# A SUPPLIER SELECTION MODEL FOR DESIGNING FRAMEWORK AGREEMENTS IN RELIEF CHAIN

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## Abstract

When a disaster occurs, disaster relief operations are undertaken immediately to help people affected by disasters. However, in the aftermath of natural disasters, relief supplies that are critical for survival may not be readily available in the desired amounts or prices. Hence, procurement is an important function for disaster relief operations. Relief organizations face with several procurement decisions in managing the relief chain. Since quick response is critical in disaster relief, designing efficient procurement methods are important for relief organizations. In this thesis, we focus on framework agreements, which allow relief organizations to guarantee availability and fast procurement of relief supplies. Given the complexities of the disaster relief operations and uncertainties regarding the occurrence of disasters, designing effective framework agreements can be difficult for relief organizations. In our study, we examine the characteristics of the contracts that are applied in relief chains and traditional supply chains, and explore the applicability of supply chain contracts as framework agreements in relief chains. We choose a quantity flexibility contract and develop a two-stage stochastic programming model that selects suppliers to an agreement and determines some contract terms for the relief organization. We develop a case study to illustrate the implementation of the proposed model and test the effects of various parameters on solutions.

**Key Words:** Disaster relief, procurement, two-stage stochastic programming, framework agreements, supply chain contracts.

İNSANİ YARDIM TEDARİK ZİNCİRİNDE ÇERÇEVE ANLAŞMALARI TASARIMI İÇİN TEDARİKÇİ SEÇİMİ MODELİ

# ÖZET

Afet olduktan sonra, afetten etkilenen insanlar için afet yardım operasyonları gerçekleştirilir. Doğal afetler sonrası, hayati kaynaklar genellikle istenilen miktarda veya fiyatta bulunmayabilir. Bu nedenle, satın alma, afet yardım operasyonları için önemli bir faaliyettir. Yardım kuruluşları, yardım zincirini yönetirken çeşitli satın alma kararlarıyla karşılaşırlar. Afet yardımında hızlılık önemli olduğundan, verimli bir satın alma metodu planlamak, yardım kuruluşları için önemlidir. Bu tezde, çerçeve anlaşmalarına odaklandık. Çerçeve anlaşmaları, yardım malzemelerinin bulunurluğunu garantilerken, hızlı bir satın almayı sağlar. Afet yardım operasyonlarındaki karmaşıklar ve afetlerin oluşumuyla ilgili belirsizlikler, yardım kuruluşları için etkili bir çerçeve anlaşması planlamayı zorlaştırır. Biz bu çalışmada, yardım zincirinde ve geleneksel tedarik zincirinde uygulanan anlaşmaların özelliklerini inceleyerek, çerçeve anlaşmasının bir çeşidi olabilecek tedarik anlaşmalarının yardım zincirine uygunluğunu inceledik. Miktarı esnek tutan bir anlaşmayı seçerek, bir yardım organizasyonu için bazı sözleşme şartlarının tasarlanması ve tedarikçilerin seçilmesi için iki aşamalı bir rassal programlama modeli geliştirdik. Önerdiğimiz modelin uygulanabilirliğini göstermek için örnek bir vaka çalışması geliştirip, çeşitli verilerin çözümler üzerinde etkisini test ettik.

**Anahtar Kelimeler:** Afet yardımı, satın alma, iki aşamalı rassal programlama, çerçeve anlaşmaları, tedarik zinciri anlaşmaları.

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**My Parents** – For their love and support.

## Dedication

To my parents

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# 1 Introduction

Natural disasters (that result from natural events such as hurricane, tsunami, earthquake, famine, flood, volcanoes, etc.) have always been a challenge for the mankind. They have always affected human settlements and well-being. The latest tragic reminder of devastation caused by the natural disasters is the earthquake in Japan. We saw how the earthquake swept over cities, generated tsunamis and led to a nuclear crisis, and caused many people to lose their lives, homes, and businesses.

When a disaster occurs, disaster relief (or humanitarian relief) operations are undertaken immediately. The aim of disaster relief operations is to help people in their survival after a sudden catastrophe (Anala, 2010). Actions taken during humanitarian relief operations are often spontaneous and disparate because of unique characteristics of the disasters. Every disaster has different characteristics and brings a new set of actors with different resources (Tomasini and Wassenhove, 2009). Therefore, disaster relief operations can't be performed in a standard way to overcome all the consequences of a disaster (Ertem et al., 2009).

In the aftermath of natural disasters, vital resources (e.g., food, water, tents, clothing, medicine, etc.) are usually not readily available. At the onset of a disaster, cash donations and on-hand inventories may be available, but they are typically not in sufficient amounts to meet the entire needs. Therefore, most of relief supplies are acquired from various sources after disaster occurrences. Hence, procurement operations are vital for disaster relief operations. The objective of procurement in humanitarian relief is to carry out activities related to procurement in such a way that "*the goods and services are at the right quality, from the right source, are at the right cost and can be delivered in the right quantities, to the right place, at the right time*" (Logistics Cluster, 2011). The procurement processes should be managed effectively for the overall success of emergency response.

However, there are some factors affecting the efficiency of procurement. These include environmental uncertainties (such as unpredictability of demands and supplier availability), customer focus related problems (e.g., ambiguous customer focus and no complaint mechanism for lack of resources), competitive priorities between relief organizations (i.e., organizations compete for scarce resources, donations, funds, etc.) and insufficient information technology (organizations rely on inefficient manual systems) (Annala, 2010). Therefore, there are challenges in designing effective and efficient procurement methods for relief organizations.

There are several issues that relief organizations need to consider while designing their procurement processes such as local versus global sourcing, partnering, framework agreements, competitive bidding, and single or multiple sourcing. Local purchasing is made according to the availability of local supplies. Compared to global sourcing, it has an advantage of prompt delivery and lower transport costs (PAHO and WHO, 2001). However, competition among organizations to purchase of a product often inflates local prices. Another point is that local suppliers can be destroyed or quantity and quality of goods may not be good enough to meet requirements. In this case, procuring globally or regionally is possible to obtain better quality and larger quantities of supplies. Even so, procurement of larger quantities of supplies from abroad and shipping may require several months (PAHO, 2000). Therefore, relief organizations need to evaluate the tradeoffs between local and global sourcing carefully. Another method is long term close partnerships with suppliers. That is, generally uncommon in relief chains because of limited funds and environmental uncertainties. Some organizations establish framework agreements with some suppliers. These agreements bind the supplier to stock an agreed amount and quality of product, and they are advantageous in terms of quick delivery. Nevertheless, these agreements often don’t guarantee maximum or minimum purchasing amounts on the side of the humanitarian organizations. Organizations also consider a competitive process (bidding) among their registered suppliers to acquire supplies in the post-disaster environment. Satisfying the requirements with competitive bidding can be difficult when different relief organizations compete for scarce resources. In addition, competitive bidding can be time consuming as relief organizations need to find and invite suppliers to bids first. Multiple or single sourcing (i.e., buying from a single supplier or multiple suppliers) is a kind of supplier selection decision and can be used with other sourcing decisions. In general, the number of suppliers affects supply availability and procurement costs.

In our study, we focus on pre-disaster planning for procurement, which is critical for achieving quick response in disaster response. In particular, we are interested in designing effective framework agreements for relief organizations, which allow relief organizations to guarantee availability and fast procurement of relief supplies. More specifically, framework agreement is a type of a contract between a relief organization and a supplier, which is typically established in the pre-disaster stage to set out the terms and conditions under which the purchases can be made when needs arise. Given the complexities of the disaster relief operations and uncertainties regarding the occurrence of disasters, designing effective framework agreements can be challenging for relief organizations. In our study, we examine the characteristics of the contracts that are applied in relief chains and traditional supply chains and explore the applicability of supply chain contracts as framework agreements in relief chains. We examine two types of contracts in the supply chain: contracts under demand uncertainty and contracts under cost uncertainty. In such contracts, both supplier and buyer share the potential risks of cost or demand uncertainty in order to improve their profits. We mainly focus on the contracts under demand uncertainty. We observe that relief organizations apply contracts mostly for the development activities because demand is more predictable at that stage. We evaluate the applicability of the contracts under the category of demand uncertainty. The type of contracts we consider the buyback, revenue-sharing, quantity flexibility, and quantity discount options. We choose the quantity flexibility contract, which sets minimum commitments on the amount of supply and allows an increased purchased amount according to capacity of the suppliers. We develop a two-stage stochastic programming model to support the decisions of a relief organization related to contract design and supplier selection. Specifically, the model determines contract decisions (i.e., which supplier(s) to make an agreement with and how much to commit) and purchasing decisions (i.e., amount of supplies to buy from the selected suppliers) while minimizing the total expected costs. A case study is also presented based on the developed model.

