STOCKING DECISIONS FOR RELIEF AID

by

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This is to certify that I have examined this copy of a master's thesis by

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and that any and all revisions required by the final
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To my family

ABSTRACT

Natural disasters are unexpected crisis events causing devastating human and financial losses. These events trigger a critical need for effective preparedness, mitigation, response and recovery operations to reduce the impact of the disasters. Humanitarian relief agencies participate in massive relief efforts to provide life-supporting resources, such as food, water, sanitation, emergency care, shelter and other essential non-food items; to distribute supplies and to coordinate international aid after a disaster. The success of such large scale and time-critical operations require effective pre-disaster planning.

In this thesis, we consider stocking decisions for humanitarian relief agencies that provide emergency relief items to people affected by natural disasters. We present a mathematical model to determine the optimum stocking quantity for one type of relief commodity. The proposed model is an extension of the well-studied newsvendor model that incorporates the disaster risk. The probability that a disaster takes place within the lifetime of the stocked commodity and the demand distribution for this commodity under such a disaster are taken into consideration in the model. We extend our model to determine the optimum stocking quantities for two agencies that stock the same commodity at different locations prone to differing disaster risk, and that work in full cooperation, just like the case of the Turkish Red Crescent and the International Federation of Red Cross and Red Crescent agencies. An equilibrium solution to the model that can be calculated numerically is derived. We investigate the characteristics of the solution under various parameter settings and identify cases where cooperation is beneficial to one or both of the agencies. We analyze the case for Istanbul to demonstrate the use of this modeling approach. The probability of a major earthquake occurrence in Istanbul and the potential demand for relief commodities throughout the city are estimated and used as inputs of the model. A numerical analysis gives insights to the potential benefits arising from cooperation of an agency in Istanbul with an outside agency. Our analysis with respect to realistic scenarios and parameter estimations provides useful guidelines for the relief agencies in Istanbul.

ÖZETÇE

Doğal afetler, meydana geldikleri ülkelerde genel yaşamı etkileyecek boyutlarda sosyal ve ekonomik kayıplara yol açan olaylardır. Doğal bir afet, etkin bir hazırlık, zarar azaltma, müdahale ve iyileştirme sürecine olan ihtiyacı da beraberinde getirir. Doğal bir afet sonrası çok sayıda konutun yıkılması veya ağır hasar görmesi sonucu, bölgede yaşayan afetzedelere hızla barınak ve yardım malzemesi sağlanması zorunluluğu ile karşı karşıya kalınmaktadır. Gerekli yardım malzemelerinin tedarik edilmesinde, afet sonrası malzeme dağıtımında ve uluslararası yardımın koordine edilmesinde, yardım ve müdahale kuruluşları büyük görev üstlenmektedirler. Böylesine büyük çapta ve zamanlama açısından kritik bir faaliyet, etkin bir afet öncesi planlamasını gerektirmektedir.

Bu tezde, afetzedelere acil yardım malzemesi sağlayan yardım kuruluşlarının malzeme depolama kararları ele alınmakta ve tek bir tip yardım malzemesi için en iyi depolama miktarını belirlemeyi amaçlayan bir matematiksel model sunulmaktadır. Önerilen model, deprem riskinin de dahil edildiği tek periyotluk Newsvendor (Gazete Bayii) Modeli esas alınarak geliştirilmiştir. Depolanan malzemenin ekonomik ömrü içerisinde ciddi boyutta bir depremin olma olasılığı ve böylesi bir afet sonrasında ortaya çıkacak olan yardım malzemesine olan talep parametreleri de modele dahildir. Kurulan model, farklı bölgelerde bulunan ve aynı tip yardım malzemesi depolayan ve birbirleriyle tam bir yardımlaşma halinde olan iki kuruluşun en iyi depolama kararını belirlemek üzere genişletilmiştir. Bu durum, Uluslar arası Kızılay ve Kızılhaç Federasyonu'nun bir üyesi olan Türk Kızılayı'nın da içerisinde bulunduğu durumla benzerlik göstermektedir. Geliştirilen modelin, iki yardım kuruluşu için en iyi depolama kararını veren denge çözümü sayısal olarak hesaplanmaktadır. Farklı parametreler kullanılarak oluşturulan durumlar için modelin çözümü incelenmekte ve yardımlaşmanın her iki kuruluş ya da kuruluşlardan biri için yararlı olduğu durumlar tespit edilmektedir. Önerilen yöntemin uygulama yoluyla gösterilmesi amacıyla İstanbul ili göz önüne alınmaktadır. İstanbul ve çevresinde, önümüzdeki yıllarda büyük bir depremin meydana gelme olasılığı ve böylesi bir deprem sonrasında çadır gibi bir yardım malzemesine olabilecek talep

hesap edilmekte ve sayısal çözümlere dahil edilmektedir. Yapılan sayısal analizler, İstanbul'daki bir yardım kuruluşunun başka bir bölgedeki yardım kuruluşuyla işbirliği sonucunda sağlanabilecek olan yarar hakkında fikir vermektedir. Gerçek senaryolara ve parametre hesaplarına dayanan model, İstanbul'da faaliyet gösteren yardım kuruluşları için yol göstericidir.

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Chapter 1

INTRODUCTION

1.1 Background and Motivation

Earthquakes, hurricanes, floods, tsunamis and tornados are natural disasters that continue to cause serious number of deaths, injuries and significant economic losses each year around the world. Natural disasters encompass an incredible range of sizes, circumstances and effects, causing widespread destruction and affecting large numbers of people across an extensive geographic area. The number of natural disasters and the number of people affected by disasters have risen during every decade from 1890 to 1950. The fatality rates have increased even dramatically since the 1950s [26]. The number of people affected by disasters and the number of disasters also continued to rise in 2005; the number of people who required immediate assistance, who injured or became homeless was seven million more compared to 2004, and the increase in the number of disasters was 18% [7]. This increase in numbers brings a significant rise in the need for effective disaster response operations to diminish the impact of the natural disasters.

Disaster response efforts take place in pre-event and post-event stages [41]. According to the Comprehensive Emergency Management concept introduced in 1978, disaster management can be grouped under four programmatic phases: mitigation, preparedness, response, and recovery [2]. Mitigation is defined as the activities that eliminate or lessen the probability of occurrence or the effect of a disaster situation. Preparedness activities prepare societies for an emergency before it occurs. Response includes the actions taken immediately before, during and after a disaster occurs to save lives, and the social, economic and political structures of the communities. Providing relief to people affected by large-scale emergencies like natural disasters is also the objective of disaster response in humanitarian relief [7]. Recovery refers to short-term and long-term activities to return life to normal.

Disaster response is a complicated phase of the disaster management cycle due to the uncertainty of the time, magnitude and the probable effects of the disaster. Distributing relief aid is one of the critical response activities.

Humanitarian relief is the provision of life-saving support to the people in need, including the victims of natural disasters. The definition given by United Nations is "aid that seeks to save lives and alleviate suffering of a crisis-affected population". Specific relief activities include providing supplies, education and agricultural support, distributing them and coordinating international aid. The greatest part of this assistance is provided by humanitarian relief agencies including the United Nations, the International Federation of the Red Cross and the Red Crescent Societies, World Vision International (WVI), the World Food Programme (WFP) and international and other national non-governmental organizations (NGOs) that can also be in cooperation with each other. Humanitarian relief agencies participate in massive relief efforts to provide life-supporting resources, such as food, water, sanitation, health care, emergency shelter, tent-town needs (catalytic heater, pillows, puffs, kitchen and cleaning equipment, sleeping bag, etc.), and other essential non-food items; distribute supplies and coordinate international aid. Having a stock of relief items on hand means providing assistance to the victims of the disaster more quickly. Therefore, giving an effective stocking decision in the pre-disaster stage is one of the most essential steps of disaster response.

The International Federation of the Red Cross and the Red Crescent Societies developed the "Code of Conduct" for the International Red Cross and Red Crescent Movement and NGOs in Disaster Relief in 1994. It was agreed upon by eight of the world's largest disaster response agencies and represents a huge leap forward in setting standards for disaster response. It is being used by the International Federation to monitor its own standards of relief delivery and to encourage other agencies to set similar standards. The Code and its principles of ethics and behaviour entered the aid lexicon, and some 149 independent humanitarian agencies had registered their support by the end of 1997. As Code use grows, agencies see the need to go further and create practical standards for the quality expected at the core of assistance. The project to develop these minimum standards in humanitarian response is dubbed as "Sphere". This international, inter-agency project follows a cooperative, collaborative process to develop a humanitarian charter for people affected by disaster

[44]. Motivated by the importance of a cooperative and collaborative disaster response, we consider the cooperation between the humanitarian relief aid agencies in this thesis.

1.2 Istanbul and Earthquake

The Marmara Region, approximately bounded by $39.5^o\ N$ to $41.5^o\ N$ and $26^o\ E$ to $31^o\ E$, is a thickly populated and industrial part of Turkey. The Marmara Region has been the site of several damaging earthquakes over the course of history. This seismic region has been extremely active during the twentieth century with two major earthquakes of magnitude 7.3 and 7.4 in 1912 and 1999, respectively. Most of the historical documentation address the damage and the need for aid in Istanbul, a populous megacity of around 11 million inhabitants [3],[14]. On August 17, 1999, when the last devastating earthquake occurred, 17,127 people lost their lives, more than 43,000 people were injured and more than 250,000 people became displaced and in need of life-supporting resources [33]. As often indicated in scientific studies, poor disaster management before, during and after the disaster as well as poor building construction causes extreme casualties [6]. The occurrence of the 1999 Kocaeli and Düzce earthquakes in the Marmara Region emphasized the need for better disaster response capability.

Earthquake risk and hazard mitigation in the Marmara Region and consequences of the last earthquakes on the Turkish economy, society, administration and environment have been extensively studied in recent years [23],[13],[15]. In addition, ways of improving the Turkish disaster management system and the importance of the role of the relief agencies in this system have been discussed in studies such as the Earthquake Master Plan for Istanbul and the ISMEP Project, proposing new organizational structures [39],[15]. These studies have become more relevant considering that another Marmara earthquake to affect mostly southern Istanbul is expected. In 2000, Parsons et al. estimated the probability that a major earthquake occurs within thirty years in the fault line that goes through the Marmara Sea, in the south of Istanbul as 62% ±15% [36]. This significant earthquake risk alerts the need to deliver sufficient relief aid within a short time frame after a disaster.

The Turkish Red Crescent, a non-governmental organization (NGO) and a member of the International Federation of the Red Crescent and the Red Cross Societies, has a big role in the disaster management system of Turkey. The Red Crescent's relief aid stocks include tents and tent-town units and a small amount of food and water. The existing water stock is refreshed every month and the tents in stock are maintained every year. The economic lifetime of the tents is about five years; after five years they are sold at a reduced price and the used tents are recycled after a disaster. In a possible disaster, the Turkish Red Crescent's current stocks can supply for 250,000 people in Istanbul and 5 million people in Turkey. If the stocking capacity is insufficient in case of a disaster, the Turkish Red Crescent obtains the needed commodities from the relief agencies they are in cooperation with. The Turkish Red Crescent has one central depot in Kartal, two local depots and three other depots in the response centers located in Bakirköy, Tuzla and Sultanbeyli districts of Istanbul. In addition, 110 branches exist in the Marmara region for local coordination. Distribution of the stocked items locally and the personnel are provided by the branches.

In this thesis, we study the stocking decisions for a relief agency that is in cooperation with other agencies, just like the case of the Turkish Red Crescent. The number of units stocked at the central and the local depots affect directly the response time and the number of people to receive aid after a disaster. Because of the uncertainty associated with the occurrence of the disaster and the needs after a disaster, how much to invest in stocks becomes a challenging decision for the relief agencies. On one hand, agencies have limitations in terms of funds and warehouse space available. On the other hand, while responding to each person in need promptly is an essential goal, agencies have responsibilities to use their funds to provide the best utility to the people. Note that overstocking prevents the use of money in a better means of service.

Although research on inventory problems is extensive in terms of theory and applications, the application of the methods in this area to the domain of humanitarian relief has been limited. Furthermore, coordination between relief agencies has not received much attention in the area of disaster management in terms of quantitative analysis. In this study, we consider stocking decisions for humanitarian relief aid agencies responding to devastating disasters. We first present a mathematical model to determine the optimum stocking quantity for one type of relief commodity. The underlying model is based on the well-studied newsvendor model but extends to incorporate the disaster risk by taking into account the probability of a destructive disaster occurrence during the life time of the commodity and the demand distribution under such a disaster. We extend our model to obtain the optimum stocking decisions for two agencies that stock the same commodity for their own use and work in full cooperation to help each other when a disaster strikes. We demonstrate the use of this modeling approach by a case analysis for Istanbul, Turkey, a metropolitan under serious earthquake risk. Our mathematical model inputs are obtained by estimating the probability of an earthquake occurrence in Istanbul and the demand for relief commodities after such an earthquake. We also develop an analysis with respect to realistic scenarios and parameter estimations in order to provide useful guidelines and insights for the relief agencies in Istanbul.

This thesis is organized as follows. The literature on quantitative methods for humanitarian relief and seismic loss estimation studies is reviewed in Chapter 2. Chapter 3 comprises the single agency model to determine the optimum stocking quantity under disaster risk. The stocking model for two agencies in cooperation deciding their optimal stocking quantity under disaster risk is also included in Chapter 3. Chapter 4 presents the results from the application of the single agency model to the Istanbul case. In Chapter 5, we present a numerical analysis to understand the nature of the equilibrium solution to the two agency model under various parameter settings. We also analyze the case of Istanbul considering an agency that responds to a local earthquake in Istanbul and cooperates with an outside agency. We investigate the potential benefits from cooperation with agencies subject to differing disaster risk. Finally, Chapter 6 presents a summary with concluding remarks.

Chapter 2

LITERATURE REVIEW

This thesis builds on three streams of literature: quantitative methods for humanitarian relief, seismic loss estimation studies and the single period inventory model. The research in the field of quantitative methods for humanitarian relief is reviewed first with an emphasis on studies regarding the stocking decisions for agencies that support emergency relief operations. We rely on previous seismic loss estimation studies to illustrate how the proposed stocking model can be used. In particular, we focus on parameter estimations with respect to the earthquake risk in Istanbul. We review the single period inventory models in which multiple parties stock the same commodity.

2.1 Quantitative Methods for Humanitarian Relief

Most of the research in the field of disaster management focuses on the aftermath of disasters, sociological, psychological and economical impacts on communities, and the organizational structure of the response system [2]. Although supply chain and logistics management has been an extensive research area in the field of Operations Research and Operations Management, quantitative tools and principles have not been widely applied to the humanitarian relief supply processes with the consideration of the particular characteristics of the relief environment, except for a limited but growing number of studies [2].

The objective of disaster response is to rapidly provide the essential commodities to areas affected by a disaster. The difficulty of estimating the timing, location and the intensity of a disaster causes a significant uncertainty in the location and the amount of the demand. Quantitative methods have been developed and applied to mostly response logistics problems such as designing a supply network, facility location and distribution of relief items. Altay and Green prepared a literature survey that describes potential research directions in disaster operations [2]. Tufekci and Wallace also discussed the role of advanced communications and computing technologies connected with the analytic procedures and models in order to provide a system view of emergency management [41].

Transportation of relief aid has been addressed by several studies. In the study conducted by Oh and Haghani in 1996, transportation of large amounts of relief aid supply was analyzed with the purpose of improving the performance of rescue operations by formulating a multi-commodity, multi-model network flow model [28]. Ozdamar et al. [30] developed a network flow model that addresses the dynamic time-dependent transportation problem. The objective of the study in [30] is to coordinate logistics support for relief operations by determining the optimal schedules for vehicles and the optimal quantities of commodities to be dispatched to distribution centers in affected areas. Barbarosoglu et al. [8] proposed a hierarchical multi-criteria methodology for the planning of helicopter logistics regarding the use of helicopters for aid delivery and rescue missions during natural disasters. The research contributed to the solutions of the routing and transportation problems experienced during the initial response phase of disaster management. Barbarosoglu and Arda developed a two-stage stochastic programming framework to formulate the transportation of relief aid commodities, expanding on Oh and Haghani's deterministic network flow problem.

Inventory management in relief settings is a domain that has seen limited applications of quantitative models. In 2006, Beamon and Kotleba [10] developed a stochastic inventory control model for long-term emergency relief efforts. They obtained optimal order quantities that are independent of vehicle or container sizes and re-order points for disaster response, assuming a continuous demand approximation. The presented multi-supplier humanitarian inventory model represented a continuous inventory review system with two options for re-supply: normal and emergency [10]. The authors also developed and analyzed three different single-item inventory management strategies: mathematical, heuristic and naive models as applied to emergency relief response operations of WVI in south Sudan, Africa. Balcik and Beamon [7] developed a model that combines facility location and stocking decisions for a humanitarian relief chain, considering the budget and capacity restrictions and multiple types of items. The effectiveness of the proposed model that is based on the maximal covering location model, was illustrated by computational experiments on a realistic problem. Our proposed stocking models differ from previous models in that they incorporate the disaster risk in a certain area. Namely, the estimated probability that a disaster occurs within the period considered and the estimated demand distribution after such a disaster are used to model the disaster risk. The other difference between the recent studies and ours is that the two agency model we developed proposes a stocking decision for relief aid agencies by taking into account the cooperation between them. In the aftermath of a disaster, unmet demand of relief items are typically fulfilled by outside aid that is received after some time. Mutual cooperation agreements among agencies facilitate a guaranteed supply of such foreign aid and may also provide benefits in terms of sharing and reducing the stocking costs. We investigate these issues by means of our proposed model.

2.2 Seismic Loss Estimation Studies

Seismic loss estimation is a methodology that consists of three basic steps: seismic hazard, vulnerability and loss estimation studies. Two recent major earthquakes on the 17 August, 1999 in Izmit and on the 12 November, 1999 Duzce in Turkey, prompted the scientists to forecast the characteristics of a potential devastating earthquake in Istanbul and estimate the substantial damage it can cause. We introduce the seismic hazard and loss estimation studies as we use them to generate realistic inputs to our models.

2.2.1 Earthquake Hazard Studies

Earthquake hazard studies have been conducted to forecast the probability of an earthquake occurrence on different fault systems. The probability calculations have been made for the North Anatolian Fault in northwestern Turkey, the San Andreas Fault in central California and the South Hayward Fault in northern California [36],[35],[38],[1],[37]. There are generally two well-known approaches for the earthquake hazard estimation: the probabilistic seismic hazard analysis and the deterministic earthquake hazard analysis. It is more reasonable to use probabilistic characteristics of an earthquake's ground motion than to use deterministic characterizations due to the uncertainties associated with the earthquake occurrence [14]. Probabilistic Seismic Hazard Analysis (PSHA) is defined as "a methodology that estimates the likelihood that various levels of earthquake-caused ground motions will be exceeded at a given location in a given future time period" [12]. There are also two main PSHA models that have been used in studies: the *time-dependent* PSHA (renewal) model and the *time-independent* PSHA (Poisson) model. Many researchers underlined that periodic occurrence of large magnitude earthquakes necessitate the use of the time-dependent (renewal) models and concluded their studies by stating that earthquake recurrence on the individual faults is more consistent with a time-dependent renewal process [14],[37],[35],[36],[38].

Earthquake studies have also made much progress in forecasting the probability of an earthquake occurring beneath the Sea of Marmara. Time-dependent PSHA models with the incorporation of stress changes caused by past earthquakes on the NAF have been used in most of the studies. The studies in which time dependence and stress transfer are added to the calculations are more prudent than the ones that use only a statistical approach for estimating the earthquake probability [35],[36]. The research conducted by Parsons et al. in 2000 proposed an interaction based probability model, including the time-dependent effect of stress transferred by the 1999 Izmit earthquake to faults nearer to Istanbul. They found a $62 \mp 15\%$ probability of strong shaking during the next 30 years and $32 \mp 12\%$ during the next decade, at time of the study. In an another study carried by Parsons in 2004, the same method was used by incorporating contemporary scientific findings into a new earthquake probability analysis and the 30 year earthquake occurrence probability in Istanbul was obtained as $41 \pm 14\%$. We use this approach for our study to estimate the 5 year earthquake occurrence probability for Istanbul.

