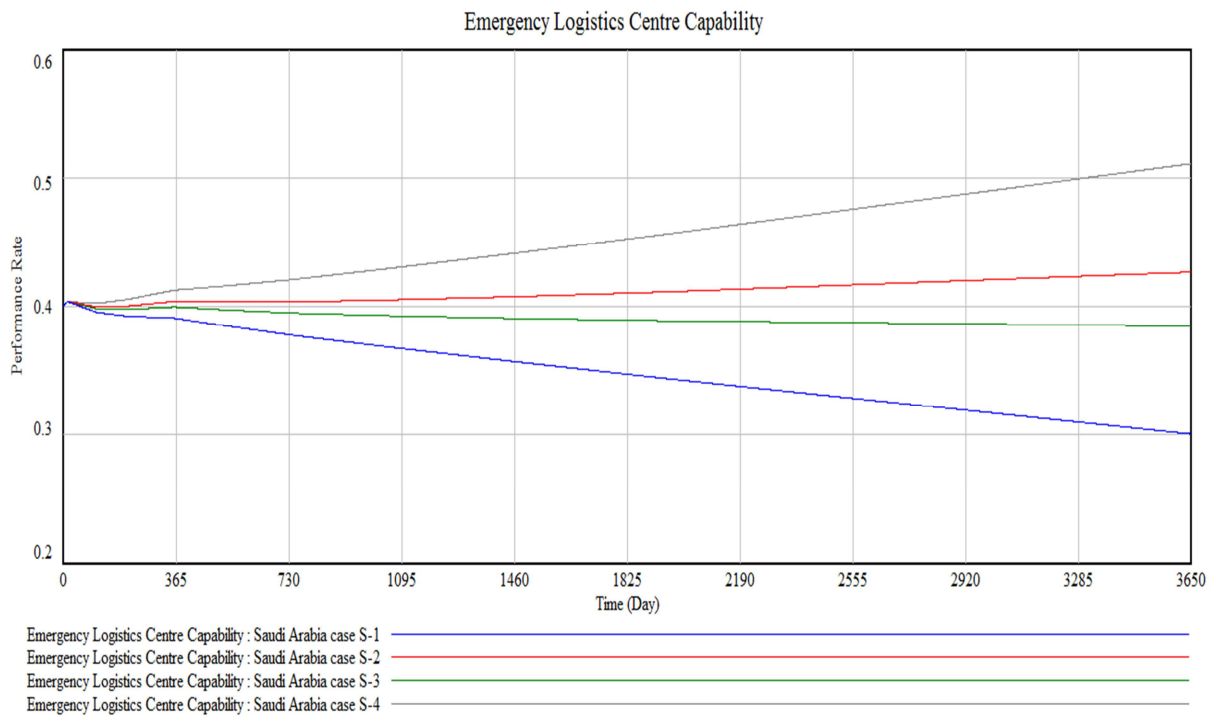


Figure 6.1 Run 1: Emergency Logistics Centre capability

Figure 6.1 shows the results of the first run. As A is standardised, scenario 4, showing optimum access (B) and weather (C) conditions, improves Centre performance to 0.5, whilst the scenario 2 with optimum access and minimal weather, shows some improvement over time. Minimum access (B) and maximum weather (C) show little improvement in performance; whilst the minimum effects of capability, weather, and access result in a reduction of performance to 0.3. Scenario 4 gives the optimum result for maximum access and weather; comparing scenarios 2 (minimum access, maximum weather) and 3 (maximum access, minimum weather) shows that performance is improved over ten years with maximum weather, whilst maximum access combined with minimum weather has a deleterious effect on performance. Thus the conclusion is that for Emergency Centre performance, good weather is more important than good access in the long run.

The next run shows the scenarios relevant to identifying changes (decrease) in the Centre capability over time.

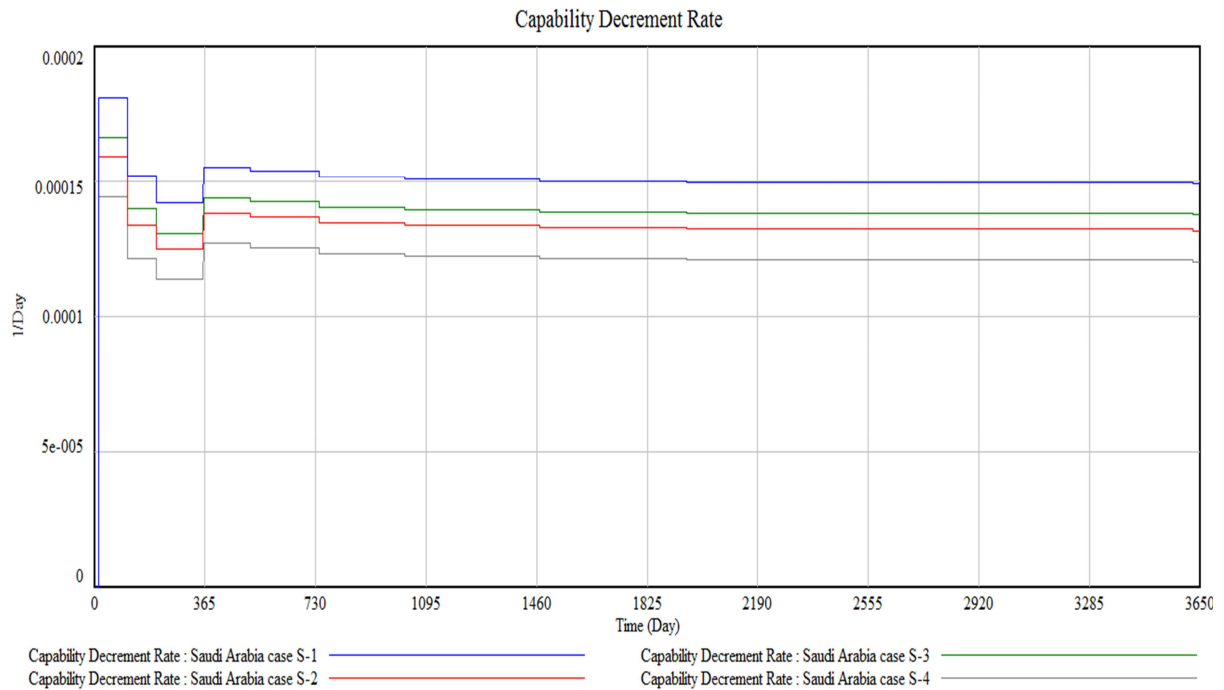


Figure 6.2 Run 2: Capability decrement rate

Decreasing capability after initial inputs during the first year in figure 6.2 shows that the Centre’s performance deteriorates more rapidly under scenario 1 (A, performance standardised at 0.4, minimum access and weather), than scenario 3 (maximum access, minimum weather), followed by scenario 2 (minimum access, maximum weather) and finally scenario 4 (maximum access and weather). This follows the logic of the first simulation where weather has a greater effect on the performance of the Emergency Logistic Centre than access to the disaster site. The conclusion of the first run simulation holds for the variable of decreasing capability.

The next simulation shows the propensity of the Centre to develop rather than deteriorate under the same conditions. This is illustrated at figure 6.3

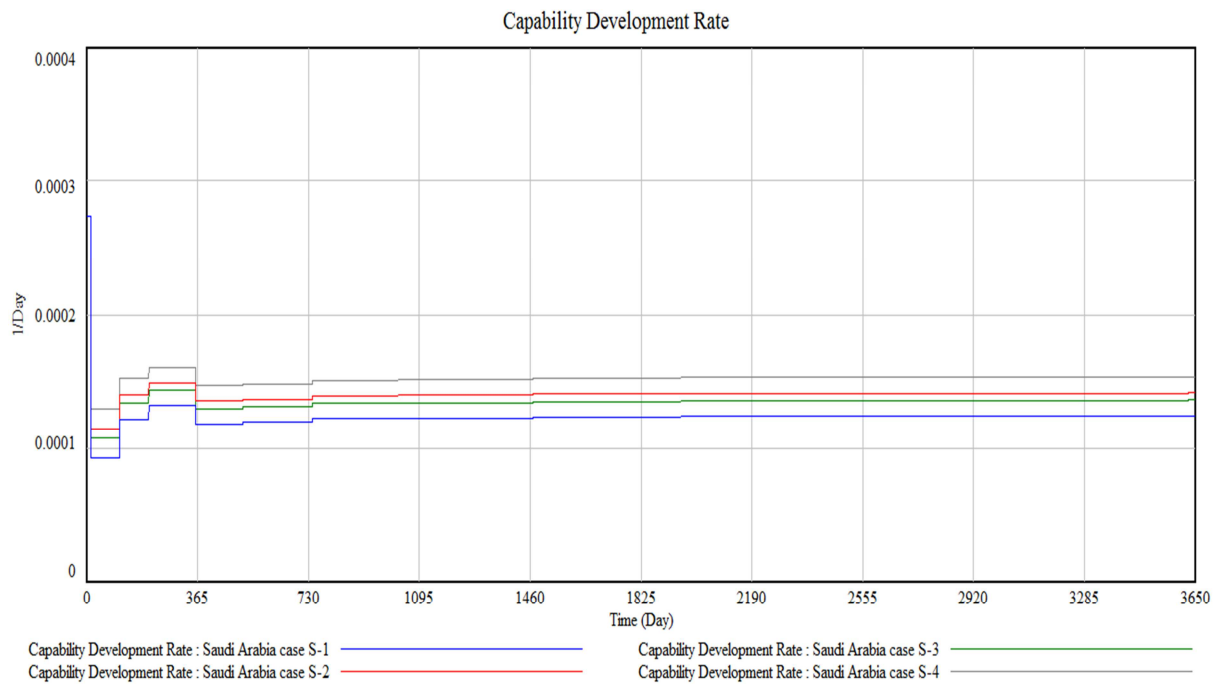


Figure 6.3 Run 3: Capability development rate

In figure 6.3 the Centre’s capability development rate improved after the first year following figure 6.1, Centre capability. Thus scenario 4 gives the optimum result (maximum access and weather); comparing scenarios 2 (minimum access, maximum weather) and 3 (maximum access, minimum weather) shows that the capability development rate improved over ten years with maximum weather. Thus the conclusion regarding weather holds.

The next run at figure 6.4 shows the effects of weather and access on response times for the emergency teams.

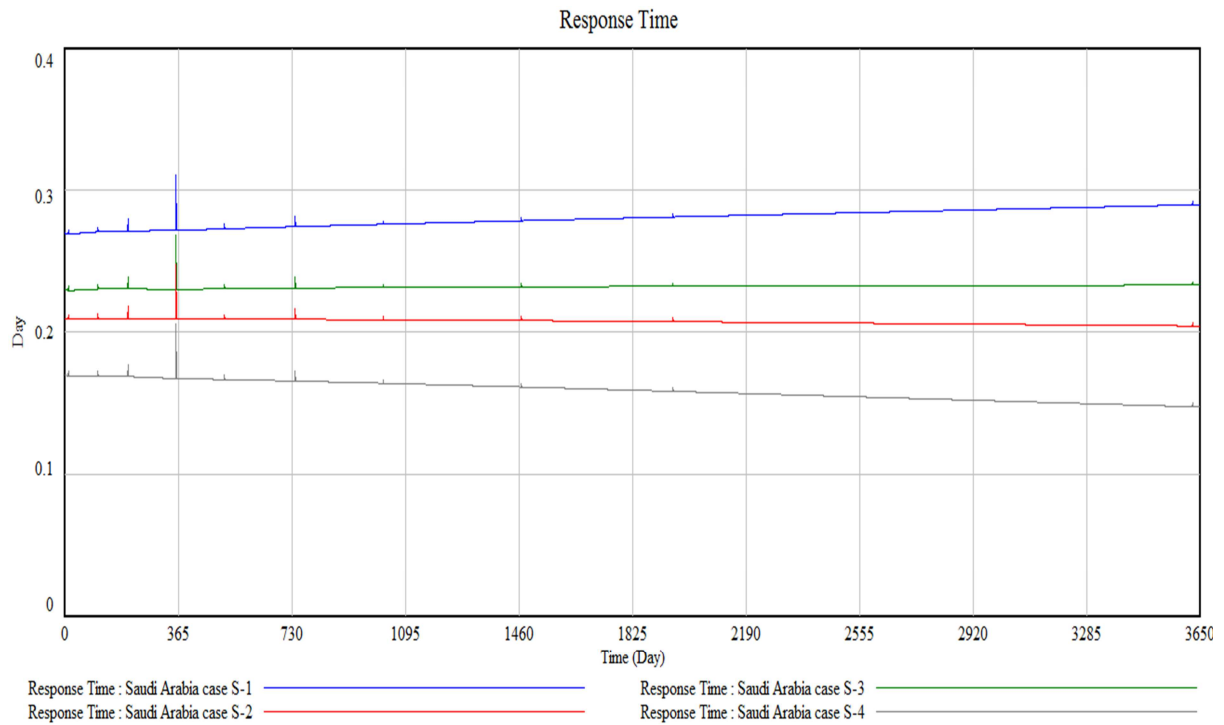


Figure 6.4 Run 4: Emergency team response times

The simulation at figure 6.4 shows increased emergency team response times, thus decreasing capability after the first year. The results therefore follow the decreasing performance rate of figure 6.2, where the minimum inputs of scenario 1 were followed by scenario 2 with minimum access and maximum weather, scenario 3 with maximum access and minimum weather, and scenario 4 where both access and weather are maximised. The conclusions from the previous runs that weather is more important than access hold for this simulation.

The next two figures, 6.5 and 6.6, depict evacuations. Figure 6.5 shows the number of victims rescued over time (minimum of 29 to maximum of 13,000 envisaged by the model), whilst 6.6 shows the accumulation rate.