This study concentrates on the procurement side of disaster relief. Despite the importance of procurement activity, the literature in this area is very limited. Inspired from the supply chain contracts and agreements, a contract design method needs to be developed for relief organizations to increase the efficiency of procurement. Our study contributes to the literature on procurement in disaster relief with a special focus on contract design. Specifically, this thesis addresses the following research questions:

1. *What types of contracts or framework agreements are appropriate for the relief chain?*
2. *Which suppliers should be considered for the chosen contracts or agreements, and how should the contract terms be set up?*

The rest of the study is organized as follows: We review the relevant literature about procurement in disaster relief and supplier selection models in the supply chain in Chapter 2. In Chapter 3, we give information about procurement in disaster relief. Specifically, we define procurement, sourcing decisions in disaster relief, and discuss the factors that affect current procurement practices. Chapter 4 examines the characteristics of contracts that are applied in traditional supply chains and the relief chains and explores the applicability of the supply chain contracts as framework agreements in relief chains. Chapter 5 gives background information related to supplier selection for framework agreements and contract design. Also, we present the problem definition and the mathematical model in Chapter 5. Chapter 6 provides computational results. Finally, Chapter 7 presents concluding remarks and future research directions.

# 2 Literature Review

In this chapter, we review the literature in two main areas: Procurement in disaster relief context and supplier selection models in the supply chain. Literature is very scant on procurement, while there are many papers that focus on supplier selection in supply chains.

## 2.1 Procurement in Disaster Relief

In this section, we provide a brief review of related literature in the context of procurement in disaster relief.

Ertem et al. (2009) present a multiple-buyer procurement auctions framework for humanitarian supply chain management. The auction-based framework includes announcement construction, bid construction and bid evaluation phases for relief organizations. The framework is developed in a way that auctioneers (buyers) and bidders (suppliers) compete among each other in multiple rounds of the procurement auction. The framework is verified by simulation and optimization techniques based on the system parameters (e.g., announcement options, priority of items, bidder strategies, etc.), and the values, behavioral changes of auctioneers and suppliers are observed. The framework helps the humanitarian organizations supply the immediate and long-term requirements in the disaster location more efficiently (Ertem et al., 2009).

Trestrail et al. (2009) consider improving bid pricing for humanitarian logistics. The authors develop a mixed integer program that mimics the US Department of Agriculture (USDA) competitive bid approach. The aim is to improve ocean carries and food supplier bid pricing strategy. The model is helpful for clients in selecting bids and determining price more methodically (Trestrail et al., 2009).

Siriariyaporn et al. (2006) address modeling power Annala (2010) studies supply networks and supplier relationships in purchasing supplies from local markets in disaster relief. The author identifies theoretical background on supply networks (humanitarian aid supply network, relations between relief actors), permanent structures (pre-positioning items and long term relations with suppliers) and temporary structures (sourcing during operations, short term relations with suppliers), local purchasing and types of supplier relationships (long- term and short-term) in the humanitarian context. Later, the author formulates a conceptual framework by linking permanent and temporary structures of supply networks, purchasing and supplier relationships together and an empirical case is conducted. This author shows that local sourcing in the disaster relief context can be successful with different supply networks and supplier relationships (Annala, 2010).

Russell (2005) studies the humanitarian supply chains and presents an analysis of the 2004 South East Asia earthquake and tsunami. The author analyzed the results of a relief supply chain survey that is given to organizations providing Tsunami relief. In the survey, results of procurement procedures used in the Tsunami relief effort are analyzed (Russell, 2005).

There are also some nonacademic sources related to the procurement. For instance, United Nations (UN) (2006) procurement practitioner's handbook gives information about common guidelines for procurement in the UN System, existing procurement manuals among the UN organizations, and known procurement practices in the UN organizations (United Nations, 2006). European commission (2010) provides humanitarian aid guidelines for procurement. Specifically, the guidelines are for the award of procurement contracts within the framework of humanitarian aid actions financed by the European Union (European Commission, 2010). Pan American Health Organization (2000) publishes about food and nutrition to plan and implement successful food relief operations. Procurement in relief is mentioned in the handbook (PAHO, 2000). PAHO (Pan American Health Organization) and WHO (World Health Organization) publish a handbook on humanitarian supply management and logistics in the health sector. In the handbook, procurement methods for emergency supplies are explained and the advantage and disadvantages are discussed (PAHO and WHO, 2001). New Zealand Government (2011) provides a quick-guide for emergency procurement. It gives guidance and key considerations to procurement for different phases of emergency (New Zealand Government, 2011).

Finally, we also make use of websites of the Logistics cluster on procurement, and the International Federation of Red Cross and Red Crescent Societies on framework agreements.

## 2.2 Supplier Selection in Supply Chains

We also review the supplier selection models that involve one or more of the following aspects that we consider in this study: quantity flexibility contracts, quantity discount schemes, and demand uncertainty.

Tsay and Lovejoy (1999) focus on quantity flexibility contracts and supply chain performance. The authors seek to address the need of a firm, who builds its supply relationships by implementing quantity flexibility contract. The authors provide a formal framework for the analysis of such contracts and propose behavioral models for forecasting and ordering policies and link these behavioral models to inventory levels and order variability for a rational way to make use of flexible supply. They find that quantity flexibility contracts can dampen the transmission of order variability throughout the chain (Tsay and Lovejoy, 1999).

Das and Malek (2003) focus on modeling the flexibility of order quantities and lead-times in supply chains. The authors propose a model in which a buyer is able to estimate the flexibility of potential supply chain partners and the annual procurement cost of a given relationship. They model supply chain flexibility in terms of the elasticity in the supply contract between a buyer and supplier. They find out that a highly flexible relationship is the one in which there is little deterioration in the procurement price and penalties under different supply conditions (Das and Malek, 2003).

Siriariyaporn et al. (2006) address modeling power portfolio with supply contracts for mitigating risks of serving uncertain demand. The authors present a short term planning model for electricity production with a portfolio of choices; self generation, forward and option contracts, and spot sale/purchase, which provides different degree of flexibility to reduce the financial and operational risks. They consider a two stage stochastic mixed integer program to determine an optimal mix of decisions for supply sources, and show that the model can be used to increases the flexibility of the system (Siriariyaporn et al., 2006).

Liao and Rittscher (2006) develop a multi-objective supplier selection model under stochastic demand conditions. The authors develop a measurement for supply chain flexibility with the consideration of demand quantity and timing uncertainties. The proposed multi-objective stochastic supplier selection model is a non-linear mixed integer combinatorial optimization problem. A genetic algorithm is used to solve the problem. They found that flexibility plays an important role in the stochastic supplier selection situation; it is in accordance with quality but conflicting with cost. These tradeoffs are valuable for final supplier selection (Liao and Rittscher, 2006).

Hazra and Mahadevan (2007) present a procurement model with capacity reservation. In their problem, demand is uncertain and the buyer wants to reserve capacity through a contract entered with a set of suppliers. The decision to reserve capacity is made in the beginning of the season and after the demand is observed, if the capacity under the demand, the buyer buys the rest from the spot market. The buyer faces with two decisions, which are how much capacity to reserve from how many suppliers. They develop closed form solutions and find out that increasing the number of pre-qualified suppliers does not provide significant advantages to the buyer, but a pre-qualified supply base with greater capacity heterogeneity will benefit the buyer (Hazra and Mahadevan, 2007).

Zhang and Ma (2009) study optimal acquisition policy with quantity discounts and uncertain demands. They consider an acquisition policy decision problem for a supply network involving one manufacturer and multiple suppliers; the manufacturer produces multiple products under uncertain demands and each supplier provides price discounts. Their problem is to determine a manufacturer acquisition policy and production levels to maximize the manufacturer expected profit according to the manufacturer and suppliers capacities. They present a mixed integer nonlinear programming formulation for the problem, for both single- and multiple-sourcing procurement policies. To solve the problem, they employ GAMS and its solvers, combining with external integration functions. They employ the model and solution approach to a volume discount example. Numerical results show both the model and the solution method is effective for the problem (Zhang and Ma, 2009).