2.2.2 Loss Estimation Studies

In recent years, a number of research efforts have focused on earthquake loss estimation. Previous earthquake loss estimation studies involved regional loss estimation studies and building-specific loss estimation studies. Regional loss estimation studies object to obtaining the estimation of economic losses over a large number structures such as city, county, state or country. Building specific loss estimation studies, on the other hand, aim to provide a more accurate estimation of earthquake losses in individual buildings located at specific sites.

The large majority of scientists in the field of loss estimation have focused on regional loss estimation studies. The research conducted by Whitman et al. and Steinbrugge et al. [40], were among the first studies to develop damage probability matrices in order to analyze the probabilistic nature of earthquake losses [43]. The methodology proposed by Streinbrugge et al. included damage probability matrices consisting of damage ratio and damage factor pairs. The output of the methodology was percentage losses for various construction types whereas the inputs to it were location, replenishment costs and data categories such as construction type. In the proposed model by Whitman et al. damage was described in terms of damage ratio and damage probability matrices were estimated for five-story buildings with different kinds of construction.

One of the most widely accepted loss estimation methodologies is the study conducted Applied Technology Council in 1985 titled "Earthquake Damage Evaluation Data for California" known as ATC-13 [5]. The study provided a way to estimate earthquake losses in industrial, commercial, residential, utility and transportation facilities in California on a regional basis: in addition to developing damage probability matrices for a broad majority of classes of construction.

The Federal Emergency Management Agency (FEMA) also published two reports in 1989 and 1994 that aim to develop a nationally applicable methodology for estimating potential earthquake losses on regional basis: FEMA-177 and FEMA-249 reports. Both FEMA studies indicated that available loss estimation studies did not properly incorporate the uncertainty in seismic risk. Therefore, a standardized regional loss estimation methodology, HAZUS, was implemented through Geographic Information System (GIS) with the agreements of National Institute of Building Sciences (NIBS) [27].

More recent regional loss estimation studies have been focused on developing empirical fragility functions for different types of building construction and for several ground motion parameters. In order to estimate regional earthquake damage and losses, the fragility functions have been implemented in HAZUS software [25].

Istanbul has also been the focus of loss estimation studies, being one of the biggest cultural, historical and economical centers in Turkey. Two comprehensive studies carried out by Japan International Cooperation Agency (JICA) and The Kandilli Observatory and Earthquake Research Institute (KOERI) include sub-district level earthquake hazard assessment, predicting casualties and building damage [23],[13]. In another study, titled "Earthquake Risk and its Mitigation in Istanbul", Erdik and Durukal [15] outlined the expected physical, social and economic industrial losses caused by an earthquake in Istanbul, and the vulnerability to a possible disaster. The study, undertaken by JICA, that strongly depends on the quality of building inventory has been a leading source for our study to obtain the damage distribution for Istanbul under a possible destructive earthquake.

2.3 The Single Period Newsboy Model with Cooperation among Suppliers

The single-period newsvendor (SPNV) problem is to find the order quantity which maximizes the expected profit in a single period probabilistic demand framework. The SPNV model assumes that if any inventory remains at the end of the period, it is salvaged with a discounted value. If the order quantity is smaller than the realized demand, the newsvendor, forgoes some profit. The SPNV problem is reflective of many real life situations and is often used to aid decision making in both at the manufacturing and retail sectors [18]. Many extensions to the SPNV model including dealing with different objectives and utility functions, different supplier pricing policies, different newsvendor pricing policies, different states of information about demand, constrained multi-products, multiple-products with substitution, random yields, and multi-location models have been proposed [24].

Game-theoretic models that impose an interaction among suppliers or retailers have been studied in the supply chain inventory management context. Gullu et al. [21] consider a decentralized supply chain with two independent retailers. In their study, in each order cycle, retailers place their orders at the supplier to minimize inventory-related expected costs at the end of their respective response times. Orders are shipped to retailers at the end of the supplier lead time that is associated with order preparation. Before retailer orders are shipped, they are given an opportunity to readjust their orders, so that both retailers can improve their expected costs. Because of the possibility of cooperation at the end of supplier lead time, each retailer will consider the other's order-up-to level in making the ordering decision. Unique equilibrium order-up-to levels for the retailers are derived under this setting. Parlar [34] analyzes a two-newsvendor SPNV problem in which when one has a shortage, a fraction of his/her customers switches to the other newsvendor. In that game theoretical SPNV problem, retailers compete on product availability. Since each player's decision affects the other's single-period expected profit, game theory is used to find the order quantities when the players use a Nash strategy. The newsvendors are assumed to have knowledge of the demand densities, substitution rates, and other parameter values. The cooperative game is also discussed and it is proved that the players always gain if they cooperate and maximize a joint objective function.

Anupundi et al. [4] develop a general framework for the analysis of decentralized distribution systems. In this study, an exogenously specified fraction of any unsatisfied demand at a retailer could be satisfied using excess stocks at other retailers. They develop a so-called "coopetitive" framework for the sequential decisions of inventory and allocation. For the cooperative shipping and allocation decision, the concept of core is used and sufficient conditions for the existence of the core is developed. For the inventory decision, they develop conditions for the existence of a pure strategy Nash Equilibrium. For this decentralized system, it is also shown that there exists an allocation mechanism that achieves the centralized solution. Ozen et al. consider a supply chain that consists of n retailers that are supplied with a single product via m warehouses. The ordered amounts of goods of these retailers become available after some lead time in the warehouses. Demand realizations are known by the retailers at the time that the goods arrive at the warehouses. The retailers can increase their expected joint profits if they can coordinate their orders and make allocations after demand realization. In this study, associated cooperative game between the retailers is considered under this setting, as well as a noncooperative game, where the retailers decide on their order quantities individually. They show that the set of payoff vectors resulting from strong Nash equilibria corresponds to the core of the associated cooperative game [31]. In another study, Ozen et al. [32] also benefit from this result for a special class of situations, called stochastic cooperation situations. This class captures a broad range of cooperation situations under uncertainty. They show that the cooperative games associated with these situations are totally balanced and, hence, they have nonempty cores.

Both the motivation and the analysis of this thesis differ from these papers in the following respects. In our work, we consider a time horizon and incorporate the risk of a rare event occurring in this time horizon and the estimated demand distribution for relief supplies after this event is realized. Our model differs from the classical SPNV model in its cycle time; the cycle time ends when a disaster occurs or the economic life of the items end. We model a system from the perspective of a non-cooperative game in which players make decisions independently. Most of the reviewed studies focus on cooperative games where groups of players may enforce cooperative behaviour, hence the game is a competition between coalitions of players, rather than between individual players. The other difference of our model is that it is based on sharing of relief commodities of the agencies rather than competition on product availability. In our setting, inadequate relief supply of an agency does not increase the other agency's payoff. Moreover, in these works, a supplier lead time is taken into account whereas considering a delay in receiving relief commodities from the other agency does not change the optimal stocking decisions. We also achieve an equilibrium of optimal stocking quantities rather than an equilibrium of order-up-to levels.

Chapter 3

MODELS TO DETERMINE THE OPTIMUM STOCKING QUANTITY UNDER DISASTER RISK

We present two single period inventory models for relief aid agencies that stock a relief commodity: the *Single Agency Model* and the *Model with Cooperation*. The *Single Agency Model* considers a relief agency that needs to decide how many units of a commodity to stock for a single period independently from the other agencies. In the *Model with Cooperation*, two agencies give their own stocking decisions considering that the other agency will provide any possible shortage in a disaster situation as much as their stocks allow.

3.1 Single Agency Model to Determine the Optimum Relief Aid Stocking Quantity

Consider a single relief aid agency that wants to pre-position relief supplies. The relief commodity may consist of a single item such as a tent or a kit of multiple items that have a known economic life time and will be salvaged if they are not used until their life time ends. The stocking decision is made for a single cycle that ends either when a disaster occurs or the items reach the end of their life time. When a disaster occurs, the realized demand is met from the stocks of the agency. We assume that there is no exogenous supply that can be received from the other suppliers in a reasonable time, if the ordered quantity is not enough for the realized demand. The total cost within the cycle can be formulated by considering two cases according to the probability that an earthquake occurs.

In the case that a disaster occurs in the area of A_1 with γ probability, two subcases appear.

If A_1 can meet the demand, an overage cost (c_o) is charged for each unit of relief commodity that is not used. In this case, the cost of stocking Q units of inventories:

$$C(Q) = c_o(Q - D).$$

If A_1 can not meet the demand, an underage cost (c_u) is charged for each unit of unmet demand. In that case, the cost of stocking Q units of inventories:

$$C(Q) = c_u(D - Q).$$

In the case that a disaster does not occur in the area of A_1 with $(1 - \gamma)$ probability, an overage cost (c_o) is charged for each unit of relief commodity that is not used. In that case, the cost of stocking Q units of inventory:

$$C(Q) = c_o Q.$$

As a result, the total cost within the cycle can be formulated as a function of the stocking quantity in the following way:

$$C(Q) = \gamma\left[c_o \max(Q - D, 0) + c_u \max(D - Q, 0)\right] + (1 - \gamma)c_o Q$$

where,

γ : probability that a disaster happens within the cycle. This probability is a random variable taking values in $[\gamma_L, \gamma_U]$ where, $\gamma_L \geq 0$ and $\gamma_U \leq 1$.

γ_U : upper bound of the probability that a disaster happens.

γ_L : lower bound of the probability that a disaster happens.

Q : stocking quantity.

D : demand for relief commodity when a disaster happens. Demand is a random variable taking positive values between D_L and D_U.

F_D : probability distribution function of the demand.

f_D : probability density function of the demand.

F_γ : probability distribution function of the probability that a disaster happens.

f_γ: probability density function of the probability that a disaster happens.

c_o : overage cost (cost of purchasing, holding, maintaining a stock unit and the opportunity cost of stocking one unit item minus its salvage value).

c_u : underage cost (cost of unsatisfied unit demand).

The expectation cost of stocking Q units in inventory is given as (expectation is with respect to demand D and probability γ):

$$E\left[C(Q)\right] = \int\limits_{\gamma_L}^{\gamma_U} \left\{ \gamma \left[c_o \int\limits_{x=D_L}^{Q} (Q-x)\, f_D(x)dx + c_u \int\limits_{x=Q}^{D_U} (x-Q)\, f_D(x)dx \right] + (1-\gamma)\, c_o Q \right\} f_\gamma(\gamma)d\gamma$$

$$\begin{aligned} E\left[C(Q)\right] &= \left[c_o \int\limits_{x=D_L}^{Q} (Q-x) f_D(x)dx \right] E[\gamma] + \left[c_u \int\limits_{x=Q}^{D_U} (x-Q)\, f_D(x)dx \right] E[\gamma] \\ &\quad + \left[c_o Q\right]\left[F_\gamma(\gamma_U) - F_\gamma(\gamma_L)\right] - \left[c_o Q\right] E[\gamma] \end{aligned}$$

$$E\left[C(Q)\right] = E[\gamma] \left[c_o \int\limits_{x=D_L}^{Q} (Q-x) f_D(x)dx + c_u \int\limits_{x=Q}^{D_U} (x-Q)\, f_D(x)dx - c_o Q \right] + \left[c_o Q\right] \quad (3.1)$$

If $D_L < Q < D_U \Rightarrow$

$$E\left[C(Q)\right] = E[\gamma] \left[c_o \int\limits_{x=D_L}^{Q} (Q-x) f_D(x)dx + c_u \int\limits_{x=Q}^{D_U} (x-Q)\, f_D(x)dx - c_o Q \right] + \left[c_o Q\right] \quad (3.2)$$

If $Q < D_L < D_U \Rightarrow$

$$E\left[C(Q)\right] = E[\gamma] \left[c_u \int\limits_{x=D_L}^{D_U} (x-Q)\, f_D(x)dx - c_o Q \right] + \left[c_o Q\right] \quad (3.3)$$

From equation (3.1), it is obvious that the expectation cost function of Q is convex, since

$$\left[c_o \int\limits_{x=0}^{Q} (Q-x) f_D(x)dx + c_u \int\limits_{x=Q}^{\infty} (x-Q)\, f_D(x)dx \right]$$

is a convex function as we know from the original Newsvendor Problem.

The aim is to find the optimal stocking quantity, Q, that minimizes the expectation cost function.

Since $E\left[C(Q)\right]$ is convex; using equation (3.1) and minimizing $E\left[C(Q)\right]$;

$$\begin{aligned} \frac{dE\left[C(Q)\right]}{dQ} &= 0 \\ E[\gamma]\left[c_o F_D(Q) - c_u(1 - F_D(Q)) - c_o\right] + c_o &= 0 \end{aligned}$$

$$F_D(Q^*) = 1 - \frac{c_o}{E[\gamma]\left[c_o + c_u\right]} \quad (3.4)$$

Minimization of the expected cost function can be analyzed in three cases for the general $E\left[C(Q)\right]$ function, according to the conditions that make $F_D(Q^*)$ positive.

3.1.1 Case I: Zero Expected Disaster Probability Case

As $E[\gamma]$ goes to 0;

$$\lim_{E[\gamma]\to 0} E[C(Q)] = c_o Q$$

Since $E[C(Q)]$ is linear as γ goes 0,

$$\min E[C(Q)] = 0 \text{ and } Q^* = 0.$$

3.1.2 Case II: Non-zero Expected Disaster Probability Case

In this case we assume that $\exists \varepsilon > 0$, such that $E[\gamma] > \varepsilon$. There are two subcases.

Case II.a:

When

$$1 - \frac{c_o}{E[\gamma]\,[c_o + c_u]} < 0,$$

that is,

$$1 - E[\gamma] > \frac{c_u}{[c_o + c_u]}. \tag{3.5}$$

Claim. $E[C(Q)]$ is monotone increasing as $0 < Q < D_L < D_U$.

Proof. Using equation (3.3), we check for all $a \geq 0$ values whether

$E[C(Q+a)] - E[C(Q)] \geq 0$.

$$E[C(Q+a)] - E[C(Q)] = E[\gamma]\left[c_u \int_{x=D_L}^{x=D_U} -a f_D(x)dx - c_o a\right] + c_o a$$

Using equation (3.5),

$$\begin{aligned} E[C(Q+a)] - E[C(Q)] &> E[\gamma]\left[c_u \int_{x=D_L}^{x=D_U} -a f_D(x)dx - \frac{E[\gamma]c_u}{1-E[\gamma]}a\right] + \frac{E[\gamma]c_u}{1-E[\gamma]}a \\ &> E[\gamma]c_u a\left[\int_{x=D_L}^{x=D_U} -f_D(x)dx - \frac{E[\gamma]}{1-E[\gamma]} + \frac{1}{1-E[\gamma]}\right] \\ &> E[\gamma]c_u a\,[-1+1] \\ E[C(Q+a)] - E[C(Q)] &> 0 \Rightarrow E[C(Q)] \text{ is monotone increasing.} \end{aligned}$$

■

Hence, optimum Q value is zero in this case.

Case II.b:

In this case,

$$1 - \frac{c_o}{E[\gamma]\,[c_o + c_u]} \geq 0$$

that is,

$$1 - E[\gamma] \leq \frac{c_u}{[c_o + c_u]}.$$

Since, $E\,[C(Q)]$ is a convex function for this case, optimum Q value is the value that satisfies Equation (3.4);

$$F_D(Q^*) = 1 - \frac{c_o}{E[\gamma]\,[c_o + c_u]}$$

Hereinafter, we call this model as the Single Agency Model.

3.2 Two Agencies in Cooperation Deciding their Optimal Stocking Quantities

This model considers a problem in which it is possible to receive exogenous supply from the other suppliers if the ordered quantity is not enough for demand after the disaster. Two relief aid agencies are considered in this cooperation and it is assumed that the agencies have mutual aid agreements that provides a mechanism to share their relief commodity stock. Here, we assume:

- The agencies are independent and give their stocking decision simultaneously or without information on the other's quantity,
- They give all of the requested amount of items in their depots when the other agency needs them,
- If two disasters occur at the same time in the areas of the agencies, the agencies do not help to each other.

Consider two relief agencies (A_1, A_2) that will decide how much to stock of the same commodity at their own depots by taking into account that they will help each other after a possible disaster.

D_i : demand for A_i when a disaster occurs. D_i is a random variable with probability density and cumulative distribution functions f_{D_i} and F_{D_i}, for $i = 1, 2$.

γ_i : probability that a disaster occurs in the area of A_i within the cycle. This probability is a random variable taking values between $\gamma_{i_L} \leq 0$ and $\gamma_{i_U} \leq 1$, for $i = 1, 2$.

Q_i : stocking quantity of A_i, $i = 1, 2$.

Q_i^* : optimal stocking quantity of A_i considering the foreign aid, $i = 1, 2$.

c_{o_i} : overage cost for agency i, $i = 1, 2$.

c_{u_i} : underage cost for agency i, $i = 1, 2$.

c_{t_i} : per unit cost of receiving exogenous supply for agency i, $i = 1, 2$. We assume that $0 \leq c_t \leq c_u$.

All the other parameters used in this model are defined similar to the *Single Agency Model*.

The cost of stocking Q_1 units of inventory for A_1, considering the foreign aid Q_2 that comes from A_2 can be determined considering three cases according to the earthquake probabilities in the areas of the agencies.

Case 1: With $(1-\gamma_2)(\gamma_1)$ probability, a disaster occurs in the area of A_1 and does not occur in the area of A_2.

Case 1.a : A_1 can meet the demand and an overage cost (c_{o_1}) is charged for each unit of relief commodity that is not used. The cost of stocking Q_1 units of inventory in this case is:

$$C(Q_1, Q_2) = c_{o_1}(Q_1 - D_1).$$

Case 1.b : A_1 can not meet the demand and requests R amount of supply from the other agency, where $R = D_1 - Q_1$.

Case 1.b1 : If $R < Q_2$, A_1 meets its excess demand with the help of A_2 and a transfer cost (c_{t_1}) is charged for each unit of relief commodity received from A_2. The cost of stocking Q_1 units of inventory in this case is:

$$C(Q_1, Q_2) = c_{t_1}(D_1 - Q_1).$$

Case 1.b2 : If $R > Q_2$, A_1 can not meet the demand even with the help of A_2. An underage cost (c_{u_1}) is charged for each unit of unmet demand and a transfer cost (c_{t_1}) is charged for each unit of relief commodity received from A_2. The cost of stocking Q_1 units of inventory in this case is:

$$C(Q_1, Q_2) = c_{u_1}(R - Q_2) + c_{t_1}Q_2.$$

Case 2: With $(\gamma_2)(\gamma_1)$ probability, two disaster occur at the same time in the areas of the agencies. Based on our assumption, the agencies do not help each other in this situation.