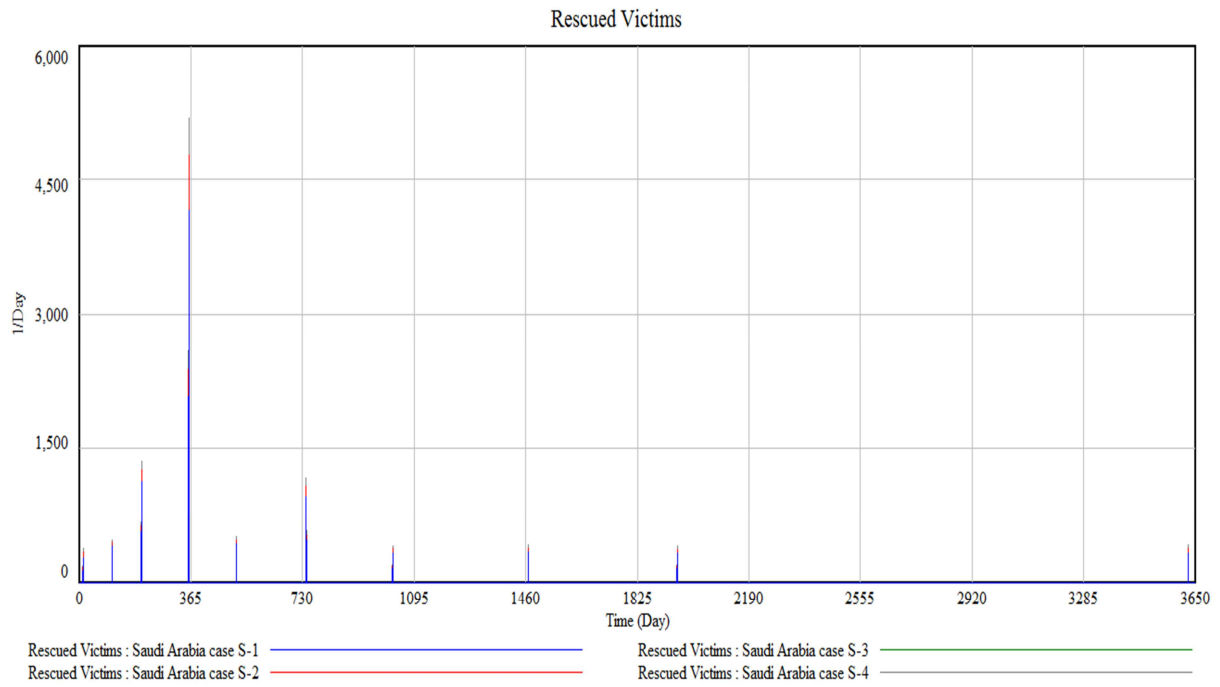


Figure 6.5 Run 5: Victims rescued from the disaster

Figure 6.5 indicates the same pattern as the other positive scenarios, that is, in the order of 4, 2, 3, and 1. Thus the greater number of victims can be retrieved under the optimum conditions of access and weather; however, the next variable of consequence is the weather, where good weather permits the evacuation of more victims than good access. Figure 6.6 is a clearer indicator of this effect.

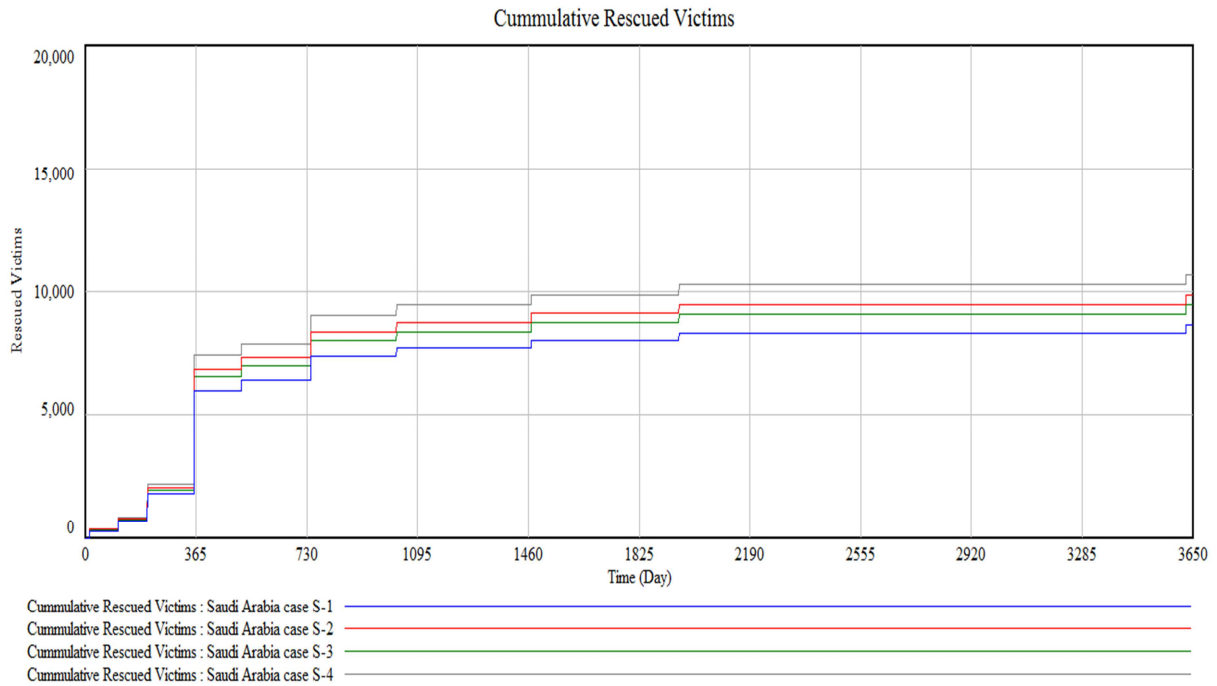


Figure 6.6 Run 6: Accumulation rate of rescued victims

Figure 6.6 confirms that, after the optimum scenario 4, scenario 2 with maximum weather accommodates a greater number of rescues. Next, the scenario relating to the variable duration of the rescue operation is shown in figure 6.7.

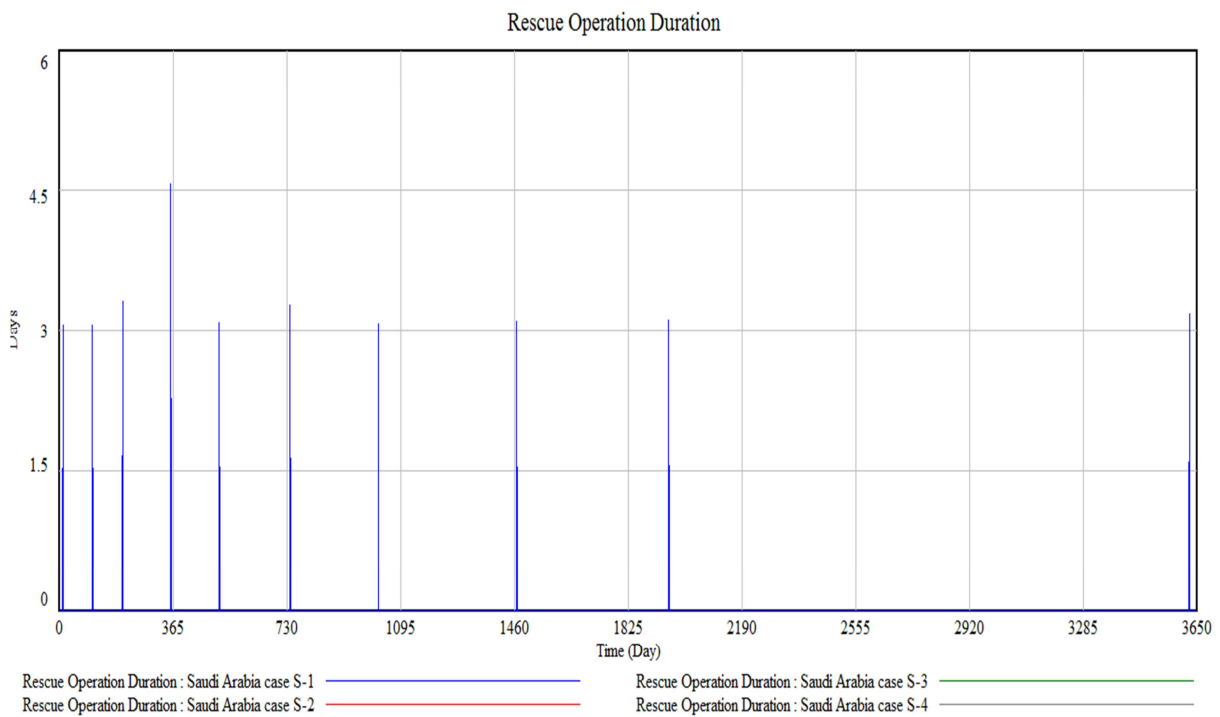


Figure 6.7 Run 7: Duration of rescue operation

The results conform to the other decreasing performance scenarios such as emergency team response times, where scenario 1's minimum inputs are followed by scenario 2 (minimum access and maximum weather parameters), scenario 3 (maximum access and minimum weather), and scenario 4 where both access and weather are maximised. This confirms that of the constraints, weather is more important than access.

The next scenario, figure 6.8, depicts the resource allocation for the rescue operation.

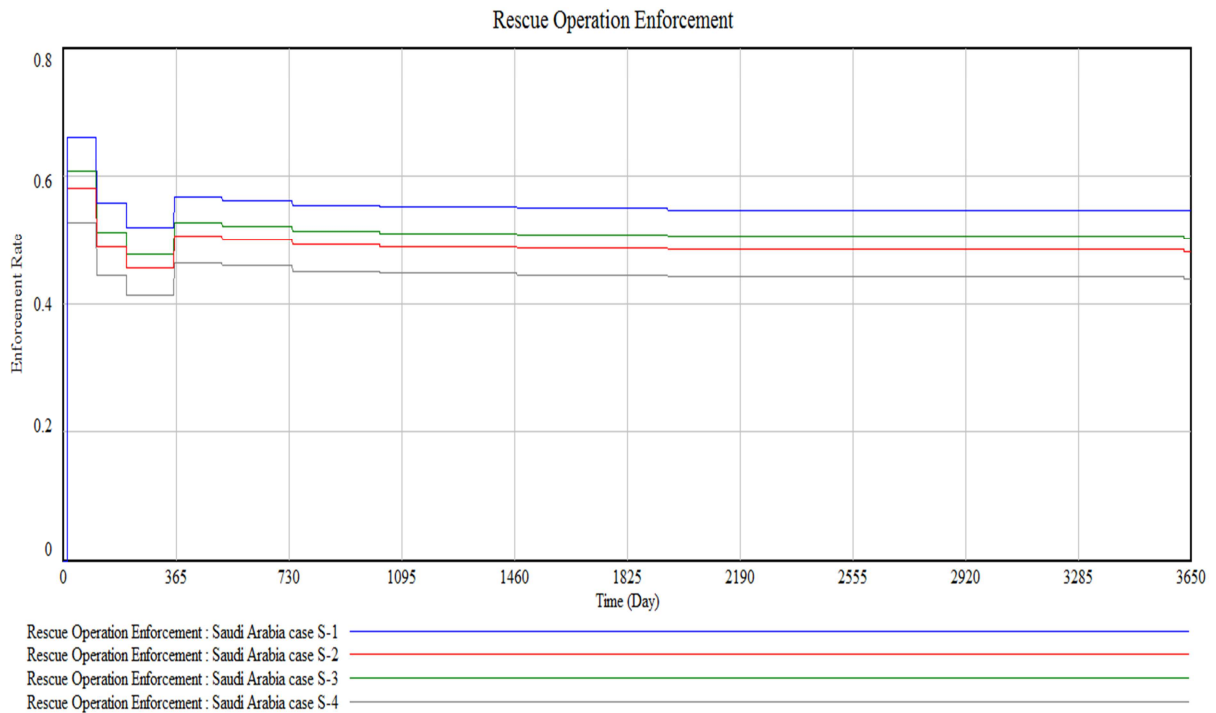


Figure 6.8 Run 8: Constraint in allocation of emergency resources

This scenario at figure 6.8 again follows the ‘negative’ scenarios, where constraints are placed on the system by the variables. In this case, the ability of the emergency centre to release resources is constrained by minimum access and weather (scenario 1) then scenario 3 with maximum access and minimum weather conditions, thirdly by scenario 2 with its maximum weather conditions, and finally by scenario 4, where both variables are maximised. The importance of good weather holds in this simulation.

This leads to the performance gap at figure 6.9. The same argument applies for this simulation.

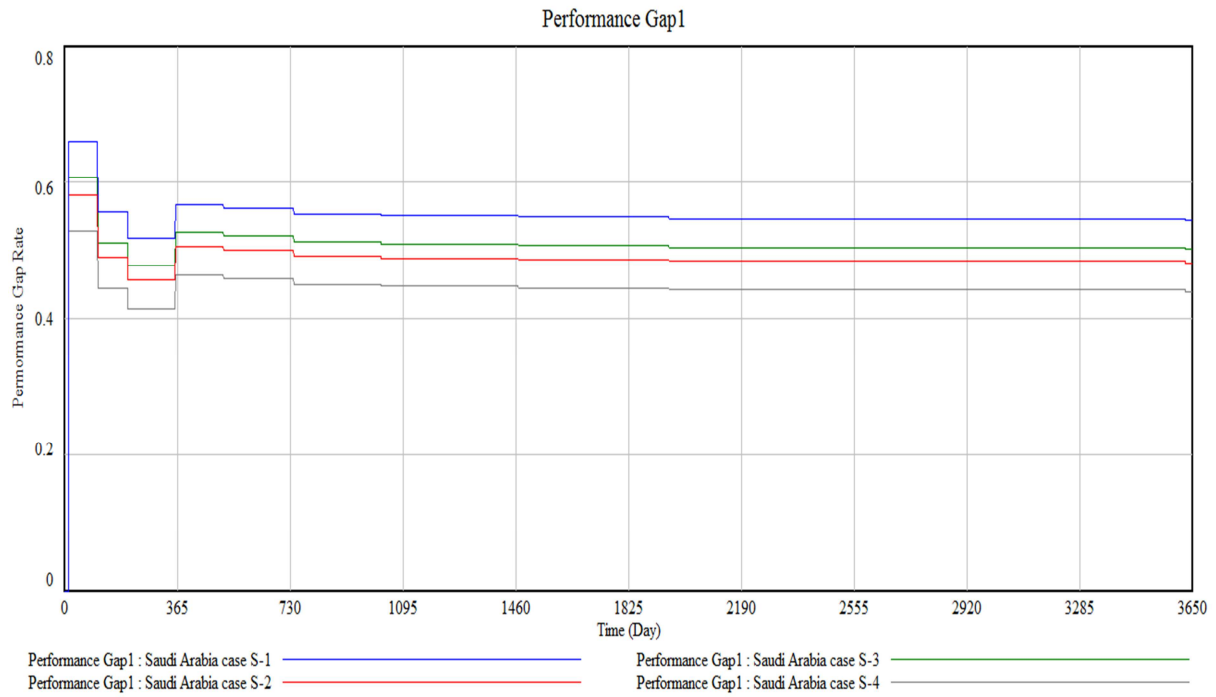


Figure 6.9 Run 9: Performance gap between optimum and minimal rescue conditions

6.2.2. Testing access and weather variables

As noted, difficulty in accessing the disaster area (B) and the effects of the weather (C) are variables that cannot be controlled by the Emergency Logistics Centre and may impact operational performance. To test the effectiveness of B and C on the model, simulations were run to test the relationships of the access and weather factors within the scenario framework (table 6.1).