Xu and Nozick (2009) consider modeling supplier selection that integrates option contracts (a contract that offers to buy or sell an asset at a specific price on a certain date) for global supply chain design. The authors focus on loss of capacity disruptions on the supplier sites and chose to use option contracts to hedge against the loss of suppliers. Their objective is to choose a set of suppliers that minimize total expected cost. They formulate a two-stage mixed integer stochastic program which optimizes supplier selection decisions, and develop an efficient heuristic based on Lagrangian relaxation and the L-shaped method to solve the model. They show that the model creates a basis for improved decision making in global supply chain by providing quantitative trade-off between cost and risks (Xu and Nozick, 2009).

Paksoy et al. (2009) address a facility location and supplier selection problem that considers supplier's product quality and contract fee. The authors propose a mixed integer linear programming model for solving a supply chain network design problem. They recommend choosing suppliers according to their raw materials quality and the supplier engagement contracts. They also consider the trade offs between raw material quality, and its purchasing and reprocessing costs. If the decision maker wants to choose a high quality supplier, he/she should bear high purchasing costs; otherwise choosing low quality raw material requires reprocessing and reprocessing costs (Paksoy et al., 2009).

Ravindran et al. (2010) present a risk adjusted multi criteria supplier selection model. The authors use a multi objective optimization model which minimizes price, lead time, MtT type risk (e.g., late delivery, low service rate, high defective rate) related to quality and VaR type risk related to disruptions due to natural events simultaneously. They solve the model by using a two phase method and illustrate it with an actual application to a global IT company (Ravindran et al., 2010).

Keskin et al. (2010) focus on integration of strategic and tactical decisions for vendor selection under capacity constraints. The authors present a challenging mixed integer nonlinear program, and propose an efficient solution approach that relies on Generalized Benders Decomposition (GBD). They examine a generalized vendor selection problem of a multi-store firm where the goal is the simultaneous determination of the set of vendors the firm should work with and how much each store should order from the selected vendors. Also they consider inventory related costs and decisions of the stores. They develop an integrated vendor selection model which is aimed at optimizing the location and inventory costs (Keskin et al., 2010).

Glock (2010) develops a multiple-vendor single-buyer integrated inventory model with a variable number of vendors. In the problem, a buyer sources a product from different suppliers, and tackles the supplier selection and lot size decisions with the objective of minimizing total system costs. The author suggests a two stage solution procedure to solve the model and shows that the solution procedure reduces the total number of supplier combinations that have to be tested for optimality and so that the complexity of the planning problem is reduced (Glock, 2010).

Bilsel and Ravindran (2011) consider a multiobjective chance-constrained programming model for supplier selection under uncertainty. The authors present a stochastic multiobjective sequential supplier allocation problem to help in supplier selection under uncertainty such as demand, product, supplier capacity, transportation cost, etc. Their model provides proactive mitigation strategies against disruptions, when there is no disruption; the model's solution is an optimal supplier order assignment, considering operational risks (Bilsel and Ravindran, 2011).

In our study, we inspire mostly from the studies of Das and Malek (2003), Liao and Rittscher (2006), Paksoy et al. (2009), Zhang and Ma (2009). We adapt parameters and decision variables from these studies, but our model is different from the related supplier selection models in one or more of the following aspects: minimum quantity commitment for quantity flexibility, quantity and lead time discounts, agreement characteristics (fixed agreement fee, penalty cost for not meeting contract requirements), fill rate requirements and demand uncertainty.

# 3 Procurement: Overview and Background

In this chapter, we give background information about procurement in humanitarian relief. Specifically, we define procurement, sourcing decisions in disaster relief, and discuss the factors that affect current procurement practices.

## 3.1 What is Procurement?

Procurement is the process of identifying and obtaining goods and services. It covers all activities from identifying potential suppliers through to the delivery from the supplier to the users or beneficiaries (Logistics Cluster, 2011). The objective of procurement in humanitarian relief is to carry out activities related to procurement in such a way that *"the goods and services are at the right quality, from the right source, are at the right cost and can be delivered in the right quantities, to the right place, at the right time"* (Logistics Cluster, 2011). It is a key activity in the relief operations because it interacts with other logistics functions within the organization, such as warehousing, distribution, finance, etc., and represents a very large proportion of the total expenditures. It should be managed effectively, because it can significantly affect the overall success of an emergency response depending on how it is managed (Logistics Cluster, 2011).

## 3.2 Factors Affecting Procurement in Disaster Relief

There are some factors about disaster relief that should be considered while discussing procurement. These are environmental uncertainties, customer focus related problems, competitive priorities between relief organizations and insufficient information technology (Chen and Paulraj, 2004).

Firstly, the environmental uncertainties arise from supplier and demand uncertainties (Davis, 1993), and it is related to nature of disasters. We don't know when or where a disaster will occur, how many people will be affected, and how much demand will occur. That's why demand is uncertain. When a disaster occurs, large number of supplies needed in shorter lead times (Balcik and Beamon, 2008). Supplier related uncertainties appear in these situations. We are not sure that whether the supplier has an available capacity, can serve in a short lead time, meets the expectations, etc. Unlike the supply chain, it is complex for the relief chain to deal with the suppliers before a disaster struck because demand is highly uncertain. It is an important problem of the procurement. Generally, relief organizations contact with suppliers after a disaster occurs, which leads to longer response times.

Secondly, in disaster relief, the concept of customer is ambiguous (Annala, 2010). Although the aid recipients are the customers, the donors play an important role and according to non-governmental organizations (NGOs), the donors are the customers (Beamon and Balcik, 2008). At an immediate response stage, large amount of supplies are pushed to the disaster location (Annala, 2010). If there is a lack of resources, there is no complaint mechanism for neither donor nor aid recipients about whether their expectations are met (Hilhorst, 2002).

Another factor is related to competitive priorities between humanitarian organizations. There is a simultaneous competition among relief organizations for financial resources, and suppliers. Thus, purchasing during a disaster response phase is difficult (Annala, 2010) and can be very expensive.

Finally, humanitarian organizations have insufficient investments in technology and lack the knowledge of the latest methods and techniques (Annala, 2010). They rely on manual systems, which is inadequate and inefficient (Annala, 2010).

The factors affecting procurement are shown in Figure 1 below.

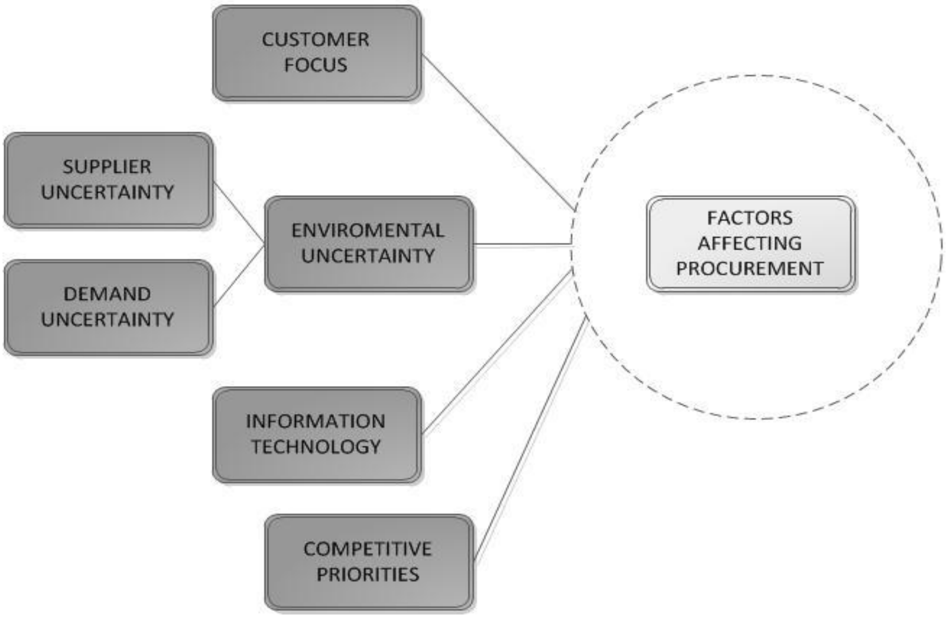


**Figure 1** Factors affecting procurement (adapted from Chen and Paulraj, 2004).

### 3.3 Procurement in Disaster Relief

There are several issues that relief organizations need to consider while designing their procurement processes, which are shown in Figure 2 and discussed below.

