A UNIFIED FRAMEWORK OF BUSINESS AND HUMANITARIAN LOGISTICS FOR NATURAL DISASTER MANAGEMENT

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Approval of the Graduate School of Social Sciences

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ABSTRACT

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Disasters demonstrate an increasing trend regardless of their types. Therefore, academicians and practitioners are trying to find ways to reduce vulnerabilities of people and systems towards catastrophic events. Today, many countries are suffering from natural disasters. For instance; our country, Turkey, which lies on an active area prone to natural disasters such as earthquakes, floods, is suffering for years. One may also recall the recent earthquakes in Japan in March, 2011 and Turkey in October, 2011. These two catastrophic events devastated both the people's life and economic situations of these two countries. In this thesis, we propose a relocation model that integrates two different approaches; namely, business and humanitarian logistics. The model involves relocation of residential, industrial, governmental and agricultural facilities.

Keywords: Humanitarian logistics, disaster management, natural disasters, unified framework, relocation

ÖZET

DOĞAL AFET YÖNETİMİ İÇİN İŞ VE İNSANİ LOJİSTİĞİN BÜTÜNLEŞMİŞ BİR ÇERÇEVESİ

Tunca Tabaklar

Lojistik Yönetimi Yüksek Lisansı, Sosyal Bilimler Enstitüsü

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Afetler, çeşitleri ne olursa olsun, artan bir eğilim içerisindeler. Bu yüzden, akademisyenler ve uygulamacılar felaket boyutundaki olaylara karşı insanların ve sistemlerin açıklarını azaltmak için yollar bulmaya çalışıyorlar. Birçok ülke doğal afetler yüzünden sıkıntılar çekmektedir. Örneğin, deprem ve sel gibi doğal felaketlere meyilli çok etkin bir bölgede yer alan ülkemiz, Türkiye, yıllardır zorluklar yaşamaktadır. Ayrıca, hatırlayacağınız gibi Mart 2011'de Japonya'da ve Ekim 2011'de Türkiye'de meydana gelen depremler hem insanların hayatına hem de bu iki ülkenin ekonomisine büyük zararlar vermiştir. Biz bu tezde, iki yaklaşımı; yani iş ve insani lojistiği birleştiren bir yeniden yerleştirme modeli öneriyoruz. Bu model konut, sanayi, kamu ve tarım tesislerinin yeniden yerleştirilmesini içermektedir.

Anahtar kelimeler: İnsani lojistik, afet yönetimi, doğal afetler, bütünleşmiş çerçeve, yeniden yerleştirme

To my parents

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CHAPTER I

INTRODUCTION

The technology is continuously evolving. However; human beings are still vulnerable towards disasters either man-made or natural. Disasters are devastating for not only the human life but also for supply chain systems and economic growth of the world. Researchers have also pointed out to this fact. For instance, as Tinguaro Rodriguez et al. (2010) state, the natural disasters have effects on population directly, but, they may also have significant effects on large sectors of the economy and the political systems in affected regions as well. Following this perspective, the logistics is an effective and efficient tool for preparing, preventing and reconstruction before or after the occurrence of the disasters owing to the fact that, logistics accounts for 80% of the disaster relief operations (Van Wassenhove, 2006).

Business logistics is traditionally defined as flow of goods and services from the point of origin to the point of consumption. The right service or product should be on the right place at the right time, in right condition and with the right cost. As we extend our approach from this general definition and viewpoint of logistics, we observe that on one hand, there is the humanitarian side of the logistics activities. This humanitarian side aims to minimize suffering and the total number of loss of human lives during or aftermath of disasters. One other primary aim of humanitarian logistics is to distribute the needed items to the victims of disasters. Business and humanitarian logistics are surely not totally isolated from each other. When commercial supply chains and business logistics are considered, there are also significant humanitarian-related factors that need to be taken into account, such as community support, skilled workforce, know-how, customers or markets. One other example of particular interest in this thesis is as follows: In a certain area, if people are affected by a fatal disaster, a supply chain of a company and also their employees may be affected.

In this thesis, our main focus is natural disasters, particularly, floods. We aim to define the fundamentals of a decision making framework in order to relocate residential, government, industrial facilities and agricultural zones to alternative areas against the risk or possibly following the occurrence of a flood. In doing so, we particularly try to recover from the previous disaster and to reduce the risk for both people and supply chains. In order to implement the idea, various scenarios are constructed. We employ mathematical modeling approaches in our methodology as a tool. In addition to the 'risk' objective, there is also a social reflection of relocation for people to alternative locations. As with any type of change, the idea of relocation causes a resistance of the affected. To account for this fact, we add a 'social resistance' component to the model, via a social cost and make the approach more realistic.

The scope of this thesis is disaster management. In particular, we analyze disaster management approach from the perspectives of both humanitarian logistics and business logistics in an attempt to propose an integrated approach. The focal disaster in the study is a natural disaster. Flood is one of the most common disasters and it is frequent in our country, Turkey. We also aim to present a discussion that investigates the parallelism between humanitarian and business logistics within the scope of disaster management. Through this analysis, we seek the cross-learning possibilities among these two viewpoints by comparing and contrasting the commonalities in their nature, objectives, costs and constraints. This analysis may very well be helpful for developing new frameworks to be more resilient against disasters.

Regardless of the frequency of disasters, the pressures on the humanitarian organizations about improving their logistics activities are increasing lately (Kovacs and Spens, 2011). Van Wassenhove (2006) states that, around 75,000 people are killed and 200 million people are affected by about 500 disasters every year. This statements and figures prove how important humanitarian logistics activities are. Kovacs and Spens (2007) review the literature by using the keywords; humanitarian logistics, disaster relief logistics and supply chains, disaster recovery logistics and supply chains, emergency logistics, humanitarian aid and emergency supply chains. This literature review reveals that a bunch of closely related terms (namely, humanitarian logistics, disaster relief logistics, disaster recovery logistics, emergency logistics and humanitarian aid) are used interchangeably by many authors. We can also observe that even the terms humanitarian supply chains and disaster relief chains are used interchangeably with the above terms, owing to the close relationship between logistics and supply chains. Occasionally, we follow the same approach within this thesis, and use these terms interchangeably, where it is in-line with the context.

Humanitarian logistics is used as an umbrella term in the literature. This term actually covers two different approaches, the first one disaster relief, which is designated for sudden-onset catastrophes, such as natural disasters (earthquakes, floods) and very few man-made disasters such as terrorist acts or nuclear accidents and the second one refers to the continuous support for developing regions (Kovacs and Spens, 2007). Disaster relief operations cover activities such as 'the transportation of first aid material, food, equipment and rescue personnel from supply points to a large number of destination nodes geographically scattered over the disaster region and the evacuation and transfer of people affected by the disaster to the health care centers safely and very rapidly' (Barbarosoğlu et al., 2002). Disaster relief operations are is highly likely to gaining importance day by day and will preserve its importance in the future. In the year 2011, 302 natural disasters occurred. Almost 30,000 people were killed and approximately 206 million people were affected as a result of these disasters. The reflection of the disasters in 2011 on the economy was a loss of US$366 billion (Cred, 2012). In this study, we focus on a class of natural disasters, therefore we concentrate on a problem that seems more akin to disaster relief operations among the set of disaster relief operations and continuous support.

The rest of the thesis is organized as follows: We proceed in this chapter by introducing the definition and types of disasters, besides; we then define the disaster management approach and identify the phases of disaster management in this chapter. In Chapter 2, we review the literature related to disaster management from the perspectives of business and humanitarian logistics and give examples of location problems regarding disaster management operations from the literature. In Chapter 3, we identify the similarities and differences between the business and humanitarian logistics. In Chapter 4, we introduce a relocation problem to demonstrate the unified framework and the proposed methodology taking into account both humanitarian and business logistics. Chapter 5 involves numeric analysis related to the problem introduced in Chapter 4. We end our study with concluding remarks and further research directions in Chapter 6.

After the Asian tsunamis in 2004, humanitarian logistics which covers disaster relief as well as continuous support for developing regions is on the focus of both logistics academics and practitioners (Kovacs and Spens, 2007). For this reason, academicians try to find the better ways for societies to be ready and resilient against the disasters, prevent loss of human life and reduce human sufferings. The two most common disasters that are subjects of researches in the literature are earthquakes and floods. In this study we focus on floods. Since, there is a few study regarding floods in the literature. Furthermore, we are living in a country whereby we observe many instances that have effects on human lives and business units simultaneously including earthquakes and floods, for this reason, we consider working on disaster management with the perspectives of both business and humanitarian logistics.

In this thesis, we first aim to find the commonalities and integrate the nature of two different approaches, business and humanitarian logistics. In order to be more resilient against the disaster, we then propose an integrated framework that may primarily be implemented in the recovery and further for mitigation phase of the disaster management.

In order to clarify the ideas developed, we create a hypothetic problem involving flood as a main disaster. We search for an optimal solution for relocation to the alternative locations in this problem using an analytical approach. The model for the problem incorporates ideas and components from commercial and humanitarian perspectives. As a result, we develop an approach which we believe can be used as a tool for both commercial and humanitarian organization at the stages of recovery of disaster management.

The main contribution of this study is that, in order to prevent and reduce the impacts of the disaster and minimizing the total loss of human lives, we propose a unified framework by integrating the objectives of business and humanitarian logistics to recover from a flood disaster and mitigate the further risks.

1.1 Disasters

Disasters are damaging events that change the system and the living conditions of human beings. Since our focus in this study is disasters, we first review the various definitions of the term "disaster" that has been used in the literature. We first observe that the definition of disaster changes according to who defines it. For instance, a disaster is defined by International Federation of Red Cross and Red Crescent Societies (IFRCa) as "a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community's or society's ability to cope using its own resources." We, living in a country that has long suffered from many disasters, can define disasters as devastating force giving people and environment fatal damages. The term disaster is also defined from different viewpoints by many academicians. Van Wassenhove (2006) defines disaster as "a disruption that impacts a system as a whole physically and endangers its priorities and goals". Altay and Green (2006) define disaster as "large, serious and intractable problem that tests the ability of communities and nations to effectively protect their populations and infrastructure, to reduce both human and property loss, and to rapidly recover."It is interesting to note that, in many studies war is excluded from disasters since humanitarian organizations do not get involved in war situations (Van Wassenhove, 2006).

1.2 Type of Disasters

Generally, disasters are classified into two categories. These are man-made and natural disasters (Van Wassenhove, 2006, Altay and Green, 2006). An alternative approach by Shaluf (2007) reclassifies the disaster types as man-made, natural and hybrid disasters. According to this approach, hybrid disasters are defined to occur as a result of human errors and natural forces. Examples of hybrid disasters are soil erosion and landslides cause of demolishing of forests by humans beings. This classification with further examples can be seen in Table 1.1.

Natural	Man-Made	Hybrid
Natural Phenomena Topographical Phenomena Hydrological Phenomena Biological Phenomena	Socio technical Warfare	Natural and Man-made Events

Table 1.1 Shaluf (2007)'s Disaster Classification

Today, most researches follow the classification by Van Wassenhove (2006). According to this study, disasters are categorized according to their occurrence types (slow-onset and sudden-onset) and their resource type (man-made and natural). A detailed view of Van Wassenhove's disaster classification can be seen in Table 1.2.

	Natural	Man-Made
Sudden-Onset	Earthquake Hurricane Tornadoes	Terrorist Attack Coup d'Etat Chemical Leak
Slow-Onset	Famine Drought Poverty	Political Crisis Refugee Crisis

Table 1.2 Disaster Classification (Van Wassenhove, 2006)

According to Below et al. (2009), that is; a database that collects the natural disasters, divided them into 4 sub-groups. These are geophysical (earthquakes, landslides, tsunamis and volcanic activity), hydrological (avalanches and floods), climatological (extreme temperatures, drought and wildfires), meteorological (cyclones and storms/wave surges) or biological (disease epidemics and insect/animal plagues).

1.3 Disaster Management

Disasters are part of human's life therefore it is important to identify and manage disasters appropriately in order to overcome their impacts with minimum possible damage and minimum possible cost. This coupled with the increasing awareness on disasters make disaster management an important approach for societies, governments and, companies.

Disaster management is a very wide topic that covers may areas in the literature. This approach has been fed from the supply chain management, industrial engineering, operations management and operations research literature (Overstreet et al., 2011). In this thesis, we look and research disaster management particularly from the logistics perspectives. One definition of disaster management is:”the organization and management of resources and responsibilities for dealing with all humanitarian aspects of emergencies, in particular preparedness, response and recovery in order to lessen the impact of disasters” (IFRCb). Figure 1.1 depicts a scheme for disaster management that involves phases and processes of involved.

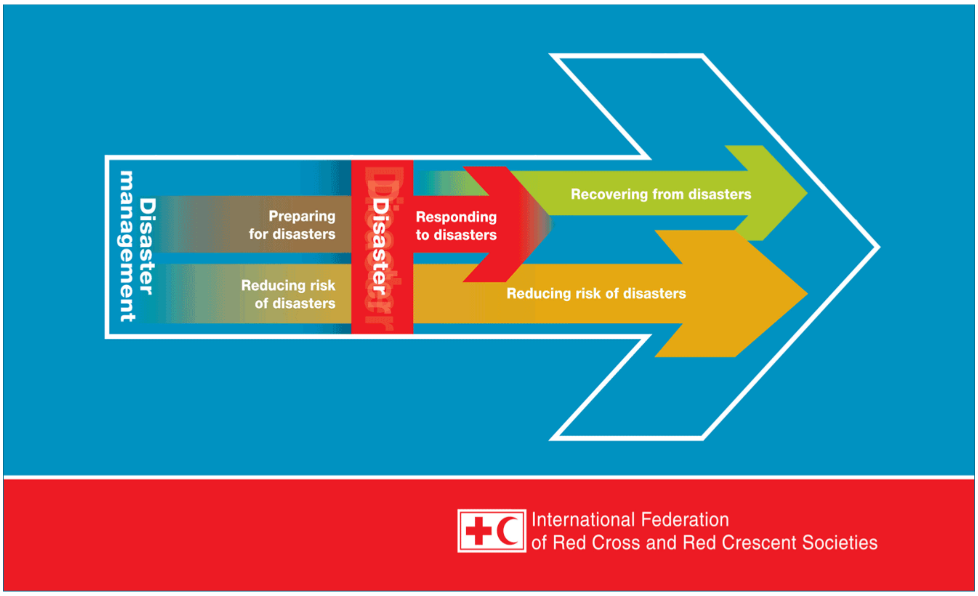

Figure 1.1 Disaster Management (IFRC)

Another definition of disaster management is: Disaster management deals with activities operated before, during and after a disaster which aims to reduce loss of human life, decreasing its impact on the economy and turning back to a state of normality (Altay and Green, 2006).