Table 6.1
Comparison between access and weather values

Scenario	B value (access)	C value (weather)	B comparison	C comparison
S1	0.4	0.4	S1 & S3	S1 & S2
S2	0.4	0.8		
S3	0.8	0.4	S2 & S4	S3 & S4
S4	0.8	0.8		

Simulations were devised for the following variables:

- Emergency Logistics Centre capability

- Duration of rescue operation
- Emergency team response times
- Accumulated rescued victims

The relationships over time between scenarios 1 and 3 were first tested. Scenario 1 depicts minimum access and weather conditions (0.4), whilst scenario 3 varies access to maximise its value (0.8) (figure 6.10). Note that 1 equates to maximum performance within the scenarios.

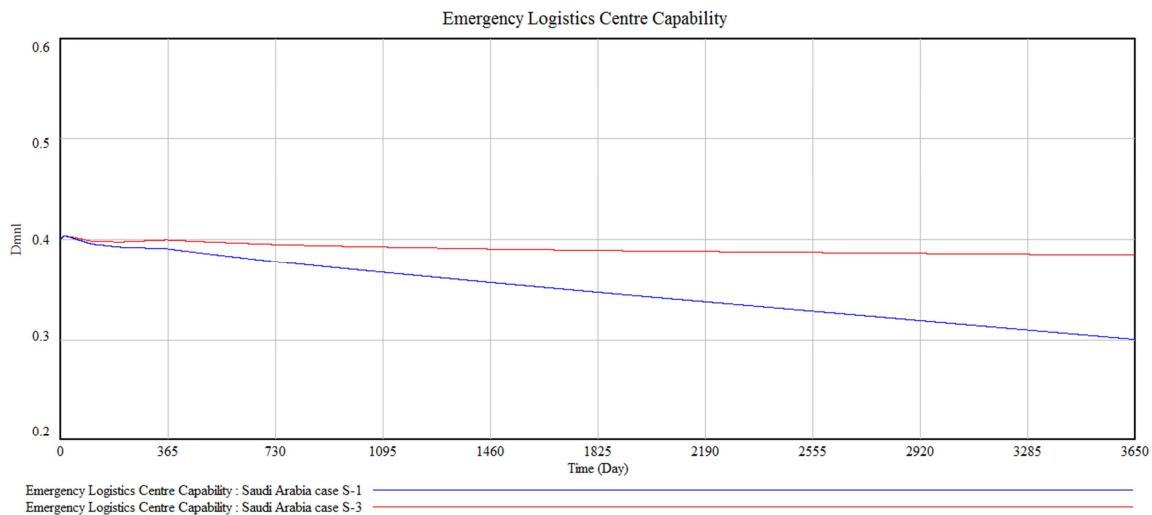


Figure 6.10 Centre capability: Comparison of scenarios 1 and 3

In figure 6.10, scenario 1 of minimum conditions, the Emergency Logistics Centre’s capability shows a significant drop in performance over time, whilst scenario 3, with maximum access (for the model) and minimum (constant) weather, shows that capability can be maintained with only a slight drop over time. Thus access to the disaster site influences Centre capability, given that weather is a constant value.

The next simulation shows the comparison of scenarios 1 and 3 on the variable duration of the rescue operation (figure 6.11).

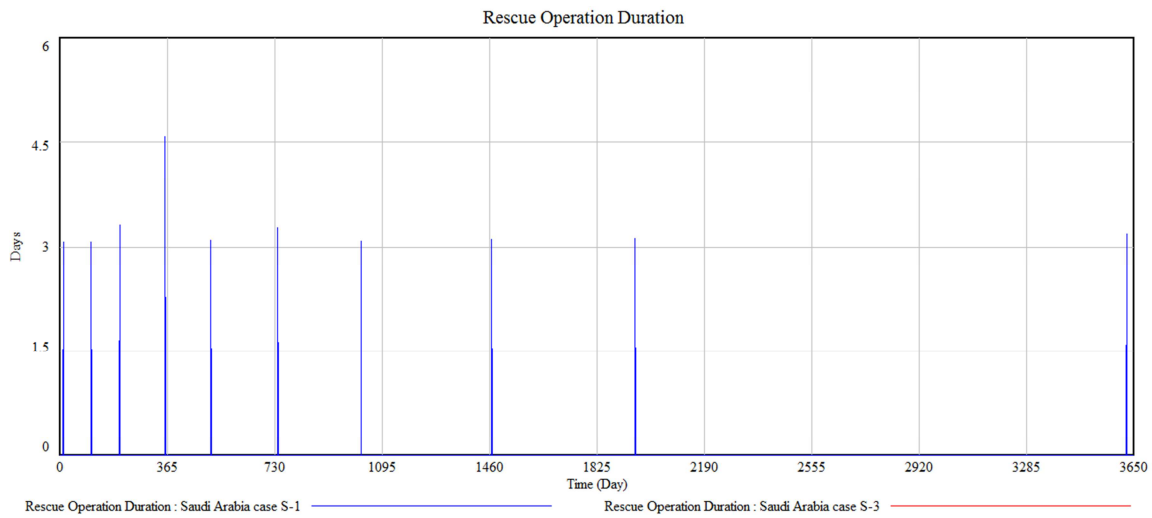


Figure 6.11 *Rescue duration: Comparison of scenarios 1 and 3*

Figure 6.11 shows confirmation of the emerging pattern, and duration of the response operations is related to access, given that weather remains at a constant (minimum) value. However, the rescue duration, given its nature, remains constant after the first year and disappears after 5 years for both scenarios. In this simulation, an increased ability by crews to access the disaster site is related to a significant drop in the duration of the rescue.

The next figure 6.12, shows the results for the response time for the emergency crews using scenarios 1 and 3, that is, the weather value ($C = 0.4$) remains constant.

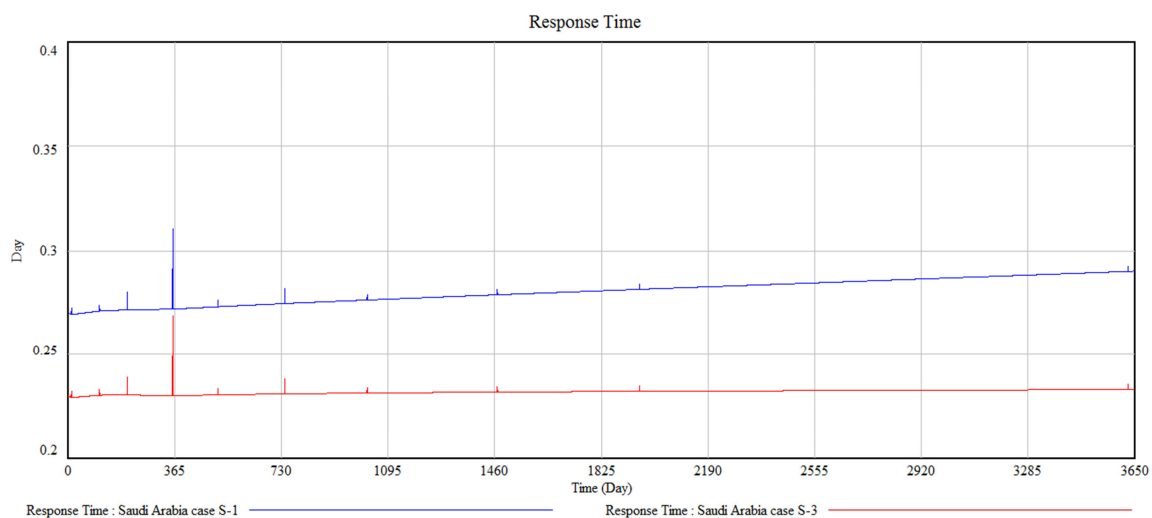


Figure 6.12 *Response time: Comparison of scenarios 1 and 3*

Given that the Centre's capability is influenced by access and weather, the constant value of weather shows that access influences the response time of the emergency teams, and that this effect

is cumulative over the 10 year period. The next iteration in this series shows the accumulation rate for rescued victims (figure 6.13).

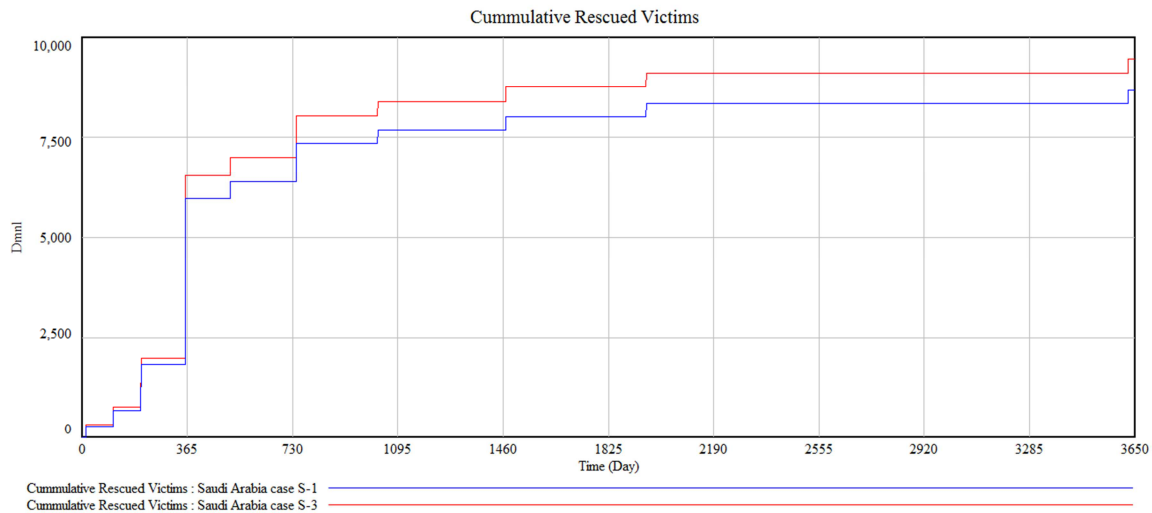


Figure 6.13 Accumulated rescued victims: Comparison of scenarios 1 and 3

The accumulation of rescued victims is greatest in the first year and tapers off at the 5-year level. Whilst the effect is not as marked as with the other model variables, access as a variable and weather as a (minimum) constant shows that fewer victims were rescued under scenario 1 than scenario 3.

The next run of simulations used scenarios 2 and 4 to validate the relationships between selected variables in the model that are not in the control of the Emergency Logistics Centre. In this set, scenario 4 shows access (B and weather (C)) at maximum rates (0.8) and scenario 2 with weather at a maximum rate (0.8), access varies (0.4). Within the scenarios, 1 is maximum performance. Figure 6.14 depicts the capability of the Emergency Logistics Centre with varied access.

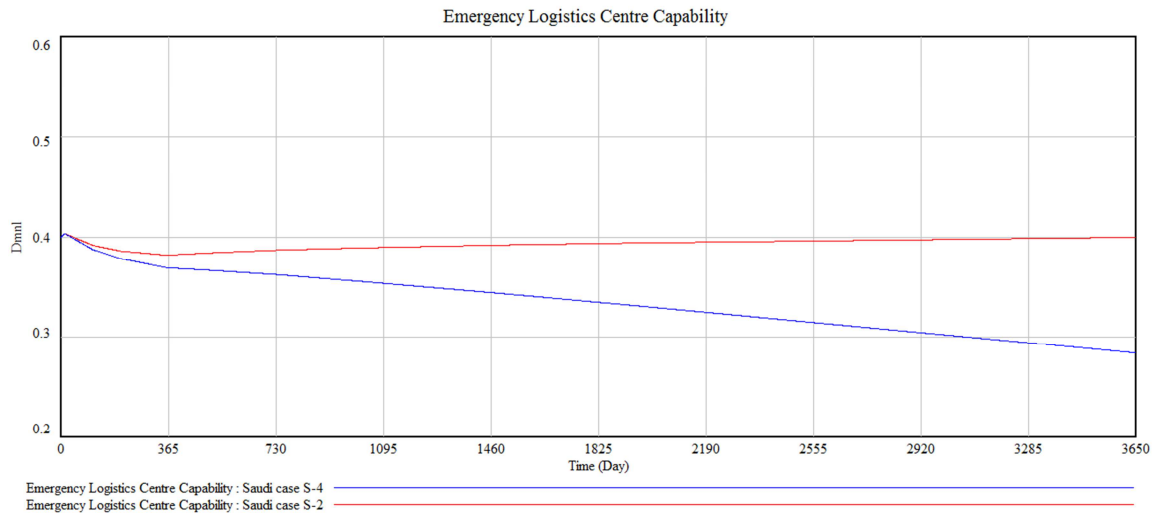


Figure 6.14 Centre capability: Comparison of scenarios 2 and 4

Figure 6.14 deviates from the pattern by showing Centre capability under maximum conditions of weather and access (scenario 4, 0.8) as falling over time, whilst restricted access for scenario 2 (at the lower value 0.4) results in Centre capability maintained throughout the simulation. This may also reflect the relative importance of weather over access.

The next simulation set shows the four selected conditions under scenarios 1 and 2. Under these conditions, scenario 1, minimum conditions (0.4) apply for access and weather, whilst access is minimised (0.4) and weather maximised (0.8) for scenario 2. Figure 6.15 depicts Centre capability.

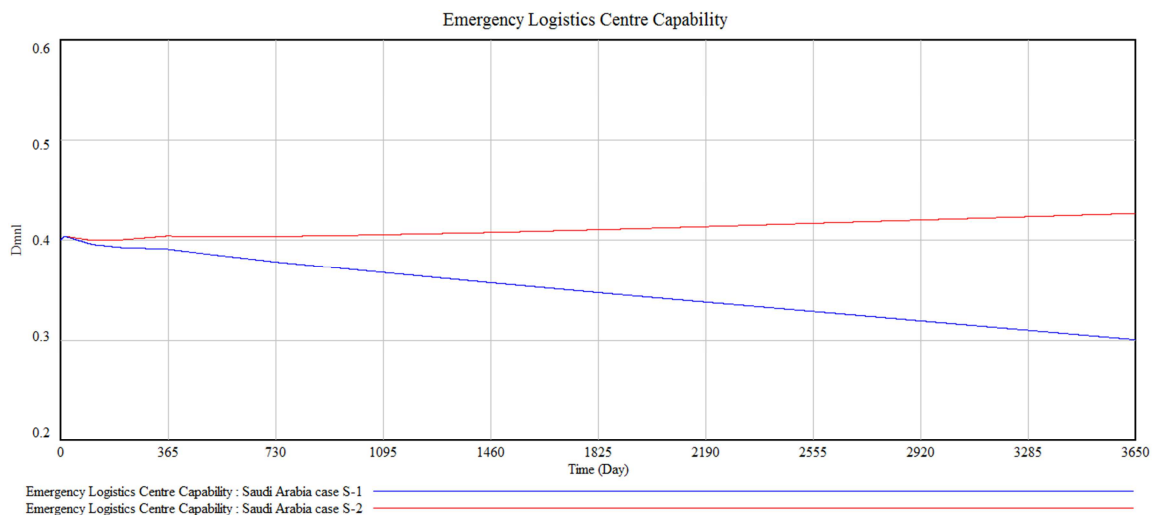


Figure 6.15 Centre capability: Comparison of scenarios 1 and 2

Under minimum conditions in scenario 1, the pattern of the variable weather influence in the model as greater than access influence is restored and the curve shows a steep fall over time. For optimum weather conditions, Centre capability actually shows a continuing, although small, rise over the 10-year period.