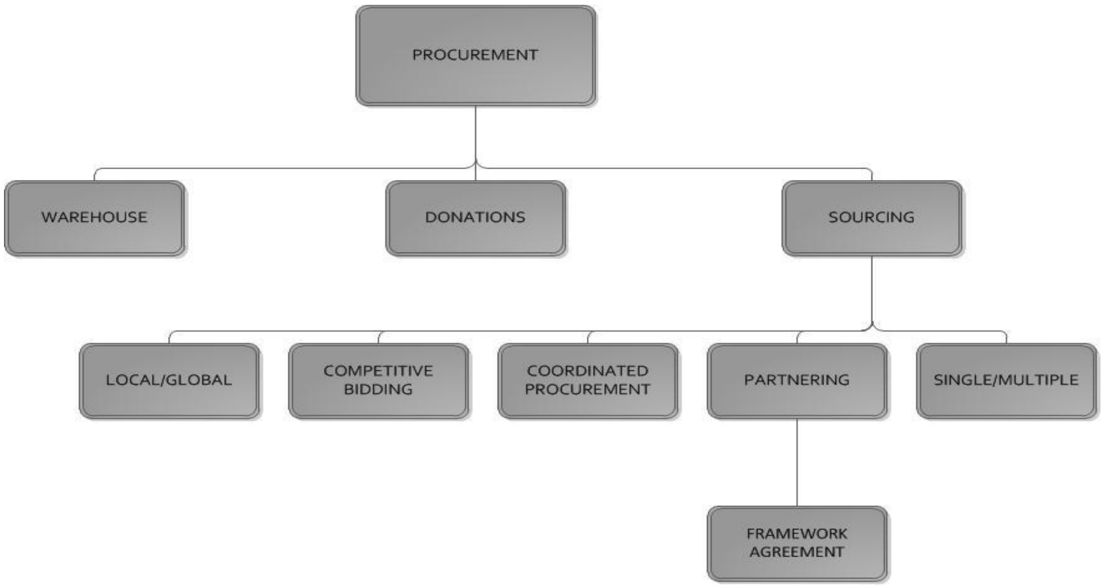


**Figure 2** Procurement methods in disaster relief.

**Pre-positioning in Warehouse**

Relief organizations pre-position relief supplies at distribution centers before a disaster strucks. However, a few organizations use this strategy because of limited funds and cost of operating distribution centers (Balcik et al., 2010). The challenge is, pre-positioning supplies in a way that they won't be affected from the impact of disaster, while at the same time they should be close enough to the disaster sites to deliver aid quickly and effectively (Balcik and Beamon, 2008). Also, pre-positioned amount is typically small compared to total demand.

**Donations**

There are in-kind (non-financial) and cash donations. In-kind donations become available after disasters (Balcik et al., 2010), and it takes time to prioritize, sort, count and match them with the current demand (Ertem et al., 2009). Cash donations are better and preferable because it is possible to purchase supplies and services (PAHO and WHO, 2001) which saves time according to in-kind donations.

**Local versus Global Sourcing**

Local sourcing is buying from local and national suppliers and global sourcing is buying from international or global suppliers. Each decision has advantages and disadvantages in terms of expected logistic costs, lead time and supply availability (Balcik and Beamon, 2008). While local sourcing is accomplished in shorter times and lower logistic costs, local suppliers may not have available quantity and quality of supplies. In this situation, global sourcing is advantageous by supply availability. However, after a disaster, global sourcing can be time-consuming; procurement of larger quantities of supplies from abroad and shipping may require several months (PAHO, 2000), and a quick response is more important.

**Competitive Bidding**

Competitive bidding is a competition between suppliers. It is also known as auction based procurement. Generally, organizations open a bid or in other words, announce the demand to their registered suppliers on their web page (Ertem et al., 2009), and suppliers offer price to satisfy the demand. The supplier who gives the lowest price is chosen. It is simple to supply immediate requirements with competitive bidding, but it becomes difficult when organizations compete for limited resources. Also, the bidding procedure is time-consuming in general. Therefore, delays may occur in procuring supplies.

**Coordinated Procurement**

Coordinated procurement occurs when relief organizations cooperate with each other in procurement. By this way, they can procure larger quantities at lower prices, and it helps to reduce the effect of agency competition on local supply prices. However, post-disaster environment makes difficult to coordinate because of lack of financial, human, technological, informational resources (Balcik et al., 2010).

**Partnering**

Partnering with suppliers is a type of coordination mechanism. It refers to a long-term relationship with suppliers, but it is not widespread in the relief sector due to environmental uncertainties and limited budgets. More specifically, long-term relations can be expensive and existing funds may not be enough to meet cost of partnering.

**Framework Agreements**

Some organizations establish framework agreements with some suppliers. For example, WFP (World Food Programme) makes long term framework agreements with suppliers on condition that supplier will hold stock. This binds the supplier to hold extra stocks. However, the agreement doesn’t guarantee maximum or minimum purchasing amounts on the relief organization side (Balcik et al., 2010). These framework agreements enable to reserve capacities, set prices and quality standards and contributes the agility of the disaster response (Annala, 2010).

**Single versus Multiple Sourcing**

Single and multiple sourcing are used along with most of the purchasing decisions (such as global/local sourcing, competitive bidding, partnering). Single sourcing is buying from one supplier and multiple sourcing is more than one. Generally, buying from single or multiple suppliers is related to supplier selection, and it is important in terms of cost, and availability of supplies. For example, humanitarian organizations avoid single sourcing because suppliers may behave like monopolistic and increase prices, while multiple sourcing removes monopolistic behavior and ensures the availability and distribution of supplies (Annala, 2010).

In general, there is evidence of a frequent lack of planning in disaster relief procurement activities. However, we observe that there is an increasing interest in the relief sector to engage into framework agreements with suppliers. In the next chapter, we discuss different types of contracts and agreements practiced in supply chains and relief chains.

# 4 Types of Contracts and Agreements

In previous chapter, procurement in disaster relief and the factors affecting the procurement are explained. We discuss that environmental uncertainties, uncertain customer focus, competition between organizations and insufficient information technology are affecting the procurement process. Also, different procurement methods can involve different challenges. For example, local procurement can be expensive during a disaster due to the competition between organizations, while global procurement can be time consuming and expensive in terms of transportation costs. Competitive bidding is difficult to accomplish when organizations compete for scarce resources. Long term close partnerships with suppliers are uncommon in relief chains because of limited funds and environmental uncertainties. However, some organizations establish framework agreements with some suppliers. These agreements bind the supplier to stock an agreed amount and quality of product, and it is advantageous in terms of quick delivery. Nevertheless, these agreements often do not guarantee maximum or minimum purchasing amounts on the side of the humanitarian organizations.

Generally, relief organizations focus on post-disaster procurement activities to acquire resources, and this may lead to slower response times in meeting needs of beneficiaries. In our study, we focus on pre-disaster planning for procurement because a quick response is very important in disaster response. That’s why we are interested in the framework agreements, because they contribute to the agility of the disaster response by allowing the pre-disaster planning. In the following sections, we examine the characteristics of the contracts that are applied in relief chains and traditional supply chains, and also explore the applicability of supply chain contracts as framework agreements in relief chains.

## 4.1 Contracts and Agreements in Traditional Supply Chains

A contract is a legally enforceable agreement between two or more parties (Wikipedia, 2010). It defines the terms and conditions of sale between the parties (a buyer and seller), therefore, the choice of contract has comprehensive results on buyer and seller profits and how profit is divided and risk is shared between the buyer and the seller (Webster, 2008, p. 97). Ideally, a contract should be structured to increase the firms profit and supply chain profits, reduce uncertainty, offer incentives (discounts, etc.) to the supplier to improve performance along key dimensions (reduced lead time, quick response, etc.) (Chopra and Meindl, 2010, p. 427). There are two general types of contracts according to Webster and Chopra & Meindl classification contracts under demand uncertainty and contracts under cost uncertainty. The following subsections address these types of contracts.