On the governmental and policy-making authority side, countries should have well-planned disaster management policies to prevent loss of human lives and reduction of the social welfare of the society. From the perspective of logistics management, we aim to contribute this literature by proposing a framework that demonstrates the possible gains from joint analysis of decisions in different fields. This is exemplified through relocation of residential and industrial zones of a certain area.

1.4 Disaster Management Stages

Disaster management is usually analyzed through defined stages that cover the time period of the activities related to disaster. This allows the development of specific methodologies and objectives for each phase and makes it easier to manage the context. With a similar idea, Adivar and Mert (2010) propose that, humanitarian and disaster relief efforts can be categorized by several dimensions such as time, authority, and disaster type. Generally, based on time, disaster management stages are categorized. The main stages are based on the time phases involved mitigation, preparedness, response and recovery (Altay and Green, 2006; Adıvar and Mert, 2010). In similar approaches, Van Wassenhove (2006) identifies the disaster management stages as mitigation, preparedness, response and rehabilitation, while Kovacs and Spens (2007) classifies these stages as preparation, immediate response and reconstruction from the humanitarian logistics perspective. We remark that, latter reference excludes the mitigation stage from the humanitarian logistics operations.

We also note that, these disaster management stages are used interchangeably in the literature. For instance, response stage (Altay and Green, 2006; Van

Wassenhove, 2006; Adivar and Mert, 2010) is replaced by immediate response (Kovacs and Spens, 2007) and recovery stage (Altay and Green, 2006; Adivar and Mert, 2010) refer to rehabilitation (Van Wassenhove, 2006) and reconstruction (Kovacs and Spens, 2007) stage in several other studies in the literature. Kovacs et al. (2010) define reconstruction as "the time when housing and infrastructure in the disaster area is rebuilt and people resettled and include recovery and rehabilitation."

In this thesis, we follow the 4-phases disaster management approach. These stages are: mitigation, preparedness, response and recovery. We now elaborate on the definitions and contents of these stages. *Mitigation* stage refers to activities that decrease the vulnerability of the community against the impacts of disasters. *Preparedness* stage covers the activities that make the government and disaster responders prepare for responding to a disaster. *Response* stage involves the activities that are essential to cover the immediate and short-term effects of a disaster that concentrates mainly on the actions necessary to save lives, to protect property and to meet basic human needs; relief, rescue, firefighting, medical service, permit control, sheltering, evacuation, law enforcement are some of the examples of disaster response activities (Mansourian et al. 2006). The *recovery* stage consists of activities which make the communities back to normal (such as reconstruction and relocation) and they should be assisting meeting mitigation and preparedness needs (Mansourian et al. 2006). We mainly focus on recovery stage in order to clarify the further discussion, Relocation, that we analyze in this thesis falls into the recovery phase.

Other lines of research have different perspectives of disaster management phases. For instance, from the perspective of operations research (Caunhye et al. 2012), the operations until the occurrence of the disaster are called pre-disaster operations: These are disaster mitigation (evacuation) and strategic planning (preparedness, facility location and stock pre-positioning). According to the operations research literature, operations that start after disaster occurrences are called short-term post-disaster operations (response) such as relief distribution, evacuation of displaced people, transportation and treatment of disaster casualties. The review article by Caunhye et al. (2012) that investigates operations research approach to disaster management excludes long-term post-disaster activities disaster recovery operations from their literature review, since these activities take place long after the occurrence of the disaster. The authors perceive recovery stage operations with a viewpoint more similar to business logistics than the humanitarian or emergency logistics. On the other hand, Kovacs and Spens (2007) exclude mitigation stage from the scope of humanitarian logistics. However, they include reconstruction, which is traditionally a part of recovery stage, as a part of humanitarian logistics. Finally, Van Wassenhove (2006) excludes both mitigation and recovery stages from the scope of humanitarian logistics.

We follow a perspective that relies on the fact that logistics processes within mitigation and recovery stages involve operations that are not only for minimizing cost but also reducing the vulnerabilities of the people. Therefore we include these two stages in the scope of humanitarian logistics as well. Howden (2009) shows the disaster management stages through the humanitarian logistics perspective. This study is important in that it identifies the involvement of logistics in every stage. The author compares the disaster management stages in terms of their period, logistics volume, requirement of supplies, urgency and procurement of supply. Howden (2009) also discuss the relationship between logistics and disaster management. He states that, at mitigation and preparedness stage the logistics involvement is low, whereas we see high logistics involvement at the response stage. At the recovery stage, involvement of logistics is medium.

<table>
<tr><th>Phase</th><th>Preparedness</th><th>Response</th><th colspan="2">Transition</th><th>Recovery</th><th>Mitigation</th></tr>
<tr><td>Period</td><td>Long Term – Continuous</td><td colspan="2">Days – Months</td><td colspan="2">Months - Years</td><td>Long Term – Continuous</td></tr>
<tr><td>Logistics Volume</td><td>Low</td><td colspan="2">High</td><td colspan="2">Medium</td><td>Low</td></tr>
<tr><td>Supplies Required</td><td>Specific standard supplies pre-positioned for disaster response</td><td colspan="2">Specific standard supplies: Food, medical supplies, water and sanitation equipment, shelter, household kits, etc.</td><td colspan="2">Varied supplies depending on the context of the disaster: reconstruction material, livelihoods equipment</td><td>Varied supplies</td></tr>
<tr><td>Urgency</td><td>Low</td><td colspan="2">High: lead times for supplies can make the difference between life and death.</td><td colspan="2">Medium: There may be government and donor pressure to complete recovery activities.</td><td>Low</td></tr>
<tr><td>Procurement of Supplies</td><td>Local</td><td colspan="2">International</td><td colspan="2">Local - International</td><td>Local</td></tr>
</table>

Table1.3 Humanitarian Logistics Throughout the Disaster Management Cycle
Source: Howden (2009)

A summary of disaster management phases in terms of period, logistics volume, supplies required, urgency, and procurement of supplies can be seen in Table 1.3 (Howden, 2009). From the table, we observe that recovery and mitigation stages involve medium and low level of humanitarian logistics activities respectively. This points out to an opportunity of introducing an integrated framework of business and humanitarian logistics, particularly concentrating on these stages of disaster management. Academic literature generally focuses on the preparation phase of disaster relief, and donors (actors that are responsible for funding) concentrate on the response phase after a disaster (Kovacs and Spens, 2007). Therefore, the recovery stage is not very much elaborated in academic researches. From this point of view, we believe that the contribution of this study to recovery stage of disaster management is significant. As Kovacs and Spens (2007) point out to similarity of recovery stage of disaster management with business logistics environment with the exclusion of profit as the primary objective. However they do not refer to this phase explicitly as recovery phase we deduced from their study that what they call reconstruction phase is actually recovery phase. This also shows that, it is more suitable to justify and implement an integrated framework of business and humanitarian logistics considering the recovery phase.

CHAPTER II

LITERATURE REVIEW

In this chapter, we aim to provide a brief overview of the literature related with the phenomena we introduced earlier. To this end, we concentrate on two related yet separate research areas; humanitarian and business logistics.

In literature review section, since the main problem is the relocation problem, which is a class of facility location problems, thus we review the literature accordingly and identify the similar facility location problems that are studied earlier

Within the line of research involved in business logistics, we review the studies that deal with disaster management, particularly with sudden-onset natural disasters such as earthquakes, floods and avalanches. Next, we take a close look at the humanitarian logistics literature, for a review of related methods that have been used. We also analyze operations research implementations that use location theory as methodology. We try to identify such methods may involve a parallelism with the problem that we analyzed.

The main objective of business logistics is to minimize the total cost and to maximize the profits, at the same time, to provide sustainability through manufacturing and servicing. However, natural disasters and the other type of disasters account for serious disruptions in supply chain activities and "business as usual" is not an option anymore (Christopher and Peck, 2004). The frequency of such disruptions is unfortunately not negligible. Supply chains are in an increasing trend of becoming vulnerable towards natural or man-made disasters (Knemeyer et al., 2009), which makes business logistics professional seek for ways against disasters. Russell (2005) states that the literature of the supply chain and business processes that cover disaster management is associated with two main themes; Continuity management and supply chain vulnerability. Other researchers add to this idea by defining business continuity management as a method that deals with providing greater assurance that the outputs of processes and services can be delivered in the face of risks. In addition, it is related with identifying and dealing with the risks which threaten to disrupt essential processes and related services as well as, mitigating the effects of these risks, and ensuring that recovery of a process or service is achievable without significant disruption to the enterprise (Gibb and Buchanan, 2006). Supply chain management perspective in recognition of disaster management is fed from the literature of supply chain risk management.

Risk management is defined as "the process whereby decisions are made to accept a known or assessed risk and/or the implementation of actions to reduce the consequences or probability of occurrence." (Norrman and Jansson, 2004). Supply chain vulnerability is defined in reference to supply chain risks as ''the propensity of risk sources and risk drivers to outweigh risk mitigating strategies, thus causing adverse supply chain consequences''. Accordingly, supply chain risk management that aims to discover the possible causes of risk and apply appropriate actions to avoid or eliminate supply chain vulnerability, is defined as “the identification and management of risks for the supply chain, through a coordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole” (Jüttner et al., 2003). According to Norrman and Jansson (2004) there is a number of business trends that makes supply chain more vulnerable to risks. These are;

- increased use of outsourcing of manufacturing and research and development to suppliers;
- globalization of supply chains;
- reduction of supplier base;
- more intertwined and integrated processes between companies;
- reduced buffers, e.g. inventory and lead time;
- increased demand for on-time deliveries in shorter time windows, and shorter lead times;
- shorter product life cycles and compressed time-to-market;
- fast and heavy ramp-up of demand early in product life cycles; and
- capacity limitation of key components.

Altay and Green (2006) examine the studies related to business continuity in the context of computer network recovery problems, buffer estimation models and selection of disaster recovery plans. The authors claim that post-disaster logistics problems should be discussed at company level. However, we remark that the overall disaster management approach needs to include a supply chain point of view, mostly in the other stages of disaster management.

In a study by Oke and Gopalakrishnan (2009), the authors identify the category of natural disasters as supply risks among supply chain risks amongst the imports, climate, man-made disasters, socio-economic and loss of supplier risks. As risks of supply chain increase, the requirement for companies increase as well to improve logistics processes and abilities that can allow them to be competent of providing an efficient and effective response and proceed with business as intended (Ponomarov and Holcomb, 2009).

As we mentioned earlier, the victims of disasters are perceived to be humans only. However, the only entities that are affected by disasters are not human beings, but also supply chains. Supply chain disruptions may be result of events such as terrorist attacks, labor strikes and power grid outages besides natural disasters (Hale and Moberg, 2005). In recent years, there were several incidents that have caused severe disruptions in the supply chains. Recall the disruptions caused by recent natural disasters. One example is the Taiwan earthquake that affected PC manufacturers Dell and Apple in 1999, hurricane Mitch that devastated banana farms, hence affecting supply chains of Dole in 1998. Hurricane Floyd has deluged the Daimler-Chrysler plant in Greenville in 1999. Another group of such effects is the disruptions caused by epidemics, such as the occurrence of mad-cow disease that caused a shortage of leather goods in Europe in 2001, the occurrence of SARS that impacted the IT supply chains in 2003. One final category of such disruptions refers to the disruptions caused by man-made disasters. Examples are fire accident at the electronics plant of a supplier in New Mexico, which caused $400 million in lost sales at Ericsson; longshoreman strikes at US ports in 2002, which caused an estimated $11 to 22 billion in lost sales, and of course terrorist acts like 9/11 that crippled transportation networks across the USA (Natarajarathinam et al., 2009).

Having faced with so many severe damages as a result of disasters, business experts are trying to improve the supply chains and strengthen them against the disasters. This idea gives rise to the concept of supply chain resilience that emerges from disaster vulnerability. One of the significant reasons for companies to put more effort towards becoming more resilient is the attempt to manage and mitigate the risk caused by global sourcing and continuous "leaning-down" trend (Christopher and Peck, 2004). The concept of resilience is related to risk and vulnerability accepts that not all risk associated with disasters and threats can be avoided, managed or removed. Instead resilience concentrates on "ability of the system to return to its original or desired state after being disturbed", thus, its capability to absorb or mitigate the effects of the disturbance (Peck, 2006). Ponomarov and Holcomb (2009) identify the essence of supply chain resilience as readiness, response and recovery. The first one of these three terms, readiness, refers to have the necessary foundation to reduce the risks. Response refers to providing efficient and effective set of actions and processes against the event. Recovery refers to being able to be back to original state or even better state after an event. The framework suggested by the authors is presented in Table 2.1. The table depicts the resilience-capabilities matrix for supply chain resilience. In this matrix, 'control' refers to the direction and regulation related to strategic and tactical actions in supply chain network, 'coherence' means understanding the results of devastating events and potential risks and 'connectedness' means behavior of people to come together during the times of disaster (Ponomarov and Holcomb, 2009).

Resilience/capabilities matrix	Readiness	Response	Recovery
Control	Logistic quality, efficiency, cost minimization, risk-hedging capabilities, back-ups of systems and processes	Timeliness, postponement	Cycle-time reduction, delivery competency
Coherence	Effectiveness of logistics processes, systematic contingency planning	Flexibility, agility, risk-sharing	Customer service, efficiency of warehouse operations, knowledge management
Connectedness	Information technology upgrades, supply chain relationship building	Information sharing	Highly integrated systems and processes

Table 2.1 Resilience-logistics capabilities matrix
Source: Ponomarov and Holcomb (2009).

A study that investigates supply chain resilience is by Christopher and Rutherford (2004). In their study, the authors propose a list of characteristics that must be processed by resilient supply chains. These characteristics include concepts of culture, awareness, stability, minimization of variability. A full list of the characteristics can be seen in Table 2.2. In this study, the authors, also provide a comparison of robust supply chains and resilient supply chains. They conclude that the terms robust and resilient are commonly used interchangeably for supply chains. However, the intention in many cases is the resilient supply chains. Therefore, we present the part of their work that discusses characteristics of resilient supply chains. One of the main properties that separate robust supply chains from resilient supply chain is robust supply chains are ‘lean-thinking’ centered, however, the latter one is risk management centered.

The Characteristics of Resilient Supply Chains
Risk management central to supply chain strategy
A culture of risk and quality awareness
Internal and external risk management
Responsive and capable of sustained response to sudden and significant shift in input
Supply chain acceleration and deceleration
Low inventory levels throughout with strategic safety stock
Critical path spare capacity in manufacturing, storage space and process capability
Mix of lean and agile processes
Effective processes
Scalable/ Adaptable
Processes are stable and under control
Non-value adding activities and processes removed
Supply chain output variability is minimized

Table 2.2 The Characteristics of Resilient Supply Chains
Source: Christopher and Rutherford (2004).

In the light of the foregoing discussion on business logistics, we now look at the humanitarian literature in an attempt to identify objectives and methods of humanitarian logistics and reveal similarities, differences with business logistics.