Case 2.a : A_1 can meet demand and an overage cost (c_{o_1}) is charged for each unit of relief commodity that is not used. The cost of stocking Q_1 units of inventory in this case is:

$$C(Q_1, Q_2) = c_{o_1}(Q_1 - D_1).$$

Case 2.b : A_1 can not meet demand and an underage cost (c_{u_1}) is charged for each unit of unmet demand. The cost of stocking Q_1 units of inventory in this case is:

$$C(Q_1, Q_2) = c_{u_1}(D_1 - Q_1).$$

Case 3: With $(1-\gamma_1)$ probability, a disaster does not occur in the area of A_1 and an overage cost (c_{o_1}) is charged for each unit of relief commodity that is not used. The cost of stocking Q_1 units of inventory in this case is:

$$C(Q_1, Q_2) = (1-\gamma_1)c_{o_1}Q_1.$$

As a result, expectation cost of stocking Q_1 units of inventory for A_1, considering the foreign aid Q_2 that comes from A_2 :

$$\begin{aligned}
E\left[C_1(Q_1, Q_2)\right] \quad = \quad & \int_{\gamma_{2_L}}^{\gamma_{2_U}}\int_{\gamma_{1_L}}^{\gamma_{1_U}} (1-\gamma_2)(\gamma_1)\left(c_{o_1}\int_{x=0}^{Q_1}(Q_1-x)\, f_{D_1}(x)dx + c_{t_1}\int_{x=Q_1}^{Q_1+Q_2}(x-Q_1)\, f_{D_1}(x)dx\right) \\
& f(\gamma_1)d\gamma_1 f(\gamma_2)d\gamma_2 \\
& + \int_{\gamma_{2_L}}^{\gamma_{2_U}}\int_{\gamma_{1_L}}^{\gamma_{1_U}} (1-\gamma_2)(\gamma_1)\left(c_{u_1}\int_{x=Q_1+Q_2}^{\infty}(x-(Q_1+Q_2))\, f_{D_1}(x)dx + c_{t_1}Q_2\right) \\
& f(\gamma_1)d\gamma_1 f(\gamma_2)d\gamma_2 \\
& + \int_{\gamma_{2_L}}^{\gamma_{2_U}}\int_{\gamma_{1_L}}^{\gamma_{1_U}} (\gamma_2)\,(\gamma_1)\left(c_{o_1}\int_{x=0}^{Q_1}(Q_1-x)\, f_{D_1}(x)dx + c_{u_1}\int_{x=Q_1}^{\infty}(x-Q_1)\, f_{D_1}(x)dx\right) \\
& f(\gamma_1)d\gamma_1 f(\gamma_2)d\gamma_2 \\
& + \int_{\gamma_{1_L}}^{\gamma_{1_U}} \left[(1-\gamma_1)c_{o_1}Q_1\right] f(\gamma_1)d\gamma_1
\end{aligned}$$

$$
\begin{aligned}
E\left[C_1(Q_1,Q_2)\right] \;=\; & \int\limits_{\gamma_{2_L}}^{\gamma_{2_U}} (1-\gamma_2)E[\gamma_1]\left(c_{o_1}\int\limits_{x=0}^{Q_1}(Q_1-x)\,f_{D_1}(x)dx + c_{t_1}\int\limits_{x=Q_1}^{Q_1+Q_2}(x-Q_1)\,f_{D_1}(x)dx\right)\\
& f(\gamma_2)d\gamma_2\\
& +\int\limits_{\gamma_{2_L}}^{\gamma_{2_U}} (1-\gamma_2)E[\gamma_1]\left(c_u\int\limits_{x=Q_1+Q_2}^{\infty}(x-(Q_1+Q_2))\,f_{D_1}(x)dx + c_{t_1}Q_2\right)\\
& f(\gamma_2)d\gamma_2\\
& +\int\limits_{\gamma_{2_L}}^{\gamma_{2_U}} (\gamma_2)\,E[\gamma_1]\left(c_{o_1}\int\limits_{x=0}^{Q_1}(Q_1-x)\,f_{D_1}(x)dx + c_{u_1}\int\limits_{x=Q_1}^{\infty}(x-Q_1)\,f_{D_1}(x)dx\right)\\
& f(\gamma_2)d\gamma_2\\
& +\left[c_{o_1}Q_1\right]\left[F_{\gamma_1}(\gamma_{1_U})-F_{\gamma_1}(\gamma_{1_L})\right]-\left[c_{o_1}Q_1\right]E[\gamma_1]
\end{aligned}
$$

$$
\begin{aligned}
E\left[C_1(Q_1,Q_2)\right] \;=\; & E[\gamma_1]\left[1-E[\gamma_2]\right]\left(c_{o_1}\int\limits_{x=0}^{Q_1}(Q_1-x)\,f_{D_1}(x)dx + c_{t_1}\int\limits_{x=Q_1}^{Q_1+Q_2}(x-Q_1)\,f_{D_1}(x)dx\right)\\
& +E[\gamma_1]\left[1-E[\gamma_2]\right]\left(c_{u_1}\int\limits_{x=Q_1+Q_2}^{\infty}(x-(Q_1+Q_2))\,f_{D_1}(x)dx + c_{t_1}Q_2\right)\\
& +E[\gamma_1]E[\gamma_2]\left(c_{o_1}\int\limits_{x=0}^{Q_1}(Q_1-x)\,f_{D_1}(x)dx + c_{u_1}\int\limits_{x=Q_1}^{\infty}(x-Q_1)\,f_{D_1}(x)dx\right)\\
& +\left[c_{o_1}Q_1\right]\left[1-E[\gamma_1]\right]
\end{aligned} \tag{3.6}
$$

The cost of stocking Q_2 units of inventory for A_2, considering the foreign aid Q_1 that comes from A_1 can be determined similarly by considering different cases.

Expectation cost of stocking Q_2 units of inventory for A_2, considering the foreign aid Q_1 that comes from A_1 :

$$
\begin{aligned}
E\left[C_2(Q_2,Q_1)\right] \quad = \quad & \int\limits_{\gamma_{1_L}}^{\gamma_{1_U}}\int\limits_{\gamma_{2_L}}^{\gamma_{2_U}} (1-\gamma_1)(\gamma_2)\left(c_{o_2}\int\limits_{x=0}^{Q_2}(Q_2-x)\,f_{D_2}(x)dx + c_{t_2}\int\limits_{x=Q_2}^{Q_2+Q_1}(x-Q_2)\,f_{D_2}(x)dx\right) \\
& f(\gamma_1)d\gamma_1 f(\gamma_2)d\gamma_2 \\
& + \int\limits_{\gamma_{1_L}}^{\gamma_{1_U}}\int\limits_{\gamma_{2_L}}^{\gamma_{2_U}} (1-\gamma_1)(\gamma_2)\left(c_{u_2}\int\limits_{x=Q_2+Q_1}^{\infty}(x-(Q_2+Q_1))\,f_{D_2}(x)dx + c_{t_2}Q_1\right) \\
& f(\gamma_1)d\gamma_1 f(\gamma_2)d\gamma_2 \\
& + \int\limits_{\gamma_{1_L}}^{\gamma_{1_U}}\int\limits_{\gamma_{2_L}}^{\gamma_{2_U}} (\gamma_1)\,(\gamma_2)\left(c_{o_2}\int\limits_{x=0}^{Q_2}(Q_2-x)\,f_{D_2}(x)dx + c_{u_2}\int\limits_{x=Q_2}^{\infty}(x-Q_2)\,f_{D_2}(x)dx\right) \\
& f(\gamma_1)d\gamma_1 f(\gamma_2)d\gamma_2 \\
& + \int\limits_{\gamma_{2_L}}^{\gamma_{2_U}} \left[(1-\gamma_2)c_{o_2}Q_2\right] f(\gamma_2)d\gamma_2
\end{aligned}
$$

$$
\begin{aligned}
E\left[C_2(Q_2,Q_1)\right] \quad = \quad & \int\limits_{\gamma_{1_L}}^{\gamma_{1_U}} (1-\gamma_1)E[\gamma_2]\left(c_{o_2}\int\limits_{x=0}^{Q_2}(Q_2-x)\,f_{D_2}(x)dx + c_{t_2}\int\limits_{x=Q_2}^{Q_2+Q_1}(x-Q_2)\,f_{D_2}(x)dx\right) \\
& f(\gamma_1)d\gamma_1 \\
& + \int\limits_{\gamma_{1_L}}^{\gamma_{1_U}} (1-\gamma_1)E[\gamma_2]\left(c_{u_2}\int\limits_{x=Q_2+Q_1}^{\infty}(x-(Q_2+Q_1))\,f_{D_2}(x)dx + c_{t_2}Q_1\right) \\
& f(\gamma_1)d\gamma_1 \\
& + \int\limits_{\gamma_{1_L}}^{\gamma_{1_U}} (\gamma_1)\,E[\gamma_2]\left(c_{o_2}\int\limits_{x=0}^{Q_2}(Q_{21}-x)\,f_{D_2}(x)dx + c_{u_2}\int\limits_{x=Q_2}^{\infty}(x-Q_2)\,f_{D_2}(x)dx\right) \\
& f(\gamma_1)d\gamma_1 \\
& + \left[c_{o_2}Q_2\right]\left[F_{\gamma_2}(\gamma_{2_U}) - F_{\gamma_2}(\gamma_{2_L})\right] - \left[c_{o_2}Q_2\right]E[\gamma_2]
\end{aligned}
$$

$$\begin{aligned}
E\left[C_2(Q_2,Q_1)\right] &= E[\gamma_2][1-E[\gamma_1]]\left(c_{o_2}\int\limits_{x=0}^{Q_2}(Q_2-x)\,f_{D_2}(x)dx + c_{t_2}\int\limits_{x=Q_2}^{Q_2+Q_1}(x-Q_2)\,f_{D_2}(x)dx\right)\\
&\quad +E[\gamma_2][1-E[\gamma_1]]\left(c_{u_2}\int\limits_{x=Q_2+Q_1}^{\infty}(x-(Q_2+Q_1))\,f_{D_2}(x)dx + c_{t_2}Q_1\right)\\
&\quad +E[\gamma_2]E[\gamma_1]\left(c_{o_2}\int\limits_{x=0}^{Q_2}(Q_2-x)\,f_{D_2}(x)dx + c_{u_2}\int\limits_{x=Q_2}^{\infty}(x-Q_2)\,f_{D_2}(x)dx\right)\\
&\quad +\left[c_{o_2}Q_2\right]\left[1-E[\gamma_2]\right]
\end{aligned} \tag{3.7}$$

The aim is to find the optimal stocking quantities, Q_1^* and Q_2^*, that minimize the expected cost function of each agency, given the quantity of the other agency. In order to analyze the convexity of the function, $E\left[C_1(Q_1,Q_2)\right]$, we give the first and second order derivatives with respect to the stocking quantity.

First order derivative of the expectation cost function of A_1 :

$$\begin{aligned}
\frac{dE\left[C_1(Q_1,Q_2)\right]}{dQ_1} &= [1-E[\gamma_2]]E[\gamma_1]\left[c_{o_1}F_{D_1}(Q_1^*) - c_{u_1}(1-F_{D_1}(Q_1^*+Q_2))\right]\\
&\quad +E[\gamma_2]E[\gamma_1]\left[c_{o_1}F_{D_1}(Q_1^*) - c_{u_1}(1-F_{D_1}(Q_1^*))\right]\\
&\quad +c_{o_1}\left[1-E[\gamma_1]\right]
\end{aligned} \tag{3.8}$$

Second order derivative of the expectation cost function of A_1 :

$$\begin{aligned}
\frac{d^2E\left[C_1(Q_1,Q_2)\right]}{dQ_1^2} &= E[\gamma_1]f\left\{_{D_1}(Q_1)\left[c_{o_1}+c_{t_1}+E[\gamma_2]\left(c_{u_1}-c_{t_1}\right)\right]\right\}\\
&\quad +E[\gamma_1]\left\{f_{D_1}(Q_1+Q_2)\left[(c_{t_1}-c_{u_1})\left[E[\gamma_2]-1\right]\right]\right\}\\
&\quad +E[\gamma_1]\left\{\left(\frac{d\left[f_{D_1}(Q_1+Q_2)\right]}{dQ_1}\right)\left[c_{t_1}Q_2\left(1-E[\gamma_2]\right)\right]\right\}
\end{aligned} \tag{3.9}$$

Since we assume that $c_t \geq c_u$ and $f_{D_1}(x)$ is the probability density function of the normal distribution for our model, $\exists(Q_1)$ such that $\frac{d^2E[C_1(Q_1,Q_2)]}{dQ_1} < 0$. As a result, $E\left[C_1(Q_1,Q_2)\right]$ is a nonconvex function. Similarly, it can be showed that $E\left[C_2(Q_2,Q_1)\right]$ is nonconvex. It can be also noted that the nonconvexity property of the expected cost function depends on the type of the probability density function, $f_{D_1}(x)$. Since it is difficult to obtain an analytical solution to the optimization problem in our model, the optimal quantities are computed numerically.

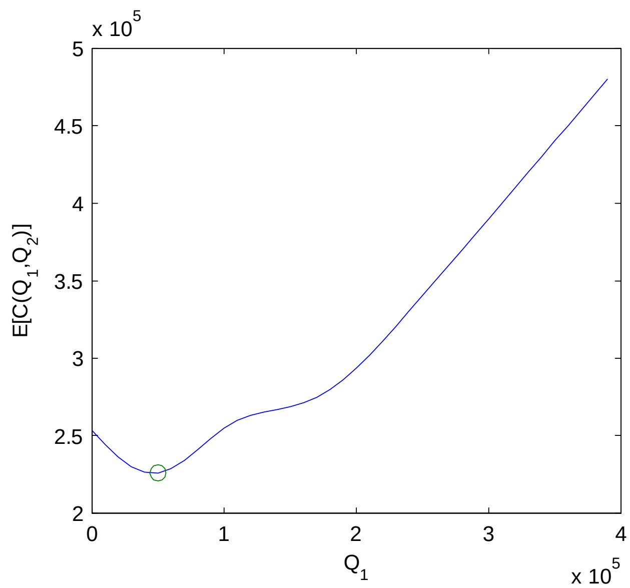
The expected of cost function differs with the other agency's stocking quantity since it is a function of both agencies' actions. Due to the term,

$$K(Q_1, Q_2) = \int_{x=Q_1}^{Q_1+Q_2} (x - Q_1)\, f_{D_1}(x) dx$$

the expectation cost function is nonconvex. In order to demonstrate the nonconvexity behaviour of the expected cost function, we present two numeric examples. These examples also show how the term that distorts the convexity of the expected cost function changes its behaviour.

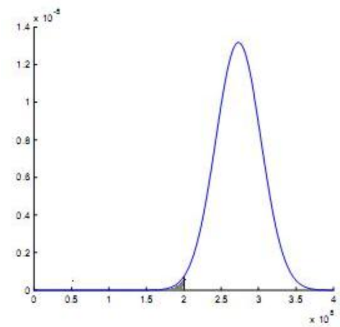
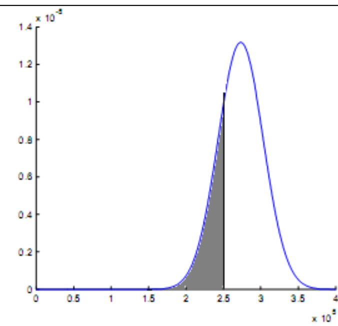
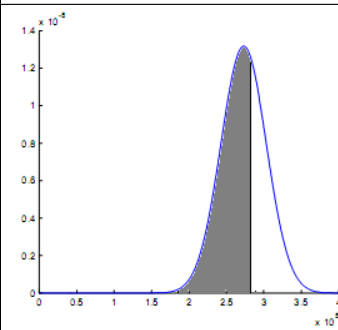
Let analyze the expected cost function when the given quantity of the other agency is specifically 150000 and assume that the probability density function of the demand is normal distribution with mean 272953 and standard deviation 30298. Table 1 presents the behaviour of the function when the given quantity of the second agency is 100000.

Table 1 The expectation of the cost function



In Table 2, we present the value of $K(Q_1, Q_2)$ term for different Q_1 values in order to explain the behaviour of the expected cost function. Since the quantity of the term $(x - Q_1)$ is the same for all Q_1 values, the shaded areas explain how the expectation of the cost increases as Q_1 value rises.

Table 2

$Q_1 = 50000$	$Q_1 = 150000$	$Q_1 = 180000$
		

The expected cost function when the given quantity of the second agency is 180000 is presented in Table 3. Table 4 also presents the value of $K(Q_1, Q_2)$ term for different Q_1 values.

Table 3 The expectation of the cost function

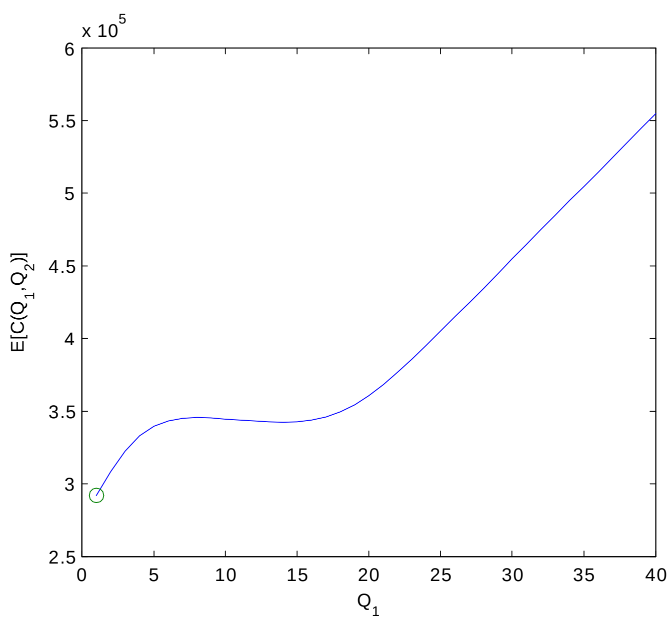
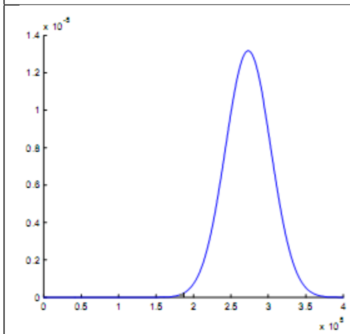
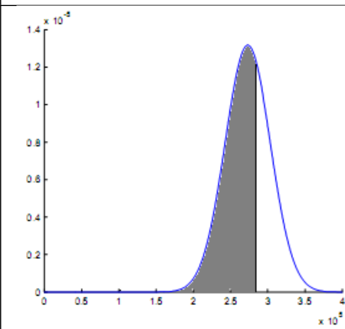
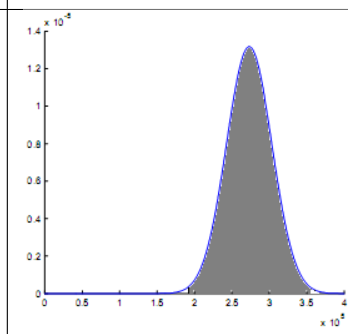


Table 4

$Q_1 = 0$	$Q_1 = 100000$	$Q_1 = 180000$
		

As it can be seen in the tables, when the stocking quantity of the second agency is given as 100000, the expectation of the cost increases rapidly as Q_1 increases. Due to the shape of the probability density function of the normal distribution, its increase lessens and then rises again. When the given quantity of the second agency is 180000, the expectation of the cost increases more rapidly since Q_2 shifts the shaded area to the right quickly. As we can see, minimum of the expected cost function is zero when Q_2 is 180000. In the case that Q_2 is 100000, the zero value of Q_1 makes the value of the expected cost function negative. Thus, the first value that makes it minimum is selected as the minimizer.

In some cases, this behaviour of the expected cost function causes jump points in the best response curves of the agencies as Q_1 values increases regularly.

In this thesis we adopt the assumption that the relief aid agencies are two rational agents and frame the problem in a game theoretical approach by modeling the contest as a two-player single stage game, then we point to the corresponding equilibrium solution as reference solution for our proposed model.

3.3 Applying the Game Theoretical Solution Approach to the Model with Cooperation

In this section we apply the pure strategy Nash Equilibrium solution concept, which is a commonly used solution approach for the question of which action should be selected in a single stage game, to our proposed model with cooperation. Here, an action is a stocking decision that is given by a relief aid agency in our setting. We first review the two basic concepts in game theory: the best response behaviour and the principle of Nash Equilibrium.

3.3.1 Best Response Behaviour

A player's best response is a strategy that provides him or her with the highest possible payoff, assuming that other players behave in a specified way. A player maximizes its own payoff in playing a best response that is a function of both players' actions. For our setting, a relief aid agency showing a behavior of best response selects the stocking quantity corresponding to the minimum expected cost in the single stage game. Thus, best response for our model can be regarded as the expected cost minimizing action. A best response function shows the relationship between one player's choice and the other's best response and a player's best response curve shows its best choice in response to each possible choice by its rival. For our model, the best response for agency A_1, given the other agency's stocking choice is computed from equation 3.8. Any solution that sets the first order derivative to zero satisfies the necessary condition for optimality and is a candidate to be a global minimizer. In order to find the global minimum solution, we select the candidate solution which minimizes equation 3.6. The best response for agency A_2 is obtained similarly. Since we can not compute the value(s) for the candidate solution(s) explicitly from equation 3.8, we implement a numeric search starting with various initial solutions.

3.3.2 Nash Equilibrium

In general, a Nash Equilibrium (NE) is a profile of strategies such that each player's strategy is a best response to the other players' strategy. Here, in the context of the single stage game, the players' strategy consists of a single specific action. We begin with some elementary definitions in order to define the Nash Equilibrium formally.