The next simulation concerns the duration of the rescue operation, and this again employs scenarios 1 and 2. As before, in scenario 1, minimum conditions (0.4) apply for access and weather, whilst access is minimised (0.4) and weather maximised (0.8) for scenario 2 (figure 6.16).

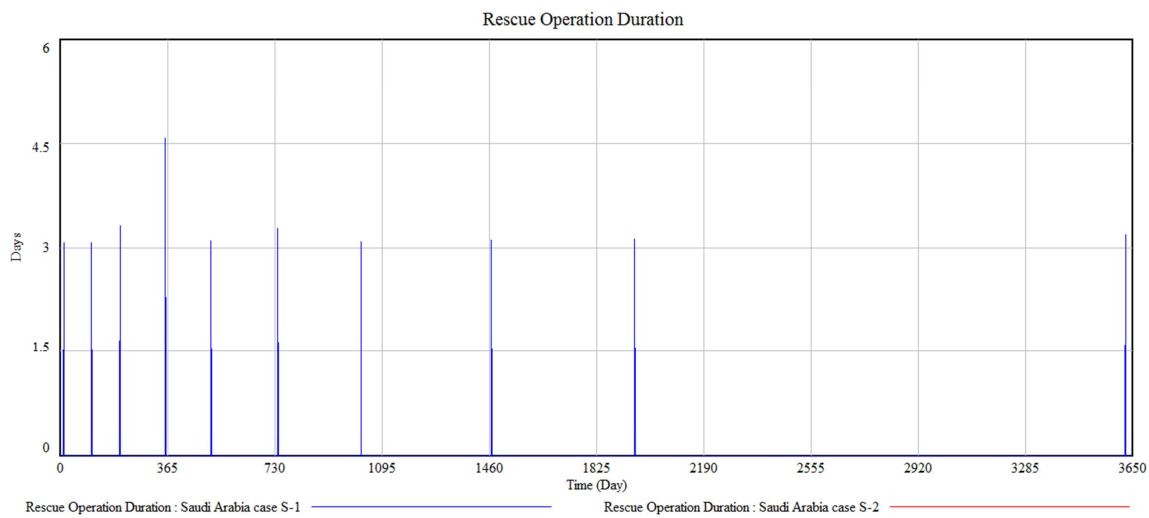


Figure 6.16 *Rescue duration: Comparison of scenarios 1 and 2*

Figure 6.16, as presented, confirms that duration of the response operations is related to weather if access remains at a constant (minimum) value. Again, the effect of weather influences the duration of the rescue.

Following duration of the rescue, response times of the rescue teams were run to test the relative influence of minimum access and weather conditions (scenario 1) and minimum access with maximum weather (scenario 2). The result is shown in figure 6.17.

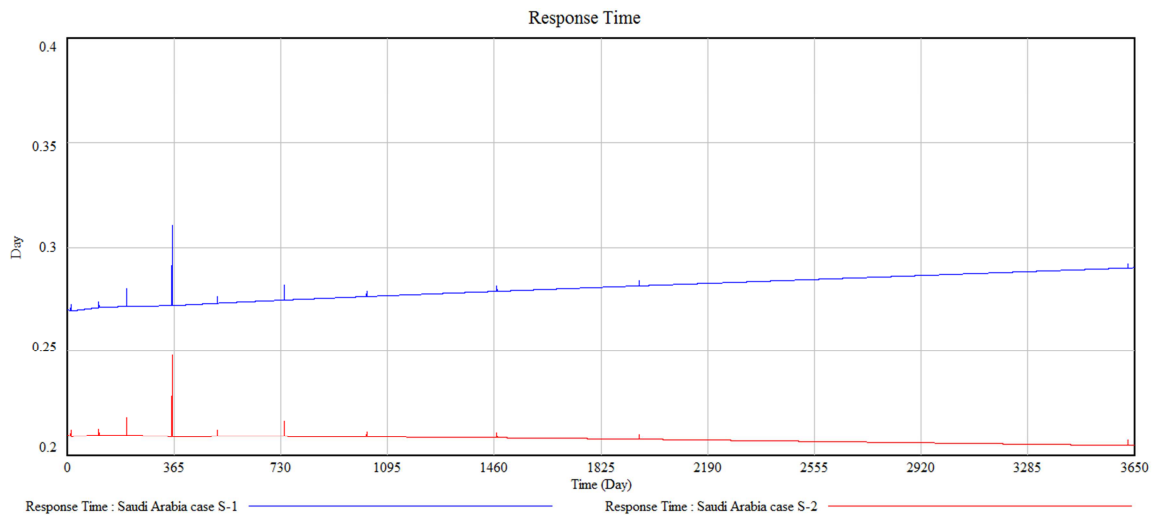


Figure 6.17 Response time: Comparison of scenarios 1 and 3

Given that the Centre’s capability is influenced by access and weather, the constant value of minimum access (scenario 1) in figure 6.17 shows that weather influences the response time of the emergency teams, and that this effect is cumulative over the 10 year period. However, weather has an enduring effect of minimising response times (scenario 2) over the period. The next simulation relates to the accumulation over time of rescued people (figure 6.18)

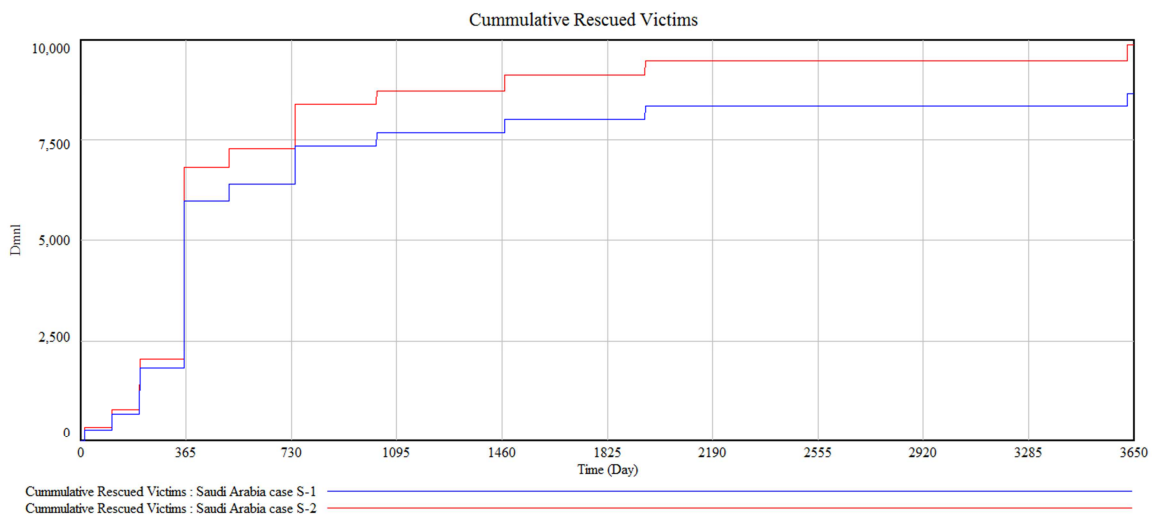


Figure 6.18 Accumulated rescued victims: Comparison of scenarios 1 and 2

As shown in previous simulation on this condition (figure 6.13), the accumulation of rescued victims is greatest in the first year and accumulates slowly for five years (figure 6.18). Whilst the effect is not markedly different from the other figure, the change to a maximum value for weather in scenario 2 allowed more victims to be rescued.

A further simulation of Centre capability tested maximum weather conditions under scenarios 3 and 4. For this run, scenario 3 is minimum access (0.4) and maximum weather conditions (0.8), and scenario 4 has both variables at 0.8 (figure 6.19).

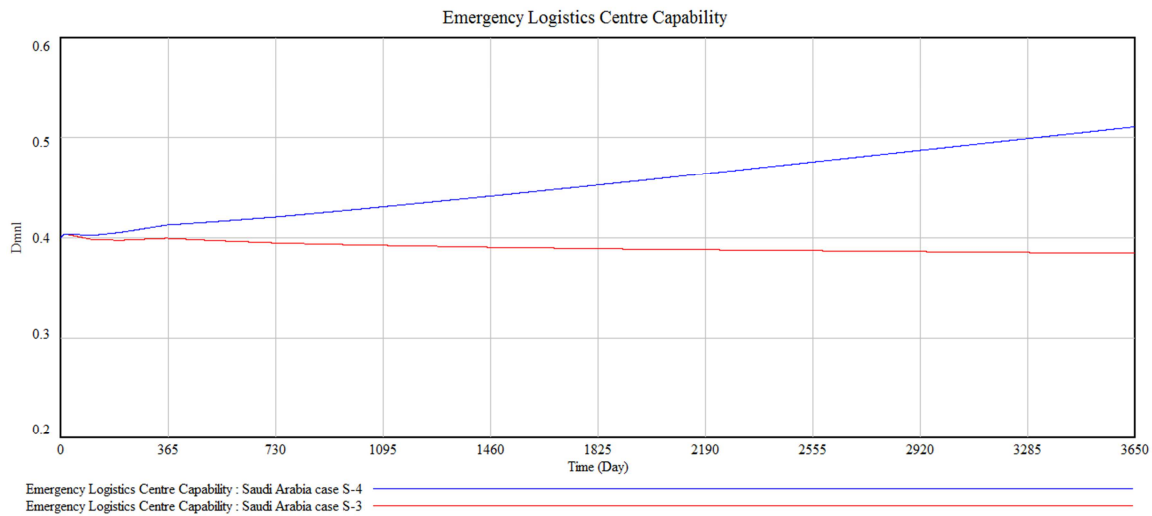


Figure 6.19 Centre capability: Comparison of scenarios 3 and 4

Under maximum conditions in figure 6.19, scenario 4 shows significant improvement in Centre capability over the decade, whilst the lower access availability in scenario 3 causes a somewhat lower performance response over the period. The influence of weather over access is more obvious in this simulation than others (figures 6.10, 6.14, & 6.15), where scenario results remained within the ranges of ± 0.3 and 0.4. In figure 6.19, Centre performance reached +0.5.

6.3 Testing model using Queensland floods data

The following section contains the scenario design and simulation results for testing the Emergency Logistics Centre capability model on the 2011 Brisbane floods. To examine the model, four scenarios were constructed containing the main values A, B and C explained above, section 6.1.1. To reiterate, these are: A for local variables, B for difficulty in accessing the disaster zone, and C for the weather variables. Local variables (A) are:

1. Emergency Logistics Centre capability
2. Capability decrement rate
3. Capability development rate
4. Emergency team response times
5. Victims rescued from disaster
6. Accumulation rate of rescued victims

7. Duration of rescue operation
8. Constraint in allocation of emergency resources
9. Performance gap between optimum and minimal rescue conditions

For all scenarios depicting each of the above variables:

- rating is 0 to 1, with 0 as very poor and 1 as excellent
- value A (local variables), is 0.8 as the Australian rescue system efficiency level was found to be very good
- values B and C are alternated between 0.4 and 0.8 for the four iterations:

$$S1 = (A=0.8, B=0.4, C=0.4)$$

$$S2 = (A=0.8, B=0.4, C=0.8)$$

$$S3 = (A=0.8, B=0.8, C=0.4)$$

$$S4 = (A=0.8, B=0.8, C=0.8).$$

6.3.1 Scenario design for Queensland floods

The four Australian scenarios for the Emergency Logistics Centre capability model were estimated for a 10-year period using the ten local variables for Queensland. The first run concerned the capability of the Emergency Logistics Centre. The model was tested through four scenarios over a period of ten years (figure 6.20).

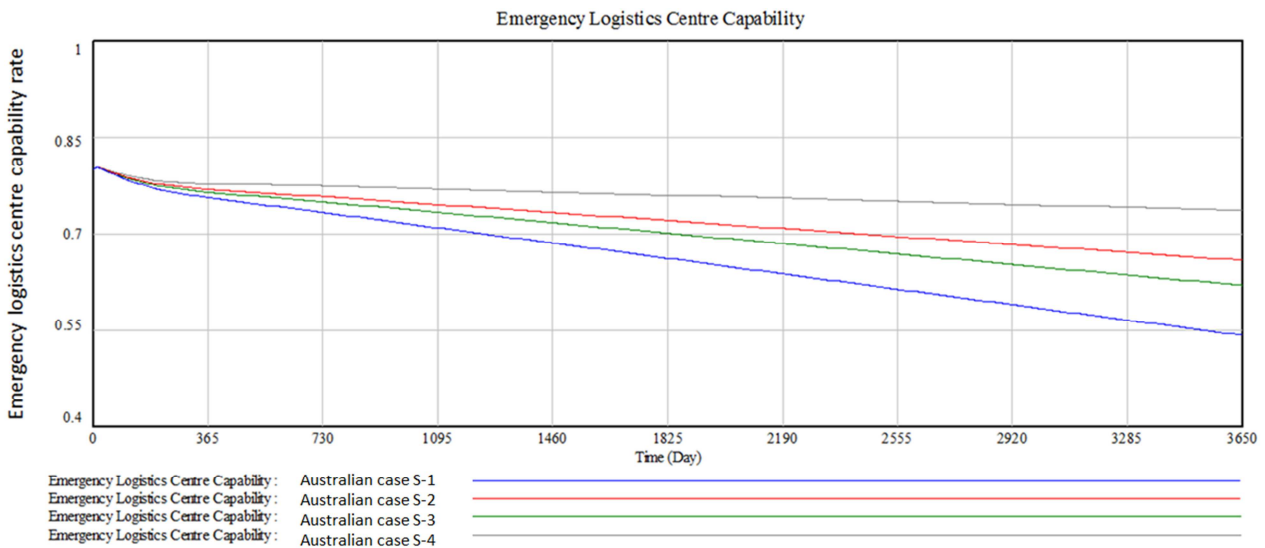


Figure 6.20 Run 10 Queensland Emergency Logistics Centre capability

Figure 6.20 shows the results of the first Queensland run (run 10) of the Emergency Logistics Centre capability model. With A (local variables) constant, all scenarios show a fall in

centre capability, with low access to a disaster site (S1, S2) being less influential as a variable than bad weather (S1, S3). Optimal access (B) and weather (C) conditions (S4) result in minor loss of capability to 0.73, whilst the worst scenario results in loss of capability to an average 0.55. Although there is declining capability under each scenario of Emergency Centre performance, in the long run good weather is more important than good access, given that all other factors remain constant.

The next run at figure 6.21 shows the effects of weather and access on response times for the Queensland emergency teams.