The main objective of humanitarian logistics is minimizing the number of loss and suffering of human beings during or aftermath of disasters. Thomas and Kopczak (2005) provide a definition of humanitarian logistics from managerial point of view as follows:, humanitarian logistics is “the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people". Based on this definition, just as in business logistics, the humanitarian logistics also concentrates on the process of flowing goods and just as in business logistics, there are "rights" of humanitarian logistics. These are to deliver the right goods or services to the right people, at the right place, in the right quantities and at the right time (Cottam et al., 2004).

Van Wassenhove (2006) gives a more objective-oriented operational definition for humanitarian logistics. The author defines humanitarian logistics as the processes and the systems consisted of circulating people, resources, skills and knowledge to help vulnerable people impacted by disasters.

Similar to the business counterpart, humanitarian logistics consist of many activities such as procurement, warehousing, fleet management, transportation of supplies and people, asset management, building management, security, information technology and radio communications. It is worthwhile to note that, compared to business logistics, humanitarian logistics has a broader scope of activities. Information technology and security might be considered as the activities of humanitarian logistics, because of the technical and military experiences of humanitarian logistics practitioners (Howden, 2009).

Humanitarian logistics is very challenging therefore; many studies in the literature emphasize the complexities of humanitarian logistics (Overstreet et al., 2011). The characteristics of humanitarian logistics operations management are "an acute time frame, linked to a disaster at a given point in time, the need to urgently gather intervention teams whose members know each other little or not at all, and the ability to mobilize numerous resources as quickly as possible and to coordinate them" (Chandes and Pache, 2010). Hence, resource management under urgency, in a very limited time and severity of impacts increase the complexity of humanitarian logistics.

Operations research is an important tool that has been employed in analyzing humanitarian logistics problems. Humanitarian operations generally have two main phases. These are pre-disaster and post-disaster operations. As can be understood from the names, while pre-disaster operations aim to prevent the damages of disaster before it happens, post-disaster operations aim to minimize the suffering and aid the people affected by the disaster. As primary areas of interest, pre-disaster operations deal with short-notice evacuation, facility location and stock pre-positioning problems, whereas post-disaster operations deal with relief distribution and casualty transportation (Caunhye et al, 2012). Although the studies in the literature tend to leave the recovery phase out of the scope of disaster logistics (Tomasini and Van Wassenhove, 2009); our viewpoint classifies the recovery phase as a component of post-disaster operations. Hence, we take recovery within the scope of humanitarian relief operations. Disaster management is very convenient for applying operations research/management science research and related techniques because of the inherent randomness, dynamic nature and the need for real-time and cost-efficient solutions (Altay and Green, 2006).

There is a rich literature on facility location problems. Facility location problems are defined as "problems investigate where to physically locate a set of facilities (resources) so as to minimize the cost of satisfying some set of demands (customers) subject some set of constraints." (Hale and Moberg, 2003). Considering the branch of facility location problems related with disaster management, the optimization models concerning with the facility location problems mostly deals with stock pre-positioning, evacuation and relief distribution (Caunhye et al, 2012). Our study aims to propose an analytical model through the introduction of a new relocation problem that deals with relocation of residential, industrial and agricultural zones and governmental facilities to alternative locations that posses lower disaster risks.

Studies relating to the model that we propose involve operations research implementations for location problems. In this thesis, we particularly propose a mathematical model regarding relocation policy at the recovery stage, following a flood disaster. The literature contains very few studies that analyze problems similar to the problem we propose in context of a disaster. Kovacs and Spens (2007) state that the academic literature tends to focus on the preparedness stage of disaster management and donors, who provide funding for humanitarian supply chains, focus on response stage. Similarly, facility location problems that we analyze that are proposed mostly for preparedness and response stages of disaster management.

Related with flood disasters; Chang et al. (2007) developed a method at the preparation stage for flood emergency logistics planning under uncertainty, based on a real-life situation. The decision variables in the model consist of the structure of rescue bodies, locations of rescue resource storages, shares of rescue resources and delivery of rescue resources. The model in their study determines disaster rescue areas and sorts out their level of emergency by minimizing the expected shipping distance. Based on the results of this model, they next introduce a two-stage stochastic programming model. This model decides on which local rescue bases should be built after the disaster, as well as, the quantity of rescue equipments in the storages, and the transportation plans for rescue equipment.

Döyen et al. (2011) develop a two-stage stochastic model for pre-disaster and post-disaster rescue centers for humanitarian relief logistics. The model assists to support an optimum pre-disaster plan with the consideration of post-disaster decisions. The model in their study, involves many decision variables, such as the location of regional rescue centers and local rescue centers, the distribution plan and quantity of relief items flows between the two types of rescue centers and, the distribution plan and quantity of relief items flows between the same type of rescue centers and backlogged demands. As methodology, they use a heuristic approach based on Lagrangean relaxation.

Bal (2011) proposes a model for Turkey and Greece for cooperating in responding to forest fires in close geographical areas of both countries. It suggests an airborne firefighting plan and involves solving location covering problem and vehicle allocation problem. The study analyzes centralized and decentralized systems for both countries. In decentralized system, there are two options; in one Turkey is the leader and in the other, Greece is the leader.

Balçık and Beamon (2008) propose a facility location model for humanitarian relief chains regarding sudden-onset disasters such as earthquakes. The authors state that the number and the locations of distributions centers and the amount of supply directly affect the response time and cost. They develop a maximal-covering type facility location model which determines the number and locations of the distribution centers in the relief network and the amount of relief supplies to be stocked at each distribution center.

Görmez et al. (2011) develop a two-stage mathematical model for responding the awaited earthquake in the near future in İstanbul. In the first stage of the model, the objective function is to minimize the demand weighted distance between the casualty locations and closest facilities. In the second-stage of the model; the objective function minimizes the average distance travelled to serve a victim and the number of new facilities to establish. The results of the models show that there needs to be a small number of facilities and their locations are robust for the particular example under consideration.

Jia et al. (2007) focus on the problem of locating medicinal supplies for large-scale emergencies. They primarily deal with locating medical reserves and how to position local staging centers to obtain, repack and allocate the medical supplies from a strategic national stockpile in case of a major natural disaster or a bioterrorist attack. They propose a general facility location problem as a covering model, *p*-median model and a *p*-center model to be suited for different large-scale emergencies. They demonstrate the implementation of the model on some descriptive examples for deciding on the locations of diverse large-scale emergency medical services. The proposed models present solutions with decreased loss of life and economic losses for the different emergency scenarios.

Dekle et al. (2005) proposes a mathematical model for a class of the covering type location problems. The model uses a two-stage approach to identify the accepted disaster recovery centers for the Federal Emergency Management Agency in Florida, against the large-scale disasters. The integer programming model determines the locations of disaster recovery centers in order to ensure each resident is within a certain miles to one of those recovery centers.

Hale and Moberg (2005) propose a four step modeling approach in order to secure multiple supply chain facilities against the supply chain disruptions by external factors such as natural and man-made disasters. In the first and second steps, they identify emergency resources needed at each secure location and the critical facilities in the supply chain, respectively. In the third step, they determine the number of emergency resource storage areas to cover the whole supply chain and the minimum distance of each facility to secure site locations. The authors suggest that their set covering model provides the managers with minimum number of secure locations and areas where secure site facilities can be built.

Ratick et al. (2008) propose a model for responding to the potential effects of natural and man-made disasters to reduce vulnerability and enhance the resilience of supply chain and other logistics activities. They use set covering location problem model to decide the number of backup facilities. They allow existing facilities to serve as backup facilities as well. The location set covering model formulations are developed in order to help supply chain and logistics managers to address vulnerabilities against different types of disasters such as natural disasters. This serves to enhance supply chain and logistics resilience.

CHAPTER III

HUMANITARIAN LOGISTICS vs. BUSINESS LOGISTICS

From an analytical point of view, humanitarian and business logistics differ primarily in terms of objectives, as well as in terms of constraints. As a natural result, their methodologies and approaches are different. To this end, in what follows, we both present a comparison of humanitarian logistics and business logistics and search for cross-learning opportunities among the two viewpoints. The similarities can be based on the natures, constraints, costs and objectives.

Lee (2004) states that supply chains should not only be fast and cost-effective, but also they should be adaptable, agile and aligned. Van Wassenhove (2006) makes the remark that humanitarian supply chains are already agile, adaptable and aligned. This observation tempts one further to hope that cross-learning possibilities exist. Naturally, we aim to take one more step ahead and demonstrate that the two viewpoints can further be integrated.

We identify the differences of business and humanitarian logistics, through a comparison and contrast of the two approaches in terms of their characteristics, objectives, constraints, nature and commonalities. Moreover, we analyze the network perspectives for business and humanitarian supply chains, whereby we identify the actors and processes of both chains.

As Van Wassenhove and Martinez (2012) state humanitarian logistics is much more different than the commercial and military logistics in that the demand and supply are unknown and dynamic. We demonstrate further differences via supporting evidences from the literature, by first starting with the definitions. As we mentioned in Chapter 2, the primary objective in humanitarian logistics is to reduce the impacts of the disaster and prevent loss of human sufferings. In contrast, the business logistics aims to minimize the total cost and maximize the profit.

However, there are many differences between the two approaches based on their goals, supply chain structures, demand types and so on. One of the differences between the two viewpoints is the characteristics of humanitarian and business logistics. According to Balçık and Beamon (2008), there are basic distinction between commercial supply chains and humanitarian relief chains in terms of their strategic goals, customer and demand characteristics, and environmental factors.

Next, we identify the characteristics of humanitarian and business logistics, respectively. Thereafter, we discuss the similarities and difference of both viewpoints. Finally, we examine these two viewpoints under the supply chain management perspectives.

3.1 Humanitarian Logistics Environment

Like with business logistics, humanitarian logistics involves flow of goods and services. Besides, it incorporates traditional supply chain activities which are planning, forecasting, procurement, transportation, warehousing, and delivery and incremental ones such as appeal and mobilization (Russell, 2005). Moreover, the author highlights the importance relief supply in disaster management context and states that relief chain links all actors such as donors, humanitarian organizations, military, governments and beneficiaries. Balcik and Beamon (2008) identify the main elements of humanitarian logistics as:

- unpredictability of demand, in terms of timing, location, type, and size,
- suddenly-occurring demand in very large amounts and short lead times for a wide variety of supplies,
- high stakes associated with adequate and timely delivery,
- lack of resources (supply, people, technology, transportation capacity, and money).

In contrast with for-profit (business) organizations, not-for-profit (humanitarian) organizations concentrate on social objectives instead of economic objectives (McLachlin et al., 2009).

Another similar characterization of humanitarian logistics is by Kovacs and Spens (2007). They identify the defining elements of humanitarian logistics based on its main aim, actor structure, phases, basic features, supply chain philosophy, transportation and infrastructure, time effects, knowledge actions, supplier structure and, control aspects. Their perception of humanitarian logistics can be seen in Table

3.1. According to the Kovacs and Spens (2007) the primary aim of humanitarian logistics is to reduce the suffering of vulnerable people. Humanitarian logistics differs from its commercial counterpart based on some basic features such as variability in supplies and suppliers, large-scale activities, irregular demand, and unusual constraints in large-scale emergencies. The authors also state that, from the perspective of supply chain philosophy, humanitarian logistics adopts a push strategy at the response stage and a pull strategy at the recovery stage.

Another study by Tomasini and Van Wassenhove (2009) make a list of characteristics of humanitarian logistics. According to this study, humanitarian logistics is identified by ambiguous objectives, limited resources, high uncertainty, urgency and politicized environment.

Humanitarian Logistics	
Main Aim	Alleviating the suffering of vulnerable people
Actor Structure	Stakeholder focus with no clear links to each other, dominance of NGOs and governmental actors
3-Phase-Setup	Preparation, immediate response, reconstruction
Basic Features	Variability in supplies and suppliers, large-scale activities, irregular demand, and unusual constraints in large-scale emergencies
Supply Chain Philosophy	Supplies are "pushed" to the disaster location in the immediate response phase. Pull philosophy applied in reconstruction phase
Transportation and Infrastructure	Infrastructure destabilized and lack of possibilities to assure quality of food and medical supplies
Time Effects	Time delays may result in loss of lives
Knowledge Actions	The nature of most disasters demands an immediate response, hence supply chains need to be designed and deployed at once even though the knowledge of the situation is very limited
Supplier Structure	Choice limited, sometimes even unwanted suppliers
Control Aspects	Lack of control over operations due to emergency situation

Table 3.1 The Characteristics of Humanitarian Logistics
Source: Kovacs and Spens, 2007

Yet one recent other study that reveals the nature of humanitarian logistics is by Overstreet et al. (2011). This study identifies those characteristics of humanitarian logistics that pose complexities, regarding natural disasters from practitioner perspective as: *unknowns* (the time, place, and severity of a disaster in terms of both people and property), *the importance of timely response*, the need for *trained logisticians*, *media and funding*, importance of *equipments and information technology* and, *interference*. Out of all of these characteristics, time is of particular importance, since the "quick response" approach is vital for receiving and supplying aid and other materials for reducing human suffering. On the other hand, media is of particular importance, since it encourages people to become more involved in disaster management practices.

McLachlin et al. (2009) identify two types of the environment of logistics environment: Uninterrupted and interrupted environments. Uninterrupted environments are stable politically and economically; logistics infrastructure and all the other actors such as customers, suppliers, service providers, and employees are in place; on the contrary, interrupted environments are represented by a lack of stability, greater complexity, and special challenges in going with more than one source of supply with shifting customer demand. They claim that, humanitarian operations take place in an unstable; interrupted environments.

3.2 Business Logistics Environment

Unlike its humanitarian counterpart, the business logistics aims to reduce cost while increasing profit. In this sense, we identify the characteristics of business logistics with regards to commercial supply chains. Since the analysis of logistics processes cannot be separated from supply chain management, we base our discussions on the characteristics of commercial supply chains. Beamon (2004) summarizes the differences of commercial supply chains and humanitarian relief chains. Since we mention in Chapter I that humanitarian logistics is an umbrella term that contains disaster relief, humanitarian relief chains reflects the characteristics of humanitarian logistics.

Apart from Kovacs and Spens (2007) study, Beamon (2004) presents the characteristics and a comparison between business and humanitarian relief chains in terms of demand pattern, lead time, inventory control, information system and performance measurement system (Table 3.2).