Let S_i denote the set of strategies available to player i (called $i's$ strategy space), and let s_i denote an arbitrary member of this set. (We will occasionally write $s_i \in S_i$ to indicate that the strategy s_i is a member of the set of strategies S_i.) Let $(s_1, ..., s_n)$ denote a combination of strategies, one for each player, and let u_i denote player $i's$ payoff function: $u_i(s_1, ..., s_n)$ is the payoff to player i if the players choose the strategies $(s_1, ..., s_n)$. Collecting all of this information together, we have:

Definition 1 *The* ***normal-form representation*** *of an n-player game specifies the players' strategy spaces* $S_1, ...S_n$ *and their payoff functions* $u_1, ..., u_n$. *We denote this game by* $G = \{S_{1,...}, S_n; u_1, ...u_n\}$.

Definition 2 *In the n-player normal form game,* $G = \{S_1, ..., S_n; u_1, ...u_n\}$, *the strategies* $(s_1^*, ...s_2^*)$ *are a* ***Nash Equilibrium*** *if, for each player* i, s_i^* *is (at least tied for) player* i*'s best response to the strategies specified for the* $n-1$ *other players,* $(s_1^*, ..., s_{i-1}^*, s_{i+1}^*, ..., s_n^*)$:

$$u_i(s_1^*, ..., s_{i-1}^*, s_{i+1}^*, ..., s_n^*) \geq u_i(s_1^*, ..., s_{i-1}^*, s_i^*, s_{i+1}^*, ..., s_n^*) \tag{3.10}$$

for every feasible strategy s_i in S_i; that is, s_i^* solves

$$\max_{s_i \in S_i} u_i(s_1^*, ..., s_{i-1}^*, s_i^*, s_{i+1}^*, ..., s_n^*)$$

NEs are consistent predictions of how the game will be played. In the sense that if all players predict that a particular NE will emerge then no player has the incentive to play differently. Thus, a NE can have the property that the players can predict it; predict that their opponents predict it, and so on. The NE is a value for the game's stability. If it is successfully established the game has a steady and therefore predictable outcome. So, the emerging steady point of the cooperation can be regarded as Nash Equilibrium from the perspective of game theory. For the proposed model with cooperation, a NE consists of Q_1^* and Q_2^* that minimizes equations 3.6 and 3.7, respectively. Here, we generate the best response curve for all possible stocking values for the other agency. We identify the NE point(s) by intersecting the two best response curves in the graphs generated.

Chapter 4

APPLICATION OF THE SINGLE AGENCY MODEL TO ISTANBUL

In this chapter, we first determine two kinds of parameter values that are needed for the application of the Single Agency Model (SAM) model to the Istanbul case: the probability that a major earthquake happens around Istanbul within our single inventory cycle and the demand distribution for relief aid in Istanbul when a major earthquake happens. We also propose an approach to set the cost parameters reasonably. Then, we solve *the Single Agency Model* using these parameters and present the numerical results.

4.1 *Estimating the Probability of the Occurrence of an Earthquake Beneath the Marmara Sea Within a Time Horizon*

4.1.1 Introduction

The North Anatolian Fault Zone is the most active fault in Turkey that has generated nine $M \geq 6.7$ earthquakes in the period between A.D. 1500 and 2000. These large earthquakes are used to build interevent and elapsed times for use in probability calculations. Six of these events (1509-1894) were assigned magnitudes from MMI values determined from damage descriptions as given in Table A1. Assignment of historical earthquakes to faults indicates possible repeated rupture of some segments. From these earthquake data, interevent and elapsed times can be estimated for three major North Anatolian fault segments (Ganos, Prince's Island, Izmit) by using the observed time difference between events and the open interval at the beginning and end of the 500 year interval between A.D. 1500 and 2000. 17 August 1999 $M = 7.4$ Izmit Earthquake also caused stress changes beneath the Sea of Marmara. So, the time-dependent effect of stress transferred by the 1999 moment magnitude $M = 7.4$ Izmit earthquake to faults nearer Istanbul is also included in this study.

In this section, new earthquake probability calculations are made for the North Anatolian fault segments using the description of earthquakes on the North Anatolian Fault Zone (NAFZ) in the Marmara Sea during the past 500 years, using the method given in [35] and

[36]. The results presented here are the probability of the earthquake occurrence beneath the Marmara Sea within five year determined from both Time-dependent and Interaction Probability Models. This time interval is also the time cycle for our Newsvendor model. The most effect of adding stress transfer to calculations is an increase in the five year probability of a $M \geq 7$ earthquake affecting Istanbul.

4.1.2 Time-Dependent (Renewal) Probability Model

A time-dependent probability calculation is based on the renewal hypothesis of earthquake regeneration wherein the likelihood of an earthquake on a given fault is lowest just after the last shock. The conditional probability that an earthquake occurs in the next ΔT years, given that it has not occurred in the last T years is given by;

$$P(T, \Delta T) = \frac{\int_{T}^{T+\Delta T} f(t)dt}{\int_{T}^{\infty} f(t)dt}$$

where $f(t)$ can be any probability density function for the earthquake recurrence intervals, T is the elapsed time and ΔT is the exposure period. The Brownian distribution is used in this study to make time-dependent probability calculations and it is given by

$$f(t, \mu, \alpha) = \sqrt{\frac{\mu}{2\pi\alpha^2 t^3} \exp\left(-\frac{(t-\mu)^2}{2\mu\alpha^2 t}\right)}$$

where μ is the average interevent time and α is the aperiodicity, equivalent in concept to the coefficient of variation (CV) in a normal distribution.

Interevent times for segments were repeatedly drawn at random from normal distributions [35]. The modeled interevent times are taken as the mean values of the normal distribution for each segment [36] as given in Table 5.The distributions that can create interevent times ranging from $\mp 80 - 100$ around the modeled values are considered.

Table 5 Modeled interevent times for fault segments on NAFZ

Fault	**Events**	**Observed Δtime in A.D 1500-2000**	**Model Int.Time**	**M**
Ganos	1766,1912	146	~ 207	~ 7.5
Prince's Island	1509,1766	257	~ 270	~ 7.3
Izmit	1719,1999	280	~ 288	~ 7.4
Cinarcik M ~ 7	1556,1754,1894	169	~ 250	~ 7.0

Thirty year (as current year is 2004) and five year (as current year is 2009) time-dependent earthquake probabilities were calculated for the three identified fault segments beneath the Sea of Marmara using the interevent times of Table 1 and aperiodicity value of $\alpha = 0.5$.No catalog is adequate to estimate the CV of the inter-event time, so a conservative value of 0.5 is used [36]. Additionally, a 30 year Poisson calculation was made for "floating" $M \sim 7$ earthquakes based on three events identified between A.D. 1500-2000 (interevent time ~ 250 years) [35]. Reported time-dependent probability values with one standard deviation are the means of 100 calculations made per segment, with interevent times drawn at random from normal distributions about the modeled interevent times. This process enables examination of standard deviations on probability values as can be seen in Table 2.

4.1.3 Interaction Probability Model

17 August 1999 $M = 7.4$ Izmit Earthquake caused stress changes beneath the Sea of Marmara. This model provides us to incorporate stress changes into the earthquake probability calculations. Dieterich [1994] derived a time-dependent seismicity rate $R(t)$, after a stress perturbation as,

$$R(t) = \frac{r}{\left[\exp\left(\frac{-\Delta\tau}{a\sigma}\right) - 1\right] \exp\left[\frac{-t}{t_a}\right] + 1}$$

where r is steady state seismicity rate, $\Delta\tau$ is stress step (Coulumb stress change), σ is normal stress, a is fault constitutive constant, and t_a is observed aftershock duration.

The transient change in expected earthquake rate $R(t)$ after a stress step can be related to the probability of an earthquake of a given size over the time interval Δt through a nonstationary Poisson process as,

$$P(t,\Delta t) = 1 - \exp\left[-\int\limits_{t}^{t+\Delta t} R(t)dt\right] = 1 - \exp\left(-N(t)\right)$$

where $N(t)$ is expected number of earthquakes in the interval Δt.

This transient probability change is superimposed on the permanent change that results from a time shift, or a change in the repeat time as discussed previously. Integrating for N(t) yields,

$$N(t) = r_p \left\{ \Delta t + t_a \ln \left[\frac{1 + \left[\exp\left(\frac{-\Delta\tau}{a\sigma}\right) - 1\right] \exp\left[\frac{-\Delta t}{t_a}\right]}{\exp\left(\frac{-\Delta\tau}{a\sigma}\right)} \right] \right\}$$

where r_p is expected rate of earthquakes associated with the permanent probability change. This rate can be determined by again applying a stationary Poisson probability expression as,

$$r_p : \left(\frac{-1}{\Delta t}\right) \ln(1 - P_c)$$

where P_c is a conditional probability calculated using the Brownian Distribution.

An interaction probability calculation that incorporates static and transient effects requires values for the stress change caused by the 17 August $M = 7.4$ Izmit earthquake (Δt), an observed aftershock duration (t_a), the combination of normal stress and constitutive constant ($A\sigma$), and the secular stressing rate ($\dot{\tau}$) on a receiver fault.

In this study the secular stressing rate on the Marmara Sea faults is calculated using a finite element model, and $A\sigma$is found using equation,

$$\dot{\tau} = \frac{A\sigma}{t_a}$$

A regional aftershock decay time for large ($M \geq 6.7$) earthquakes was found by Parsons et al. from the 1939–1999 triggered earthquake sequence along the North Anatolian fault to be 35 years [36].

The mean stress change on Marmara Sea faults is a 0.04 MPa ($\Delta\tau$) stress increase and stressing rate on each fault derived from the fault geometry and the observed strain rate is 0.01 MPa/yr ($\dot{\tau}$) [36],[35].

Reported interaction probability values (one standard deviation) are also the means of 100 calculations made per segment, with interevent times drawn at random from normal distributions about the modeled interevent times and with the given parameter values for stress change, stressing rate and transient duration.

4.1.4 Numerical Results

In this section, we demonstrate the implementation of the method presented in [35]. The results of thirty year probability calculations are checked with the results of the ones in Parson's model and it is concluded that they are reasonably close to each other. Then we present five year probability calculations that will be used in the application of the proposed model which provides to determine the optimum stocking quantity under disaster risk. Thirty and five year probability calculation are given in Table 6 and Table 7, respectively. In tables, the earthquake probability values for each segments computed using time-independent Poisson distribution, Time-Dependent (Renewal) Probability Model and Interaction Probability Model are demonstrated. The combined time-dependent probability for all segments is also presented in results. $\boldsymbol{\sigma}_T$ and $\boldsymbol{\sigma}_I$ refer to the standard deviation of results of the time-dependent probability model and the interaction probability model, respectively.

Table 6 Thirty year Probability Calculations

Fault	**Poisson**	**Time-Dependent**	**Interaction**	$\boldsymbol{\sigma}_T$	$\boldsymbol{\sigma}_I$
Ganos	0.14	0.1590	0.1887	0.1368	0.1424
Prince's Island	0.11	0.2047	0.2105	0.0791	0.0774
Izmit	0.10	~ 0	~ 0	-	-
Cinarcik M ~ 7	0.11	0.11	0.11	-	-
Combined	0.38	0.3431	0.3595	0.1123	0.13

Table 7 Five year Probability Calculations

Fault	**Poisson**	**Time-Dependent**	**Interaction**	$\boldsymbol{\sigma}_T$	$\boldsymbol{\sigma}_I$
Ganos	0.023	0.0227	0.0277	0.0120	0.0163
Prince's Island	0.018	0.0353	0.0396	0.0102	0.0092
Izmit	0.017	~ 0	~ 0	-	-
Cinarcik M ~ 7	0.019	0.019	0.019	-	-
Combined	0.058	0.0587	0.0650	0.0151	0.0166

The probability of a $M \geq 7$ earthquake rupturing beneath the Sea of Marmara is $4.84 - 8.16\%$ in the next five years if a time-dependent model that includes coseismic and postseismic effects of the 1999 $M = 7.4$ Izmit earthquake is used. We use this result in the application of our Single Agency Model and the Model with Cooperation to determine the optimal relief aid stocking quantity for Istanbul.

4.2 Demand Estimation for Relief Aid in Istanbul

4.2.1 Introduction

An earthquake, occurring beneath the Sea of Marmara may cause several damage in Istanbul as a huge number of buildings are expected to collapse after a $M \geq 7$ earthquake. A study carried out by Japan International Cooperation Agency (JICA) in 2002 analyzed the risk in Istanbul on the basis of different earthquake scenarios. This JICA report provides information on the earthquake risk in the districts of Istanbul and the estimation of demand for relief aid in these districts. It should be noted that the earthquakes considered in the JICA study are similar in magnitude and intensity characteristics to those given by Parsons in 2004, in which earthquakes with $M \geq 7$ are considered, and Parsons et al. (2000), in which earthquakes causing equal or greater than 8 shaking intensity are considered [22].

In this section, we use the estimates of damage that would result from the earthquake scenarios reported in the JICA study to determine the demand distribution for relief aid in different districts of Istanbul after a devastating earthquake within the next five years.

4.2.2 The JICA Study

The JICA (Japan International Cooperation Agency) study was performed by the team organized jointly by Pacific Consultants International and OYO Corporation under the contract with JICA. It was a comprehensive study on disaster prevention and mitigation for Istanbul including seismic microzonation.

In this section, we intend to calculate the probable damage and the associated relief supply demand distribution in Istanbul. In the JICA study, four scenario earthquake models were determined to be used in the analysis. Parameters of each model were defined as shown in Table 8. Scenario fault models are also presented in Figure 1. Model A was the most probable model and Model C was the worst case. On the basis of high conditional probabilities, a moment magnitude 7.7 earthquake associated with the rupturing of four segments in the Marmara Sea is selected as the "Worst Case Scenario Earthquake".

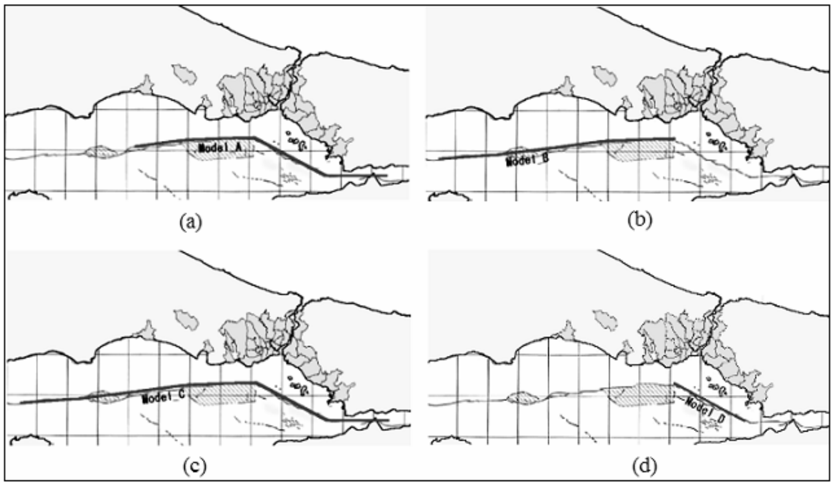


Figure 1 Scenarios; (a),(b),(c),(d) are Models A,B,C,D, respectively

Table 8 Parameters of the scenario earthquake models

	Model A	Model B	Model C	Model D
Length (km)	119	108	174	37
Moment magnitude (Mw)	7.5	7.4	7.7	6.9
Dip angle (Degree)	90	90	90	90
Depth of upper edge (km)	0	0	0	0
Type	Strike-slip	Strike-slip	Strike-slip	Normal fault

In this section, we consider the data of the "Worst Case Scenario Earthquake" while modeling the demand distribution for needed tents after an earthquake, regarding the number of damaged buildings as the number of needed tents after an earthquake. Characteristics of demand distributions for relief aid that are obtained for thirty districts of Istanbul that is expected to be affected by a possible earthquake can be found in Table 5, Table 6 and Table 7.

4.2.3 Damage Ratios for Districts of Istanbul

In the study conducted by JICA, earthquake damage scenario results indicate that a massive number of buildings will be damaged. It is estimated that a total of approximately 272,953 buildings (37.7% of the total) will be damaged beyond repair on the basis of the "Worst Case Scenario Earthquake"

The methodology used for damage estimation is presented in Figure 2. Damage states for the buildings were defined as “Heavily damaged”, “Moderately damaged” and “Partly damaged”. Fragility functions were obtained employing a probabilistic method. These functions were utilized to compute damage ratios. And finally, damage ratios for the districts are used while computing the number of damaged buildings and multiplied by the number of buildings that is counted in the inventory to estimate the number of damaged buildings.

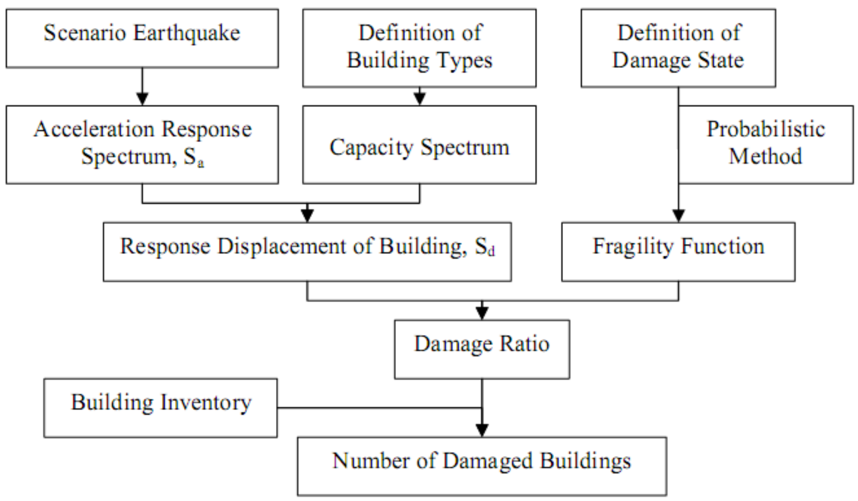


Figure 2 Flowchart of the methodology used for damage estimation

In this section, we consider the "heavily", "moderately" and "partly" damaged buildings as "unusable" and include them to calculations of the number of tents needed. For the worst case scenario earthquake, a breakdown of the estimated damage ratios and building damages at the district level is given in Table B1**.**

4.2.4 Demand Estimation Model

Our models need the distribution of demand in order to find the optimal stocking quantity. However, disasters are rare events and there is hardly enough past data to estimate the distribution of demand for relief commodities in a specific disaster situation with sufficient precision. The approach in this study to overcome this problem is to use the point estimation in the JICA study as the mean of demand and add a demand variation with parameters α and β. We assume a normal distribution with estimated mean and variation values.

The severity of an earthquake can be expressed in terms of both *intensity* and *magnitude*

[42]. So, the magnitude of an earthquake describes the absolute size of the event and it can be considered as a measure of the energy released by the earthquake. Although earthquakes of similar magnitudes can cause differing levels of damage according to the difference in their depth or mechanism of fault rupture, generally higher magnitude earthquakes are much more devastating than the smaller ones. The moment magnitude of "Worst Case Scenario Earthquake" is 7.7 as it can be seen in Table 4. The damage ratios for districts of Istanbul given in Table B1, are the results of an earthquake whose magnitude is 7.7. As the magnitude of the earthquake differs, demand for relief aid differs, too. In Section 4.1, five year earthquake probability calculations are made for the North Anatolian fault segments using the description of $M \geq 7$ earthquakes on this fault. Since the magnitude of the earthquake is not a certain value for these calculations, the demand variation parameter α will provide us to add the demand ratio variability that comes from the uncertainty of the earthquake magnitude to our demand estimation.