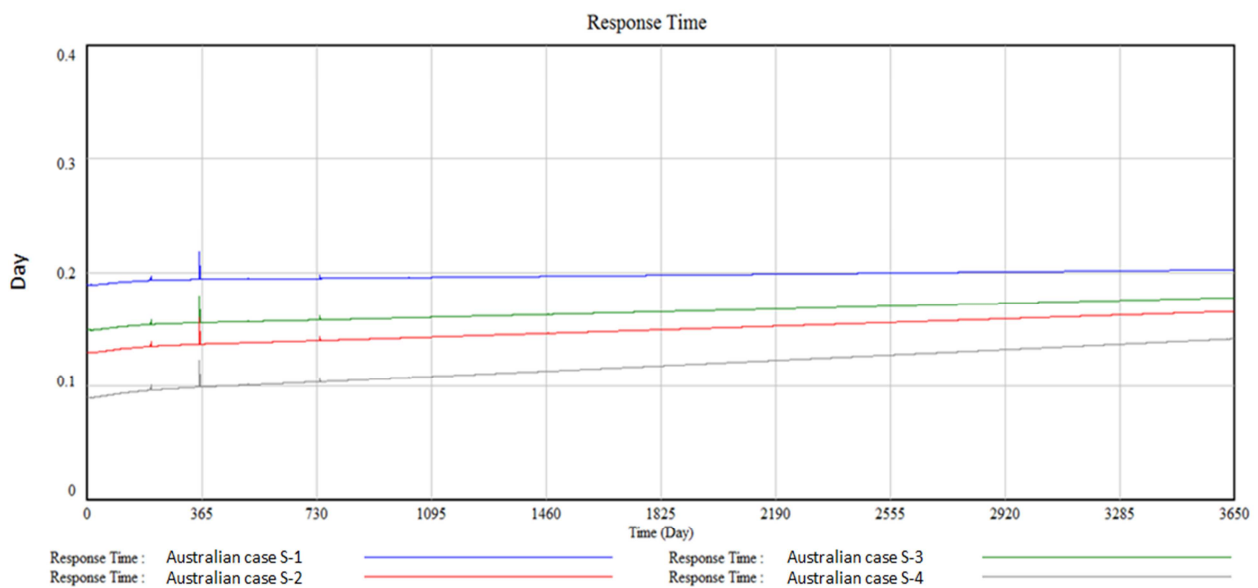


Figure 6.21 Run 11: Queensland emergency team response times

The simulation at figure 6.21 records converging emergency team response times over the decade, with scenario 4 showing the greatest curve, that is, reduced response. Scenario 1, with the lowest ranking of access and bad weather at the disaster site showed no movement over the timeline. Weather again was a strong variable.

Figure 6.22 shows the numbers of victims rescued over time (minimum of 29 to maximum of 13,000 envisaged by the model) and figure 6.23 shows the accumulation rate for such rescues.

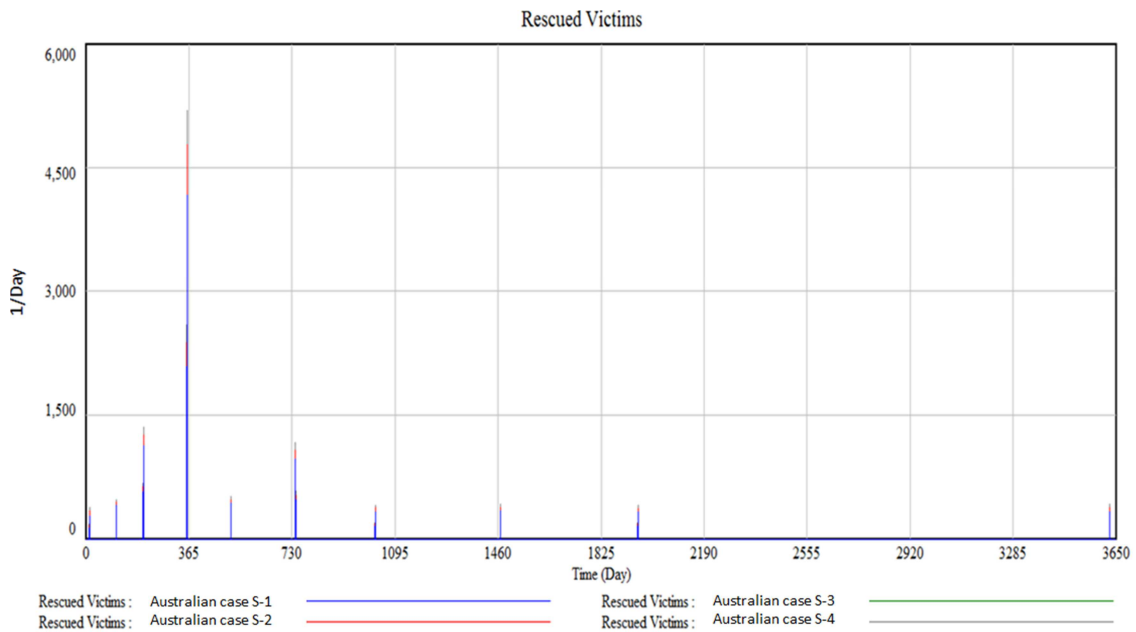


Figure 6.22 Run 12: Queensland victims rescued from the disaster

Figure 6.22 shows continuation of the effects of weather on rescues, that is, scenarios in the order of 4, 2, 3, and 1. Whilst the optimum number of victims can be retrieved under better conditions of access and weather; good weather permits the evacuation of more victims than good access. Figure 6.23 also illustrates this effect on the capability of the Queensland teams in their rescues, should another disaster occur without further resource input.

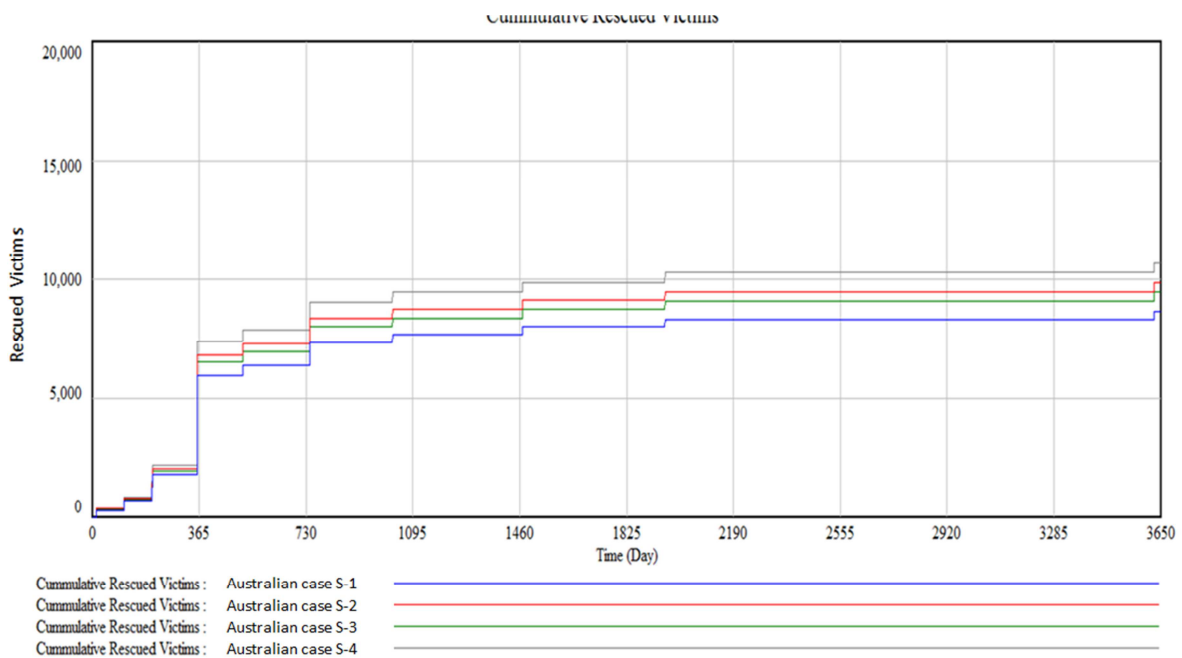


Figure 6.23 Run 13: Accumulation rate of rescued victims in Queensland

Figure 6.23 confirms that, after the optimum scenario 4, better weather conditions of scenario 2 accommodates a greater number of rescues.

The scenarios relating to the variable duration of the rescue operation are depicted at figure 6.24.

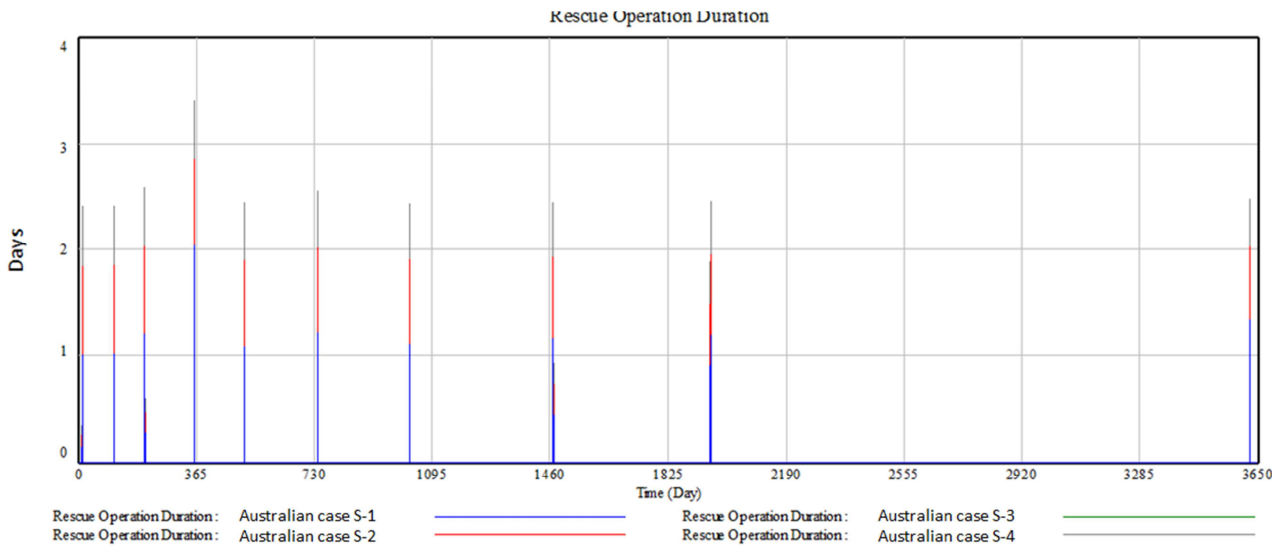


Figure 6.24 Run 14: Duration of Queensland rescue operation

The results at figure 6.24 show that after the initial rescue (365 days), the centre can maintain the performance of its emergency crews over time. However, this is influenced by the weather moreso than access. In this run, continuity of the scenario formation occurs: scenario 1's minimum inputs are followed by scenario 2 (minimum access and maximum weather parameters), scenario 3 (maximum access and minimum weather), and scenario 4 where both access and weather are maximised.

The next scenario, figure 6.25, depicts the resource allocation for the rescue operation.



Figure 6.25 Run 15: Constraint in allocation of Queensland’s emergency resources

The figure 6.25 again follows the ‘negative’ simulations, where the variables place constraints on the simulation. In this case, the emergency centre’s release of resources for the teams is constrained by minimum access to the disaster site and bad weather (scenario 1) then scenario 3 with maximum access and minimum weather conditions, thirdly by scenario 2 with its maximum weather conditions, and finally by scenario 4, where both variables are maximised. Thus weather remains the key variable. However, these variables do not alter the long term trends.

This leads to the performance gap at figure 6.26, which evidenced similar effects from the influence of weather.

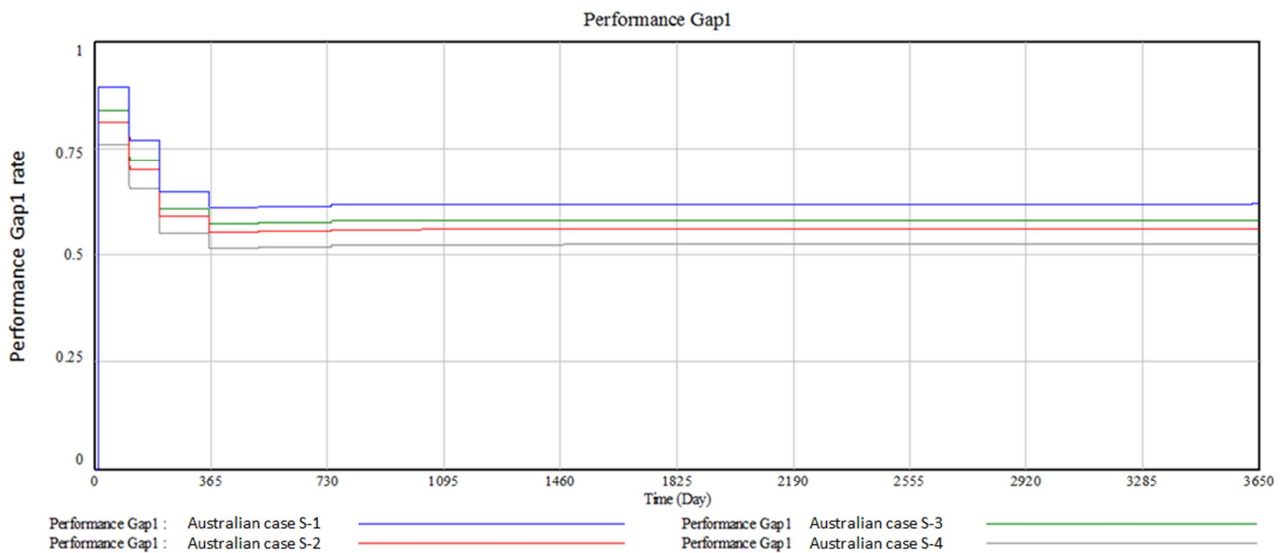


Figure 6.26 Run 16: Performance gap in Queensland rescue conditions

Figure 6.26 shows that the performance gap between the scenarios in simulating the Queensland emergency centre’s ability to respond is greatest shortly after the disaster, with a decreasing rate to day 365, whereupon it is then constant for the long run. This gap continues the placement of weather as the defining variable, followed by access to the disaster site, given that local conditions remain constant.

This completes the model run iterations. The next section discusses these results.

6.4 Case studies discussion

The Saudi case study involved testing the Emergency Logistics Centre capability model using the results obtained from the qualitative research analysis. This analysis concerned answering the research questions:

1. What were the responsibilities of the various Saudi organisations during the 2009 and 2011 Jeddah floods, and how did they coordinate their activities?
2. What is the optimum national emergency relief framework?
3. What are the optimum operational strategies for emergency relief?
4. How can the effects of a disaster be mitigated efficiently and effectively?