	Commercial Supply Chains	Humanitarian Relief Chains
Demand Pattern	Relatively stable, predictable demand patterns. Demand occurs from fixed locations in set quantities.	Demand is generated from random events that are unpredictable in terms of timing, location, type, and size. Demand requirements are estimated after they are needed, based on an assessment of disaster characteristics.
Lead Time	Lead time determined by the supplier-manufacturer-DC-retailer chain.	Approximately zero lead times requirements (zero time between the occurrence of the demand and the need for the demand), but the actual lead time is still determined by the chain of material flow.
Distribution Network Configuration	Well-defined methods for determining the number and locations of distribution centers.	Challenging due to the nature of the unknowns (locations, type and size of events, politics, and culture), and "last mile" considerations.
Inventory Control	Utilizes well-defined methods for determining inventory levels based on lead time, demand and target customer service levels.	Inventory control is challenging due to the high variations in lead times, demands, and demand locations.
Information System	Generally well-defined, using advanced technology.	Information is often unreliable, incomplete or non-existent.
Strategic Goals	Typically: to produce high quality products at low cost to maximize profitability and achieve high customer satisfaction.	Minimize loss of human life and alleviate suffering (Thomas, 2003).
Performance Measurement System	Traditionally: focused on resource performance measures, such as maximizing profit or minimizing costs.	Primary focus on output performance measures, such as the time required to respond to a disaster (Thomas, 2002) or ability to meet the needs of the disaster (customer satisfaction).
What is " Demand"?	Products.	Supplies and People.

Table 3.2 Comparison of Commercial Supply Chains and Humanitarian Relief Chains
Source: Beamon (2004).

	Commercial supply chain	Humanitarian relief chain
Strategic goals and objectives	To produce high quality products at low cost to maximize profitability and achieve high customer satisfaction (Beamon, 2004). Maximizing profit or minimizing costs.	Minimize loss of life and alleviate suffering in disasters (Beamon, 2004) Minimizing the time required to respond, maximizing the ability to meet the needs of the disaster.
Agility	Lean-Agile (Goldsby et al. , 2006)	Agile (Oloruntoba and Gray, 2006)
Players	NGOs Donors Public sector Government	UN, international organizations such as the Red Cross and Red Crescent, Government, NGOs (Beamon and Balcik, 2008; Van Wassenhove, 2006)
Demand charactersitics	Relatively stable, predictable demand patterns. Demands occur from fixed locations in set quantities (Beamon and Balcik, 2008)	Demand is generated from random events, unpredictable in terms of time, location, type and size (Beamon and Balcik, 2008; Beamon and Kotleba, 2006)
Distribution network configuration	Well-defined with predetermined number of locations for distribution (Beamon, 2004)	Undefined because of the nature of the unknowns (locations, type and size of the events, politics and culture) (Beamon, 2004)
Inventory control	Relatively less challenging (Beamon, 2004)	Extremely challenging (Beamon, 2004)
Revenue sources	Revenue from sales (Moore, 2000)	Charitable donations from individuals and cooperations (Thomas and Fritz, 2006; Tomasini and Van Wassenhove, 2009). Government funding In-kind donations (Moore, 2000)
Performance measurement	Reliability (fill rates, delivery performance, order fulfillment), Responsiveness (lead times), Flexibility (supply chain response times, production flexibility), Cost (total cost, costs of goods sold, value-added productivity, warranty costs or returns processing cost), Assets (cash-to-cash cycle time, inventory turnouts) (Wisner et al. 2005).	Resource (total cost, distribution cost, cost of supplies, number of relief workers, $ spent per aid recipient, donor $ received per time period) Output (total amount of disaster supplies, target fill rate achievement average response time, minimum response time) Flexibility (units of supply provided, number of different types of items provided) (Beamon and Balcik, 2008).

Table 3.3 Comparison of two types of chains (Adivar et al. 2010)

Adivar et al. (2010) contribute the literature by comparing commercial supply chains, humanitarian relief chains and social welfare chains. Table 3.3 shows the authors' perspectives on comparison between commercial supply chains and humanitarian relief chains. The authors structure their comparison on a very wide literature review and made a comparison in terms of strategic goals and objectives, agility, players, demand characteristics, distribution network configuration, inventory control, revenue sources and performance measurement. The comparison table is similar to comparison table of Beamon (2004) but a more contemporary and updated one.

3.3 Commercial Supply Chain vs. Humanitarian Supply Chain

A comparison of business and humanitarian logistics from the perspective of supply chain structures also reveal significant differences. Commercial supply chains involve members such as suppliers, manufacturers, distributors and consumers as shown in Figure 3.1. When business logistics is considered, the members have the profit motive and operate in an environment that is mostly uninterrupted. Interruptions occur rarely. However, in humanitarian logistics, members are mostly non-profit organizations and their usual environments are interrupted in nature (McLachlin et al., 2009). The actors of humanitarian supply chains consist of donors, suppliers, governments, non-governmental organizations, aid agencies, military and logistics service providers (see Figure 3.1). According to Kovacs and Spens (2007), donors are significant actors of humanitarian supply chains since they provide funding for key relief activities. This dominating effect of donors tends to affect the alignment of humanitarian supply chains. That is humanitarian supply chains generally tend to focus on the response phase of the disaster relief.

The institutions involved in humanitarian logistics are typically not-for-profit companies. Whereas in business logistics companies work towards increasing profits. That is, they are for-profit organizations. Different from for-profit firms, not-for-profit (NFP) organizations highlight social, environmental, or humanitarian objectives, rather than economic ones (McLachlin et al., 2009). According to the authors, the NFP serves two types of customers. The first types of customers are beneficiaries and recipients (those require food) and the second type of customers donors who provide funding. The customer oriented approach suggests that since donors are customers in NFP, these organizations should be mindful of donor wishes and mission statement, which can lead to constraints on the use of funds. In such humanitarian environments, NFP organizations face rigid competition for donor support, instead of competition for traditional customers. Marketing effort of NFP include selling ideas to donors (upstream) instead of selling goods to customers (downstream).

Kovacs and Spens (2007) also identify military as another actor in humanitarian supply chains. Military is the provider of communications, logistics and planning capabilities to the relief operations. One recent example was observed by the authors during Katrina hurricane relief operations. Host governments are also actors, who manage assets such as warehouses and fuel depots. Finally, host country logistics service providers are important actor that can either ease or restrict the effectiveness of humanitarian logistics operations. The motives of participating for suppliers are different and the customers are not voluntary customers in humanitarian supply chains.

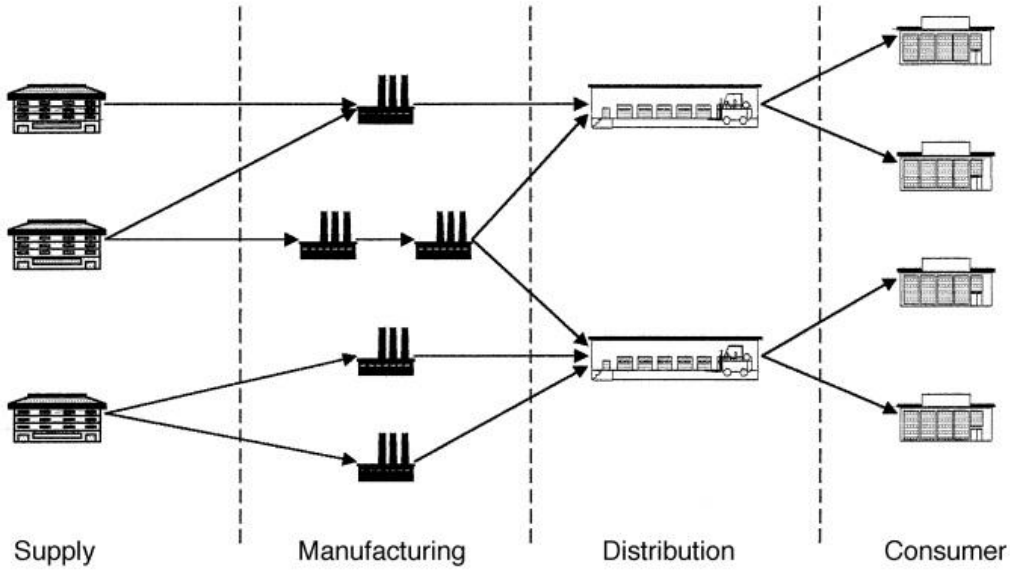

Figure 3.1 Supply Chain Structure (Beamon, 1999)

According to Tomasini and Van Wassenhove (2009), in business supply chains there are three types of flows which sometimes are referred as three B's: Boxes (material), Bytes (information) and Bucks (financial). Humanitarian supply chain also involves these B's with the addition of two more flows, specifically, important for humanitarian supply chain. These are bodies for people and brains for skills and knowledge. The determinant of businesses is customers however the humanitarian operations are determined by donors supply.

Humanitarian supply chains are generally unstable, prone to political and military effect, and ineffective due to the lack of mutual planning and collaboration. They operate with insufficient logistics infrastructure. Moreover, they have safety and security, and involve a large number of stakeholders with various objectives (McLachlin et al., 2009).

The preceding discussion, as supported by Tables 3.1 through 3.3 suggest that humanitarian and business logistics differ from each other in many contexts. Therefore commercial supply chains and humanitarian supply chains differ as well. The differences are imposed mainly by those respective environments. We also remark that humanitarian logistics has more challenges compared to the business counterpart. The main challenge is being an unstable environment. One example of such a challenge, as noted by Tatham and Pettit(2010) is global warming. Global warming treats the countries such as Bangladesh where almost 40 million of the population lives just less than 2 meters above the water level.

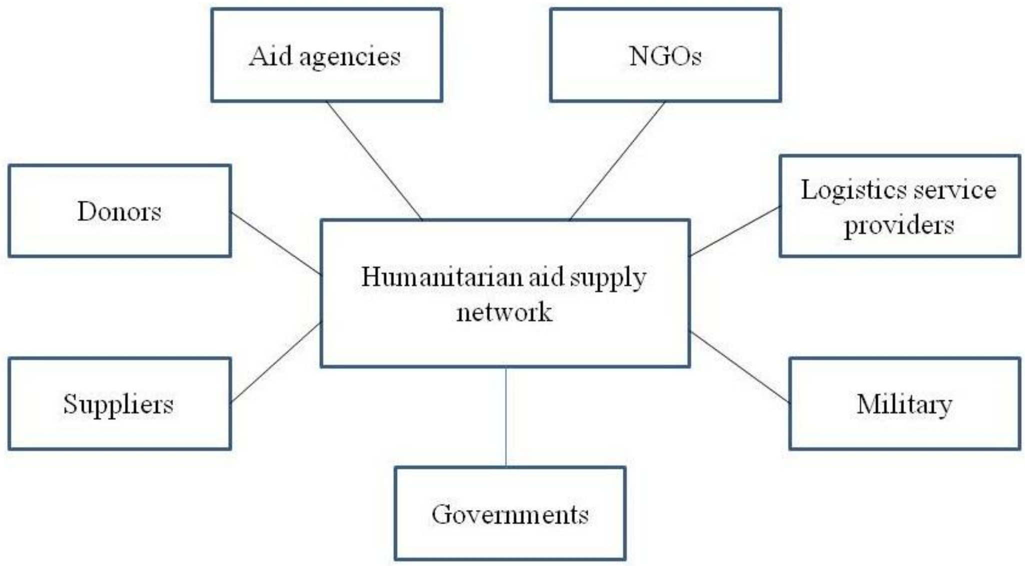

Figure 3.2 Actors of humanitarian supply chains (Kovacs and Spens, 2008)

In the next chapter, we propose an implementation of a decision making framework that integrates both humanitarian and business motives. This implementation considers the relocation of facilities. In this context, our aim is to build a relocation policy that serve humanitarian and business logistics objectives.

CHAPTER IV

PROBLEM DEFINITION, METHODOLOGY AND THE MATHEMATICAL MODEL

In this chapter, we introduce the relocation problem that will demonstrate an implementation of integrated framework for humanitarian and business logistics. Before we go into a detailed discussion of the problem, we provide an overview of the problem and discussion of the nature of floods in the next two subsections respectively. While we present an overview about our problem we also explain why we deal with this kind of problem in this study. Next, we define the types of flood and we explain the reason behind why we chose flood as the focal disaster in our problem. We present real-life example to support the underlying ideas.

4.1 Overview of the Problem

Our country, Turkey, lies on an active area which is prone to natural disasters such as earthquakes, floods and avalanches. This fact provides us a good enough motivation to choose our topic for the thesis. Since we propose that a common framework that integrates business and humanitarian logistics objectives, a viable starting point is to define the underlying problem structure over which these approaches will be based. In the preceding chapters, we argued that the natural disasters are in the scope of this thesis. Specifically, we deal with recovery phase of a flood disaster. In order to implement our ideas, we construct a hypothetical problem which reflects post-disaster situation of a district. We later provide an argument whereby the ideas developed may also refer to the mitigation phase.

We chose flood as a focal disaster since floods are the most common and most devastating disasters in Turkey, following the earthquakes in terms of number of people affected, and economic damages. For these reason it is important to develop well-managed policies against floods.

We focus on the recovery phase of the disaster management. Recall that disaster management involves four main phases; mitigation, preparedness, response and recovery.

In the hypothetical problem, our aim is to propose a relocation policy of residential, governmental, industrial facilities and agricultural zones. The framework we develop enhances the analysis of the outcomes regarding the policies of joint and independent consideration of relocation objectives, constraints and parameters. The independent decision setting refers to traditional implementations of humanitarian and business logistics approaches.

Next, we explain floods in terms their nature, types and provide real-life examples from Turkey. In the subsection that follows the next, we define and construct the hypothetical problem and explain the related methodology.

4.2 A Brief Discussion of Floods as Natural Disasters

Flood is one of the most frequent natural disasters that is seen in Turkey. Every year, many people dies because of the damages of floods, and a higher number of people are affected. From 1955 to 2007, 1235 people were killed and 61,000 buildings were collapsed or become unavailable in Turkey according to General Directorate of State Hydraulic Works (DSİ) (Ergünay, 2007). Kron (2005) defines flood as “temporary covering of land by water as a result of surface waters escaping from their normal confines or as a result of heavy precipitation”. Another definition is given by Lindell, Prater and Perry (2007). The authors define flood as “an event in which abnormally large amount of water accumulates in an area in which it is usually not found”.

According to Search and Rescue Association (AKUT) the main reasons of floods are heavy and last-long rainfalls, melting of ice, and dam failures and so on, and there are some factors that increase the risk of flood such as rainfall intensity, duration of rain, topographical surveying, soil structure and inadequate infrastructure. One of the most common problems regarding high flood risk in Turkey is the settlement on coastal areas or river basins with open treat of floods.

Floods may be categorized with respect to their sources and the occurrence times. Floods are divided into three main categories which are river flood, flash flood and storm surge (Kron, 2005). According to Barredo (2007) river floods is the result of heavy and persistent rainfalls for several days or week over large areas. Flash floods are the result of rapid rises in water level within several seconds to several hours; storm surge flood is a very rare type of flooding water that is pushed up onto dry land by onshore winds (Perry, 2000).Table 4.1 based on Lindell, Prater and Perry

(2007) demonstrates a more detailed classification of types of floods along with their characteristics.