Moreover, the demand variation parameter α can be considered as the term that includes the variability due to the uncertainty of damage state of the buildings. Regarding all these uncertainties in the values used while computing the demand quantity, the parameter α can be also considered as the error term in our *Demand Estimation Model.*

The impact of an earthquake can vary due to the damage states of the buildings. Since the constructions have different seismic vulnerabilities, the increase in the earthquake magnitude can cause different type of damage in the buildings. For instance, a building that is estimated to be moderately damaged for a 6.7 magnitude earthquake can be a heavily damaged building for a 7.0 magnitude earthquake. However, the same rise in earthquake magnitude may not change the damage state of a building that is estimated to be heavily damaged. We consider a β parameter in order to observe the effects of different magnitude earthquakes on the number of damaged buildings in different conditions. β parameter can also be regarded as a coefficient corresponding to the contribution of different damage states to the standard deviation of the demand distribution. This parameter provides us to control the degree of variation for the buildings that are predicted to be in different damage states.

Let,

N_i : Number of the buildings in district i.

R_{ij} : Damage ratio for the buildings that is in damage state j, in district i.

α : Demand variation parameter. α is a random variable.

β_j : Coefficient chosen to control the degree of variation for the type of buildings that is in damage state j. Damage states can be "Heavily damaged (State 1)", "Heavily and Moderately damaged"(State 2) or "Heavily, Moderately and Partly damaged"(State 3).

Demand for relief aid in district i,

$$\begin{aligned} D_i &= \sum_{j=1}^{3} N_i \left(R_{ij} + \beta_j \alpha\right) \\ \text{where } \alpha &\backsim N(0,1) \text{ and } j = 1, 2, 3. \end{aligned}$$

When we assume that α has a normal distribution and β_j is a constant coefficient, D_i's are also normally distributed with mean,

$$\mu_{D_i} = N_i \left(\sum_{j=1}^{n} R_{ij} \right) \tag{4.1}$$

and standard deviation,

$$\sigma_{D_i} = N_i \left(\sum_{j=1}^{n} \beta_j \right). \tag{4.2}$$

4.2.5 Application of the Demand Estimation Model to Istanbul

We apply the proposed demand estimation model to Istanbul, considering the case of Turkish Red Crescent that stocks tents. Demand distributions for tent are calculated for all districts of Istanbul independently and then the total demand distribution in Istanbul is obtained. Here we note that it is possible to utilize a SAM for each district independently, using the demand distribution for that district, to obtain the quantity to be stocked in each district. In what follows we use a single model with total demand distribution to find the stocking quantity for the city.

We determine three different demand distributions for Istanbul setting different β values. In the first one, we consider that the contributions of all damage states have $\beta_j = 0.01$. In the other cases, the coefficients are modified according to the damage states' contribution to the variation of the demand.

The β parameters that is used to determine the demand distributions are given in Table 9. Demand distribution of each district is normally and independently distributed with the mean and standard deviation values computed from equations 4.1 and 4.2. The parameters of the obtained demand distributions for each district are given in Tables 10 and 11.

Table 9 β_j values for different demand distributions

	β_1	β_2	β_3
Demand1	0.01	0.01	0.01
Demand2	0.1	0.01	0.001
Demand3	0.1	0.1	0.1

Table 10 Mean and standard deviation values of the distribution of demand in the districts of Istanbul

District	$\boldsymbol{\mu}$	$\boldsymbol{\sigma_1}$	$\boldsymbol{\sigma_2}$	$\boldsymbol{\sigma_3}$
Adalar	4254	127.6	472.2	1276.2
Avcilar	8270	248.1	418	2481
Bahcelievler	12305	369.1	1365.9	3691.5
Bakirkoy	6792	203.7	753.9	2037.6
Bagcilar	15771	473.1	1750.6	4731.3
Beykoz	4481	134.4	497.4	1344.3
Beyoglu	10989	329.6	1219.8	3296.7
Besiktas	4175	125.2	463.4	1252.5
Buyukcekmece	1806	54.1	200.5	541.8
Bayrampasa	10261	307.8	1139	3078.3
Eminonu	7279	218.3	808	2183.7
Eyup	9426	282.7	1046.3	2827.8
Fatih	18900	567	2097.9	5670
Gungoren	6402	192	710.6	1920.6
Gaziosmanpasa	15551	466.5	1726.2	4665.3

Table 11 Mean and standard deviation values of the distribution of demand in the districts of Istanbul

District	μ	σ_1	σ_2	σ_3
Kadikoy	13569	407	1506.2	4070.7
Kartal	10198	305.9	1132	3059.4
Kagithane	8134	244	902.9	2440.2
Kucukcekmece	20641	619.2	2291.2	6192.3
Maltepe	9503	285	1054.8	2850.9
Pendik	15263	457.8	1694.2	4578.9
Sariyer	4437	133.1	492.5	1331.1
Sisli	6093	182.7	676.3	1827.9
Tuzla	6344	190.3	704.2	1903.2
Umraniye	9434	283	1047.2	2830.2
Uskudar	10361	310.8	1150.1	3108.3
Zeytinburnu	10184	305.5	1130.4	3055.2
Esenler	9111	273.3	1011.3	2733.3
Catalca	564	16.9	62.6	169.2
Silivri	2498	74.9	277.3	749.4
TOTAL	272953	8188.6	30298	818.8

4.3 Determination of Cost Parameters

In this section, we give the definition of the underage, overage and transfer costs for our models to determine the optimum stocking quantity under disaster risk.

The overage cost (c_o) is the cost of having one unit left at the end of our time cycle. It is charged if a disaster does not occur or demand for relief commodity is lower than our stock. As we explain in Section 3.1, the overage cost consists of five different costs. The overage cost is defined as,

$$c_o = c_{pt} + c_h + c_m + c_{op} - c_s$$

where,

c_{pt} : cost of purchasing a tent,

c_h : holding cost per item per cycle time,

c_m : maintainance cost for each item per cycle time,

c_{op} : opportunity cost of stocking one unit item during the cycle time,

c_s : unit salvage value of the tents at the end of the cycle time.

Here, the opportunity cost (c_{op}) is important for our stocking relief commodity problem. Since the main goal of disaster response is to provide more aid to the victims of the disaster, where we use our financial resources is an important issue. This cost is also the cost of using money to purchase a tent instead of providing another service to the people.

The other important parameter for our stocking problem is the underage cost (c_u) which is the cost of being one unit short. Since this opportunity cost depends on the strategy of the relief aid agency, it is also related to the economic situation of the country. We assume the premise that being short by one unit in meeting demand of the victims of the disaster is more costly for an agency in an economically more developed country. We use the data from the Global Competitiveness Report (CPR) 2008-2009. The report assesses "the ability of countries to provide high levels of prosperity to their citizens, in turn, how productively a country uses available resources" [20].

We define the underage cost (c_u) as,

$$c_u = R * c_{pp}$$

where,

c_{pp}: cost of purchasing a prefabricated house as a substitute for a tent.

R : ranking ratio of the country according to the CPR.

$$R = \frac{s_i}{s_{best}}$$

where,

s_i : score of the country according to the CPR,

s_{best} : score of the first ranked country.

In order to determine the underage cost, we multiply this ranking ratio with the cost of purchasing a prefabricated house, which is used as a proxy to represent the shelter cost for a family that cannot be provided a tent. We assume that the opportunity cost of not providing adequate level of service as expected by the victims of disaster is the cost of purchasing a prefabricated house, which the people have to pay if if they are not provided a tent.

The values of these parameters are given in Table C1.

4.4 Using the Single Agency Model to Decide on Optimal Tent Stocking Quantity for Istanbul

4.4.1 Introduction

In this section, we apply the Single Agency Model (SAM) to determine the optimal quantity of tents to be stocked at the central depots of the Turkish Red Crescent for the purpose of responding to an earthquake in Istanbul. We use the proposed parameter values that are obtained in Sections 4.1, 4.2 and 4.3; namely the expected probability of the earthquake occurrence beneath the Marmara Sea, the demand distribution for relief aid in Istanbul and the cost parameters.

4.4.2 Solving SAM Numerically

In Section 4.2, demand distribution for shelter units in Istanbul was obtained. The expectation cost function of SAM was given in equation (3.2) and equation (3.3).

In the case that $D_L \leq Q < D_U$,

$$E\left[C(Q)\right] = E[\gamma]\left[c_o \int\limits_{x=D_L}^{Q} (Q-x) f_D(x)dx + c_u \int\limits_{x=Q}^{D_U} (x-Q)\, f_D(x)dx - c_o\right] + c_o Q$$

where, $f_D(x)$ is the probability density function of normal demand with mean mu and standard deviation sigma. D_L and D_U are the lower and upper bounds of the demand distribution, respectively. Then, the expectation cost function is computed by the following.

$$\begin{aligned} E\left[C(Q)\right] \quad = \quad & E[\gamma]\left\{c_o\left[\left(\frac{\mu-Q}{2}\right)\left(\operatorname{erf}\left(\frac{D_L-\mu}{\sqrt{2}\sigma}\right)-\operatorname{erf}\left(\frac{Q-\mu}{\sqrt{2}\sigma}\right)\right)+\frac{\sigma}{\sqrt{2\pi}}\left(e^{-\frac{(Q-\mu)^2}{2\sigma^2}}-e^{-\frac{(D_L-\mu)^2}{2\sigma^2}}\right)\right]\right\} \\ & +E[\gamma]\left\{c_u\left[\left(\frac{\mu-Q}{2}\right)\left(\operatorname{erf}\left(\frac{D_U-\mu}{\sqrt{2}\sigma}\right)-\operatorname{erf}\left(\frac{Q-\mu}{\sqrt{2}\sigma}\right)\right)+\frac{\sigma}{\sqrt{2\pi}}\left(e^{-\frac{(Q-\mu)^2}{2\sigma^2}}-e^{-\frac{(D_U-\mu)^2}{2\sigma^2}}\right)\right]\right\} \\ & -E[\gamma]c_oQ + [c_oQ] \end{aligned}$$

In the case that $Q < D_L < D_U$,

$$E\left[C(Q)\right] = E[\gamma]\left[c_u \int\limits_{x=D_L}^{D_U} (x-Q)\, f_D(x)dx - c_o Q\right] + [c_o Q]$$

In this case, we have

$$\begin{aligned} E\left[C(Q)\right] &= E[\gamma]\left[c_u\left(\frac{x-Q}{2}\,\mathrm{erf}\left[\frac{x-\mu}{\sqrt{2}\sigma}\right]_{D_L}^{D_U} - \frac{\sigma}{\sqrt{2}}\left[\frac{x-\mu}{\sqrt{2}\sigma}\,\mathrm{erf}\left(\frac{x-\mu}{\sqrt{2}\sigma}\right) + \frac{1}{\sqrt{\pi}}e^{-\frac{(x-\mu)^2}{2\sigma^2}}\right]_{D_L}^{D_U}\right) - c_oQ\right] \\ &\quad + [c_oQ] \end{aligned}$$

4.4.3 Numerical Studies

We use the five year earthquake probability calculations for the city of Istanbul determined in Section 4.1 while obtaining the numerical results. The five year probability calculations are used in SAM with a $\mp\sigma$ deviation. So, the explanatory graphs are obtained according to three earthquake scenarios that differ in terms of this variability in the probability of the earthquake occurrence. Hence, we have worst, best and the most probable case earthquake scenarios. The mean value of the calculated probability is called the most probable case. The worst and best cases are the ones in which the probability value deviates from the mean by $+\sigma$ and $-\sigma$, respectively.

In Section 4.2, calculated mean and standard deviation values for demand were found by using different β_j values, where β_j is a coefficient chosen to control the degree of variation for the type of buildings in damage state j. Demand distributions used in this part are obtained by using the β_j values given in Table 12.

Table 12 Characteristics of Different Demand Types

	Mean (μ)	Standard Deviation (σ)
Demand1	272953	8188.6
Demand2	272953	30298
Demand3	272953	818.8

The input parameters used to obtain the graphs are given in Table 13. Worst, most probable and best cases refer to the earthquake probability; Demand1, Demand2 and Demand3 terms refer to the variability in demand. The expected earthquake probabilities in different scenarios are also given in Table 14. We set the upper bound D_U and the lower bound D_L of the demand as $\mu + 10\sigma$ and $\max\{0, \mu - 10\sigma\}$, respectively.

Table 13 Earthquake Probabilities in Different Scenarios

	Expected Probability ($E[\gamma]$)
Worst Case	0.0801
Most Probable Case	0.065
Best Case	0.0499

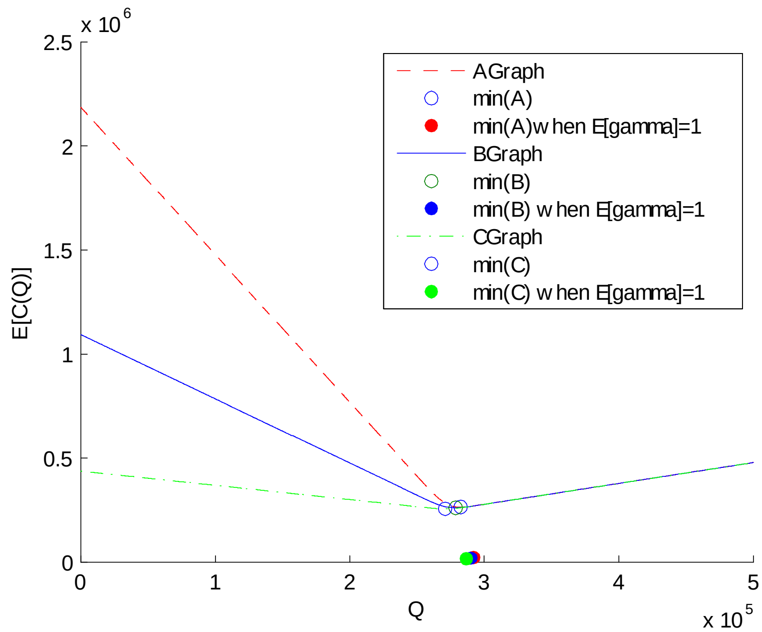
Table 14 Input Values for the Graphs

	Worst Case	*Most Probable Case*	*Best Case*
Demand1	G1	G2	G3
Demand2	G4	G5	G6
Demand3	G7	G8	G9

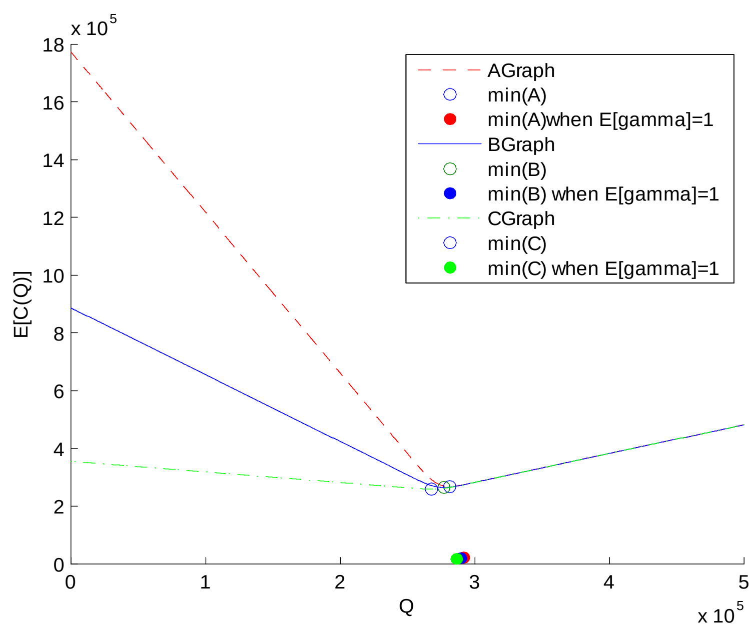
4.4.4 Results and Consequences

Reported A graphs are the stocking quantity-expectation cost graphs that are determined by setting the ratio of underage and overage costs $\left(\frac{c_u}{c_o}\right)$ as 100 , B graphs and C graphs are the ones that are obtained by setting the ratio as 50 and 20, respectively. The graphs represent the relation between the stocking quantity and the expected cost of stocking that amount of item, using different overage and underage cost values. Circles represent the minimum of the drawn graphs while dots refer to the optimal stocking quantity value of the original newsvendor problem in the generated settings, representing the case when the probability that the eartquake occurs is 1..