### 4.1.1 Contracts under Demand Uncertainty

Demand uncertainty means unknown market demand on the buyer side, and it creates considerable risks in a supply chain, especially when replenishment lead times are long and selling season is short (Webster, 2008, p. 99-100). The buyer assesses market potential and sizes up the risks by ordering too much or too little. The seller receives the order and produces and delivers the product. Seller's profit is largely set, but demand uncertainty is reflected in uncertainty in buyer profit. In this case, both buyer and supplier benefit from a contract that shares the demand uncertainty (Webster, 2008, p. 99-100) and improve overall supply chain profits. There are some contracts suitable for this situation as follows (Chopra and Meindl, 2010, p. 428):

- Buyback or returns contracts
- Quantity flexibility contracts
- Revenue-sharing contracts
- Quantity discount contracts

In the following subsections (4.1.1 and 4.1.2), we explain each contract and discuss the risks, advantages and disadvantages of these contracts. Moreover, we mention a level of control needed by a buyer or a supplier. We adapted three levels of control from Balcik et al. (2010): high, medium and low. A high level of control needs frequent controls, while a medium level needs occasional controls, and a low one requires no/little controls by the supplier or the buyer. In addition, through the subsections 4.1.1 and 4.1.2, the buyer refers to actually the retailer who buys from a manufacturer and sells to an end customer. The supplier/seller (have the same meaning) refers to the manufacturer who produces goods for use or sale.

**Buyback Contracts**

A buyback contract allows the buyer to return unsold inventory up to a specified amount, at an agreed-upon price (Chopra and Meindl, 2010, p. 428). The seller specifies a wholesale price along with a buyback price at which the buyer can return any unsold units at the end of a season. The buyback contract encourages the buyer to increase the level of product availability, which results to higher profits for the supplier and the buyer. On the other hand, when the buyer orders higher quantities, actual customer demand is lost. Furthermore, the supplier may have surplus inventory, which must be disposed at the end of the season (Chopra and Meindl, 2010, p. 430). Therefore, the supplier carries the inventory risk and requires verifying left over units, which means that a high level of control is needed. This type of contract is frequently used in the publishing, music and apparel industries (Webster, 2008, p.100). Figure 3 illustrates the buyback contract. As seen in the figure, the seller specifies a wholesale price to the buyer, and the buyer sells the goods in the market place. If the demand of the buyer is less than expected, the buyer can return unsold goods (at an agreed buyback price, up to a specified amount).

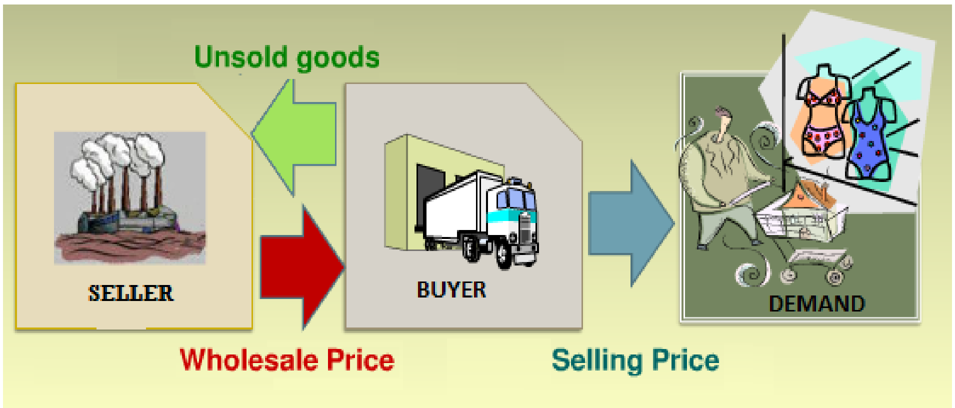


**Figure 3** Buyback contract (Adapted from Docstoc, 2011).

## Quantity Flexibility Contracts

Under quantity flexibility contract, the buyer pays a wholesale price to the seller, and then he has a chance to change the quantity ordered after observing demand (Chopra and Meindl, 2010, p. 432). The buyer can adjust to the order up or down within agreed quantity range at a specified time interval (Webster, 2008, p. 100). If demand is low, and the order quantities of the buyer are reduced, the seller will have the risk of unwanted products at the end of the season. The supplier requires to be good at gathering market intelligence and improving its forecasts closer to the point of sale to avoid surplus inventory (Chopra and Meindl, 2010, p. 434). Nevertheless, the quantity flexibility contract provides a better demand and supply match. This type of contract is often used in the electronics industry and fashion apparel industry (Webster, 2008, p.100) and requires a medium level of control by the buyer. The buyer should occasionally control the supplier related data (capacity, reserve quantity) over the contract period. Figure 4 shows the quantity flexibility contract. Accordingly, the buyer pays a wholesale price, and can change the order (at the agreed quantity range and at the specified time interval) according to demand realized.

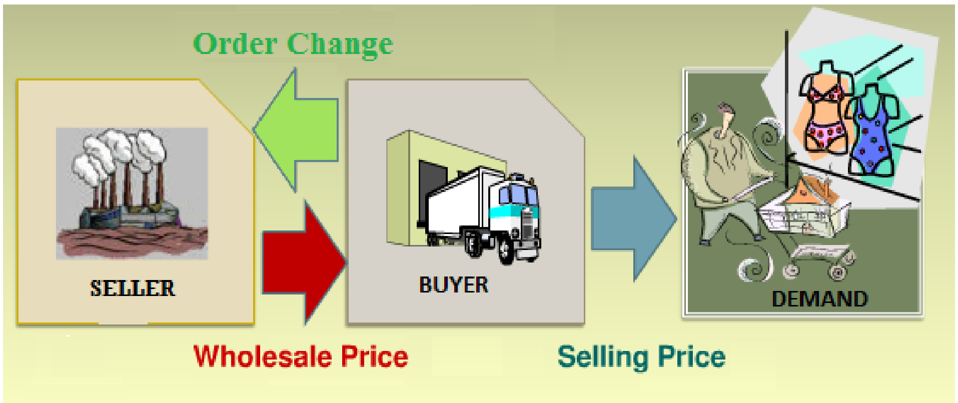


**Figure 4** Quantity flexibility contract (Adapted from Docstoc, 2011).

## Revenue Sharing Contracts

Revenue sharing contract sets a low price to the buyer and in return, the buyer pays the seller some percentage of sales revenue from the product (Webster, 2008, p.100). The revenue sharing contract requires an information infrastructure (a high level of control) that allows the supplier to monitor sales at the buyer; however, it can be expensive to build such a system (Chopra and Meindl, 2010, p. 432). This type of contract is best suited for products with low variable cost and a high cost of return; an example for this contract is between video rentals and movie studios (Chopra and Meindl, 2010, p. 432). Revenue sharing contract sets a low price to the buyer which is advantageous, but the supplier bears some demand risk as the buyer shares its revenue in return. In addition, it can be difficult for the supplier to follow the sales when there are multiple buyers. Figure 5 demonstrates the revenue sharing contract. The seller applies a percentage discount on the wholesale price and when the buyer sells the products, the buyer shares a percentage of revenue.

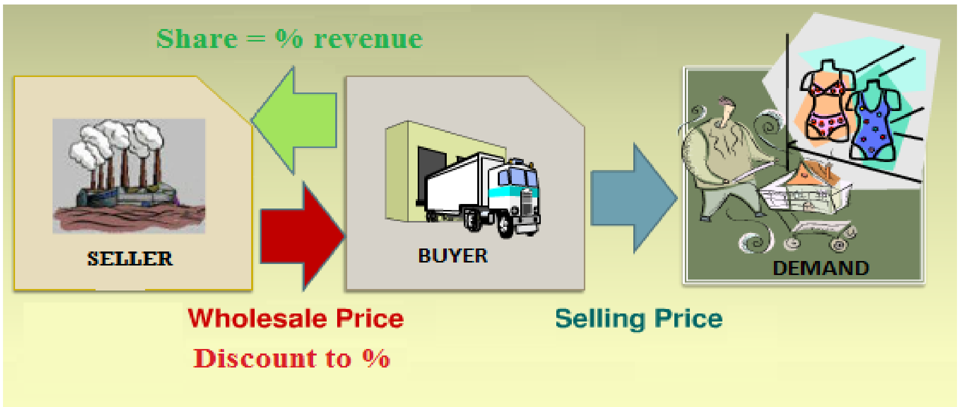


**Figure 5** Revenue sharing contracts (Adapted from Docstoc, 2011).

**Quantity Discount Contracts**

In quantity discount contracts, if the buyer purchases larger lot sizes, the wholesale prices go down (Erhun and Keskinocak, 2003). This type of contract is used when the seller has a high fixed cost, and wants to encourage the buyer to purchase more units (Chopra and Meindl, 2010, p.434). This type of contract increases demand variation, because the buyer orders less frequently when large quantities are ordered (Chopra and Meindl, 2010, p. 435). In this case, the buyer takes a risk of overstocking (Shin and Benton, 2007) and there is a low level of control by the supplier because just a buying and selling relationship occurs. Figure 6 shows the quantity discount contact. As seen in the figure, the seller applies a discount on the wholesale price. Quantity discounts can be applied together with other types of contracts; for example, a quantity flexibility contract can involve the characteristics of the quantity discount contracts (such as supplier can provide a quantity discount schedule and apply discount for the quantities ordered.)