Types	Characteristics
Riverine Flooding	Flooding occurs when surface runoff gradually rises to flood stage and later falls.
Flash Flooding	Flooding occurs when runoff reaches its peak in less than six hours, which usually occurs in hilly areas with steep slopes and sparse vegetation. It also can occur in urbanized areas with rapid runoff from impermeable surfaces such as streets, parking lots, and building roofs.
Alluvial Fan Flooding	Flooding occurs in deposits of soil and rock found at the foot of steep valley walls.
Ice/debris Dam Failures	Result when an accumulation of material temporarily blocks the flow of water and raises its surface above the stream bank before giving way.
Surface Ponding	Occurs when water accumulates in areas so flat that runoff cannot carry away the precipitation fast enough.
Fluctuating Lake Levels	Occur over short-term, seasonal, or multi-year periods especially in lakes that have limited outlets or are entirely land-locked.
Control Structure (dam or levee) Failure	Has many characteristics in common with flash flooding.

Table 4.1 Types of Flooding

4.3 A Hypothetic Problem

In this section, we present and model a hypothetical problem that primarily focuses on a relocation problem. Based on the model we demonstrate and analyze the outputs a set of sample problems. The numeric analysis reveals the details of the process of relocation policy.

We, now, start with the scenario description of the problem under consideration. By relocation policy, we mean to define relocating residential, industrial, agricultural zones and governmental facilities with the aims of decreasing the risk of further disasters and recover losses of post-disaster situation. Moreover, we aim to relocate facilities with the objective of both reducing the human sufferings and the disruption in the commercial supply chains.

Alternate recovery strategies might involve reconstruction of the disaster prone area, since a large-scale disaster may destroy the infrastructure of the whole area such as roads, bridges and homes (Van Wassenhove, 2006). Reconstruction may also involve the establishment of the new area with early warning systems to prevent the future disasters such an implementation points to an area of intersection of reconstruction and mitigation as the warning system of the reconstruction phase may reduce impacts of possible future disasters. can be also counted as one of the mitigation for the occurrence of the disasters. Based on this example, we can argue that disaster management stages link to each other. For this reason, we can say that disaster management stages link to each other, forming closed-loop system, since all stages affect each other and the initiators of the following stages.

Relocation policy can be implemented by two different approaches. These are permanent and temporary relocation. In terms of disaster management, temporary relocation is implemented at the mitigation or preparedness stages as in the case with short-notice evacuation and also at the response stage as in the case with evacuation of affected people.

The hypothetical problem that we deal with, analyzes a geographical area. As with many geographical areas that involve residence, our area includes residential, industrial governmental and agricultural facilities. Therefore a relocation policy may be implemented as an integrated policy on humanitarian and commercial related issues and attempt to relocate all the facilities including residential, industrial, agricultural zones and governmental facilities at the same time or it may as well consider relocating each type of facility independent. Different alternatives may be conducted and modeled by including or excluding various objective function components. For instance, we can relocate the residential clusters jointly with the industrial clusters, with the thinking that the two types of facilities are highly dependent on each other. The other option would be to relocate residential or industrial clusters independently.

The need for relocating all these facilities may arise from reducing the damage risk of disasters on both human lives and business enterprises. In other words, the need for relocation in a district may arise as a result of a disaster, or the perceived risk of a future disaster political re-planning. We have seen examples of relocation on; terrorist attacks, potential threat of tsunamis, floods and earthquakes.

As mentioned above, relocation may be decided as a result of potential threat or post-disaster effects of a disaster. In this implementation, we analyze the case of relocation in the recovery period. We take the disaster to be a flood. Flood is the type of disaster that affects the second highest number of people in Turkey after earthquakes. A list of main disasters along with their times of occurrence and total number of people affected can be seen in Table 4.2.

Disaster	Date	No. Total Affected
Earthquake	28.06.1998	1,589,600
Earthquake	17.08.1999	1,358,953
Flood	20.05.1998	1,240,047
Earthquake	30.10.1983	834,137
Earthquake	18.09.1984	375,038
Earthquake	18.10.1984	375,035
Earthquake	13.03.1992	348,850
Earthquake	22.07.1967	326,073
Flood	04.11.1995	306,617
Earthquake	01.05.2003	290,520

Table 4.2 Top 10 Natural Disasters in Turkey for the period 1900 to 2012 sorted by numbers of total affected people
Source: EM-DAT: The OFDA/CRED International Disaster Database www.em-dat.net – Université Catholique de Louvain - Brussels - Belgium

In the problem under consideration we assume that the area suffers from frequent flood disasters. Although the area is not totally under high flood risk, we suggest that the interactions between the components make it worthwhile to consider alternatives of an overall relocation. From our perspective, relocation policy would have utilities for residents, who live in this area, since this relocation policy is not a forced relocation; it rather aims to reduce risks and recovery for residents. However, we are aware that there will always be a social resistance against relocation. As well as utilities for human beings, the relocation scheme will have utilities for industrial environment as well. The decreased risk of disaster, improved performance based on interaction with counterparts, are main advantages expected from relocation of industrial facilities. Therefore, we hope to demonstrate a framework that poses mutual benefits for all parties involved.

The focal disaster is a flood, thus, the focal area is flood-prone area. The occurrence of flash-floods is high throughout the year. We may assume that part of the area is originally established in a river basin. In order to implement relocation policy, the alternative locations must be identified. One important characteristic of the problem is that the facilities in the area (i.e the residential, industrial, governmental facilities and agricultural zones) have mutual communication, which is the real case in real life. Therefore, any relocation policy needs to consider this mutual communication, either explicitly or implicitly. This mutuality can be explained by real life examples: For instance, industrial facilities provide their workforce from the households living in the residential facilities. The industrial facilities also may obtain some new materials from th agricultural zone. People living in residential facilities as well as industrial business units need to interact with governmental facilities to receive public service, utilities such as electricity, water etc. Hence, the facilities are in interaction with one another. This interaction may be perceived also as a supply-demand relationship. Therefore, we suggest that, while considering relocation, it is crucial to provide sustainability of this relationship. Figure 4.1 demonstrates the types of facilities and the area under consideration.

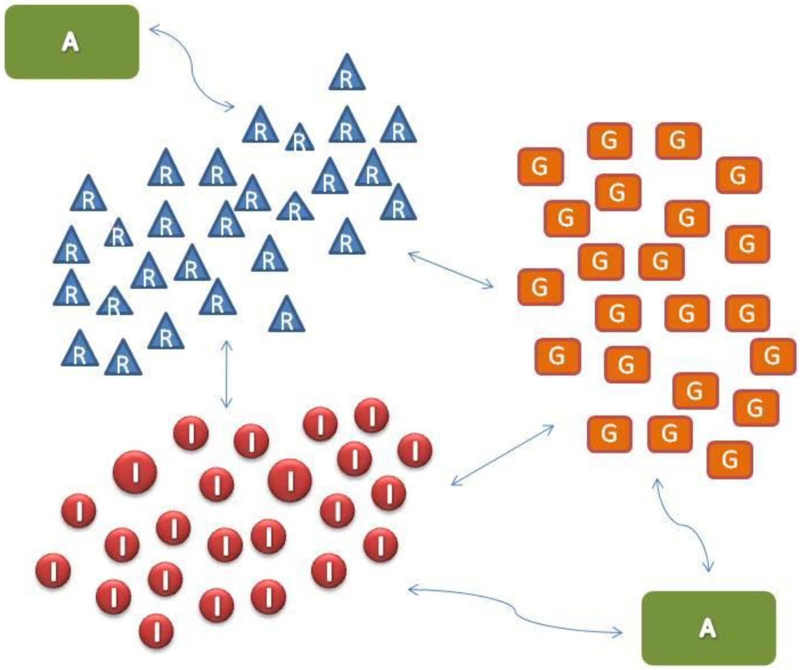

Figure 4.1 Types of facilities and the area under consideration

The area under consideration is entered around a residential zone with low population density. The residential area is closely interrelated with governmental and industrial facilities. Governmental facilities such as schools, public offices, police and fire station, primarily serve the households in the area. Moreover, they employ people from the same residential area. Thus, there is a two-way flow of people and services between residential and governmental facilities. The industrial buildings such as warehouses, small factories are acting with same manner as the governmental facilities do. They also employ the people from the same residential district as with governmental facilities. There is a two-way flow of raw materials and goods as well as the flow of people and services between the residential, agricultural and industrial areas.

We, further, assume that the district under consideration also involves several agricultural zones. Although this area is not physically connected to the other zones, people from the area may work in agricultural areas and there is a flow of agricultural goods between the zones. Therefore, we can say that, although the agricultural zone is not physically connected, it is economically and socially connected to other zones. Therefore, we also include agricultural zones in our relocation analysis that is a part of recovery operations. The relocation of agricultural zones is unique in the literature, as far as our knowledge is concerned.

In the area there are four types of facilities, these are i) residential, ii) industrial, iii) governmental, iv) agricultural. There are multiple facilities in each type. The first step in the recovery phase problem following the occurrence of the disaster is the identification of the alternative locations for relocation of the facilities. The alternatives are selected among suitable potential locations. Each location has its own level of distance to other locations, utility and social resistance.

We assume that each facility may represent a single unit or a cluster of the type of facility it belongs to, such as a group of houses may be represented by a single facility. Therefore, the population density or importance of a facility is reflected by a weight assigned to each facility. The type of facilities can be relocated simultaneously to an alternative location or each type of facility may be relocated independently.

From our perspective, the utility of a person may increase by moving to a closer but less risky area.. However, we take into account the social resistance and other disutility factors such as longer distances from initial location or from related facilities and costs. The consideration of such factors makes the model closer to reality and increases the chances of implementation of resulting decisions.

For deciding on the relocation of residential, industrial, agricultural zones and governmental facilities under consideration in our district, we utilize several objectives to guide our decisions. One objective, clearly, would be to minimize the total cost of relocation. The cost may consist of investment for new locations and the cost of the actual process of relocation. We also believe that there are other significant ‘cost’ items; which should be taken into consideration. Social resistance is one major component of such costs. People naturally show resistance to leaving the area they are used to live. This resistance is usually independent of how comfortable the new suggested location is. This is more associated with losing the overall environment that they have connections with. We assume that the disutility represent social cost is proportional to the distance between new and current locations of the residents, the difference between level of closeness to their neighbors, their environment and other facilities such as governmental facilities and industrial and agricultural zones. The objective function must reflect the difference associated with the overall risk resulting from the current locations of the facilities and those following relocation. Therefore, the objective function component associated with risks is represented as the weighted sum of risks of existing facility locations. Different weights arise from factors such as number of people living in a facility, the criticality of a facility in terms of people’s lives, the distance of residential facilities to other types of facilities.

One other cost component is associated with the investment required for opening new areas for relocating facilities. Such costs include the land investment as well as the investments for infrastructure. The other major cost is the transportation cost of relocating facilities to alternative locations.

The problem may be analyzed through several perspectives. Since the decision makers are different for diverse facilities, the relocation is actually planned and implemented separately by different bodies. For instance, industrial facilities in the industrial zone are owned by individuals, who normally themselves decide on their new locations themselves. Governmental facilities such as public offices, schools and police and fire stations are managed by government bodies. New community residence areas are established by the governmental organizations budget to help residents recover from the effects of disasters. Even though government and residential relocation decisions mainly rely on the governmental bodies, the actual implementations are not coordinated. In many cases, they are managed independently. However, there are also cases where decision making bodies (government) decide on new, more organized locations for even industrial facilities. We consider independent as well as simultaneous relocation with varying objectives towards fulfillment of both humanitarian and business logistics.

Once, one aims to decide on the new locations, a significant deal of data needs to be collected. Location decisions are strategic, high-cost decisions; therefore, data requirements are especially important.

To begin with, the need to assess the alternate locations on which the current facilities may possibly be relocated. Associated with each alternative location, we need to identify the required investments and the associated risk of locating new facilities on that point. We also require;

- Current location specifies (coordinates, travel distances, disaster risks, etc.)

- Quantifying the flow of demand between facilities such as number of people in need, amount and frequency of the service

- Distances between alternate and current location as well as between pairs of alternative locations

- Identifying a measure to quantify the disutility as a function of distances.

Constraints

In order to properly identify the set of feasible solutions to the problem, we need to define the constraints of the problem. The foremost constraint, clearly would state that each facility must be properly relocated into a proper new location.

We may also have a constraint on the total cost of the relocation. In many cases the overall risk associated with the area should be reduced by a predetermined amount. A similar constraint may alternatively pose an upper bound on the overall risk associated with the new locations. It would also make sense that there is a limited budget for relocation. One other restriction may be on the distance that a facility may be moved to.

The cost of relocation is represented by the weighted sum of distances between each facility's current and new locations. The weights represent the cost of "moving" the associated facility one distance unit away from its current location.

The investment for each new alternative location is assumed to be computed using some methodology such as market research and comparison analysis. The objective function component that is the sum of the investment costs of alternative locations are actually utilized with respect to the resulting plan. This cost component is typically measured by the weighted sum of distances between the pairs of facilities (of the same type or of different types) where the weights represent the amount of flow (service demanded or flow of goods) between associated facility pairs. Relocation of facilities most probably change the distances between facility pairs, thus the cost of service. Since, we are primarily interested in the incremental cost of service associated with relocation; the objective function needs to involve the weighted sum of distances between new and current locations of pairs of facilities.

The cost of social resistance is represented as the sum of two components. The first component stands for the social cost associated with moving away from the existing location. That is shown as the weighted sum of the distance between the new and existing location of a residential facility. The weights stand for the social cost of moving a facility one unit distance away from its current location.

We are aware of the fact that it is not always realistic to model such costs as linear functions of distances; but we assume that we consider relocations within a reasonable distance where the cost relationship may be well approximated by a linear function.

The second component of social costs aim at showing the resistance to moving away from facilities which have a mutual communication with the associated facility. In doing so we assume that there is a positive utility in the case that the new location of the facility is closer to its relocated facilities than it was earlier. The cost, thereafter can be represented by the weighted sum of the differences between the distances of the new locations of the facility under consideration and each of its communicating facilities (based on the relocation plan) and the associated existing locations.

The overall cost of district also involves the cost associated with supplying the goods and services demanded by facilities from facilities of the same type and facilities of the different types.

One primary aim of relocating facilities in an area is to decrease the risk of disasters the community is prone to. The objective function, therefore involves a total risk component. We remark that this part of the objective refers to the mitigation stage of the disaster management.

4.4 Methodology

In this section, we first demonstrate the mathematical model, the components of which are discussed in the previous section. We then propose a solution methodology for the problem. We use analytical approach; primarily, we build mathematical model in order to decide on the optimal new locations for the facilities. We use the GAMS (The General Algebraic Modeling System) software to solve the resulting mathematical model. We solve a set of sample problems with various structures in a hope to observe the characteristics of an optimal solution as dependent on problem parameters.