The research questions resulted in identification of the civil defence framework which has since evolved to meet international standards, the benchmark for national emergency frameworks. Following this, an optimum operational response strategy was proposed through dynamic system

modelling. After developing the Emergency Logistics Centre model, the model was loaded with the results from questioning Saudi officials on their views regarding satisfactory response standards for the 2009 and 2011 Jeddah floods. Whilst there was criticism of the organisational structures, there was little criticism of the personnel involved, and this was expected, given the cultural bias against personal criticism.

The Emergency Logistics Centre model was programmed for 9 iterations concerning standards relating to resources supply and replenishment, emergency crew activities, rescues constraints and performance gaps (local variables). In a range of zero (very poor) to one (excellent), 0.4 was generally selected as a measurement to account for the performance level derived from the qualitative research results of sub-standard emergency responses. However, there were also two factors that were beyond the control of the Centre management, that of weather and ability for the crews to access the disaster area. To test the model, four scenarios were constructed for the model to test the effect of weather and access on the model.

Overall performance of the Emergency Logistics Centre was subjected to four iterations (runs of the model). The first tested all minimum and maximum conditions of weather and access, finding that optimum conditions of both prevailed, improving performance of the Centre. However subsequent tests comparing the variables identified weather as having a greater influence on Centre operations than that of crews' field access. This result for the superiority of good weather and good access also held true with subsequent tests on variables of decreasing Centre capability (i.e., use of resources), increasing capability (replenishment of resources), operational response times, evacuations, length of time for operational engagement, operational enforcement (resource maintenance during operations), and thus performance of the operation over time. Testing between the two variables for the greater influence of weather or access also resulted in the greater influence of weather over the period for all local variables.

Thus after examining all the performance variables in the model, the performance rate of the Emergency Logistics Centre model is increased as the factors B (difficulty of access) and C (weather condition) improved, as shown through comparing curves for scenarios 2 and 4 with scenarios 1 and 3. At scenario 1, the factors B and C were allocated the same value (0.4) of minimum conditions for weather and access, so the performance rate for the Emergency Logistics Centre model gradually decreased. Under the maximum conditions for B and C (0.8) of scenario 4, Centre performance gradually increases. However, comparison between curves for scenario 2 (B 0.4, C 0.8) and scenario 3 (B 0.8, C 0.4) results in weather conditions more influential on Centre performance than the access difficulty factor.

The system dynamics model Emergency Logistics Centre was developed and validated. It showed that modelling organisational dynamics in specific situations allows better understanding of the behaviours that develop and the potential policies that may be used to improve performance. Using the Centre model, decision makers can use different values for local variables to test the systems response to provide optimum pathways for their resources and actions according to the disaster relief operation.

6.4.1 Comparison of Saudi and Queensland simulations

The first comparison run of the Emergency Logistics Centre capability for Saudi Arabia showed that from a low initial competence rating (0.4), the Saudi centre improved over time, with the best case scenario reaching an average 0.51 rating (0 = poor, 1 = excellent). The scenarios S2 and S3 either showed a moderate improvement or decline, with weather more influential than access over time. Scenario 4, reflecting poor access and weather, showed the greatest decline to 0.3 (poor competence). However, starting from a higher competence rating of 0.8, all scenarios of the Queensland test run showed declining competence from the best case (S4) of a decline to 0.74 and the worst case (S1) 0.55. Again, weather was the influential variable. It would appear that the Saudi centre was showing some improvement over time, whereas the Queensland teams may have reached an optimum level and require further resource input to maintain their high capability.

Moving to emergency team response times depicted by the simulation, the Saudis showed widening response rates over time, as weather and access impeded their movements. On the other hand, the Queensland scenarios showed convergence, with better capability diminishing over time and all scenarios converging towards the norm (average 0.5). Arguably, the lower capability of the Saudi resource centre tends towards divergence of the scenarios due to missing equipment, training, or the effects of the disaster, whilst , without further input, the Queensland centre can maintain its competence, but is unable to improve response times.

For the victims rescued from the disaster and the accumulated figures for such victims, the Saudi and Queensland response counts and trends matched. Again, weather was the deciding factor in all cases. For both countries, centre capability did not impede or assist teams in the field in their mission.

The duration of the rescue differed between the Saudi and Queensland emergency teams, with the rescue operations reaching a maximum of 4.5 days (average 3 days) for the Saudis. For Queensland, the best case scenario (4) peaked at 3.5 days in the first year, and averaged 2.5 days with peak conditions for the remainder of the run. Worst case scenario (4), with both access and

weather lows, was on average one day. Comparison of this simulation showed that, whilst the trends showed little differentiation, capacity was influenced by Queensland's initial centre capability level.

There was a significant difference in resource allocation trends between the Saudi and Queensland models, where the Saudi resources were replenished after day 365 whilst the Queenslanders were not. However, the resources available to the Queenslanders were at all times more (0.51-0.88) than the Saudi supplies (0.41-0.68). Trends remained flat for the long run, with no divergence for either simulation run. These results may be interpreted as a reaction to the disaster by the Saudi authorities in a one-off large allocation of resources then returning to a 'maintenance' mode. Long range planning by the Queensland government arguably allowed for regular resourcing (equipment, supplies, training) so that supply replenishment did not peak.

Finally, the performance gap between the best and worst case scenarios for Saudi Arabia and Queensland mirror the resource allocation simulation. For the Saudis, the performance gap rate ranged between a low 0.41 and medium 0.68, whilst Queensland had a higher performance, but a similar range from (0.51-0.88).

Thus overall, Queensland emergency teams performed at a higher level than their Saudi counterparts, although the balance of constraints was similar for both. Access to the disaster site was important, however, weather impacted all rescue missions at all times.

6.5 Chapter summary

This chapter presents the two case studies for the Emergency Logistics Centre capability model. After explaining the characteristics of the two simulations, the model was loaded with the two sets of data and runs were made for a series. The series included Emergency Logistics Centre capability, emergency team response times, number of rescued victims, duration of rescue operation, allocation of resources and performance gap for each case study, and for Saudi Arabia, additional comparisons were made to track the primary variable. A comparison of simulation results showed that the Queensland Emergency Response Centre could recover capability after servicing a disaster; however in both cases and for all simulations, weather was a barrier in delivery of services and the capability of each centre. The next chapter moves to the discussion for the study.

Chapter 7 Discussion

This thesis considers an appropriate emergency response system for Saudi Arabia. Based on initial floods in Jeddah in 2009, a detailed study was used to research the existing emergency response system, and changes to the Saudi emergency response system that were in place when another flood brought the city to a halt in 2011. Further, international standards were reviewed, together with other nations' responses to their disasters. A qualitative survey was undertaken to discover the public sector's response to the efficacy of the emergency relief system before and after the 2009 floods, and to use these results to develop a systems dynamics model, the Emergency Logistics Centre model. The model was then validated through testing using the results of the qualitative analysis.

This chapter moves to a discussion of the qualitative findings in regards to the literature and the reports from official sources and as they were reported in the media. These are presented as answers to the research questions, which include a discussion of the Emergency Logistics Centre model with regards to the international studies.

7.1 Saudi emergency response system

Due to the number of large disasters that occurred around 2008-2011, the United Nations renewed emphasis on addressing large-scale emergency response issues. In the event of a sudden onset national emergency, the United Nations' Office for the Coordination of Humanitarian Affairs (2014) responds through its Disaster Assessment and Coordination facility. Saudi Arabia is a full member of the Office, and thus part of international forums deciding on disaster risk abatement policies and national emergency logistics framework standards. One such standard is the Multi-cluster/sector Initial Rapid Assessment (MIRA) Manual that provides a decision pathway based on a data-collecting instrument, the Humanitarian Dashboard. As well as guidelines for disaster response organisations, the Disaster Assessment and Coordination facility advises on organisational and operational matters for its members and associate governments (Fritz et al., 2012).

At the national level, the Saudi Civil Defence Council develops policies and regulations for all emergency response stakeholders. The Council directs the Civil Defence Administration Committee and the General Directorate of Civil Defence, which have a very broad responsibility for planning, resourcing, managing and executing all emergency response measures (Ministry of the Interior, 2013). Each regional civil defence organisation prepares local emergency response plans

and leads a coordinated response in the event of an emergency. These regional groups comprise representatives from the Ministries, non-government agencies, and commercial firms such as utilities and telecommunications. Red Crescent is resourced to provide regular medical support during the hajj with paramedics, ambulances, an air ambulance fleet, and seasonal medical centres (IFRC 2012, 29 October). Red Crescent is also responsible for medical actions and evacuation in the event of a crisis.

In the three national disaster examples, Queensland, New Zealand and Japan, the types of government were found in chapter 2 to influence their emergency response frameworks, although the responsible agencies had similar administrative, coordinating, and operational structures. Given the federal Australian structure, the Queensland government had full responsibility for its 2011 flood event (Queensland Floods Commission of Enquiry 2012). Both New Zealand and Japan have a unitary form of government with a high level of organisational and policy standardisation among their semi-autonomous regions. The Kingdom of Saudi Arabia is also a unitary form of government, with jurisdictional and operational control over its 13 provinces.

For Queensland, the *Disaster Management Act 2003* establishes a disaster management hierarchy at state, district and local government level. Response to an emergency is first the responsibility of the local government, which then calls for further assistance. On a state level, Emergency Management Queensland develops a policy framework and the state disaster management plan, and coordinates a large-scale disaster response, liaising with Commonwealth agencies. However, the Queensland Police Service is responsible for coordinating the emergency response by appointing district disaster co-ordinators for the largely volunteer State Emergency Services, including the Fire and Rescue Service, and Queensland Ambulance coordinates land and air medical services during an emergency (Queensland Floods Commission of Enquiry, 2011). The 2011 flood event showed that local governments had varying capability in responding to the crisis and to communicating with people in the affected areas. Further, non-government organisations such as the Red Cross, responsible for emergency centres, were not widely recognised in the emergency services structure, nor were the contributions of neighbourhood leaders (Queensland Floods Commission of Enquiry, 2012).

New Zealand has a Ministry of Civil Defence and Emergency Management, with a National Crisis Management Centre. The Centre's responsibility in a crisis is to manage and control the entire response and subsequent recovery at all levels, national, regional, and on the field. The Centre coordinates Civil Defence Management Groups, the police, fire and health services, lifeline utilities, and non-government organisations. All respondents must dedicate a coordinator and a

secretariat for communications (New Zealand Ministry of Civil Defence and Emergency Management, 2013). Although there appeared to be adequate official response to the Christchurch disaster, McLean et al. (2012) advocated for coordination with skilled volunteers who were first on the field after the event. This was also evident in the Queensland report (Queensland Floods Commission of Enquiry, 2012).

In Japan, the Minister for Disaster Management and the Central Disaster Management Council provide disaster management policies and strategies to guide regional, local and organisational plans (Asia Disaster Reduction Centre, 2012). The propensity for earthquake and tsunami damage for the Japanese islands focuses attention on a central government response; however, during the 2011 tsunami, this concentration of decision making was impacted through the event itself, so that communications were frequently lost during the initial stages of the event (Chang et al., 2011).

Given the government structures, the New Zealand and Japan centralised approach appeared to offer the best option for Saudi Arabia; however, there was an issue in that the Japanese command structure was itself disrupted by the event (Chang et al., 2011). This risk could be mitigated by designating alternate responsibility structures and communication channels. Further, whilst both Japan and New Zealand populations had high community awareness of the countries' propensities for earthquake; in the Queensland event, as in Jeddah, there was little public knowledge of flood risk, or time for warning before the event.

The first research question concerned the responsibilities of the various Saudi organisations during the 2009 and 2011 Jeddah floods and their levels of efficiency. Analysis of the primary research data showed that the study participants rated the General Directorate of Civil Defence's response time and efficiency for the 2009 disaster relief operation as fair to good, whilst for the response to the 2011 floods efficiency and cost structures were ranked fair. In Saudi Arabia, the Red Crescent is responsible for the medical response which was rated fair for the 2009 floods, and for the 2011 event, efficiency was rated highest as good to very good. The performance of local volunteer response groups was initially rated poor for the 2009 event; however this improved markedly in the 2011 floods for response time and their resources were deemed by the study participants as ranging from good to very good.

Improving performance concurs with Goodwin (2013) who found that communication transfer improved for public health emergencies in the United States through organisational and communication channel interventions, although there was a barrier when responsible individuals in

the command line turned off their mobile phones. In a review of the literature, Bharosa et al. (2010) found that for a government emergency response coordinator, the extended vertical communication lines through the various agencies were a barrier to effective communications, and the agencies' various decision making systems and policies tended to restrict inter-agency communications. At an individual level, Bharosa et al. found, as Goodwin (2013), that there were issues with individuals, this time in their desire to gain information relevant to their situation rather than passing along data of use to other sectors.

The finding for the first research question is therefore that the study respondents viewed Saudi emergency response system, that is, its structures and coordination between organisations, as adequate for an adverse event, such as flooding or a storm. Further, the hajj is an annual event where the possibility for a health crisis (or another flood such as Jeddah's in 2009) is high on the government's agenda and thus the emergency response capability of the General Directorate of Civil Defence is regularly exercised. This level of preparedness was inadequate according to critics of the Saudi system, who point to the lack of standard operating procedures, adequate governance of systems, and the need for information-sharing communication channels among organisations and external to the country (Alamri, 2011; Al-Awai, 2012; Al Harithy, 2010; Al-Saggaf, 2012; Al-Saud, 2010; Al-Sibyani, 2013; Baglia et al., 2012).

However, emergency response systems are continually evolving, and social media capabilities and technological innovations, such as satellite communications for data transmission, require constant monitoring by the authorities. Further, continuing public awareness and emergency crew training programs are necessary (Baglia et al. 2012).

7.2 Optimal emergency response framework

As noted in the previous section, emergency response systems at every level require continual attention to ensure relevance and efficiency, and this extends to the international coordinator (United Nations Economic and Social Council, 2013). In audit, the Economic and Social Council stated that the complexities and expenditure levels of global humanitarian aid (some \$US100m p.a.) necessitated that the Council review the structures and operations of the Office for the Coordination of Humanitarian Affairs. This decision led to the development of a mid-term strategic framework for the Office to test competencies and priorities for the period 2014-2017. As stakeholders, member states including Saudi Arabia were called upon to evaluate the Office and its coordinating United Nations' agencies (U.N. Economic and Social Council, 2013).

Saudi Arabia's membership responsibilities in the U.N.'s humanitarian affairs call for greater attention by the Kingdom to international humanitarian response issues, particularly with the propensity among its neighbours for natural disasters, such as earthquakes and drought. Whilst the focus for this study and thus the survey questions were directed to the Kingdom's internal organisations and operations, there is undoubtedly a responsibility for the emergency relief organisation, in this case Civil Defence, to advise the Minister for the Interior regarding a Saudi response on request from the United Nations for resources. A recent instance of this was the drought in the Horn of Africa, where Saudi Arabia contributed strongly to the Office for the Coordination of Humanitarian Affairs to become its third-largest donor with funds of \$US58 million (Slim, 2012). This international donation conforms with Oloruntoba and Gray's (2006) 'agile humanitarian chain' where agility is in the context of donor governments' aid, and is specific to short term direct relief and distribution in an international crisis, rather than long term investment in infrastructure and systems. Bhattacharya et al. (2014) expanded on this model recently to enhance transparency in the supply chain by providing a centralised financial system within the specific international aid operation.