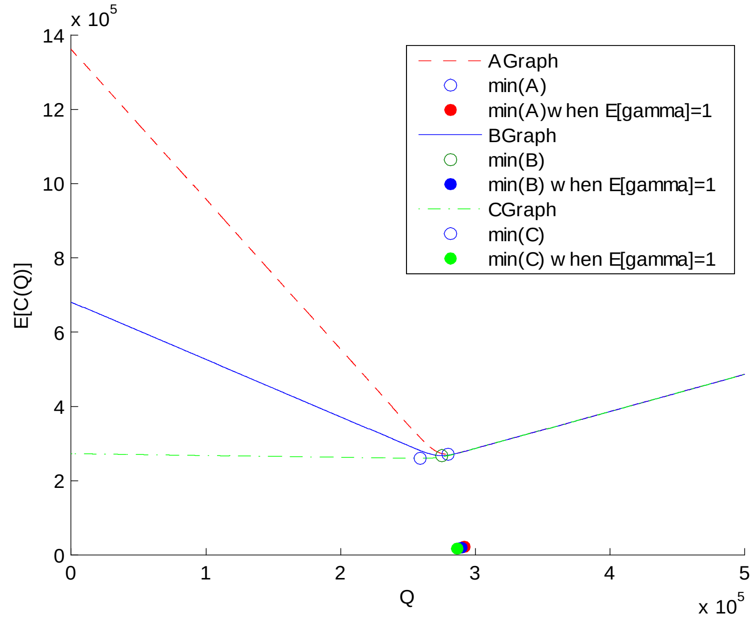
ABC Graphs 1 Worst Case-Demand1



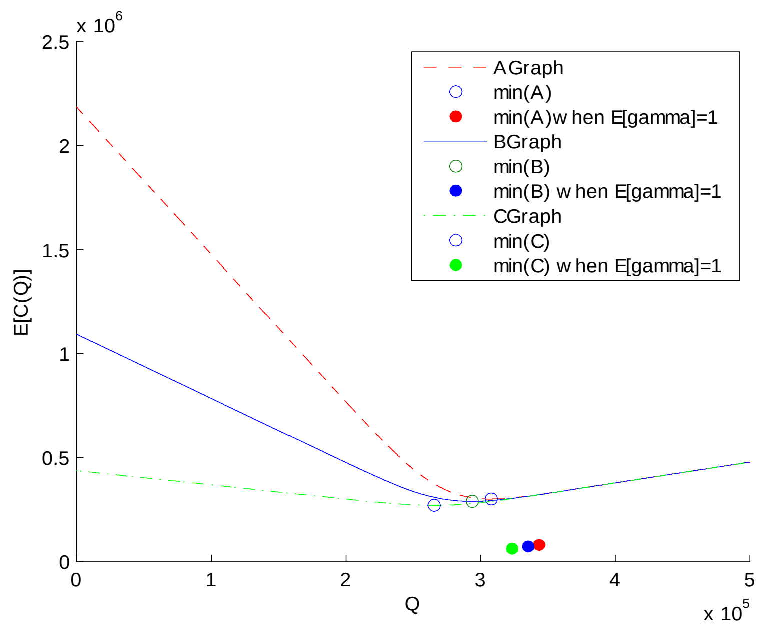
ABC Graphs 2 Most Probable Case-Demand1



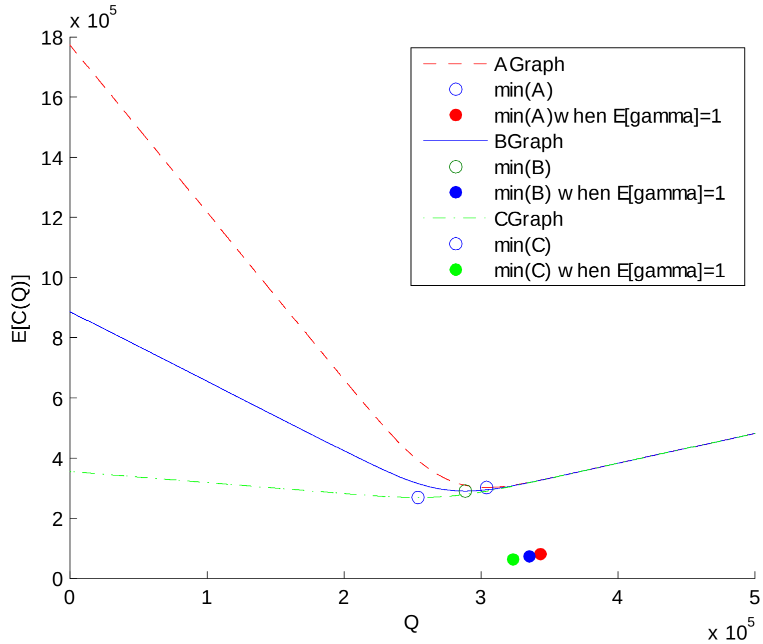
ABC Graphs 3 Best Case-Demand1



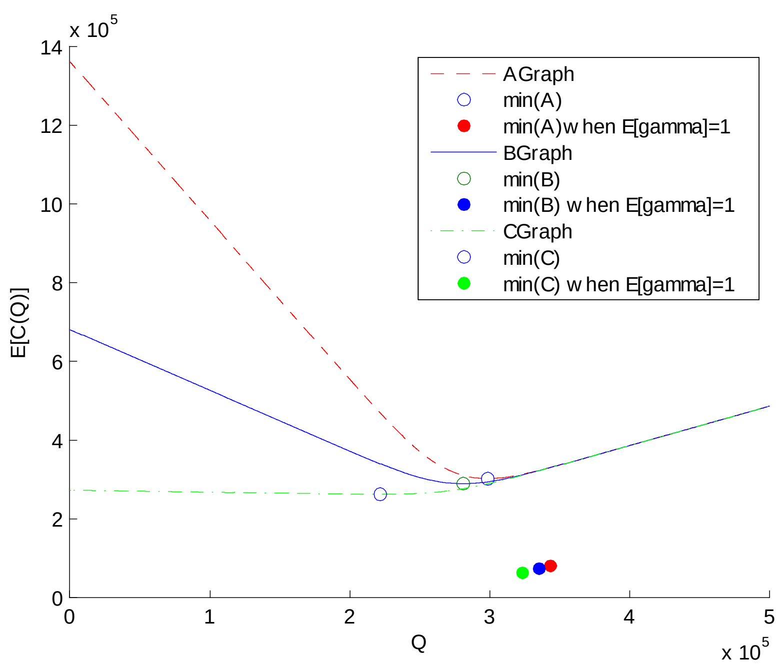
ABC Graphs 4 Worst Case-Demand2



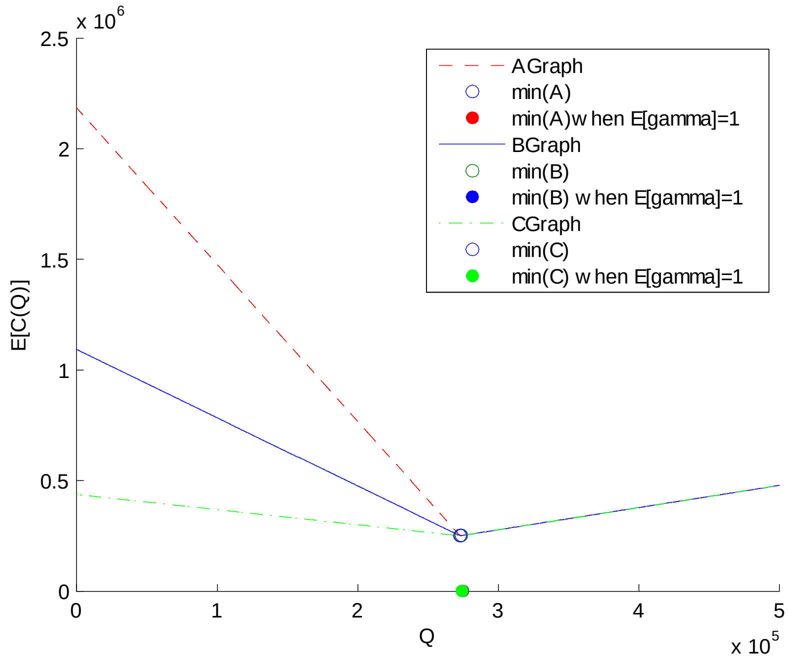
ABC Graphs 5 Most Probable Case -Demand2



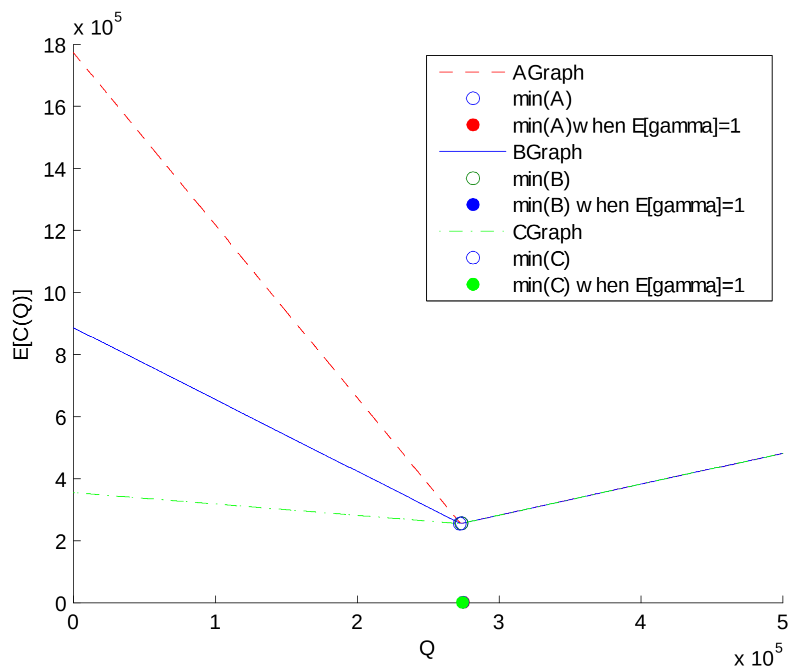
ABC Graphs 6 Best Case -Demand2



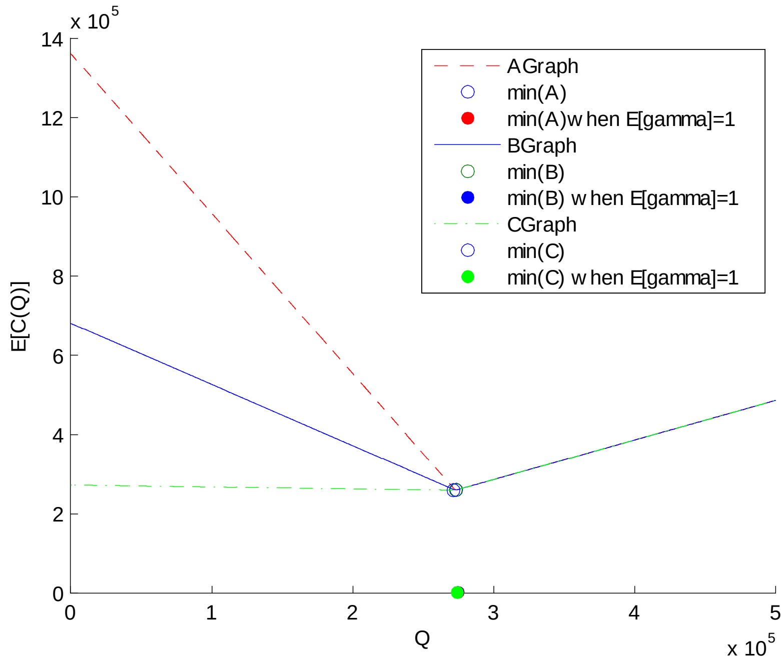
ABC Graphs 7 Worst Case -Demand3



ABC Graphs 8 Most probable Case -Demand3



ABC Graphs 9 Best Case-Demand3



The presented graphs demonstrate the behaviour of the expected cost function of stocking Q unit items of relief supply, the optimal stocking quantities for this settings and the ratio of underage and overage costs increase simultaneously. As the standard deviation of demand decreases, the minimum points of the graphs for different ratio values approach to each other. The optimum stocking quantity values of the original Newsvendor Problem are higher for all A,B and C graphs since the optimal quantity increases as the probability of a disaster occurrence increases.

According to the proposed solution in Chapter 1, optimum stocking quantity Q^* is the value that satisfies equation (3.4),

$$F_D(Q^*) = 1 - \frac{c_o}{E[\gamma]\,[c_o + c_u]}.$$

The optimum values, found by solving this equation is given in Table 15. The characteristics of the input values are the same as the ones that are used while determining A, B and C graphs.

Table 15 Optimum Stocking Quantities

	Q^*		Q^*		Q^*
A1	282430	B1	278610	C1	270990
A2	281360	B2	277210	C2	267870
A3	279890	B3	275180	C3	259130
A4	308010	B4	293890	C4	265710
A5	304050	B5	288700	C5	254150
A6	298620	B6	281180	C6	221810
A7	273900	B7	273520	C7	272760
A8	273790	B8	273380	C8	272440
A9	273650	B9	273180	C9	271570

We demonstrate the optimal stocking quantity values for all generated cases in Table 15. As it can be seen in the table, the values are between 221810 and 308010, and are mostly around 270000. With a similar analysis, decision makers can decide the optimal stocking quantities for a different type of a disaster in a different area and a different relief commodity by estimating the model parameters specifically for their risk circumstances..

Chapter 5

ANALYSIS OF THE MODEL WITH COOPERATION

This chapter includes the analysis and an application of the Two Agency Model (TAM) formulated in Chapter 3. We first give a numerical analysis in order to describe the effects of the model parameters such as the probability of the occurrence of an earthquake within a time horizon and demand for relief aid, on the equilibrium solution. Then we demonstrate the developed modeling approach for a case analysis for Istanbul, using the estimated model parameter values obtained in Chapter 4.

The Nash Equilibrium is a stable operation point, where neither player can gain a higher payoff as introduced in Section 3.3. Also, a player maximizes its own payoff in playing a best response that is a function of both players' actions. Thus, an expected cost minimizing action can be regarded as best response for our setting. To describe the Nash Equilibrium concept in our formulated model, we generate the best response curves for each agency and find numerically where these best response curves intersect.

5.1 Numerical Analysis

This section includes numerical analysis to understand the nature of the equilibrium solution under various parameters settings. The effects of the parameters, the earthquake occurrence probability and the demand for relief aid, are shown by comparing the cooperations with the agencies that have different characteristics. We compare the advantage of one cooperation over another by comparing the stocking quantities of the agencies in each scenario investigated.

5.1.1 Difference in the Value for the Probability of Earthquake

We examine the behaviour of the equilibrium of TAM in different cooperation scenarios when the areas of two distinct relief aid agencies have different or similar earthquake risk.

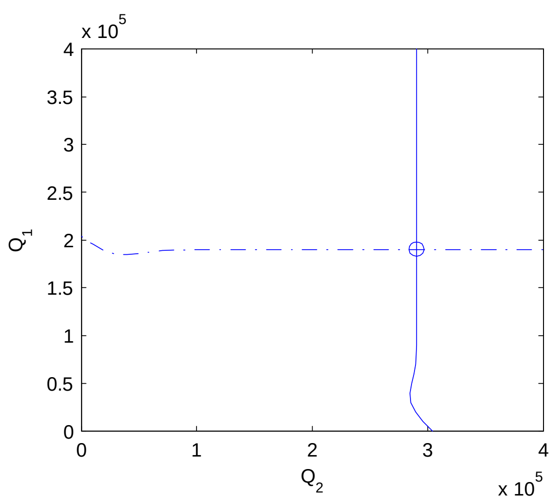
We first generate five different scenarios in terms of the probability of the occurrence of an earthquake. Demand distributions in the areas of the agencies are kept the same in all scenarios in order to identify the change in the roles of the agencies as the expected earthquake occurrence probability changes.

The characteristics and the numerical results of the generated cooperation scenarios are given in Table 16. The normal distribution with mean μ and standard deviation σ is used to describe the uncertainty in estimated demand. γ refers to the forecasted earthquake occurrence probability. r and s represent the ratio of underage and overage costs $\left(\frac{c_u}{c_o}\right)$, and the ratio of underage and transfer costs $\left(\frac{c_u}{ct}\right)$, respectively. A_1 refers to Agency 1 that cooperates with Agency 2 (A_2) during the execution of scenarios. We determine the characteristics of the base case cooperation regarding the current stocking quantity of the Turkish Red Crescent and the parameter values obtained in Chapter 4. As the underage cost value depends on the decision makers, we use the ratio of underage cost and overage costs that roughly corresponds to the stocking quantity of the Red Crescent in our analysis. Demand distribution for relief aid and the expected earthquake probability value are also taken as in case G2 introduced in the previous chapter.

The drawn graphs are the best response curves of the agencies and the intersection points shown in the figures mark the equilibrium stocking decisions.

Table 16 P Scenarios

Scenario P1

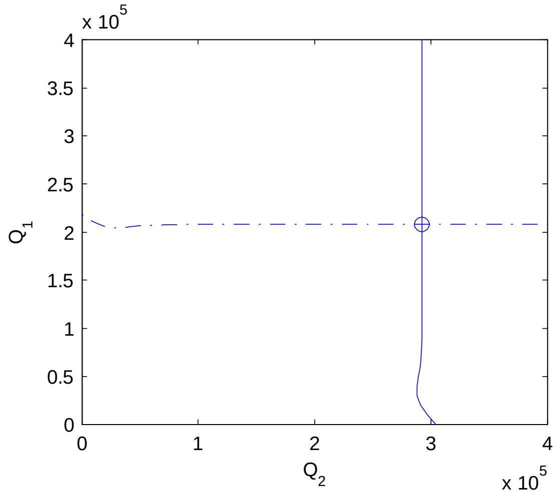


$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	c_u/c_o	c_u/c_t
$\gamma_1 = \gamma_2$	$\mu_1 < \mu_2$	$\sigma_1 = \sigma_2$	$r_1 = r_2$	$s_1 = s_2$

	$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	r	s
A_1	0.065	172953	30298	100	2
A_2	0.065	272953	30298	100	2

	Q_1	Q_2
Eq. Point:	190290	290290

Scenario P2

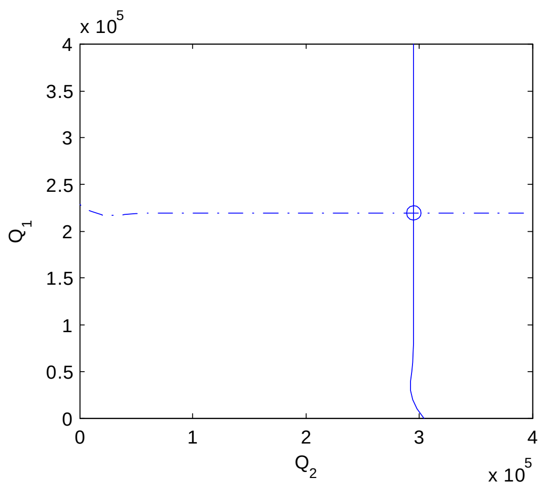


$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	c_u/c_o	c_u/c_t
$\gamma_1 > \gamma_2$	$\mu_1 < \mu_2$	$\sigma_1 = \sigma_2$	$r_1 = r_2$	$s_1 = s_2$

	$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	r	s
A_1	0.15	172953	30298	100	2
A_2	0.065	272953	30298	100	2

	Q_1	Q_2
Eq. Point:	208120	292170

Scenario P3

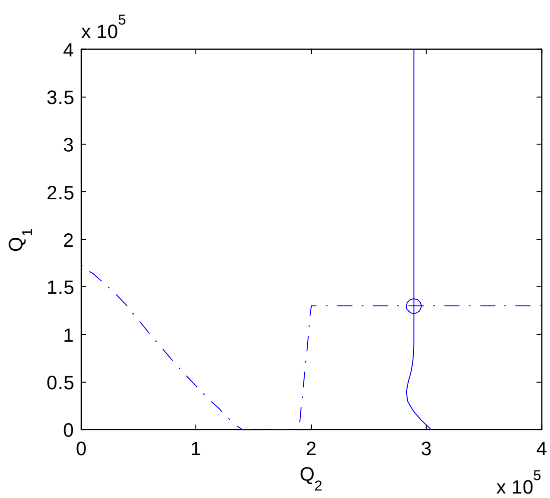


$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	c_u/c_o	c_u/c_t
$\gamma_1 >> \gamma_2$	$\mu_1 < \mu_2$	$\sigma_1 = \sigma_2$	$r_1 = r_2$	$s_1 = s_2$

	$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	r	s
A_1	0.3	172953	30298	100	2
A_2	0.065	272953	30298	100	2

	Q_1	Q_2
Eq. Point:	219700	295030

Scenario P4

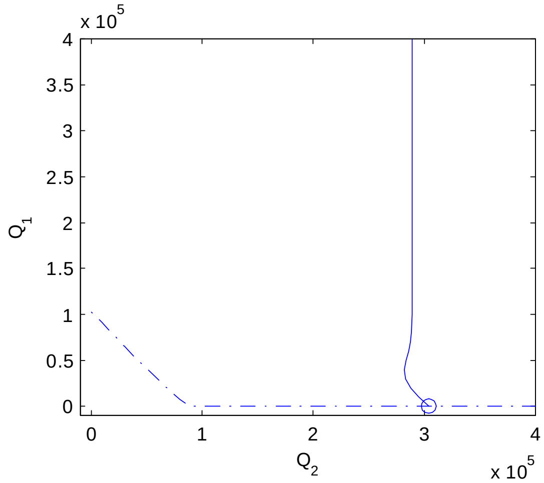


$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	c_u/c_o	c_u/c_t
$\gamma_1 < \gamma_2$	$\mu_1 < \mu_2$	$\sigma_1 = \sigma_2$	$r_1 = r_2$	$s_1 = s_2$

	$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	r	s
A_1	0.02	172953	30298	100	2
A_2	0.065	272953	30298	100	2

	Q_1	Q_2
Eq. Point:	130409	289200

Scenario P5



γ	μ	σ	c_u/c_o	c_u/c_t
$\gamma_1 << \gamma_2$	$\mu_1 < \mu_2$	$\sigma_1 = \sigma_2$	$r_1 = r_2$	$s_1 = s_2$

	γ	μ	σ	r	s
A_1	0.01	172953	30298	100	2
A_2	0.065	272953	30298	100	2

Eq. Point:

Q_1	Q_2
0	304050

The optimum stocking quantities of the agencies and the optimal quantities without cooperation are given in Tables 17 and 18, respectively.

Table 17 Equilibrium points of P scenarios

Scenario	P1	P2	P3	P4	P5
A_1	190290	208120	219700	130400	0
A_2	290290	292170	295030	289200	304050

Table 18 Stocking quantities of the agencies without cooperation

Scenario	P1	P2	P3	P4	P5
A_1	204050	218590	228650	173330	102360
A_2	304050	304050	304050	304050	304050

In scenario P1, we analyze a cooperation between two agencies that have the same expected earthquake probability but different estimated mean of the demand for relief commodity. Under this cooperation, the agency in the area that is estimated to have a smaller mean of the demand prefers to stock less relief supply than the other agency.

In scenarios P2 and P3, the first agency has a higher expected earthquake probability, but a smaller estimated mean of the demand for relief aid. In that kind of cooperation, the first agency prefers to stock less supply than the second agency. As the expected earthquake probability increases, stocking quantity of the first agency increases. One important insight that can be inferred from this kind of cooperation is that the demand parameter is more dominant than the earthquake probability parameter under this setting. The agency in the area that is estimated to have less mean of the demand stocks less supply than the agency in the area that has a lower earthquake risk.

In scenario P4, the first agency's area has a lower expected earthquake probability and a smaller amount of estimated mean of the demand. Under this kind of a cooperation, the first agency stocks less relief commodity than the other agency. The reason of the jumps in the best response graph of the first agency is due to the term that distorts the convexity of the expectation cost function, as explained in Section 3.2.

In scenario P5, the difference in the expected earthquake probabilities of the agencies is higher than in scenario P4. Under this cooperation, the first agency does not stock any commodities while the other agency gives the same stocking decision as it gives without cooperation. This is an interesting case, where we observe that the first agency relies completely on outside help from the second agency.

As shown in Tables 17 and 18, in all scenarios, cooperation is beneficial to both of the agencies or it does not change the stocking decision of one of the agencies. In scenario P5, the first agency prefers not to stock; which means that it gets maximum benefit from the cooperation.