Following the solution of the problem, we employ sensitivity analysis by varying a group of problem parameters and constraints to see their effect on the validity of the best solutions to the original problem. We also analyze the effect of changes in the objective function components on the solution of the problem. We finally test the effect of different approaches on the relocation policy, namely humanitarian and business logistics approaches. To do this, the relocation policy would be implemented by two different approaches. These approaches are independent and joint approaches. With independent approach we aim to demonstrate traditional approach either with humanitarian or business objectives. For instance; we may relocate residential areas with the humanitarian related factors in the objective function and constraints to serve the humanitarian logistics objectives. Alternatively, as a second option, we can consider relocating just industrial facilities only to alternative location with fewer disaster risks. With second option, we may aim to make the commercial supply chain member in the industrial area more resilient. In doing so; we also make the whole supply chain more resilient against natural disasters, and hence we serve the objectives of business logistics and commercial supply chains. In this policy analysis part, we try to fulfill our main objective, which aims to integrate the two different approaches; humanitarian and business logistics, and besides we try to demonstrate the possibilities of exchanging of tools between these two approaches.

We also provide extensions to our model, in order to represent various scenarios. Each scenario represents different decision making situations, such as existence of budget constraints, relocating facilities within a time interval of several years as opposed to relocating them all at one time, the possibility of closing down facilities, and changing sequences of locating facilities.

The mathematical programming model that we developed is a linear integer programming model. The closest facility location model from the literature to our problem is multiple facilities with mutual communication problem. The multifacility mutual communication (MMC) problem aims to find the locations of m new facilities such that the sum of the fixed location cost of each new facility, the cost of interaction between the new facilities and existing facilities and the cost of interaction between pairs of new facilities is minimized. The interaction cost between a pair of facilities is a generallay taken to be a function of the distance (or travel time) between the facilities (Chhajed and Lowe, 1992). Our relocation problem is similar to MMC problem. Our model also deals with different types of facilities. We have residential, industrial, governmental and agricultural facilities. We also explicitly consider interactions between the facilities that our relocation policy deals with.

Our relocation problem diverges from MMC problem. To begin with, we neglect the interactions amongst the same type of facilities or assume they do not exist. Besides, our problem is not a location problem but a relocation problem since we do not build just new facilities to alternate location instead we move the current facilities to the alternative locations. Owing to the way we construct our problem, the new locations are heavily dependent on current locations. We also have differences in terms of objective function and constraints. Our objective function includes additional terms involving distances, social costs and risks. We aim to calculate social cost based on the difference between the new and current facility locations and desirability level of the new facility locations.

For real sized problems involving more than 50 facilities to locate and number of alternate locations the same order of magnitude, solution of the mathematical programming model that we generate becomes computationally prohibitive. To that end, we use a two-phase approach. This approach calls for the sequential solution of two problems. The first problem aims to find the optimal assignments of facilities to zones. Each zone is a collection of physically close (cluster of) alternate locations. We further make the reasonable assumption that locations in the same zone share very close values of disaster risks, distances to existing facilities and social desirabilities. Having made the decision on which facility to relocate in which zone, a Phase II problem is solved for each zone. For each zone, the Phase II problem takes as input the facilities that are allocated to that zone in the solution of the Phase I problem, and decides on the assignment of those facilities to locations within that zone.

The objective function in the Phase I problem considers all possible cost components, including interaction, investment, relocation, risk and social resistance. The Phase II problem assumes that the budgetary costs are taken care of in Phase I, therefore the objective function of the Phase II problem is composed of risk costs and social resistance costs; since these costs are considered only in the aggregate sense in Phase I, as a uniform flat cost for each location in the same zone. The constraints of Phase I and Phase II problems are similar, with the difference that the constraints of the Phase I problem are stated in terms of zones (collection of alternate locations) whereas the constraints of the Phase II problem are stated in terms of alternate locations.

4.5 The Model Definition

We now present the details of our mathematical model. In doing so, we state the mathematical model first in the general format, then we give the 2-phase formulation. The two formulations share common specifics. We point out to differences wherever required, otherwise, we state the details as common to both formulations.

We use the following particular order in defining the model: We start with a discussion of parameters. We then define the decision variables and constraints. The components of the objective function will be introduced finally. We would like to remark that this model has a broad range of generality. That is, even though we generated this model having floods in an area, in Turkey, in mind, the methods we developed are valid for any type of disasters in any geographical areas, provided that, we can identify the associated parameters.

Parameters

Associated with each current facility (as well as alternative locations or zones), we have an associated risk. The risk can be taken as the assessed risk for the type of disaster under consideration flood) or it can be a composite measure concerning a family of disasters.

The overall risk associated with a relocation decision is assumed to be equal to the sum of risks values of associated locations of all facilities. For each alternative location, we assume that we have a measure of the cost of relocating a facility in that location. This cost represents the investment in land construction. The actual cost of transporting the contents of a facility to its new location is neglected.

For a pair of locations such that the first location is an existing facility location and the second location is an alternative location for that facility or a zone that involves a group of alternative locations, we define a social cost to represent the level of discomfort or resistance that may be encountered by moving the facility to the new location. This cost can be calculated in different ways. We assume that the social cost is proportional to the distance between two locations (new and current) and inversely proportional with the desirability of the new location. That is, there will be a higher social cost as a facility (a residence, governmental or industrial facility) is moved further away from its current location. On the other hand, people will be more willing to move to more desirable locations (more developed areas, better climate, less risk of disasters etc.)

For each pair of facilities of different types, we identify the level of interactions between the facilities. For residential areas and industrial facilities, this value may represent the average number of people employed, vehicles and materials flowing from and to the associated industrial facilities. This interaction will act towards keeping the new locations of the facilities close to each other.

In many cases, especially for residential areas, the relocation to a new area imposes additional costs. If the area is not previously populated, it is highly likely that the infrastructures for road, electricity, telecommunication, water and other vital services are incomplete. Therefore, an additional investment is required to establish new residential facilities in this location. This infrastructure investment is usually independent of the particular number of new residences. The planning and the investment is mostly based on an estimated potential number of residences, or on the actual size of the area.

Decision Variables

The main decision variables are the new locations, for each type of facility. Each decision imposes a new (hopefully improved) level of overall risk for the set of facilities under consideration. As a byproduct of the location decisions, we also compute level of closeness to related facilities, total number of new sites opened and total investment.

$$
\begin{aligned}
Min\ Z = & \sum w(distances\ to\ facilities\ of\ the\ same\ type) \\
& + \sum w(distances\ to\ service\ facilities) \\
& + \sum w(cost\ of\ establishing\ facilities) + \sum w(risk) \\
& + \sum w(social\ cost)
\end{aligned}
$$

Constraints

In this problem, the main constraint is that each facility under consideration needs to be an appropriate location. Clearly there will be other constraints imposed by social and economic conditions. For instance, we may require that a given set of facilities cannot be further away from each other by more than a given distance for security reasons and ease of service. Moreover, we need to create extra constraints such as; total social cost cannot exceed a given maximum number or total risk for a cluster cannot exceed a given maximum number. The other constraints are interaction and capacity constraints; like every residential cluster must be within a given distance form a government facility since they are connected with service demand flow or the capacities of every type of facilities.

4.6 The Mathematical Model

Even though the mathematical model may be used to solve the problem based on the associated objective function and constraints in one shot, we prefer to use a 2 phase approach in the solutions that we report. The first phase takes a more overall approach to the problem, by identifying to which area to relocate each facility; rather than deciding on the exact location. The first phase provides a general viewpoint and gives pointers to the total costs, total risks and total social resistance that will result from relocation of facilities. This information is very useful and can be utilized for strategic planning purposes. The output of Phase I is both a feasibility check for relocation in terms of budgets, social resistance and overall risks, and an input for more detailed planning. To do this, the first phase of the model aggregates these locations into zones. We assume that a collection of alternate locations can be grouped into zones that share common characteristics that are very close to each other. This is true for all facility types (residential, governmental, industrial and agricultural facilities) that is; the first phase makes an aggregate planning of the locations, taking into account the overall risks, investments and relocation costs. Hence, we separate the more strategic, feasibility oriented from the more detailed, operational oriented decisions.

Second phase, Phase II is more on the operational level and makes a detailed planning which takes as input the result of the phase I and runs one optimization for each zone (collection of locations)to decide on the exact locations. In the second phase, the objective function may now primarily focus on risk minimization since investments and other related costs are taken care of in Phase I. Thus, Phase II considers interactions and eligibility of particular locations within a zone for locating types of facilities. We assume that a collection of alternate locations can be grouped into zones that share common characteristics that are very close to each other.

The term eligibility mentioned above refers to the whether a potential location is suitable for locating a type of facility. Not all areas are suitable for agricultural facilities. The soil type, slope, climate characteristics eligibility in such a case. Similarly, a location is eligible for relocating a residential facility only if geological construct, shape and infrastructure are suitable.

Our model can be extended by adding other relevant constraints to the problem. For instance; due to specific factors related with social resistance, we may limit the distance between the existing and new locations of several facilities. That is, resident of an area may not be willing to move to new locations that are more than a given distance away from their current location. One other example may be the case where the government facilities should be within the reach from every facility that may be willing to get service from that government facility in no more than a given time period.

One main reason for relocation refers to the mitigation phase of disaster management in an attempt to the reduction of risk associated with disasters. Therefore, we may impose the condition that the total risk associated with new locations should demonstrate an improvement. That is, the total risk of new locations should be less than the total associated risk of current locations. Actually we may also impose same specific bounds on the total risk or on the average risk for new locations.

Below we present our model formulation in the syntax of GAMS software:

Sets

$r \epsilon R$	set of residential facilities
$i \epsilon I$	set of industrial facilities
$g \epsilon G$	set of government facilities
$a \epsilon A$	set of agricultural facilities
$q \epsilon Q$	set of alternate locations
$z \epsilon Z$	set of zones

Parameters

d_{rq}^{R}	distance between residential facility r and location q
d_{iq}^{I}	distance between industrial facility r and location q
d_{gq}^{G}	distance between governmental facility r and location q
d_{aq}^{A}	distance between agricultural facility a and location q
d_{q1q2}	distance between location q1 and location q2

l_{zq}	1 if location q is in zone Z
	0 otherwise
n_z	number of locations in zone Z
$maxz$	maximum number of locations in a zone
$maxfill$	maximum percentage of locations to fill in a zone
V_z	investment for opening zone Z for relocation

e_q^R	1 if location q is eligible for locating residential facilities
	0 otherwise
e_q^I	1 if location q is eligible for locating industrial facilities
	0 otherwise
e_q^G	1 if location q is eligible for locating governmental facilities
	0 otherwise
e_q^A	1 if location q is eligible for locating agricultural facilities
	0 otherwise

W_r^R	size of residential facility r
W_i^I	size of industrial facility i
W_g^G	size of governmental facility g
W_a^A	size of agricultural facility a

$initialdist_r^R$	initial distance between components of residential facility r

$initialdist_i^I$	initial distance between components of industrial facility i
$initialdist_g^G$	initial distance between components of governmental facility g
$initialdist_a^A$	initial distance between components of agricultural facility a

α_r^R	Allowable ratio by which components of residential facility r can be placed away from each other (as compared to initial locations)
α_i^I	Allowable ratio by which components of industrial facility i can be placed away from each other (as compared to initial locations)
α_g^G	Allowable ratio by which components of governmental facility g can be placed away from each other (as compared to initial locations)
α_a^A	Allowable ratio by which components of agricultural facility r can be placed away from each other (as compared to initial locations)

$maxdist_r^R$	Maximum allowable distance to move residential facility r to
$maxdist_i^I$	Maximum allowable distance to move residential facility i to
$maxdist_g^G$	Maximum allowable distance to move residential facility g to
$maxdist_a^A$	Maximum allowable distance to move residential facility a to

$servdist_{ri}^{RI}$	Maximum allowable service distance for residential facility r and industrial facility i
$servdist_{rg}^{RG}$	Maximum allowable service distance for residential facility r and governmental facility g
$servdist_{ra}^{RA}$	Maximum allowable service distance for residential facility r and agricultural facility a
$servdist_{ig}^{IG}$	Maximum allowable service distance for industrial facility i and governmental facility g

$servdist_{ia}^{IA}$	Maximum allowable service distance for industrial facility i and agricultural facility a
$servdist_{ga}^{GA}$	Maximum allowable service distance for governmental facility g and agricultural facility a

$totalrisk^{R}$	Maximum allowable risk for residential facilities
$totalrisk^{I}$	Maximum allowable risk for industrial facilities
$totalrisk^{G}$	Maximum allowable risk for governmental facilities
$totalrisk^{A}$	Maximum allowable risk for agricultural facilities
$totalrisk$	Total risk of existing facilities
β	Maximum allowable ratio of total risk of new locations and total risk of existing locations
K_q	Disaster risk of location q

M_r^R	Weight(number of residents) of residential facility r
M_{i}^I	Weight(importance) of industrial facility i
M_g^G	Weight of governmental facility g
M_a^A	Weight of agricultural facility a

inv_q	investment for establishing a facility in location q

C_{rq}^R	Cost of moving residential facility r to location q
C_{iq}^I	Cost of moving industrial facility i to location q
C_{gq}^G	Cost of moving governmental facility g to location q
C_{aq}^A	Cost of moving agricultural facility a to location q

S_q	Desirability of location q
Sr^R	Maximum allowable residential-related social resistance
Sr^I	Maximum allowable industrial-related social

	resistance
Sr^G	Maximum allowable governmental-related social resistance
Sr^A	Maximum allowable agricultural-related social resistance

Int_{ri}^{RI}	Level of interaction between residential facility r and industrial facility i
Int_{rg}^{RG}	Level of interaction between residential facility r and governmental facility g
Int_{ra}^{RA}	Level of interaction between residential facility r and agricultural facility a
Int_{ig}^{IG}	Level of interaction between industrial facility i and governmental facility g
Int_{ia}^{IA}	Level of interaction between industrial facility i and agricultural facility a
Int_{ga}^{GA}	Level of interaction between governmental facility g and agricultural facility a

P_{int}	Weight of interactions in objective function
P_{inv}	Weight of investments in objective function
P_{mov}	Weight of moving costs in objective function
P_{social}	Weight of social resistance in objective function
P_{risk}	Weight of risk in objective function

Decision Variables

R_{rq}	1 if residential facility r is moved to alternate location q
	0 otherwise
I_{iq}	1 if industrial facility i is moved to alternate location q
	0 otherwise
G_{gq}	1 if governmental facility g is moved to alternate location q
	0 otherwise
A_{aq}	1 if agricultural facility a is moved to alternate location q
	0 otherwise

O_z	1 if new zone z is opened for relocation
	0 otherwise

L^R_{rq1q2}	1 if components of residential facility r are located in q1 and q2
	0 otherwise
L^I_{iq1q2}	1 if components of industrial facility i are located in q1 and q2
	0 otherwise
L^G_{gq1q2}	1 if components of governmental facility g are located in q1 and q2
	0 otherwise
L^A_{aq1q2}	1 if components of agricultural facility a are located in q1 and q2
	0 otherwise

$(that\ is;\ L^{R}_{rq1q2} = R_{rq1}.R_{rq2}\ , we\ needto\ have: L^{R}_{rq1q2} \geq\ R_{rq1} + R_{rq2} - 1)$