As noted, the study respondents approved of the operational response of the General Directorate of Civil Defence during the flood crises; however, they criticised its response preparation and planning. The participants placed priority for future action for the General Directorate of Civil Defence on identifying gaps in the emergency response system; improving cooperation between Civil Defence, the Red Crescent as an integral member of the emergency response system, and the local groups (police, fire fighters, and city teams); and to improve community awareness and preparedness for crises. This system conforms to findings of Dash et al. (2013) and Melnyk et al. (2014) who proposed disaster supply chain models that included political, structural, and operational factors.

To this end, a dynamic systems model was developed in this study in part to answer research question 2, which concerned an optimal network structure for emergency relief. The Emergency Logistics Centre model shown at figure 5.2 is primarily a dynamic systems model to assist decision making during an emergency. It comprises a series of interconnected nodes capable of collecting discrete data and analysis outcomes to support agency decision making at a national, regional, and individual organisation level (Gonçalves, 2008). Nevertheless, by its nature, the model comprises node responsibilities (agencies) where communication lines and resource flows dictate the need for logistics administration and action centres. This summary for a node-resource-distribution framework is supported by Aslanzadeh et al. (2009) and Beamon and Balcik (2008), although

Beresford and Pettit (2009) used the Thai tsunami response to include local communication networks, early warning systems, and risk mitigation rather than relying on resource storage capacity.

Management of emergency response resources is usually the domain of government, however Maon et al. (2009) questioned whether the private sector is not better placed to conduct a logistics operation such as emergency relief resources. Hofmann et al. (2013) concurred, citing adaptive workflow management systems such as designing the system to incorporate geographic imaging systems and real time analysis of situational resource flows. Real time data access and analysis, that is, improved communications, is another optimal model considered by Preece et al. (2013) to merge data flows from disparate systems of various agencies into a primary disaster model. Preece et al.'s finding is supported by this study's Emergency Logistics Centre model which incorporates data entry at such nodes. Other sources of real time data could be crowd-sourcing (Crooks & Wise, 2013) and this was advocated by the Japanese, New Zealand and Queensland disaster investigators. Fatti and Patel (2013) and Shonrim and Foody (2013) also pointed to the potential for local government and the population to plan and work together in addressing future catastrophic events.

In flood zone preparedness, found in this study in 2009 not of an acceptable standard, Alferi et al. (2012) noted that governments were using risk abatement strategies, such as early warning systems. This was a major change recommended after the 2009 rain event in Jeddah, where the Presidency of Meteorology and Environment is now the first agency responsible for early warning of rain events. Also relevant to this study, and charges of building on flood-prone wadis (Al-Saud, 2010; Wagner, 2011; Manani & Fadel, 2010); Vörösmarty et al. (2013), Scheid et al. (2013) and Wu et al. (2013) posited that climate change/global warming increased the risk of flooding around the world through more severe rain events and urbanisation of coastal plains. Wright (2014) also noted that flood risk comprises rain events, topography, and drainage networks, and that urban locations intensify risk. However, the timeframes of rain events and the nature of the urbanisation (large blocks of flats, and paved roads and gutters) remained a challenge. Wright questioned whether flood abatement strategies could counter the effects of extreme rainfall and this has implications for assessing flood risk. In a similar geography to Jeddah in Egypt, Ghoneim and Foody (2013) came to a similar conclusion as Wright, noting that the location of the rain event and permeability of the surface, rock, vegetation or urban development also affected the nature of the flooding. Ghoneim and Foody developed a rapid assessment model of rain event hazards in mountainous desert which is also applicable to the Hijaz mountains.

The conclusion for the optimal response structure for the General Directorate of Civil Defence is therefore to act as advocate for risk management practices and infrastructure to prepare the country for such sudden onset events. Whilst Civil Defence has its operational agenda, it is best placed to disseminate information to relevant agencies, collaborate with United Nations and similar international agencies, and most importantly, to continue awareness programs for the Saudi population, especially those in the areas of most risk.

7.3 Optimal emergency response operations

This section discusses the third research question concerning the optimum operational strategies for the General Directorate of Civil Defence structure. This follows on from the discussion in section 7.2 and is chiefly addressed by the Emergency Logistics Centre model.

In an emergency situation, response times for the emergency crews and the duration of the intervention were deemed to be influenced by the two variables, weather and access to the field, and these impacted the number of victims who could be retrieved from the crisis. The remaining variables concerning resources and flows were in fact ‘receivers’ of the effects of weather and access, and they in turn contributed to the efficiency of the Centre’s operation. Inability of one of the receiving nodes to recover efficiently would have an ongoing effect through the model.

The Emergency Logistics Centre model differs in aim and complexity from previous Saudi system developers, such as that of Alshehri et al. (2013) or Momani and Fadil (2010). Following the logic in model development of Gonçalves (2008), the model varies also from more general system developers such as Bello and Aina (2014), Besiou et al. (2011), or Keller and Al-Madhari (1996). It can also be adapted as a model for a variety of crises and locations.

Optimum field-based emergency response strategies present a significant field of research and the literature review conducted for this study showed several systems designs, stochastic and dynamic, that contributed to resolving different aspects of the problem. Many researchers used systems modelling to show relationships between decision making levels, between rescuers, health-care workers, administrators and transporters, and significantly, modelling transport and logistics. Below is a summary of the research that contributed to formulation of the Emergency Logistics Centre model:

- Demand models: Sheu (2009, 2010)
- Evacuation: dynamic network models (Chalmet et al., 1982; Hamacher et al., 2013; Hoppe & Tardos 2000; Kongsomsaksakul et al., 2005; Saadatseresht et al. 2009)

- Path selection/optimal deployment: (Özdamar & Demir, 2012; Yi & Kumar, 2007; Yuan & Wang, 2009)
- Vehicle routing problem approaches: Dantzig and Ramser (1959) followed by Garvin et al. (1957) and Gavish and Graves (1982) with commodity flow models, and Balinski and Quandt (1964) with the set-partitioning problem. Metaheuristics (Taillard et al. 2001) include ant colony optimisation (Bell & McMullen, 2004; Bullnheimer et al., 1999; Wassan et al., 2013). Other models included Bent and van Henterynck (2006); Karaoglan et al. (2012), and Afsar, et al. (2014).
- Travelling salesman problem: addressed from different aspects by Gendreau et al. (1999), Nagy and Salhi (2005), Ropke and Pisinger (2006), and later by Hyytiä et al. (2010), Häme, Penttinen, and Sulonen (2010). Kaji (2001) and Tsai and Tsai (2002) used tabu search among other approaches.
- Nodes: dynamic systems models for no-notice evacuation (Auld et al., 2012; Chiu & Zheng, 2007; Zhang et al., 2010; Zhou et al. 2010)

There are few existing post-disaster models. Gonçalves (2008) and Ramezankhani and Najafiyazdi (2008) proposed simulation modelling as a valid approach to complex emergency relief systems characteristics of dynamic inputs, long time delays, multiple feedback, and responsive decision making. At a national level, and using different objectives, emergency relief models were constructed by Pettit and Beresford (2005) and Helbing (2012).

In response, in this study, the Emergency Logistics Centre model was ‘loaded’ with known data on Saudi budget, management, and human and physical resources. It also included modalities of communications, coordination with its international and internal partners, and expenditure/replenishment rates for these resources. These factors comprised the Centre’s capability. In using predictive variables not in control of the Centre, the model for this study followed Rawls and Turnquist (2010), who approached the resources availability using a two-stage stochastic integer program to provide for hurricanes or other immediate disaster threats. Zhang and Xu (2010) and Li et al. also used such models for reorder of supplies. Section 5.3.2 describes the construction technique and the literary basis of the model.

Thus the Emergency Logistics Centre model provides a ‘template’ for both research questions 2 and 3: the optimal emergency relief structure is produced through using the nodes and dynamic pathways for emergency relief. In the event of an international emergency, such as assisting in a tsunami or earthquake, the Saudi Emergency Logistics Centre produced by the model

exists within a bureaucratic structure that supplies resources as skilled professionals, finance, communications, and logistics (supplies and distribution). These are transported to a national or international disaster zone where the model is used in its operational phase. The variables for the model that account for weather and access to the victims are values that enhance the operational phase of the model, allowing for an optimal response as shown in the case study at chapter 6.

7.4 Efficient response to an emergency

The Saudi Civil Defence Council comprises 16 policymakers and representatives from the service industry, such as Red Crescent, hospitals and utilities. The Council is supported by a Civil Defence Administration Committee and Regional Civil Defence Committees, who also report through their bureaucratic structures. The Regional Committee's administration provides emergency response plans, communicates with stakeholders, trains and directs all response teams, thus it leads a coordinated response (Ministry of Interior, 2013). The Municipality of Jeddah has the prime responsibility for infrastructure relating to flood mitigation. In the preparation stage for disaster control, the Municipality provides planning and maintenance of the infrastructure, and training for its teams.

Response to an emergency event is proportional to the extent of the disaster, and international attention is drawn to flood mitigation infrastructure, strengthening and monitoring building codes to strengthen buildings against earthquake, and storm and tsunami defences along coastlines, especially those areas subject to urbanisation (Alferi et al., 2012, Vörösmarty et al., 2013). Variables in an event are also being examined, for example, during the rain event in Queensland's catastrophic flooding from storage, rapidly rising waters also impacted Victoria 1500 km to the south. The three-month rain event after drought in September 2010 resulted in floodwaters up to February 2011 spreading across one-third of the state and caused \$AU1.3b damage (Comrie, 2011). In other rain events, deluges cause mudslides and devastation in mountainous country. Thus as well as the size of a disaster, its timelines may be sudden, such as Jeddah's floods in 2009, medium term such as the Victorian floods, or long-term, as the drought in Africa.

For very poor countries, the United Nations is the responsible organisation, drawing together resources from its members to respond to the disaster (OCHA, 2013). For countries with some resources, a disaster may be 'manageable' such as the 2003 tsunami, or if devastating like the

Christchurch earthquake, the local response units will need assistance. All these factors influence the larger structure of the Emergency Logistics Centre's efficient and effective response.

Other aspects of optimal disaster response studied by researchers include medical. Aung and Whittaker (2013) supported the notion of a primary healthcare system where details of victims could be recorded as assistance was rendered. Others had more than one objective to their research, such as Kussel et al. (2012) and Wu et al. (2013), who devised systems for plotting pathways of a flood from its primary source for Namibia and China (Yangtze) respectively, which could be used for disease control, leading to risk maps on flood and disease. Meanwhile, Fatti and Patel (2013) argued that populations may distrust local government capability and lack of robust governance in responding to an event; whilst the local government officials cited a lack of resources and interlinking responsibilities with other agencies. In Saudi Arabia, the Presidency of Meteorology and Environment has the responsibility for the level of alerts of a rain event, and the Geological Survey organisation, which established a seismic warning system, for earthquakes which generally occur in the north-west of the country (Pallister et al., 2010). Thus there is potential for the regional government and the population to seek a more productive environment to plan and work together in addressing future catastrophic events.

Of the research reports, findings for enhanced community awareness and crews training such as those of Fatti and Patel (2013) and Schad et al. (2012) were supported by the respondents in this study. Maon et al. (2009) went further and included community participation into the communication and training systems, and this found support in all international disaster studied: Goss and Teagarden (2011) regarding Tokohu in Japan, McLean et al. (2012) in Christchurch in New Zealand, and the Queensland Floods Commission of Enquiry (2011) in Queensland.

Of the efficient response communication systems, Saudi's unitary system both assists information and communication technology. Whilst from the technology side, all organisations should be synchronised according to standards and capacity, the country's public sector is not successful in implementing such projects or in benefitting from productivity increases from technology (Almajed & Mayhew, 2013). This raises issues of use of data analysis or research findings, and the resolve of executive management in embedding technological change into the organisations.

7.5 Chapter summary.

This chapter discussed the findings of the research in the context of the research questions and the literature on comparable countries' experiences. It was found that whilst the study participants rated the country's response to the initial rain event, this had markedly improved by the second event in 2011. Whilst the pre-disaster response structure remains, the responsibilities of the various stakeholder organisations are now better defined, and public awareness and warning systems secured.

The findings extended to 'best practice' which for Saudi Arabia now includes the United Nations Disaster Assessment and Coordination agency. The Kingdom can contribute its knowledge and experience managing flash flooding of desert and coastal plains subject to increased urbanisation. There is also an opportunity for the Emergency Logistics Centre capability model to be used in similar geographic and urban situations to test the preparedness of the emergency response teams and that of their various organisations. The next chapter is the conclusion of the thesis, summarising the value of the model in response to future events.

Chapter 8 Conclusion

This research concerned the quality of Saudi Arabia's response to flood disasters in 2009 and again in 2011. This, the final chapter, comprises a summary of the chapters, the conclusions for the thesis, benefits and limitations of the thesis and suggestions for future research.

8.1 Thesis summary

The literature review explored theoretical and practical approaches to identify models that could be relevant to an emergency centre response to both prepare and respond to Jeddah's emergency agencies to floods or catastrophic events. Within the systems planning field, management of resources such as supply chains, resource inventories, evacuation characteristics and hazard assessment systems were discussed. Theory included the vehicle routing problem, multi-commodity flow problem, dynamic network flows, and communications and information sharing. A multi-commodity flow problem was selected for this research: a discrete time model for dynamic emergency logistical planning.

The following chapter presented the international and selected national emergency response organisations and discussed their response plans. These included not-for-profit aid agencies such as the Red Cross and the Red Crescent. Recent crises relevant to Saudi Arabia's economic and social development were selected: in Japan, the 2011 Tōhoku earthquake and tsunami; the New Zealand (Christchurch) earthquakes, 2010 and 2011 and the Brisbane, Queensland, floods of 2010-2011. Further, the Saudi disaster management structures were discussed; the Civil Defence Council, and the Civil Defence Administration Committees. The responsibility pathways through to local operations were explained in detail. Next, the events of the two Jeddah floods and their outcomes were presented. The outcomes were summarised as a lack of coordination or preparedness, and thus a lack of credible response due to inadequate leadership. Further, the authorities did not seek to communicate or engage with the population. In the next event, social media exposed the issues and the government's response was far improved. Systemic issues of *wasta* were exposed and retributions continued in the courts for years. By the 2011 event, remedial infrastructure was generally operational, crews were trained; the various security, health and emergency organisations were in communication. Heavy rainfall across the country since has been well managed with little loss of life and less property damage. This investigation answered the first two research questions

regarding the emergency response structure for the Kingdom, and the optimum design to respond to future events.