**Figure 6** Quantity discount contract (Adapted from Docstoc, 2011).

### 4.1.2 Contracts under Cost Uncertainty

Suppliers don't normally know the exact cost to provide a product or service to a buyer ahead of time. Cost uncertainty introduces the risk of lower than expected profit, perhaps the point of loss for the supplier. In this case, the buyer and the supplier can make contracts that allocate the risks to increase the overall supply chain profits. Here below examples of contracts that cost uncertainty is shared (Webster, 2008, p.98):

- Fixed price (lump sum) contract
- Cost plus fixed fee contract
- Fixed price plus incentive contract

**Fixed Price (lump sum) Contract**

In a fixed priced contract, the seller specifies a fixed amount of money to the buyer for a fixed amount of supplies or services provided, which is not subject to adjustment (Business Dictionary, 2011). This type of contract is used when costs can be estimated with reasonable accuracy (eHow, 2011). Both parties (the supplier and the buyer) accept certain risks when they enter into the contract. The supplier caries the maximum risk because he bears the risk of cost escalations (eHow, 2011); if a problem occurs, the supplier must accomplish the work with the agreed amount of money. However, the seller is setting the price in such a way as to be compensated for taking risks. Actually, in this contract, it may happen that the buyer is paying more than would have been necessary (Newell, 2002, p. 186).

In fixed price contracts, the buyer doesn't interest whether the seller spends more or less. The buyer is only interested in if the seller performs the work or not (Newell, 2002, p. 186). The advantages of fixed price contract for the buyer are: the buyer knows the total price at project starts and has less work to manage (a low level of control by the buyer). The disadvantages are: the seller may not complete some of the contract statement if they begin losing money, and the seller may inflate the price to prevent potential risks (PMP PREPARATION, 2009). This type of contracts is used generally in construction area. Figure 7 illustrates the fixed price contract. The seller specifies a fixed price to the buyer, and no adjustment is made.


**Figure 7** Fixed price contract (Adapted from Docstoc, 2011).

**Cost plus Fixed Fee Contracts**

In a cost plus fixed fee contract, the buyer pays for the contract requirements and a fixed fee. Fixed fee is considered as the profit of the seller. The buyer bears all cost uncertainty that's why the buyer may want to access to detailed cost data (Webster, 2008, p. 101), so a high level of control is necessary by the buyer.

The advantage of this contract for the buyer is that final cost can be cheaper than the fixed price contract because the supplier doesn't inflate the cost to cover the risk. In addition, the supplier has a little incentive to cut corners (attempt to save money). On the other hand, the buyer has uncertainty what the final cost will be and requires cost control by the buyer. It is mostly used when the cost of final cost can't accurately estimated (Wikipedia, 2011). Figure 8 shows the cost plus fixed fee contract. The buyer pays for the contract requirement which is the total cost and a fixed fee (profit of seller).


**Figure 8** Cost plus fixed fee contract (Adapted from Docstoc, 2011).

**<u>Fixed Price plus Incentive Contracts</u>**

In a fixed price plus incentive contract, there is an agreed price for the provided supplies or services, and plus there is an incentive fee in case of the seller delivers the supplies or performs the service earlier than agreed-upon time. In this situation, the seller takes a risk of meeting the conditions. If the seller completes the task early, he will take the incentive fee. Otherwise, no incentive fee is paid. There is a low level of control by the buyer, the buyer is only interested in whether the seller performs the work. The advantage of this contract for the buyer is that the seller has a motivation to complete the job early. The disadvantage arises if the buyer really needs the job to be completed early and the seller does not accomplish (Newell, 2002, p. 188). The fixed price plus incentive contract is shown in Figure 9. The seller specifies a fixed price to the buyer, and the buyer gives an incentive fee to motivate the seller to complete the job early.


**Figure 9** Fixed price plus incentive contract (Adapted from Docstoc, 2011).

Table 1 summarizes the supply chain contracts under cost and demand uncertainty.

**Table 1** Attributes of supply chain contracts and agreements.

| Contracts | Demand Uncertainty | Cost Uncertainty | Level of Control |
|---|---|---|---|
| Buyback Contracts | Yes | - | High by the supplier |
| Quantity Flexibility Contracts | Yes | - | Medium by the buyer |
| Revenue Sharing Contracts | Yes | - | High by the supplier |
| Quantity Discount Contract | Yes | - | Low by the supplier |
| Fixed Price (lump sum) Contracts | - | Yes | Low by the buyer |
| Cost plus Fixed Fee Contracts | - | Yes | High by the buyer |
| Fixed Price Incentive Contracts | - | Yes | Low by the buyer |

## 4.2 Relief Chain Contracts and Agreements

Previous section discusses the supply chain contracts and agreements, and this section introduces the literature related to the relief chain contracts and agreements. The related literature is very scant; we found the related information from practitioners' handbooks of agencies; United Nation, European Commission and International Federation and website of International Federation of Red Cross and Red Crescent Societies (IFRC). Moreover, the information from available resources doesn't describe the contract terms or aspects in detail. We observe that humanitarian organizations apply these contracts mostly for the development activities because demand is more predictable at that stage. These contracts are not widely implemented and coping with cost uncertainty is the major concern.

In addition, the contracts and agreements in the relief chain have different terms, and conditions when compared to the supply chain contracts and agreements because of unique characteristics and challenges. The most common types of contracts (United Nations, 2006) which are under cost uncertainty and demand uncertainty:

<u>Contracts under cost uncertainty</u>

- Fixed price (lump sum or a unit price) contracts
- Reimbursable cost contracts
- Combinations of fixed price and reimbursable cost contracts

Contracts under demand uncertainty

- Framework agreements

**Lump Sum Contracts**

Similar to the fixed price contracts applied in supply chains and described before, with a lump sum contract, the supplier agrees to perform a work for one fixed price, without considering the final cost. Lump sum contracts are used when the content, the duration of services and the required output of the supplier are clearly defined for assignments. They are widely used for simple planning and feasibility studies, environmental studies, detailed design of standard or common structures, preparation of data processing systems, and so forth. Payments are linked to outputs (such as reports, drawings, and bills of quantities, etc.) Lump sum contracts are easy to manage because payments are due on clearly specified outputs (United Nations, 2006). It requires a low level of control because the buyer doesn't need to control the cost data except the performance of the supplier. The supplier carries the risk of higher final cost, and should perform the work even the agreed price doesn't meet the requirements. Lump sum contracts are mostly suitable for development activities.

**Fixed Unit Price Contracts**

In a unit price contract, the supplier agrees to supply goods or services at fixed unit prices, and the final price is dependent on the quantities needed to fulfill the work. Large quantity changes can lead to decreases in unit prices. This type of contract is suitable when it is impossible to determine the quantity of services, works or goods required from the supplier because of the nature of the work, service, or goods. In this case, the buyer is at risk for the final total quantities (e.g., the final cost is not known) (United Nations, 2006). Because of this, the buyer should control the supplier's expenses (a high level of control is necessary).

**Cost Reimbursable Contracts**

Cost-reimbursable contracts are recommended only in exceptional circumstances such as conditions of high risk or where costs can't be determined earlier with enough accuracy. Such contracts should include appropriate incentives to limit cost (e.g., ceiling price). The risk of the contract is carried by the buyer as the supplier has no incentive to control costs, or to finish early or in time. The buyer has to closely monitor and manage the contract (high level of control) (United Nations, 2006).