RI_{riq1q2}	1 if any component of residential facility r is moved to q1 and any component of industrial facility i is moved to q2
	0 otherwise
RG_{rgq1q2}	1 if any component of residential facility r is moved to q1 and any component of governmental facility g is moved to q2
	0 otherwise
RA_{raq1q2}	1 if any component of residential facility r is moved to q1 and any component of agricultural facility a is moved to q2
	0 otherwise
IG_{igq1q2}	1 if any component of industrial facility i is moved to q1 and any component of governmental facility g is moved to q2
	0 otherwise
IA_{iaq1q2}	1 if any component of industrial facility i is moved to q1 and any component of governmental facility g is moved to q2
	0 otherwise
GA_{gaq1q2}	1 if any component of governmental facility g is moved to q1 and any component of agricultural facility a is moved to q2
	0 otherwise
$(that\ is\ RI_{riq1q2} =\ R_{rq1}.I_{iq2}, we\ need\ to\ have\ RI_{riq1q2}\ \geq\ R_{rq1} + I_{iq2} - 1)$	

RI^{s}_{riq1q2}	1 if residential facility r in q1 receive service from industrial facility i in q2
	0 otherwise
RG^{s}_{rgq1q2}	1 if residential facility r in q1 receive service from governmental facility g in q2
	0 otherwise
RA^{s}_{raq1q2}	1 if residential facility r in q1 receive service from agricultural facility a in q2
	0 otherwise
IG^{s}_{igq1q2}	1 if industrial facility i in q1 receive service from governmental facility g in q2
	0 otherwise
IA^{s}_{iaq1q2}	1 if industrial facility i in q1 receive service from agricultural facility a in q2
	0 otherwise
GA^{s}_{gaq1q2}	1 if governmental facility g in q1 receive service from agricultural facility a in q2
	0 otherwise

b^{R}_{rq}	Undesirability of moving residential facility r to location q
b^{I}_{iq}	Undesirability of moving industrial facility i to location q
b^{G}_{gq}	Undesirability of moving governmental facility g to location q
b^{A}_{aq}	Undesirability of moving agricultural facility a to location q

U_q	1 if location q is used for locating facilities
	0 otherwise

$\sum_q e_q^R . R_{rq} = W_r^R$	Use appropriate number of eligible locations to relocate facilities
$\sum_q e_q^I . I_{iq} = W_i^I$	
$\sum_q e_q^G . G_{gq} = W_g^G$	
$\sum_q e_q^A . A_{aq} = W_a^A$	
$\sum_q R_{rq} + \sum_q I_{iq} + \sum_q G_{gq} + \sum_q A_{aq} \leq U_q$	

$\sum_{r,q} l_{qz} . R_{rq} + \sum_{i,q} l_{qz} . I_{iq} + \sum_{i,q} l_{qz} . G_{gq} + \sum_{i,q} l_{qz} . A_{aq} \leq (maxfill) n_z . O_z$	Do not fill any zone beyond allowable percentage

$L_{rq1q2}^R \geq R_{rq1} + R_{rq2} - 1$	Constraints to correctly define variables
$L_{iq1q2}^I \geq I_{iq1} + I_{iq2} - 1$	
$L_{gq1q2}^G \geq G_{gq1} + G_{gq2} - 1$	
$L_{aq1q2}^A \geq A_{aq1} + A_{aq2} - 1$	

$RI_{riq1q2} \geq R_{rq1} + I_{iq2} - 1$	Constraints to correctly define variables on the left hand side
$RG_{rgq1q2} \geq R_{rq1} + G_{gq2} - 1$	
$RA_{raq1q2} \geq R_{rq1} + A_{aq2} - 1$	
$IG_{rgq1q2} \geq I_{iq1} + G_{gq2} - 1$	
$IA_{iaq1q2} \geq I_{iq1} + A_{aq2} - 1$	
$GA_{gaq1q2} \geq G_{gq1} + A_{aq2} - 1$	

$RI_{riq1q2} \geq RI^{S}_{riq1q2}$ $\sum_{q1,q2} RI^{S}_{riq1q2} = 1$	Every component of a facility should receive service from only one component of some other facility
$RG_{rgq1q2} \geq RG^{S}_{rgq1q2}$ $\sum_{q1,q2} RG^{S}_{rgq1q2} = 1$	
$RA_{raq1q2} \geq RA^{S}_{raq1q2}$ $\sum_{q1,q2} RA^{S}_{raq1q2} = 1$	
$IG_{igq1q2} \geq IG^{S}_{igq1q2}$ $\sum_{q1,q2} IG^{S}_{igq1q2} = 1$	
$IG_{igq1q2} \geq IG^{S}_{igq1q2}$ $\sum_{q1,q2} IG^{S}_{igq1q2} = 1$	
$IA_{iaq1q2} \geq IA^{S}_{iaq1q2}$ $\sum_{q1,q2} IA^{S}_{iaq1q2} = 1$	
$GA_{gaq1q2} \geq GA^{S}_{gaq1q2}$ $\sum_{q1,q2} GA^{S}_{gaq1q2} = 1$	

$\sum_{\substack{q1,q2 \\ q1<q2}} d_{q1q2} \,.\, L^{R}_{rq1q2} \leq (1+\alpha^{R}_{r}).\,initialdist^{R}_{r}$	Do not place components of same facility apart from the allowed limit (as a function of the initial distances of components)
$\sum_{\substack{q1,q2 \\ q1<q2}} d_{q1q2} \,.\, L^{I}_{iq1q2} \leq (1+\alpha^{I}_{i}).\,initialdist^{I}_{i}$	
$\sum_{\substack{q1,q2 \\ q1<q2}} d_{q1q2} \,.\, L^{G}_{gq1q2} \leq \left(1+\alpha^{G}_{g}\right).\,initialdist^{G}_{g}$	
$\sum_{\substack{q1,q2 \\ q1<q2}} d_{q1q2} \,.\, L^{A}_{aq1q2} \leq (1+\alpha^{A}_{a}).\,initialdist^{A}_{a}$	

$d^{R}_{rq}.R_{rq} \leq maxdist^{R}_{r}$
$d^{I}_{iq}.I_{iq} \leq maxdist^{I}_{i}$
$d^{G}_{gq}.G_{gq} \leq maxdist^{G}_{g}$
$d^{A}_{aq}.A_{aq} \leq maxdist^{A}_{a}$

$RI^{S}_{riq1q2}.d_{q1q2} \leq servdist^{RI}_{ri}$
$RG^{S}_{rgq1q2}.d_{q1q2} \leq servdist^{RG}_{rg}$
$RA^{S}_{raq1q2}.d_{q1q2} \leq servdist^{RA}_{ra}$
$IG^{S}_{igq1q2}.d_{q1q2} \leq servdist^{IG}_{ig}$
$IA^{S}_{iaq1q2}.d_{q1q2} \leq servdist^{Ia}_{ia}$
$GA^{S}_{gaq1q2}.d_{q1q2} \leq servdist^{GA}_{ga}$

$\sum_{r,q} k_q\, M^{R}_{r} R_{rq} \leq totalrisk^{R}$
$\sum_{i,q} k_q\, M^{I}_{\imath} I_{\imath q} \leq totalrisk^{I}$
$\sum_{g,q} k_q\, M^{G}_{g} G_{gq} \leq totalrisk^{G}$
$\sum_{a,q} k_q\, M^{A}_{a} A_{aq} \leq totalrisk^{A}$
$\sum_{r,q} k_q\, M^{R}_{r} R_{rq} + \sum_{i,q} k_q\, M^{I}_{\imath} I_{\imath q} + \sum_{g,q} k_q\, M^{G}_{g} G_{gq} + \sum_{a,q} k_q\, M^{A}_{a} A_{aq} \leq \beta.totalrisk$

$b^{R}_{rq} = \frac{1}{S_q}.d^{R}_{rq}$
$b^{I}_{\imath q} = \frac{1}{S_q}.d^{I}_{iq}$
$b^{G}_{gq} = \frac{1}{S_q}.d^{G}_{gq}$
$b^{A}_{aq} = \frac{1}{S_q}.d^{A}_{aq}$

$\sum_{r,q} b^{R}_{rq}\, M^{R}_{r} R_{rq} \leq Sr^{R}$
$\sum_{i,q} b^{I}_{iq}\, M^{I}_{i} I_{\imath q} \leq Sr^{I}$
$\sum_{g,q} b^{G}_{gq}\, M^{G}_{g} G_{gq} \leq Sr^{G}$
$\sum_{a,q} b^{A}_{aq}\, M^{A}_{a} A_{aq} \leq Sr^{A}$

Objective Function

$Min\ Z = P_{int}\left(\sum_{q,r,i,g,a} Int_{ri}^{RI}.d_{q1q2}.RI_{riq1q2}^{S} + Int_{rg}^{RG}.d_{q1q2}.RG_{rgq1q2}^{S} + Int_{ra}^{RA}.d_{q1q2}.RA_{raq1q2}^{S} + Int_{ig}^{IG}.d_{q1q2}.IG_{igq1q2}^{S} + Int_{ia}^{IA}.d_{q1q2}.IA_{iaq1q2}^{S} + Int_{ga}^{GA}.d_{q1q2}.GA_{gaq1q2}^{S}\right)$	(1)
$+ P_{inv}\left(\sum_{z} V_z O_z + \sum_{q} inv_q U_q\right)$	(2)
$+P_{mov}\left(\sum_{r,q} C_{rq}^{R} R_{rq} + \sum_{i,q} C_{iq}^{I} I_{iq} + \sum_{g,q} C_{gq}^{G} G_{gq} + \sum_{a,q} C_{aq}^{A} A_{aq}\right)$	(3)
$+P_{social}\left(\sum_{r,q} M_r^R.b_{rq}^R.R_{rq} + \sum_{i,q} M_i^I.b_{iq}^I.I_{iq} + \sum_{g,q} M_g^G.b_{gq}^G.G_{gq} + \sum_{a,q} M_a^A.b_{aq}^A.A_{aq}\right)$	(4)
$+ P_{risk}\left(\sum_{r,q} k_q.M_r^R.R_{rq} + \sum_{i,q} k_q.M_i^I.I_{iq} + \sum_{g,q} k_q.M_g^G.G_{gq} + \sum_{a,q} k_q.M_a^A.A_{aq}\right)$	(5)

The objective function minimizes the total interaction between the facilities (1), total investment (2), total moving cost (3), total social resistance to relocation cost (4) and total risk associated with disaster (5).

Below are the objective functions GAMS formulations of Phase I and Phase II (Table 4.3 and Table 4.4).

Phase I- Base Model GAMS Formulation
objective .. f =e= pint*(sum((r,i,z1,z2),IntRI(r,i)*d(z1,z2)*Rv(r,z1)*Iv(i,z2)) +sum((r,g,z1,z2),IntRG(r,g)*d(z1,z2)*Rv(r,z1)*Gv(g,z2)) +sum((r,a,z1,z2),IntRA(r,a)*d(z1,z2)*Rv(r,z1)*Av(a,z2))) + pinv*(sum(z,v(z)*O(z))) + pmov*(sum((r,z),CR(r,z)*Rv(r,z)) + sum((i,z),CI(i,z)*Iv(i,z)) +sum((g,z),CG(g,z)*Gv(g,z)) +sum((a,z),CA(a,z)*Av(a,z))) + psocial*(sum((r,z),bR(r,z)*s(z)*mR(r)*Rv(r,z)) + sum((i,z), bI(i,z)*s(z)*mI(i)*Iv(i,z)) + sum((g,z), bG(g,z)*s(z)*mG(g)*Gv(g,z)) + sum((a,z), bA(a,z)*s(z)*mA(a)*Av(a,z))) + prisk*(sum((r,z),k(z)*mR(r)*Rv(r,z)) + sum((i,z),k(z)*mI(i)*Iv(i,z)) + sum((g,z),k(z)*mG(g)*Gv(g,z)) + sum((a,z),k(z)*mA(a)*Av(a,z)))

Table 4.3 Phase I- Base Model GAMS Formulation

Phase II- Base Model GAMS Formulation

```
objective .. f =e=
pint*(sum((r,i,qz1a,qz1b),IntRI(r,i)*dz1(qz1a,qz1b)*Rv1(r,qz1a)*Iv1(i,qz1b))
+sum((r,g,qz1a,qz1b),IntRG(r,g)*dz1(qz1a,qz1b)*Rv1(r,qz1a)*Gv1(g,qz1b))
+sum((r,a,qz1a,qz1b),IntRA(r,a)*dz1(qz1a,qz1b)*Rv1(r,qz1a)*Av1(a,qz1b))
+sum((r,i,qz2a,qz2b),IntRI(r,i)*dz2(qz2a,qz2b)*Rv2(r,qz2a)*Iv2(i,qz2b))
+sum((r,g,qz2a,qz2b),IntRG(r,g)*dz2(qz2a,qz2b)*Rv2(r,qz2a)*Gv2(g,qz2b))
+sum((r,a,qz2a,qz2b),IntRA(r,a)*dz2(qz2a,qz2b)*Rv2(r,qz2a)*Av2(a,qz2b))
+sum((r,i,qz3a,qz3b),IntRI(r,i)*dz3(qz3a,qz3b)*Rv3(r,qz3a)*Iv3(i,qz3b))
+sum((r,g,qz3a,qz3b),IntRG(r,g)*dz3(qz3a,qz3b)*Rv3(r,qz3a)*Gv3(g,qz3b))
+sum((r,a,qz3a,qz3b),IntRA(r,a)*dz3(qz3a,qz3b)*Rv3(r,qz3a)*Av3(a,qz3b))
+sum((r,i,qz4a,qz4b),IntRI(r,i)*dz4(qz4a,qz4b)*Rv4(r,qz4a)*Iv4(i,qz4b))
+sum((r,g,qz4a,qz4b),IntRG(r,g)*dz4(qz4a,qz4b)*Rv4(r,qz4a)*Gv4(g,qz4b))
+sum((r,a,qz4a,qz4b),IntRA(r,a)*dz4(qz4a,qz4b)*Rv4(r,qz4a)*Av4(a,qz4b)

   + prisk*(sum((r,qz1),k1(qz1)*mR(r)*Rv1(r,qz1)) +
sum((i,qz1),k1(qz1)*mI(i)*Iv1(i,qz1)) + sum((g,qz1),k1(qz1)*mG(g)*Gv1(g,qz1))+
sum((a,qz1),k1(qz1)*mA(a)*Av1(a,qz1))
+sum((r,qz2),k2(qz2)*mR(r)*Rv2(r,qz2)) + sum((i,qz2),k2(qz2)*mI(i)*Iv2(i,qz2)) +
sum((g,qz2),k2(qz2)*mG(g)*Gv2(g,qz2))+ sum((a,qz2),k2(qz2)*mA(a)*Av2(a,qz2))
+sum((r,qz3),k3(qz3)*mR(r)*Rv3(r,qz3)) + sum((i,qz3),k3(qz3)*mI(i)*Iv3(i,qz3)) +
sum((g,qz3),k3(qz3)*mG(g)*Gv3(g,qz3))+ sum((a,qz3),k3(qz3)*mA(a)*Av3(a,qz3))
+sum((r,qz4),k4(qz4)*mR(r)*Rv4(r,qz4)) + sum((i,qz4),k4(qz4)*mI(i)*Iv4(i,qz4)) +
sum((g,qz4),k4(qz4)*mG(g)*Gv4(g,qz4))+
sum((a,qz4),k4(qz4)*mA(a)*Av4(a,qz4)))
```

Table 4.4 Phase II- Base Model GAMS Formulation

4.7 Experimental Design

For an implementation, we make experimental runs with hypothetic data. We perform several scenarios to implement experimental design. In this section, we present the findings of the model with different data sets.