The primary research began with the methodology at chapter 4. To answer the remaining research questions regarding optimal operational structures and policies, a system dynamics framework was selected. A multi-methods research design produced a questionnaire for all past and present positions in the public organisations and the Red Crescent, responsible for patient transport. Causal loop and stock and flow models were shown as stages for producing the Emergency Logistics Centre capability model, based on models prepared by Gonçalves (2008) and Besiou et al. (2011). Chapter 5 moved to the results, initially the demographics of the study participants, and their descriptive analysis. The results of the modelling were included. Chapter 6 comprised case study data to test the Emergency Logistics Centre capability model, and this comprised testing weather and access variables given a numerical readiness for Saudi and Queensland data. Queensland's emergency response structure was allocated a higher value than Saudi Arabia, given its longer history. The results for the comparison were that, whilst the Queensland Emergency Response Centre was capable of recovering competency more quickly than Saudi Arabia after servicing a disaster; however, weather was the determinant in delivery of services and the capability of each centre. The next section presents the conclusions from the wider discussion at chapter 7.

8.2 Outcomes from study

The outcomes from the study led to the following conclusions, summarised as follows:

- For a government emergency response coordinator, the extended vertical communication lines through the various agencies were a barrier to effective communication.
- The study respondents viewed Saudi emergency response system as adequate for an adverse event. However, the level of preparedness did not accord with critics of Saudi system, who pointed to the lack of standard operating procedures, and the need for information sharing communication channels among organisations and external to the country. The Emergency Logistics Centre capability model responds to these needs by providing a set of nodes relevant to each responsibility centre and the nodes facilitate information on resource use and replenishment, and barriers.
- To ensure a robust response to a natural disaster, all levels of the emergency response framework should be subject to testing and standardisation through regular and ad hoc trials and training. This should also include feedback reports to ensure that observed

issues are addressed, and that new research findings are assessed and if relevant, incorporated into the Saudi emergency response system. Finally, each node should allow for alternate resources and routes to meet the system needs in the event of an overwhelming disaster such as that which disrupted the Japanese response.

- Difficulty in accessing the disaster area and the effects of the weather are variables that cannot be controlled by the Emergency Logistics Centre for Saudi Arabia and may impact operational performance.
- Based on the comparison of simulated results of different scenarios, for Emergency Centre performance, good weather is more important than good access in the long term period. Further, the Centre's capability development rate improved after the first year and scenario 4 (maximum access and maximum weather) gives the optimal result.
- Increased emergency team response times decrease capability for all the scenarios for Saudi Arabia after the first year.
- Greater numbers of victims can be retrieved under the optimum conditions of access and weather; however, weather is the next variable of consequence where good weather permits the evacuation of more victims than good access. Scenario 2 (maximum weather and minimum access) is the next most efficient case after scenario 4 in rescuing the greater number of victims.
- The ability of the Emergency Centre to release resources is constrained by minimum access and weather (scenario 1).
- The accumulation of rescued victims is greatest in the first year and tapers off at the 5-year level. Fewer victims were rescued under scenario 1 than scenario 3.
- Results of the Queensland Emergency Logistics Centre capability model indicate a similar trend. All scenarios show a fall in centre capability with low access to a disaster site being less influential than bad weather. Optimal access and weather conditions (scenario 4) result in minor loss of capability to 0.73 whilst the worst scenario results in loss of capability to 0.55. In the long run good weather is more important than good access, given that all other local factors remain constant.
- Emergency team response time converges over 10-year period with scenario 4 showing the highest curve, that is, reduced response. Scenario 1 showed no movement over the timeline.
- The comparison run of the centre capability for Saudi Arabia indicated that from a low initial competence rating (0.4), the centre improved over time, with the best case

scenario reaching an average of 0.51 rating. However, for Queensland, starting from a higher competence rating of 0.8, all scenarios test run showed declining competence rating to 0.74 for scenario 4 and 0.55 for scenario 1. It appeared that the Saudi centre was showing some improvement over time, whereas the Queensland teams may have reached an optimum level and require further resource input to maintain high capability.

- The Saudi results showed widening emergency team response times, as weather and access impeded their movements. On the other hand, Queensland showed convergence with better capability diminishing over time and all scenarios converging towards 0.5.
- The duration of the rescue differed between the Saudi and Queensland teams with rescue operation reaching a maximum of 4.5 days for Saudi and 3.5 days for Queensland. There was also significant difference in resource allocation trends between the two models. Moreover, the performance gap between the best and worst scenarios mirrors the resource allocation.

8.3 Benefits and limitations of this research

The benefits of this research are that it provides a critical analysis of the events from the 2009 Jeddah floods in regards to the Civil Defence organisation and the improved response from the government which mitigated destruction for the 2011 and subsequent events. Whilst this review is of value, the development of the Emergency Logistics Centre capability model leads to an integrated dynamics system approach whereupon all contributing organisations can test preparations, that is, their resources, training and the interaction with other contributors. Further, the model shows that in all simulations, weather has a greater influence on emergency operations than access to the site. The model is therefore a unique instrument for testing preparation for policy as well as preparedness.

The limitations of the model are confined to the events depicted; other outcomes may emerge from the use of different variables or values. However, the model was validated and its outcomes are consistent and reliable for the events tested.

8.4 Further research

There are several directions for future research. The Emergency Logistics Centre model may be loaded with data concerning Saudi or other Gulf country events; or it could be used to develop scenarios from the data used in this research, which now reflects current Saudi circumstances.

Further, given scarcity of full data flows in the region, the model may be used by other Emergency Control Centres in emerging countries using their data and scenarios to test their readiness for a disaster event. It is highly recommended that researchers use this approach, as constant focus on the possibility of an adverse event such as fire, flood, earthquake or tsunami encourages stakeholders to adopt a new approach to an unpredictable event.

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Appendix 1 Responsibilities of the Regional Committee for Civil Defence (Makkah)

Providing protection to both people, public and private properties in addition to the sources of national wealth from the dangers of disasters and war.

- 2) Establishing public safety in all activities that are considered to be necessary to life, industrial , agricultural, commercial, and residential.
- 3) Providing all the regions of the kingdom with different services concerning fires, rescue services, and ambulance.
- 4) Proposing of the plans, projects, and civil defence measures and follow up implementation.
- 5) Implementing all what is related to its major concerning the plans, projects, civil defence procedures, in addition to the decisions issued by the council of civil defence and the Interior Minister and Head Council of the civil defence.
- 6) Setting the rules and means of safety in the industrial, agricultural, commercial, residential, and follow up application in the sectors and government and civil institutions.
- 7) Inspection work for the business and residential and industrial, agricultural facilities in order to ensure the availability of procedures and required safety and risk control and intervention to avoid before they occur.
- 8) Quick intervention in incidents of fire in order to control and eradicate it before it develops.
- 9) Rapid interference in different cases of rescue as they occur under normal circumstances.
- 10) Take appropriate action to address the disaster according to the decision taken by the prime Minister of the Interior and the Head Council of the civil defence in order to take advantage of the possibilities of military forces and others, and whatever it needs requiring the necessary people, tasks, and tools to assist them in performing their functions.
- 11) Preparing the rules of protection from disaster risks and preparing contingency plans.
- 12) Initial and rapid intervention in emergency situations.
- 13) Coordinating and communicating with governmental sectors and other agencies responsible for the implementation of civil defence work in emergency situations.
- 14) Organising the intervention work in the disastrous areas and to save the injured and assist them.
- 15) Evacuating residents from the affected areas.
- 16) Removing the effects of the disaster in harmonization with the competent authorities.
- 17) Preparing emergency rooms.
- 18) Preparing and training of the volunteers in order to be able to do the work of the civil defence.
- 19) Representing the Kingdom in the organizations, conferences, international, and domestic seminars and workshops for civil defence.
- 20) Proposing the agenda of the civil defence and preparing the necessary studies of these issues before the council (Ministry of Interior, 2013).

Appendix 2 Emergency Logistics Questionnaire

Please complete the following questions to the best of your knowledge.

A. Disaster profile

Hazards

1- Complete the database regarding to the natural disasters, industrial accidents and population displacements, which occurred between the years 2009 to 2012.

2- What is the impact of most damaging hazards occurring in the country, on communities, infrastructure, environment etc.

Vulnerability/ Communities

3- What are the different type and level of disaster risk and vulnerability in your districts?

4- Are villages (rural areas) prone to disaster identified?

5- How ready are communities to understand official warnings and react?

6- What percentages of vulnerable areas in the country have evacuation plans/maps?

B. National policies, plans and projects

Policies

7- Is there a national disaster management policy, act or related legislation? Specify.

8- Are there national disaster management plans and procedures? Specify.

Projects/ Programmes

9- List the past, current and future projects in disaster management sector, specifying the owners (UN, the World Bank, Local Government...) and the executors of the projects (National Gov. NGOs...):

10- Are there any disaster awareness and public information projects or programmes being undertaken in the country?

Training

11- What is the disaster management training strategy and/or plan of the country with regards to disaster management?

12- Has disaster management training been undertaken in the country? Is so what which organisation (s)? What form of training has been utilised and who has been the audience?

Type of Training

Audience

Trainer

13- Where are the training centres located?

14- Is there training at the community level?

C. Government structures:

15- What is the structure/ organigram for disaster management in the country? What is the number of personnel in each organisation/ agency?

See the heading What major historic infrastructures are likely to be affected by future disasters? What actions have been taken to reduce the risk?

List of all governmental organisations related to disaster management

Mitigation

Preparedness

Relief

Reconstruction

16- Is there a national disaster management office/ ministry or a national disaster response mechanism?

Yes or No? if Yes please specify

17- Is the office in charge of disaster management a military force/ formation?

18- What are the criteria for recruitment in the offices of disaster management? (Military ranks...)

19- Which governmental entity has the mandate of assisting during a disaster?

- Army
- Fire fighters
- Police
- Others “NGOs”
- All

20- How are various sectors such as (agriculture, health, infrastructure, education, Water resources, Interior) engaged in risk management is-sues?

21- How is the ministry of health organised for preparedness ?

22- What ministry is in charge of maintaining law and order during disaster?

23- What entity co-ordinates the actions of all of the ministries?

24- Is there a published overview to ensure a common understanding of the precise roles of and inter-relationships between different bodies (minis-tries, NGOs, Offices, ...)

25- What is the structure/ organisation of the Red Cross/Crescent?

26- What are the functions of the Red Crescent?

27- Is the Red Crescent responsible for operation in any other countries?

28- How are the RC volunteers trained?

D. UN Country Office

29- List of UN offices in the country

30- Is there an effective UN Disaster Management Team?

31- How is co-ordination between different agencies done for disaster mitigation, relief and reconstruction?

E. Material and human resources

32- Is there an information management system for disaster response management? What organisation manages the system?

❖ *Early Warning Systems*

33- What early warning systems are in place? Where?

34- Flood, mudflow, hazardous meteorological events

35- Seismic hazard: Institute of Seismology

36- Drought:

❖ *Relief Resources*

37- Identify human resources available for disaster management in the country

38- Identify materials available for disaster management in the country (for different organisations: RC, CDO,)

❖ *Communications*

40- How are the warnings transmitted to officials and to the population? (Channels of dissemination)

41- How are the warnings transmitted to officials and to the population? (Channels of dissemination)

42- What are the means of communications? (e.g. HF radio, normal phone lines). How dependable are these communication means?

F. Funding

43- What has been the impact of disaster in the country during the past 5 years? (GDP, development)

44- Average budget of the government per year allocated for:

- Mitigation:
- Preparedness:
- Relief:
- Reconstruction:

45- Average cost of disaster to the government per year?

- Relief
- Reconstruction

Please rely in your experience rate the following questions:

➤ *Dependent Variable Questions*

1. Timely Response/Response Time

a. How will you rate Civil Defence Organisation in terms of response time or timely response?

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

b. How will you rate THE RED CRESCENT in terms of response time or timely response?

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

c. How will you rate THE OTHER NGOs in terms of response time or timely response?

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2. Regarding the duration of the operation necessary for disaster mitigation,

a. How will you rate CDO?

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

b. How will you rate THE RED CRESCENT?

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

c. How will you rate the Other NGOs?

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

3. Do you feel the number of people served is adequate for?

a. CDO

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

b. The Red Crescent

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

c. the Other NGOs

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

4. In terms of unit cost of service, which in other words, means administrative cost per person served,

a. How would you rate CDO?

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

b. How would you rate The Red Crescent?

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

c. How would you rate the Other NOGs?

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

➤ *Independent Variable Questions*

(Funding, Manpower, Training, Coordination)

1. Funding: Total Budget (in million \$),

a. Do you believe the CDO Annual Budget significantly influences its performance?

Rate this budget factor as a significant determinant of performance.

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

b. Do you believe the RED CRESCENT Annual Budget significantly influences its performance?

Rate this budget factor as a significant determinant of performance.

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

c. Do you believe the Other NGOs Annual Budget significantly influences its performance?

(Data not made available) Rate this budget factor as a significant determinant of performance.

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2. Manpower: Number of Employees

a. Do you believe the number of CDO employees significantly influences its performance?

Rate this factor, in terms of number of employees (FTE Equivalent), as a significant determinant of performance.

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

b. Do you believe the number of The Red Crescent employees significantly influences its performance? Rate this factor, in terms of number of employees (FTE Equivalent), as a significant determinant of performance.

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

c. Do you believe the number of The Others NGOs employees significantly influences its performance? Rate this factor, in terms of number of employees, as a significant determinant of performance.

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

3. Training (Number of Hours)

Do you have the proportional training or disaster and emergency preparedness training exercise or workshop?

Yes(2)

No(1)

If yes

please specify

a. Do you believe the training CDO employees receive in disaster management significantly influences its performance? Rate this training factor as a significant determinant of performance.

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

c. Do you believe the training The Red Crescent employees receive in disaster management significantly influences its performance? Rate this training factor as a significant determinant of performance.

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

d. Do you believe the training the others NGOs employees receive in disaster management significantly influences its performance? Rate this training factor as a significant determinant of performance.

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

4. *Coordination (Number of Meetings)*

a. Do you communicate and coordinate with other agencies and organisations during the disaster?

Yes (2)

No(1) ,

If

yes please specify

b. Do you believe the coordination of activities by CDO with other relevant agencies during the disaster cycle significantly influences its performance? Rate this coordination factor as a significant determinant of performance.

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

c. Do you believe the coordination of activities by the Red Crescent with other relevant agencies during the disaster cycle significantly influences its performance? Rate this coordination factor as a significant determinant of performance.

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

d. Do you believe the coordination of activities by other NGOs with other relevant agencies during the disaster cycle significantly influences its performance? Rate this coordination factor as a significant determinant of performance.

Flood Disaster in Jeddah City In

2009

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)

2011

Score Excellent (5) Very Good (4) Good (3) Fair (2) Poor (1)