5.1.2 Difference in Demand Characteristics

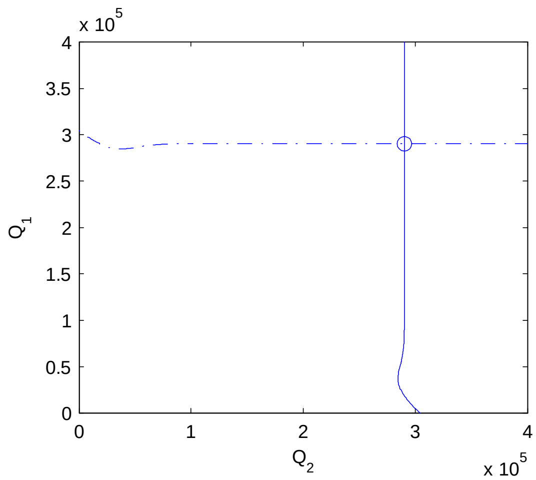
The following analysis of TAM shows how the demand for relief aid affects the stocking decisions of the agencies.

We generate four cooperation scenarios and compare the stocking decisions of the agencies when the estimated demand characteristics of their areas are different. We keep the expected earthquake occurrence probabilities of the agencies' areas the same.

The characteristics of the generated cooperation scenarios and the numerical results of these cooperations are given in Table 19. $\boldsymbol{\mu}$ and $\boldsymbol{\sigma}$ represent the mean and the standard deviation of the expected demand distribution for relief aid respectively. $\boldsymbol{\gamma}$ refers to the expected earthquake occurrence probability within a time horizon. r and s refer to the ratio of underage and overage costs $\left(\frac{c_u}{c_o}\right)$, and the ratio of underage and transfer costs $\left(\frac{c_u}{ct}\right)$, respectively.

Table 19 D-Scenarios

Scenario D1



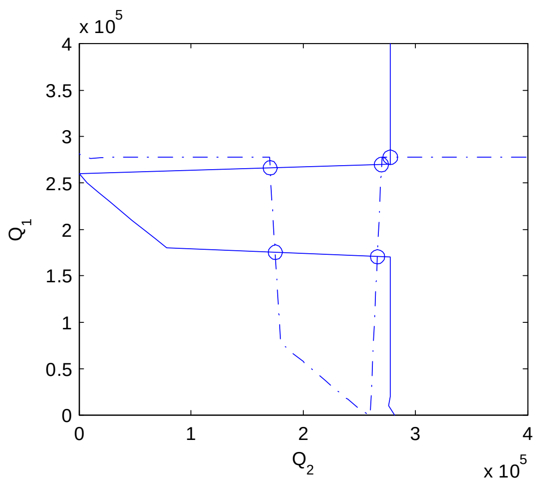
γ	μ	σ	r	s
$\gamma_1 = \gamma_2$	$\mu_1 = \mu_2$	$\sigma_1 = \sigma_2$	$r_1 = r_2$	$s_1 = s_2$

	γ	μ	σ	r	s
A_1	0.065	272953	30298	100	2
A_2	0.065	272953	30298	100	2

Eq. Point:

Q_1	Q_2
290290	290290

Scenario D2



γ	μ	σ	r	s
$\gamma_1 = \gamma_2$	$\mu_1 = \mu_2$	$\downarrow \sigma_1 = \sigma_2 \downarrow$	$r_1 = r_2$	$s_1 = s_2$

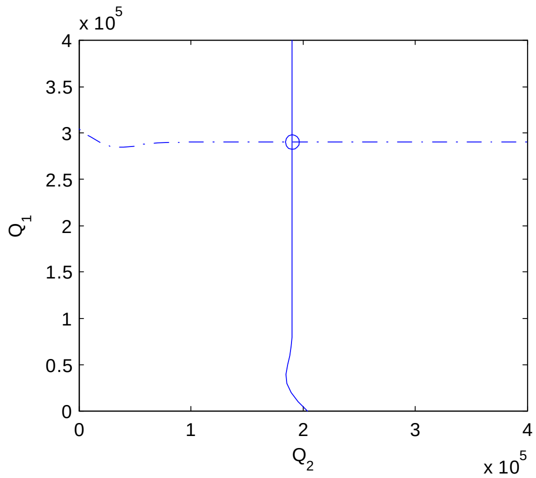
	γ	μ	σ	r	s
A_1	0.065	272953	8188	100	2
A_2	0.065	272953	8188	100	2

Eq. Point:

(Multiple Eq)

Q_1	Q_2
170580	266140
175140	175140
266140	170580
269710	269710
277640	277640

Scenario D3

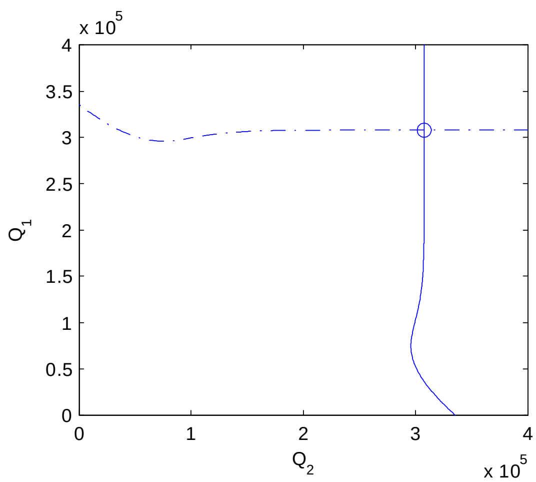


$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	r	s
$\gamma_1 = \gamma_2$	$\mu_1 > \mu_2$	$\sigma_1 = \sigma_2$	$r_1 = r_2$	$s_1 = s_2$

	$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	r	s
A_1	0.065	272953	30298	100	2
A_2	0.065	172953	30298	100	2

	Q_1	Q_2
Eq. Point:	290290	190290

Scenario D4



$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	r	s
$\gamma_1 = \gamma_2$	$\mu_1 = \mu_2$	$\uparrow \sigma_1 = \sigma_2 \uparrow$	$r_1 = r_2$	$s_1 = s_2$

	$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	r	s
A_1	0.065	272953	60596	100	2
A_2	0.065	272953	60596	100	2

	Q_1	Q_2
Eq. Point:	307630	307630

We next interprete the equilibrium points of TAM under the given scenarios. Note that the estimated mean of the demand is related to the population of the area as well as the vulnerability of the buildings in that area. As we argued before, standard deviation also refers to the impact of the magnitude of a potential earthquake as well as the uncertainty in the damage states of the buildings in the area and the accuracy of our demand estimation.

The achieved optimum stocking quantities of the agencies and the optimal quantities without cooperation are given in Tables 20 and 21, respectively.

Table 20 Equilibrium points of D scenarios

Scenario	D1	D2	D3	D4
A_1	290290	ME	290290	307630
A_2	290290	ME	190290	307630

Table 21 Stocking quantities of the agencies without cooperation

Scenario	D1	D2	D3	D4
A_1	304050	281360	304050	335160
A_2	304050	281360	204050	335160

In scenario D1, we consider a cooperation between two agencies in the areas that have the same characteristics in terms of the estimated mean of the demand and the probability that a major earthquake occurs within a time horizon. The equilibrium behaviour of the model shows that two agencies prefer to stock the same amount of relief supply. This cooperation can be regarded as "sharing cooperation" since the agencies get the same benefit.

Scenario D2 is very similar to scenario D1 in terms of the expected earthquake probability and estimated mean of the demand, but differs in standard deviation of the forecasted demand. Despite of this similarity between the two scenarios, uncertainty in estimated demand generates multiple equilibrium solutions. The effect of low standard deviation of the expected demand offsets the model in ways that make it possible for more than one set of stocking quantities to constitute an equilibrium. The reason of the jumps in the best response curves of the agencies is again the term that distorts the convexity of the expectation cost function, as explained in Section 3.2.

In scenario D3, the first agency cooperates with an agency in the area that has the same earthquake risk but lower estimated mean of demand. In this kind of a cooperation, our model reaches a solution in which the first agency stocks the same amount of supply as it should stock without cooperation while the second one stocks a amount.

Scenario D4 is a modified version of scenario D1, in which the standard deviation of the agencies are higher. This cooperation generates a single equilibrium where the agencies again stock the same amount of relief commodity that are smaller than the optimal quantities without cooperation. This cooperation can also be regarded as a sharing cooperation.

It can be inferred from Tables 20 and 21 that in all scenarios, the cooperation would be beneficial or at worst ineffective for the agencies since the multiple equilibria points are smaller than their estimated mean of the demand values.

5.2 Analysis of the Model with Cooperation for the Istanbul Case

We analyze the equilibrium behaviour of TAM in the Istanbul case in order to obtain insights of the benefits of the cooperation between the agencies and the advantageous cooperations in terms of stocking quantities.

5.2.1 Cooperation Scenarios

We generate five different cooperation scenarios in terms of the expected earthquake occurrence probability and the estimated demand for the Istanbul case in order to analyze the cooperations with the agencies in different areas. We also consider two types of scenarios for these cooperation scenarios. A type of scenario assumes that the standard deviation of the estimated demand for relief aid is smaller than the one in B type of scenario. This analysis enable to examine the effect of the variability in expected demand on the equilibrium of the proposed model.

We determine the underage and overage cost values for Istanbul to be used in numerical analysis as explained in Section 4.3. We have defined the overage cost value as,

$$c_o = c_{pt} + c_h + c_m + c_{op} - c_s.$$

In this analysis, we assume that the sum of holding, maintaining and opportunity costs for a five year time cycle is 25% of the cost of purchasing a tent. Salvage value is set as 30% of the cost of purchasing a tent. We use the data that from the Turkish Red Crescent for the purchasing costs.

For the determination of the underage cost, we consider the cost of purchasing a $65m^2$ prefabricated house that has a capacity to provide sheltering to four people. The score of Turkey in the CPR is 4.15 while the score of the first ranked country, the USA is 5.74.

We also consider the value of the transfer cost as 50% of the underage cost. Since we define it as the per unit cost of receiving exogenous supply, it can be considered as a value that depends on the distance between the agencies. Numerical values of the parameters are given in Table C1.

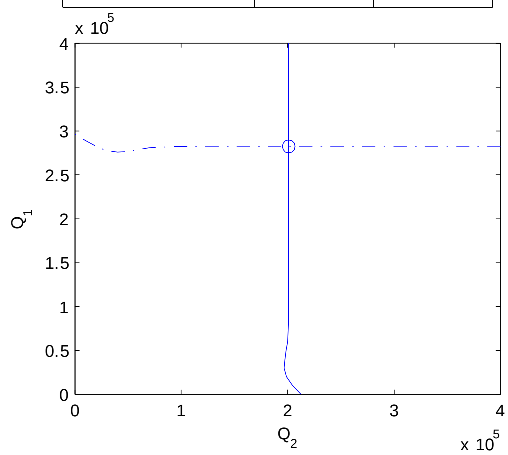
The characteristics and the results of the different cooperation scenarios are given in Table 22. $\boldsymbol{\mu}$ and $\boldsymbol{\sigma}$ refer to the mean and standard deviation of the expected demand while $\boldsymbol{\gamma}$ represents the expected earthquake probability. r and s refer to the ratio of the underage and overage costs and the ratio of the underage and transfer costs for the agencies, respectively. Also, the first agency represents the relief aid agency in Istanbul. CV_A refers to the coefficient of variation values of the A type of cooperation scenarios and the coefficient of variation values for B type of cooperation scenarios are 2 times greater than CV_A values. The dashdotted lines indicate the best response curves of the first agency (in Istanbul) while the solid lines correspond to the ones of the second agency.

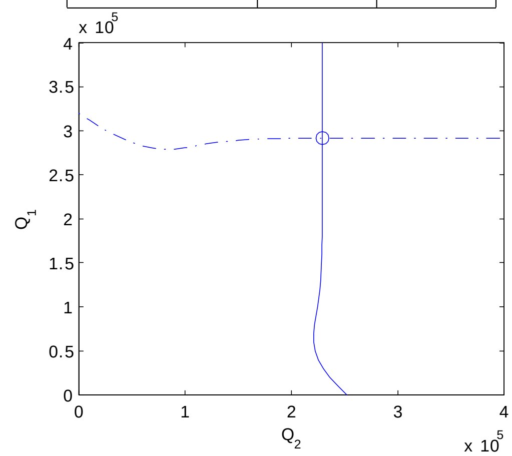
Table 22 A and B type of scenarios for Istanbul

Scenario 1			$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	r	s	$\boldsymbol{\sigma}$(A Sc)	$\boldsymbol{\sigma}$(B Sc)	CV_A
$\gamma_1 < \gamma_2$	$\sigma_1 = \sigma_2$	A_1	0.065	272953	68.92	2	30298	60596	0.111
$\mu_1 > \mu_2$	$r_1 = r_2$	A_2	0.15	172953	68.92	2	30298	60596	0.175

A Scenario	Q_1	Q_2
Eq. Point:	282320	201050

B Scenario	Q_1	Q_2
Eq. Point:	291640	229160

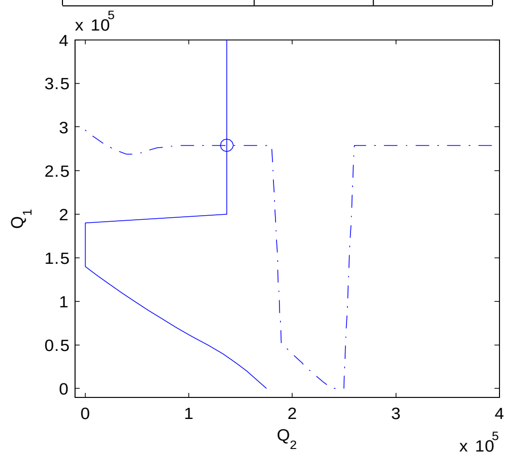


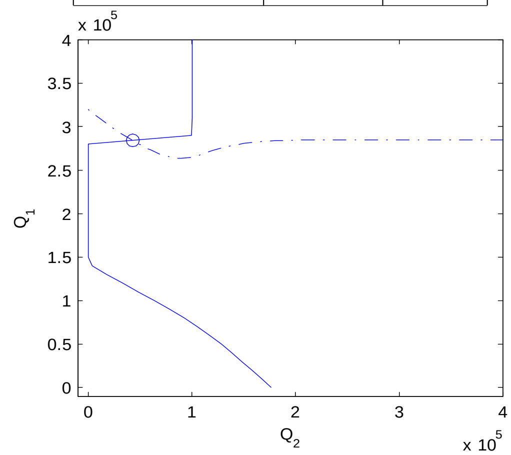


Scenario 2			γ	μ	r	s	σ(A Sc)	σ(B Sc)	CV_A
$\gamma_1 > \gamma_2$	$\sigma_1 = \sigma_2$	A_1	0.065	272953	68.92	2	30298	60596	0.111
$\mu_1 > \mu_2$	$r_1 = r_2$	A_2	0.03	172953	68.92	2	30298	60596	0.175

A-Scenario	Q_1	Q_2
Eq. Point:	278950	136720

B-Scenario	Q_1	Q_2
Eq. Point:	284320	43098

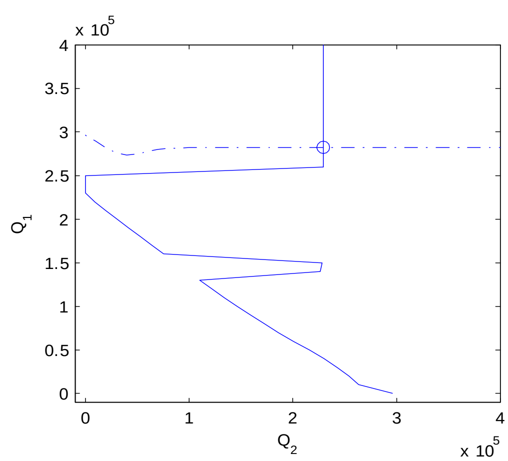


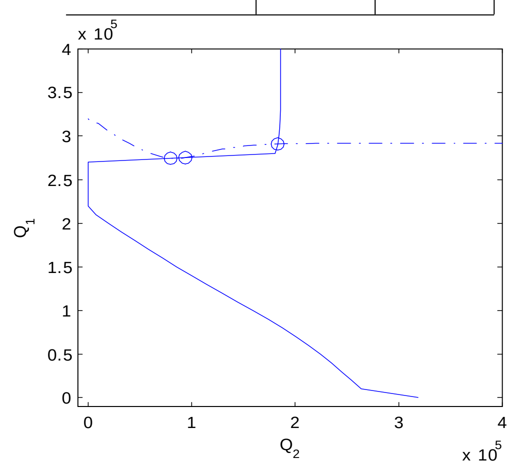


Scenario 3			γ	μ	r	s	σ(A Sc)	σ(B Sc)	CV_A
$\gamma_1 = \gamma_2$	$\sigma_1 = \sigma_2$	A_1	0.065	272963	68.92	2	30298	60596	0.111
$\mu_1 = \mu_2$	$r_1 > r_2$	A_2	0.065	272963	67.39	1.95	30298	60596	0.111

A Scenario	Q_1	Q_2
Eq. Point:	282190	229430

B Scenario	Q_1	Q_2
Eq. Point:	274430	79850
(ME)	275220	94020
	290790	183090

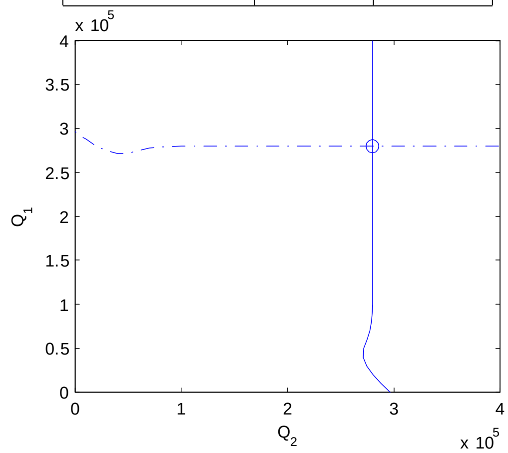


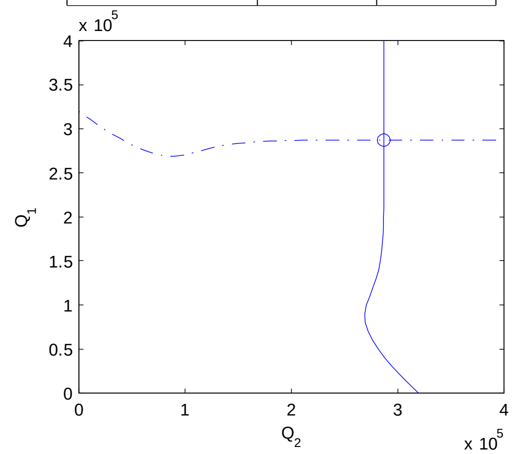


Scenario 4			γ	μ	r	s	σ(A Sc)	σ(B Sc)	CV_A
$\gamma_1 = \gamma_2$	$\sigma_1 = \sigma_2$	A_1	0.065	272963	68.92	2	30298	60596	0.111
$\mu_1 = \mu_2$	$r_1 = r_2$	A_2	0.065	272963	68.92	2	30298	60596	0.111

A Scenario	Q_1	Q_2
Eq. Point:	280000	280000

B Scenario	Q_1	Q_2
Eq. Point:	287040	287040

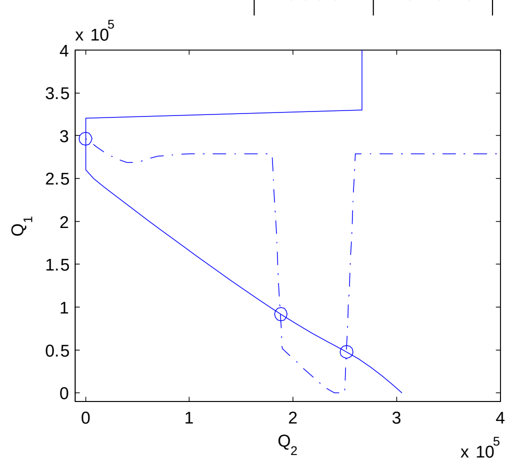


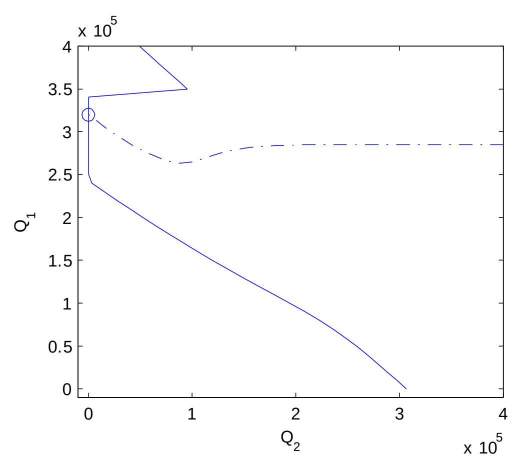


Scenario 5			γ	μ	r	s	σ(A Sc)	σ(B Sc)	CV_A
$\gamma_1 > \gamma_2$	$\sigma_1 = \sigma_2$	A_1	0.065	272953	68.92	2	30298	60596	0.111
$\mu_1 < \mu_2$	$r_1 = r_2$	A_2	0.03	302953	68.92	2	30298	60596	0.10

A Scenario	Q_1	Q_2
Eq. Point:	296350	0
(ME)	91890	188240
	47790	251710

B Scenario	Q_1	Q_2
Eq. Point:	319740	0





We next present insights to the potential benefits from cooperation of an agency in

Istanbul with an outside agency.