The base model that we consider involves 20 residential clusters, 3 industrial facility clusters, 4 governmental facility clusters and 2 agricultural zones. We assume that the group of decision makers has agreed on 4 alternate location zones to be considered for relocation. We assume that the zones are currently not populated and do not involve any infrastructure, therefore, all locations within a zone are eligible for relocation. However, opening a zone for relocation requires extra investment. The data associated with the problem can be found in appendix. The phase 1 of the problem identifies the assignment of facilities to zones. The second phase of the problem decides on the exact locations of the facilities within given zone.

In order to solve the problem we used GAMS software 22.5. We used a HP Probook with AMD Triple Core Processor 1.80 GHz, 4GB RAM with Windows 7 Professional operating system.

4.8 Extensions of the Mathematical Model

In this subsection, we present how the mathematical model can be modified to accommodate various decision making settings. Through the alternate models developed, we also believe that it is possible to observe the changes in the solution structures and we have the opportunity to compare the results and make a before-after analysis.

The first modification we consider is a setting characterized by limited budgets being available over consecutive time periods. That is, each time period has a budget limit; new budget is released only in the following period. The decision we need to make every period is, then, to identify the best choice of facilities to relocate in that particular period. The base model assumed that all relocations are realized at the same period. Although this gives an overall idea, it is usually not possible to make all relocations at the same time. The main reasons being that relocation all type of facilities (residential, industrial, governmental and agricultural) are costly and time-taking activities. Therefore, it seems wiser to make a time phase planning of relocations. Usually this time horizon takes a time of several months to several years. In that case we may assume that we have a planning horizon of T periods. Each period can accommodate a certain number of relocations along with a certain budget. The problem structure in that case will be very much similar to the base problem structure, however we need to decide for each period, which facilities to relocate and budget for relocations.

The main point we raise in proposing this model, is the effect of simultaneous decisions of interacting facilities that is we take into account the interaction of residences with industrial or agricultural facilities and plan the relocation simultaneously. However, in many cases these decisions are made independently, or due to time and budget restrictions these are done sequentially. The next model we consider tries to answer the question of how much the ordering of decisions affect the performance of relocation. That is; we try to identify, for instance, whether moving residential facilities first, then industrial facilities, then agricultural facilities has an advantage over an alternate ordering of these decisions, for instance, the act of moving industrial facilities first, then residential facilities and then agricultural facilities. The model actually requires running the initial model sequentially, each time for one type of facilities, based on the particular order.

In the base model, we consider zones as new areas for relocation, however in some cases it may be better to use locations that are already populated. Such zones then will have smaller or even no requirements for investing in infrastructure. They may have lower social resistance, for instance, if the area is already populated with residential clusters. However, the contrary may also be true there may be a high social resistance against moving industrial facilities to a zone with residential settlement.

The fourth extension we consider refers to a situation where it is viable not to relocate some of the facilities. That is, the case where we consider the shut-down option. This scenario makes sense, especially in the case of relocating governmental and industrial facilities to already populated zones. If the destination zone already involves governmental facilities, it may not make sense to duplicate these by relocating an existing facility. Similarly, it may be cost wise inappropriate to relocate industrial facilities. In both cases, shutting down the existing facility may turn out to be a better option. However, in such a case, we need to identify how to transfer the interactions of the facilities that will be shut down.

4.9 Numeric Analysis

As we mentioned earlier, we have 20 residential, 3 industrial, 4 governmental and 2 agricultural facilities in our sample problem. We, here, present numeric result of the base model and two of the extensions. The tables 4.5 to 4.10 shows the relocating of residential (R), industrial (I), governmental (G), agricultural (A) to zones (Z); 1, 2, 3 and 4 under different conditions. On the tables, “1” refers to the zone where a facility relocated and “0” refers to otherwise. Table 4.3 demosntrates the relocated zones of facilities in the base model.

R/Z	1	2	3	4
1	0	0	0	1
2	0	0	0	1
3	0	0	0	1
4	1	0	0	0
5	1	0	0	0
6	1	0	0	0
7	1	0	0	0
8	1	0	0	0
9	1	0	0	0
10	0	1	0	0
11	0	1	0	0
12	0	0	1	0
13	0	1	0	0
14	0	1	0	0
15	0	1	0	0
16	0	0	0	1
17	0	0	0	1
18	0	0	0	1
19	0	0	0	1
20	0	0	0	1

I/Z	1	2	3	4
1	0	1	0	0
2	0	1	0	0
3	1	0	0	0

G/Z	1	2	3	4
1	0	0	0	1
2	0	1	0	0
3	0	0	1	0
4	0	0	0	1

A/Z	1	2	3	4
1	1	0	0	0
2	0	0	0	1

Table 4.5 The zone decisions of the base model.

In the base model, we made some modifications. We increase the interaction between the residential facilities and industrial facilities to see the changes in new relocation zones. In the modified model, we increase the interaction between residential and industrial facilities almost five-fold. Table 4.6 shows the new relocation decisions of the model after modification.

R/Z	1	2	3	4
1	0	0	1	0
2	0	0	1	0
3	0	0	1	0
4	0	0	1	0
5	1	0	0	0
6	0	0	1	0
7	0	0	1	0
8	1	0	0	0
9	0	1	0	0
10	0	1	0	0
11	1	0	0	0
12	1	0	0	0
13	0	1	0	0
14	0	1	0	0
15	0	1	0	0
16	0	0	0	1
17	0	1	0	0
18	1	0	0	0
19	0	0	0	1
20	0	0	0	1

I/Z	1	2	3	4
1	0	1	0	0
2	0	1	0	0
3	0	0	1	0

G/Z	1	2	3	4
1	1	0	0	0
2	1	0	0	0
3	0	0	1	0
4	0	0	1	0

A/Z	1	2	3	4
1	1	0	0	0
2	0	0	0	1

Table 4.6 The modification results of the base model

As we mentioned in the previous section, we made some extensions on the model. One of the extensions is limited budget consideration. In this extension, we assume that we have limited budget when we make relocation decisions. These limited budgets are available over the consecutive time periods. For instance, we have 4-year period and each period we have a limited budget to relocate facilities. Table 4.7 shows the decisions of the model when relocation under consideration of limited budget.

R/Z	1	2	3	4
1	0	0	0	1
2	0	0	0	1
3	0	0	0	1
4	0	0	0	1
5	0	0	1	0
6	0	0	0	1
7	0	0	0	1
8	0	0	1	0
9	1	0	0	0
10	1	0	0	0
11	0	0	1	0
12	1	0	0	0
13	1	0	0	0
14	1	0	0	0
15	1	0	0	0
16	0	1	0	0
17	0	1	0	0
18	0	1	0	0
19	0	1	0	0
20	0	1	0	0

I/Z	1	2	3	4
1	1	0	0	0
2	1	0	0	0
3	0	0	0	1

G/Z	1	2	3	4
1	0	1	0	0
2	0	1	0	0
3	0	0	1	0
4	0	0	1	0

A/Z	1	2	3	4
1	0	0	1	0
2	0	1	0	0

Table 4.7 Limited budget consideration on relocation of facilities

On this limited budget consideration, we made some modification, such as increasing the interaction between residential and agricultural facilities. Table 4.8 shows the relocation decisions of the model under this occasion. We increased the interaction between residential and agricultural facilities almost 5-fold.

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R/Z	1	2	3	4
1	1	0	0	0
2	0	1	0	0
3	0	1	0	0
4	0	0	1	0
5	0	0	1	0
6	0	0	0	1
7	0	0	0	1
8	0	0	1	0
9	1	0	0	0
10	0	0	1	0
11	0	0	1	0
12	1	0	0	0
13	0	0	1	0
14	0	0	1	0
15	1	0	0	0
16	0	1	0	0
17	0	1	0	0
18	0	1	0	0
19	0	1	0	0
20	0	1	0	0

I/Z	1	2	3	4
1	0	0	1	0
2	1	0	0	0
3	0	0	0	1

G/Z	1	2	3	4
1	1	0	0	0
2	0	0	0	1
3	1	0	0	0
4	1	0	0	0

A/Z	1	2	3	4
1	0	0	1	0
2	0	1	0	0

Table 4.8 Modification of the limited budget model

In another extension of the model we consider shutdown option. This option refers to relocating facilities to an existing zone where some of the facilities have already been established such as governmental and industrial facilities. In this occasion instead of relocating governmental facilities and industrial facilities, we shutdown these facilities to reduce the investment cost and moving cost. Table 4.9 shows the decisions of shutdown option.

R/Z	1	2	3	4
1	1	0	0	0
2	0	1	0	0
3	0	1	0	0
4	1	0	0	0
5	1	0	0	0
6	1	0	0	0
7	1	0	0	0
8	1	0	0	0
9	1	0	0	0
10	0	0	0	1
11	0	0	0	1
12	0	0	0	1
13	0	0	0	1
14	0	0	0	1
15	0	0	0	1
16	0	1	0	0
17	0	1	0	0
18	0	1	0	0
19	0	1	0	0
20	0	1	0	0

I/Z	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	1	0	0	0

G/Z	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0

A/Z	1	2	3	4
1	0	0	0	0
2	0	1	0	0

Table 4.9 The decisions of shutdown option

In the shutdown option, we modify the model by increasing the weight of residential facilities. We increased the weight six fold. Table 4.10 shows the model decisions after modification. When we increase the weight of residential facilities 6-fold, the model decides shutting down all the industrial, governmental and agricultural facilities.

R/Z	1	2	3	4
1	1	0	0	0
2	1	0	0	0
3	0	1	0	0
4	0	1	0	0
5	0	1	0	0
6	1	0	0	0
7	1	0	0	0
8	1	0	0	0
9	1	0	0	0
10	0	1	0	0
11	0	0	0	1
12	0	0	0	1
13	0	0	0	1
14	0	1	0	0
15	0	0	0	1
16	1	0	0	0
17	0	1	0	0
18	0	1	0	0
19	1	0	0	0
20	0	1	0	0

I/Z	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0

G/Z	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0

A/Z	1	2	3	4
1	0	0	0	0
2	0	0	0	0

Table 4.10 The modified model results with shutdown option

Even though we have a complete set of runs for Phase I and Phase II formulations, 7 different scenarios, and 3 extensions of the GAMS model, we choose to demonstrate only a representative subset of the results. We include these results to demonstrate various analysis that can be carried out by the use of the formulations that we developed and we believe that these examples are adequate to indicate that our model can be adapted to many alternate situations. Clearly, meaningful deductions from the results of the model can be made only in the presence of reliable, verified input data, whereas we have made runs using hypothetical data only.

CHAPTER V

CONCLUSION AND FURTHER RESEARCH

In this study, we introduce related terminology regarding to disaster management. We give definitions of the disasters and disaster management; moreover, we identify the classifications of disaster and disaster management stages.

We review disaster management literature from the perspective of business and humanitarian logistics perspectives. Since we deal with a problem which is a class of location problems, we review the literature in detail, and search for the location problems in disaster management. Furthermore, to propose a unified framework, we did a comparison between the humanitarian and business logistics.

We propose a mathematical model for relocation at the recovery stage following a disaster. The area under consideration is prone to flood risk. We constructed an integer programming model which relocates the residential, governmental, industrial and agricultural facilities with the objective of minimizing the sum of tangible costs such as investment and transportation costs as well as intangible costs such as those associated with disaster risks and social resistance. We propose this model for flood-risky area; however it can be used for all kind of disasters as long as we compute the associated parameters. The mathematical model serves the objectives of both humanitarian and business logistics approaches. Although in practice the decision makers for this kind of relocation policy involve many actors and bodies, in this problem we assume that there is only one decision-making mechanism.

We solve our proposed model in two phases. The first phase decides the zones that the facilities move to and the result of the first phase is used as an input for second phase of the problem. In the second phase; the mathematical model chooses the locations for relocation within a zone. For the solution of the problem, we use GAMS software to find the optimal solution.

The model is heavily dependent on the identification of several parameters. To start with, we have to measure the disaster risks associated with each zone and location. Moreover, we have to come up with measure of a social resistance which is not well-defined. In our model, we used hypothetical values. We suggested methods for identifying these parameters. However the methods we suggest need proof using surveys etc. or they may be other factors that affect parameters. This identification of parameters would be in the scope of other studies.

Clearly, it is not very easy to measure social resistance. The methodology we suggest uses two main determinants for social resistance. One is distance, the other is desirability. We assume a directly proportional relation with distance and an inversely proportional relation with desirability. However, this method needs proof using field studies and surveys. There may be other factors affecting social resistance. This would be in the scope of further scope.

The way we handle different objectives is by assigning weights to objectives. One may also use tools from multi-objective optimization theory. However, we are more interested in choosing an alternative among feasible ones and its implications. A multi-objective approach may be incorporated in future studies that may follow this.

We take parameters as point values. It is very unlikely that we can identify, say, risks or even distances as point values. Since parameters have direct effect on decisions made using the model, the inherent deviations of parameters from estimated values are significant. We handle this variability of the parameters by running multiple versions of the mathematical model, allowing parameters to vary within a range each time. Still however, a more systematic approach (such as robustness, mini-max regret, sensitivity analysis) can be applied to arrive at more reliable decisions.

In one of the extensions, we consider shutting down the facilities. This is valid in cases where a facility can take service from an existing other facility in its new zone. A similar idea arises in a case where relocating facilities to a new zone which has, say, no governmental facilities. In that case we may consider adding new facilities that will serve newly relocated facilities. Assume you move 5 residential and 2 industrial facilities to a new zone that was not populated earlier. Now, the new zone contains 7 facilities, however there is no governmental facilities, since each of the facilities is highly likely to demand service from governmental facilities. It would be correct to consider establishing a governmental facility. This may also be investigated in future studies. Our model can handle this situation with some modifications in the constraint set. In this modification, we allow the model to open new facilities, this cause the decision makers extra investment cost. At the same time, when we do not open a new facility, the distance between facilities, say, interaction cost will increase. Our model can easily incorporate such an extension by modifications in the objective function and constraint set.

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