**Framework Agreements**

Framework agreements are agreements with one or more suppliers that set out terms and conditions under which specific purchases can be made throughout the term of the agreement. Framework agreements are used to cover agreements, which set terms and conditions for subsequent purchases but place no obligations to purchase goods, or services (European Commission, 2010). They are used for commodities where there is a high demand for large quantities of the same commodity. Suppliers are selected based on their price, reliability, production capacity, stock availability and previous performance. The selected suppliers agree to supply a certain commodity at a certain price for a particular period of time (such as two years). Framework agreements can be used for pre-positioning stock as a global strategy. The selected suppliers also agree to reserve and store an agreed quantity of commodities either at their own warehouses or at the regional ones. This pre-positioning of stock guarantees stock level at any given time. The only exception to this is when replenishment is necessary after a large-scale sudden-onset emergency.

The advantage of the framework agreements is building robust relations with reliable suppliers for ensuring quality, timely deliveries and costs reductions (European Commission, 2010). Suppliers also have the advantage of a guaranteed order over a particular period of time with the additional advantage of higher-order volumes (IFRC, 2011). The main disadvantage is that a precise volume and timing of delivery may not be defined at the outset (European Commission, 2010) due to demand uncertainty. Also, the supplier related data (stock availability and reserve quantities) require a medium level of control over the contract period.

Russell (2005) analyzes a survey related to relief supply chain that is given to organizations providing Tsunami relief. The survey showed that 56% of the relief organizations had framework agreements on non-food items and 50% for medical items. 70% of the organizations had these contracts with vehicle suppliers, given that vehicles are critical resources in the relief effort. Food supplies were generally not covered under pre-established agreements due to the issues of spoilage, and interest in purchasing food locally when possible (Russell, 2005).

Table 2 shows the attributes of the relief chain contracts and agreements.

**Table 2** Attributes of the relief chain contracts and agreements.

| Contracts and Agreements | Demand Uncertainty | Cost Uncertainty | Level of Control |
|---|---|---|---|
| Lump Sum Contracts | - | Yes | Low by the buyer |
| Fixed Unit Price Contracts | - | Yes | High by the buyer |
| Cost Reimbursable Contracts | - | Yes | High by the buyer |
| Framework Agreements | Yes | - | Medium by the buyer |

### 4.3 Cross Learning: Adaptability of Supply Chain Contracts to Relief Chains

Supply chain contracts are widely implemented in industry. However, we do not see many relief organizations applying them, especially in planning for relief operations. It is because there are various implementation drawbacks.

For example, buyback contracts are unsuitable for quick onset disasters because procured and shipped items can be damaged in the disaster area, and logistics can be expensive to send leftover items. However, it may be possible to apply the buyback contract effectively if the supplier has a capacity to hold the procured items and deliver them according to the demand. In this case, the supplier requires an effective reverse logistic system otherwise its logistic costs may be increased (Simchi-Levi et al., 2003, p. 130) and bears an inventory holding cost. Buyback contracts may be used for a short term period in pre-disaster warehouse planning, for cyclic disasters such as hurricanes. The relief organization can order higher quantities and at the end of the hurricane season, they can return leftover units to the supplier at the agreed-upon price.

Revenue sharing contracts are not applicable to the relief environment because there is no revenue; the only effort is to deliver the needs of beneficiaries. We observe that fixed price, fixed price incentive, and cost plus fixed fee contracts are used in the relief chains mostly for development activities. These contracts are recommended only where costs can't be determined earlier with enough accuracy. Quantity discount contracts are used together with most of the contracts, and advantageous in terms of supplying higher quantities with lower costs.

Quantity flexibility contracts are applicable to relief chain. The relief organization will commit some amount at the pre-disaster period. Later, they can adjust the commitment up to available capacity of the supplier at the post-disaster stage when demand is realized. The relief organizations guarantee availability of an agreed amount at the post-disaster stage. However, the seller has a disadvantage of carrying inventory.

Table 3 below summarizes the implementation of the supply chain contracts and agreements in the relief chain with the risks, advantages and disadvantages. Some of the contracts are currently observed in the relief chain while some of them are not. These contracts maybe applied in some way but we couldn't find any information from the academic literature or any other resources available.

**Table 3** Applicability of the supply chain contracts and agreements to the relief chain and the risks, advantages, disadvantages.

| Contracts and Agreements | Currently Observed? | How to Implement? | Advantages | Disadvantages | Risks |
|---|---|---|---|---|---|
| Buyback Contract | No | It can be used in pre-disaster warehouse planning for cyclic disasters.<br><br>The supplier holds the items and delivers according to demand. | The relief organization can return left over units at the buyback price. | Logistic costs | The supplier bears logistic and holding cost when he holds and delivers. |
| Revenue Sharing Contract | No | Not suitable to the relief environment. | - | - | - |
| Quantity Flexibility Contract | No | Relief organizations commit some amount at the pre-disaster stage and adjust the commitment up to available capacity of the supplier if needed. | Supply availability at the post-disaster stage and contribute to agility in procurement. | The supplier bears an inventory cost. | Supplier carries the risk of excess inventory because of demand uncertainty. |
| Quantity Discount Contract | Yes | The supplier applies a discount if the buyer purchases larger lot sizes. | Buying larger quantities with lower costs. | Increases demand variation. | The buyer takes a risk of overstocking. |
| Fixed Price Contract | Yes | Fixed amount of money paid for a fixed amount of supplies or service provided. | The buyer knows the total price at project starts. | The seller inflates prices to avoid the risk of cost escalations. | The supplier caries the risk of cost escalations. |
| Cost Plus Fixed Fee Contract | Yes | The buyer pays for the contract requirements and a fixed fee. | Final cost can be cheaper than the fixed price contract. | The buyer has uncertainty what the final cost is. | Cost uncertainty at the buyer side. |
| Fixed Price Incentive Contract | Yes | There is an agreed price for the provided supplies or services, and plus there is an incentive fee. | The seller has a motivation to complete the job early. | The buyer may really want the job to be completed early, and the seller may not accomplish. | The seller takes a risk of meeting the conditions early. If the seller cam not, no incentive fee is paid. |

We find that buyback, quantity discount and quantity flexibility contracts are suitable for the relief chain as they can deal with demand uncertainty. Quantity flexibility contract seems more applicable to the relief chain according to the other contracts because demand uncertainty is managed by setting minimum commitments for supplies and allowing maximum purchases according to capacity of the suppliers. Our focus is on designing a quantity flexibility contract as a framework agreement by integrating it with quantity discount contracts and supplier selection decision.

# 5 Supplier Selection for Contract Design

Relief organizations provide life saving assistance such as nutrition, water, sanitation, protection to people affected by disasters. Their aim is to respond to emergencies as quickly as possible. However, since emergencies may have complex results (e.g., loss of life, epidemics, damage of economics and society, poverty), organizations should make plans before emergencies occur. If the relief organizations do not plan their resources (e.g., equipments, trained personnel, supplies, etc.) effectively, this may lead to chaos during an emergency. The relief organizations face with difficulties when they make emergency plans because demand, time, location, type and size of the disasters are unknown a priori.

In the previous chapter, the supply chain and the relief chain contracts and agreements are identified and examined to understand whether the supply chain contracts or agreements are applicable to the relief chain as a framework agreement. We decide to design a quantity flexibility contract with quantity discounts as a framework agreement by considering supplier selection decision. In this chapter, we first give background information related to supplier selection for framework agreements and contract design (section 5.1). Then, we define the problem related to the relief organization who wants to design framework agreements, and develop a mathematical model for the problem (sections 5.2 and 5.3).

## 5.1 Background

Supplier selection is a process which buyers identify and evaluate the suppliers to make a contract. In this way, buyers verify the supplier's qualifications prior to awarding the contract. The primary goal is to avoid the poor outcomes of the supplier non-performance (such as late delivery, non-delivery, or delivery of non-conforming goods), and a secondary goal is simply to ensure that the supplier will be a responsible and responsive partner with the buyer (Beil, 2010).

Figure 10 shows the supplier selection process. Supplier selection has two stages; firstly, eligibility of the suppliers is determined according to basic requirements (quality of goods, capacity of the supplier, etc.) set by the buyer. Suppliers who have passed the requirements are eligible for a contract award referred to as pre-approved suppliers or registered suppliers (Beil, 2010). Later, the supplier(s) is selected from among the pre-approved suppliers for contracting.