The calculated optimum stocking quantities of the agencies and the optimal quantities without cooperation for the generated scenarios are given in Table 23. The percentage differences in optimal stocking quantities of the agencies with and without cooperation are given in Table 24. In Table 23, "Separated" column includes the stocking quantities of the agencies for all A and B types of scenarios when they give their decision separately. "Coordinated" column gives the stocking quantities when the agencies are in cooperation. A_I and A_O refer to the agency in Istanbul and an outside agency, respectively.

Table 23 Separated and Coordinated Stocking Quantities

	Separated					
	A Scenarios			**B Scenarios**		
	A_I	A_O	$TOTAL$	A_I	A_O	$TOTAL$
Sc.1	296350	212600	508950	319740	252250	571990
Sc.2	296350	174720	471070	319740	176490	496230
Sc.3	296350	295850	592200	319740	318740	639480
Sc.4	296350	296350	592700	319740	319740	639480
Sc.5	296350	304720	601070	319740	306490	626230

	Coordinated					
	A Scenarios			**B Scenarios**		
	A_I	A_O	$TOTAL$	A_I	A_O	$TOTAL$
Sc.1	282320	201050	483370	291640	229160	520800
Sc.2	278950	136720	415670	284320	43098	327418
Sc.3	282190	229430	511620	ME	ME	ME
Sc.4	280000	280000	560000	287040	287040	574080
Sc.5	ME	ME	ME	319740	0	319740

Table 24 Difference in Stocking Quantity (%)

	A Scenarios			**B Scenarios**		
	A_I	A_O	$TOTAL$	A_I	A_O	$TOTAL$
Sc.1	$\downarrow$ 4.73	$\downarrow$ 5.43	$\downarrow$ 5.03	$\downarrow$ 8.79	$\downarrow$ 9.15	$\downarrow$ 8.95
Sc.2	$\downarrow$ 5.87	$\downarrow$ 21.75	$\downarrow$ 11.76	$\downarrow$ 11.08	$\downarrow$ 86.52	$\downarrow$ 34.02
Sc.3	$\downarrow$ 4.78	$\downarrow$ 22.45	$\downarrow$ 13.61	ME	ME	ME
Sc.4	$\downarrow$ 5.52	$\downarrow$ 5.52	$\downarrow$ 5.52	$\downarrow$ 10.23	$\downarrow$ 10.23	$\downarrow$ 10.23
Sc.5	ME	ME	ME	$\longrightarrow$ 0	$\downarrow$ 100	$\downarrow$ 48.94

Scenario Analysis

Scenario 1 Higher Earthquake Probability and Lower Estimated Mean of Demand Cooperation When the agency in Istanbul cooperates with an agency in an area that has higher expected earthquake probability but smaller amount of estimated mean of the demand, both of the agencies stock higher amount of relief commodity than their estimated mean of demand values. The Istanbul agency decreases its stocking quantity as 4.73% of its optimal quantity without cooperation while the coefficient of variation value of the demand is 0.111. As the coefficient of variation value rises, the benefit from the cooperation increases to 5.03 %.

Scenario 2 Lower Earthquake Probability and Lower Estimated Mean of Demand Cooperation In this scenario, we consider a cooperation in which the agency in Istanbul cooperates with an agency in an area that has lower expected earthquake probability and estimated mean of the demand value. The results show that the optimal stocking quantity of the Istanbul agency decreases by 5.87% under this cooperation while the cooperated agency's optimal stocking quantity reduces by 21.75%. In terms of the total benefit of the agencies, A and B types of scenarios are respectively 11.76% and 34.02% beneficial comparing to the scenario without cooperation. As the uncertainty in the expected demand rises, the agencies get more benefit from the cooperation. The jumps in the best response curves result from the nonconvex behaviour of the expected cost function explained in Section 3.2.

Scenario 3 Lower Ratio Cooperation If the agency in Istanbul cooperates with an agency that has smaller ratio of underage and overage costs, it gives a stocking decision that decreases its optimal quantity by 5.87% with the cooperation. There is an approximately 21% decrease in the other agency's stocking quantity. The uncertainty in the expected demand distribution and the benefit gained from the cooperation increases simultaneously. The nonconvexity of the expected cost function again causes to jumps in the best response curves. As the coefficient of variation value of the demand rises, the solution reaches a multiple equilibrium behaviour. This cooperation can be regarded as beneficial for both of the agencies as the stocking quantities are smaller than those without cooperation.

Scenario 4 Same Characteristics Cooperation In this scenario, we consider a cooperation in which the agency in Istanbul cooperates with an agency that has the same expected earthquake probability and estimated demand characteristics. In the case of smaller coefficient of variation, both of the agencies decreases their optimal stocking quantities by 5.52%. As the coefficient of variation value of the demand rises, the decrease in the stocking quantities becomes 10.23%. This cooperation can be regarded as a sharing cooperation since the agencies get the same benefit.

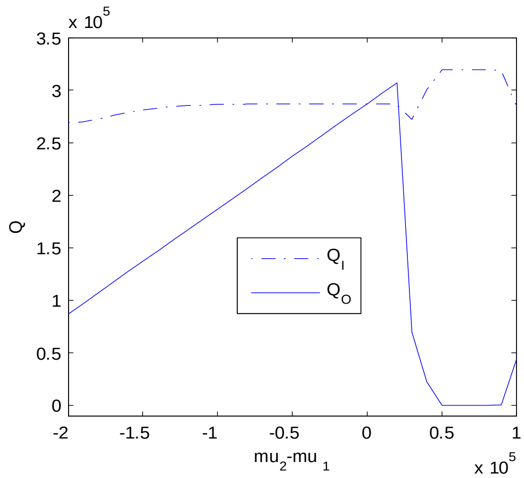
Scenario 5 Lower Earthquake Probability and Higher Estimated Mean of Demand Cooperation If the agency in Istanbul cooperates with an agency that has lower expected earthquake probability but higher estimated mean of demand value, the solution again reaches a multiple equilibrium behaviour. As the coefficient of variation of the demand increases, the cooperation reaches a solution that the second agency become free rider and prefer not to stock any commodities. The stocking decision of the agency in Istanbul does not change with this cooperation.

Sensitivity Analysis

In this subsection, we vary the model parameters systematically for the Istanbul case: estimated mean of the demand for relief aid, expected earthquake probabilities and the transfer costs of the agencies. When the cooperation produces multiple equilibria, we choose the solution candidates that have minimum sum of stocking quantities, as the optimal solution.

The numerical analysis that explains the effect of the estimated mean of the demand on the stocking decisions of the agencies is given in Table 25. r and s represent the ratio of underage and overage costs ($\frac{c_u}{c_o}$) and the ratio of underage and transfer costs ($\frac{c_u}{c_t}$), respectively.

Table 25



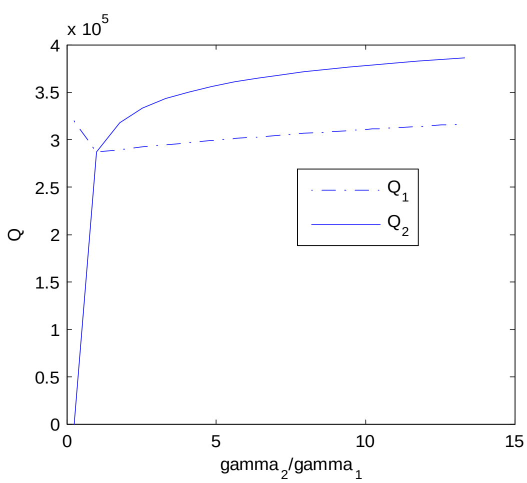
$\boldsymbol{\gamma}$	$\boldsymbol{\sigma}$	r	s
$\gamma_1 = \gamma_2$	$\sigma_1 = \sigma_2$	$r_1 = r_2$	$s_1 = s_2$

	$\boldsymbol{\gamma}$	$\boldsymbol{\sigma}$	r	s
A_1	0.065	30298	68.92	2
A_2	0.065	30298	68.92	2

The graph shows that when the expected mean of the demand values of the agencies' areas are equal to each other, they are in a sharing cooperation. As the difference of their expected mean of the demand values increases, the optimal stocking quantities of the agencies differ from each other.

The effect of the expected earthquake probability value on the stocking quantities is demonstrated in Table 26.

Table 26



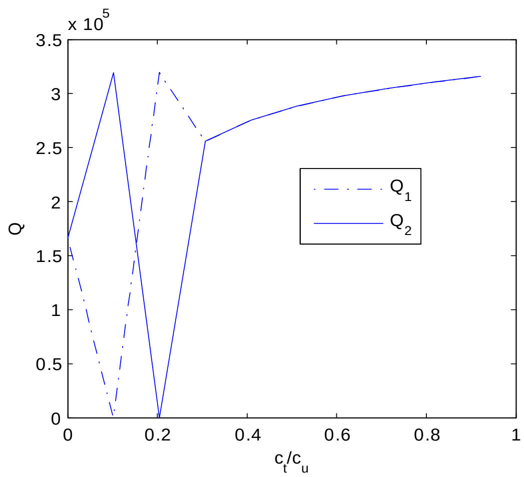
$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	r	s
$\mu_1 = \mu_2$	$\sigma_1 = \sigma_2$	$r_1 = r_2$	$s_1 = s_2$

	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	r	s
A_1	272953	30298	68.92	2
A_2	272953	30298	68.92	2

The insight that can be inferred from this graph is that the the agencies stock the same amount of relief commodity when their expected earthquake probabilities are equal to each other. After this equilibrium point in the graph, the quantities differ from each other as the ratio of their expected probability values increases. In the cases that this ratio is very low, the agency in the area that has smaller expected probability prefers not to stock any relief commodity.

Table 27 shows the behaviour of the optimal stocking quantities as their transfer cost changes between 0 and c_u.

Table 27



$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	r
$\gamma_1 = \gamma_2$	$\mu_1 = \mu_2$	$\sigma_1 = \sigma_2$	$r_1 = r_2$

	$\boldsymbol{\gamma}$	$\boldsymbol{\mu}$	$\boldsymbol{\sigma}$	r
A_1	0.065	272953	30298	68.92
A_2	0.065	272953	30298	68.92

The graph demonstrates that the optimal stocking quantities of the agencies and their transfer cost increase simultaneously. The reason of the jump in the graph is that the cooperation achieves a multiple equilibria solution when the ratio of the transfer cost and the underage cost is 0.1 and 0.2. Since we choose the stocking quantities that minimizes the total expected cost in our computations, the selected solution is not the one in which the stocking quantities of the agencies are equal to each other.

Concluding Remarks

Our analysis with respect to realistic scenarios and parameter estimations provides some guidelines for the relief agencies in Istanbul. Considering both the insights on the effects of problem parameters on the solutions and the scenario analysis for Istanbul, the beneficial cooperations for Istanbul agency in terms of the stocking quantity can be identified.

- It is advantegeous to cooperate with an agency in an area that has higher earthquake risk in terms of the earthquake probability and the demand for relief aid as we observed that cooperating with the Istanbul agency is beneficial for an outside agency in the second scenario.

- The agency that has higher ratio of the underage and overage costs can be considered to be one of the most advantageous agencies to be in cooperation with. If we consider how our cost parameters were generated, an agency that is in the area with high living standards or wellfare is one of the best candidate agencies to be in cooperation with.

- Cooperating with an agency in an area that is closer to Istanbul is one of the most beneficial decisions since we consider the transfer cost as a value that depends on the distance between the agencies.

- When Istanbul has a chance to choose one of the agencies that have similar characteristics in terms of the expected mean of demand for relief aid, cooperating with the one that has minimum expected earthquake probability is more beneficial.

- Cooperating with an any agency that has the characteristics introduced in generated scenarios is always a useful decision. Cooperation becomes much more beneficial when there is a high uncertainty in the demand for relief aid because of the uncertainty in the earthquake magnitude or in the conditions of the buildings.

Chapter 6

CONCLUSION

In this thesis, we have taken into consideration the stocking decisions given by humanitarian relief agencies. One of the main complications in disaster response operations can beconsidered to be the insufficient relief supply to meet the demand for a large number of people, as well as the lack of coordination between the agencies. Humanitarian relief agencies such as the members of International Federation of Red Cross and Red Crescent Agencies, play an important role in relief activities worldwide. Since it is almost impossible to know the timing and the intensity of any earthquake, it is very difficult to estimate the impact, damage and resource needs exactly in advance. Thus, the development of quick response and efficient disaster relief plans poses itself as a complex decision problem. In this thesis, we aimed to provide useful guidelines for the relief agencies by proposing a mathematical model. To the best of our knowledge, this thesis provides the first study on the quantitative analysis of cooperation among agencies in the disaster management domain.

First we have developed a mathematical model to determine the optimum stocking quantity of a single agency under a disaster risk. Our proposed model is based on the well-studied Newsvendor Model. Since the most important parameters that make the decision of stocking relief supply complex are the probability of the occurrence of a disaster within a time horizon and the number of people in need of relief supply, we expanded the Newsvendor Model by incorporating these two parameters. We also considered the cooperation between the humanitarian relief agencies. Assuming a mutual agreement between the agencies, we have proposed a model that determines the stocking quantities of two relief aid agencies that is in cooperation with each other. Under the assumption that the relief aid agencies are rational agents, we have analyzed the problem in a game theoretical approach and suggest a game theoretical equilibrium solution to model.

We have demonstrated the use of our solution approach by an application of the model to the case of Istanbul. We estimated the parameters of our model, i.e. the probability of the occurrence of an earthquake within a time horizon and the demand distribution for relief aid under such a disaster, by modifying the proposed approaches in existing studies specifically for the needs of our model. Using the JICA's proposed results for the number of the buildings that is estimated to be damaged after a possible disaster and the current literature on predicting earthquake probability, we have estimated the characteristics of these two parameter values for Istanbul. We have investigated the characteristics of the solution under various parameters settings and identified cases where cooperation is beneficial to one or both of the agencies. Our scenario analysis provides useful guidelines to the humanitarian relief aid agencies in Istanbul.

Two extensions of our model are possible. First, when more than two agencies cooperate with each other in order to provide relief supply after a disaster, the situation of the agency that needs relief supply is similar to the model with two agencies. The exogenous supply that will come from all of the agencies in the cooperation is an outside source for that agency just like in the model with cooperation. However, now an additional mechanism is needed for the supply decisions. In the case that outside help is needed, from which agencies the deficient units will come from has to be resolved by a protocol or some sort of a mechanism that may consider proximity and availability. This remains to be investigated as future work.

As a second extension, we can consider multiple agencies that respond to a disaster in a particular area. In this problem, the stocking quantity to meet the relief aid demand in this area can be obtained by using our Single Agency Model. The arising problem is how the different agencies supply the relief aid. Since reputation is one of the most valuable assets to manage and maximize, agencies would want to provide supply to the victims of natural disasters as much as possible. This also may bring a competetion between them rather than a cooperation. Hence, a new mechanism that coordinates the relief operations of the agencies in a particular area can be developed as a future research direction.

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Appendix A

A.D. 1500-2000 EARTHQUAKE CATALOG EVENTS

Table A1

Earthquake	**Magnitude**
10.Sept.1509	7.4
10.May.1556	7.1
25.May.1719	7.4
2.Sept.1754	7.0
22.May.1766	7.2
5.August.1766	7.6
10.July.1894	7.0
13.Sept.1912	7.4
17.August.1999	7.4

Appendix B

DEMAND ESTIMATION IN DISTRICTS OF ISTANBUL

Table B1 Results of estimated building damages obtained by JICA. H: Heavily, M: Moderately, P: I

Dist.	**Dist. Name**	**Total # of**	**H**		**H+M**		**H+M+P**	
		Buildings	#	%	#	%	#	%
1	Adalar	6.522	1.710	26,20	2.830	43,40	4.254	65,20
2	Avcılar	14.030	2.311	16,50	4.696	33,50	8.270	58,90
3	Bahçelievler	19.690	3.184	16,20	6.764	34,40	12.305	62,50
4	Bakırköy	10.067	2.119	21,00	4.103	40,80	6.792	67,50
5	Bağcılar	36.059	2.899	8,00	6.949	19,30	15.771	43,70
6	Beykoz	28.280	521	1,80	1.376	4,90	4.481	15,80
7	Beyoğlu	26.468	2.644	10,00	5.495	20,80	10.989	41,50
8	Beşiktaş	14.399	692	4,80	1.644	11,40	4.175	29,00
9	Büyükçekmece	3.348	415	12,40	914	27,30	1.806	53,90
10	Bayrampaşa	20.195	2.846	14,10	5.532	27,40	10.261	50,80
11	Eminönü	14.149	2.156	15,20	4.106	29,00	7.279	51,40
12	Eyüp	25.718	2.044	7,90	4.414	17,20	9.426	36,70
13	Fatih	31.947	5.776	18,10	10.996	34,40	18.900	59,20
14	Güngören	10.655	1.550	14,60	3.376	31,70	6.402	60,10
15	Gaziosmanpaşa	56.484	2.183	3,90	5.628	10,00	15.511	27,50
16	Kadıköy	38.615	2.312	6,00	5.554	14,40	13.569	35,10
17	Kartal	24.295	2.236	9,20	4.841	19,90	10.198	42,00

Dist.	**Dist.Name**	**Total # of**	**H**		**H+M**		**H+M P**	
		Buildings	#	%	#	%	#	%
18	Kağıthane	28.737	1.286	4,50	3.148	11,00	8.134	28,30
19	Küçükçekmece	45.817	4.915	10,70	10.325	22,50	20.641	45,10
20	Maltepe	25.313	1.824	7,20	4.167	16,50	9.503	37,50
21	Pendik	39.877	3.128	7,80	6.956	17,40	15.263	38,30
22	Sarıyer	30.781	462	1,50	1.255	4,10	4.437	14,40
23	Şişli	22.576	884	3,90	2.232	9,90	6.093	27,00
24	Tuzla	14.727	1.456	9,90	3.079	20,90	6.344	43,10
25	Ümraniye	43.473	1.152	2,60	3.095	7,10	9.434	21,70
26	Üsküdar	43.021	1.301	3,00	3.477	8,10	10.361	24,10
27	Zeytinburnu	15.573	3.036	19,50	5.999	38,50	10.184	65,40
28	Esenler	22.700	1.655	7,30	3.922	17,30	9.111	40,10
29	Çatalca	2.573	74	2,90	194	7,50	564	21,90
30	Silivri	8.534	407	4,80	981	11,50	2.498	29,30
	Total	724.623	59.176	8,20	128.047	17,70	272.953	37,70

Appendix C

NUMERICAL VALUES OF THE COST PARAMETERS

Table C1

Cost of purchasing a tent (c_{pt})	746.6 TL
Cost of purchasing a prefabricated house (c_{pp})	67561.7 TL