**Figure 10** Supplier selection process.

In the selection process, the performance of the relief chain must be considered. In this study, we are interested in evaluating the cost of supplies and the sufficiency of the supplies provided by selected suppliers. We assume that the list of pre-approved suppliers is already determined, and so we focus on selecting suppliers for contracts.

Contracts should be written to be enforced otherwise it would be difficult to understand which party is telling the truth about whether there was an agreement or if so what the terms are (EzineArticles, 2011). A contract should include basically (Logistics Cluster, 2011):

1. Name and description of parties, description of equipment or service provided.
2. Duration of the contract.
3. Responsibilities (minimum order quantity, ordering methods, required shipping, etc.)
4. Price (what is not included, what is included, volume discounts, tax applied, etc.)
5. Delivery (delivery terms, delivery time, who pays for delivery, penalties for late delivery, etc.)
6. Payment (payment terms, invoice address, currency specified, etc.)

7. Warranty (how long, for what, etc.)
8. Termination
9. Damages and Liabilities (insurance)
10. Additional terms and conditions (confidentiality, addition of products)
11. Representations (signatures, attachments like price list, amendments, etc.)

From the web site of logistic cluster, we find an example of the framework agreement for medium and lower thermal resistance blankets, that is available at Appendix A.

## 5.2 Problem Definition

In this study, we consider a relief organization who wants to make use framework agreements with relief suppliers to ensure purchasing a product in the event of disaster. We assume that the relief organization has pre-approved suppliers, who meet pre-determined performance requirements. Our objective is to support the decisions of the relief organization in choosing one or several supplier(s) among the pre-approved suppliers and making agreements with the selected suppliers to guarantee the availability of supplies to buy in the event of disaster.

As discussed in section 4.3, quantity flexible contracts are suitable to implement in the relief chain because demand uncertainty can be managed with this contact and it allows the relief organization to order higher quantities. Therefore, we consider adapting a quantity flexibility contract as a framework agreement. According to the agreement considered, the relief organization commits to purchase a minimum quantity during a fixed contract term, such as a year or two years. However, the relief organization can alter up the actual total purchase quantity when/if necessary provided that the supplier capacity is sufficient. If the relief organization purchases under the committed minimum quantity, a penalty cost is incurred at the end of the contract term for the relief organization. The supplier is responsible for providing the supplies in the amount of the agreed minimum quantity to the relief organization when requested. A fixed agreement fee is paid to the supplier as a representative of the commitment. In our problem setting, we assume that the agreement fee is fixed and does not change with the minimum quantity that the relief organization commits.

The relief organization is given the unit price of items; we assume that the unit price from each supplier includes both transportation and purchasing costs. Yearly capacities of the suppliers are also known in terms of volume. Suppliers are capable of delivering the requested products but have different logistics capacities that is, the suppliers can only deliver to specific locations in their service areas.

Moreover, suppliers offer quantity discounts to the relief organization for different quantity and lead time intervals. For instance, the quantity and lead time discount schedule for the unit price for a supplier which offers three quantity discount intervals and three lead time intervals is characterized as follows:

$$C(Q, LT) = \begin{cases} P_0 & if\ 1 \le Q \le Q_1\ and\ 1 \le LT \le LT_1 \\ P_1 & if\ 1 \le Q \le Q_1\ and\ LT_1 < LT \le LT_2 \\ P_2 & if\ 1 \le Q \le Q_1\ and\ LT_2 < LT \le LT_3 \\ P_3 & if\ Q_1 < Q \le Q_2\ and\ 1 \le LT \le LT_1 \\ P_4 & if\ Q_1 < Q \le Q_2\ and\ LT_1 < LT \le LT_2 \\ P_5 & if\ Q_1 < Q \le Q_2\ and\ LT_2 < LT \le LT_3 \\ P_6 & if\ Q_2 < Q \le Q_3\ and\ 1 \le LT \le LT_1 \\ P_7 & if\ Q_2 < Q \le Q_3\ and\ LT_1 < LT \le LT_2 \\ P_8 & if\ Q_2 < Q \le Q_3\ and\ LT_2 < LT \le LT_3 \end{cases}$$

In the above discount schedule, Q is the quantity bought and LT is the lead time. A unit price is associated with each quantity and lead time interval. One quantity interval can include different lead time intervals, and the price discount increases as the lead time or quantity increase. The price given for the first quantity and lead time interval ($P_0$) is the base price without any discounts applied. Accordingly, when a disaster scenario occurs, the organization can buy from one of the quantity intervals from the corresponding supplier.

We use a scenario approach to characterize the uncertainty of disaster demands. More specifically, each scenario represents the location and amount of demand that may occur due to a potential disaster. That is, there may be more than one demand scenario associated with a single location. We assume that the amount of demand due to a scenario is affected by the impact level of the disaster. A probability is associated with the occurrence of a scenario.

The purchased volume amount from a supplier in a time period under a given scenario can't exceed the capacity of that supplier in that time period under that scenario. The minimum quantity that the relief organization chooses to commit from a supplier during a contract period is dependent on the expected amount of supplies that will be purchased from the supplier under different scenarios.

The objective is to find the supplier(s) who offers the minimum cost which includes fixed agreement fee, penalty cost and cost of purchasing. Hence, this limits the number of suppliers to be selected for the agreement.

We also assume that the relief organization wants to ensure a minimum fill rate for each scenario; more specifically, a percentage of the demand must be fulfilled for each scenario. Furthermore, the relief organization can impose fill rate constraints for different lead time intervals; for instance, the relief organization may want some proportion of demand to be satisfied more quickly. Depending on the scenarios or the organization's general purchasing policy, the relief organization can consider satisfying all of the demand from the agreed supplier(s), or alternatively, can buy only some fraction of the demand via agreements. For instance, if the relief organization wants to fulfill the majority of demand from the local market at a specific disaster region/location for various reasons (such as lower local market prices in the region), a small fraction of demand can be satisfied via agreements.

In summary, this study considers a relief organization which wants to make a framework agreement(s) with a selected supplier(s). The supplier selection problem for contract design in humanitarian relief can be defined as follows.

<u>Given:</u>

- Set of pre-approved suppliers
- Yearly capacities of suppliers
- Unit price of suppliers (including purchasing and transportation costs)
- Unit penalty cost of suppliers
- Fixed agreement fee
- Quantity discount intervals
- Lead time discount intervals
- Set of demand scenarios
- Minimum fill rate for each scenario
- Limits for the number of suppliers selected to an agreement

Determine:

- One or several suppliers among the pre-approved suppliers to an agreement.
- Minimum quantity commitment that the buyer commits to purchase from the selected suppliers during a contract term.
- Amount of supplies purchased from the selected supplier(s) at the time of the disaster.

To:

- Minimize total expected costs (i.e., sum of fixed agreement costs, expected purchasing costs, and expected penalty costs) over the duration of the contract.

## 5.3 Model Development

In our study, we assume that all contract decisions must be taken in the pre-disaster stage and purchasing decisions at the post disaster stage, which enables us to model the problem as a two-stage stochastic program. In the model, contract decisions, which involve the selection of suppliers and minimum quantity commitment for each supplier, are first-stage decisions. In the second stage, decisions are related to purchase amounts from suppliers (at which lead time and quantity interval), and determining whether the relief organization bought below minimum quantity by the end of the contract term. At the first stage, supplier and buyer related parameters are known. At the second stage, demand related parameters become known and the relief organization purchases from the selected supplier(s). If the total purchased over the contract term is less than the committed quantity, the relief organization should pay a penalty for the amount less than the quantity committed.

The notation for our model is as follows:

***Sets:***

$I$ Set of pre-approved suppliers; $i \in I$

$M$ Set of quantity intervals; $m \in M$

$L$ Set of lead time intervals; $l \in L$

$S$ Set of demand scenarios; $s \in S$

***Parameters:***

*Supplier related parameters:*

$C_i$ = Capacity of supplier *i* (volume),

$P_{is}^{lm}$ = Unit price offered by supplier *i* for scenario *s* for the lead time interval *l* and quantity interval *m* ($/unit),

$[q_{ilms}^{low}, q_{ilms}^{high}]$ = The lower and upper quantity limits associated with quantity interval *m* and lead time interval *l* offered by supplier *i* associated with scenario *s* (units),

$\delta_i$ = Per unit penalty cost for purchases under the minimum quantity from supplier *i* ($/unit),

$F_i$ = Fixed agreement fee with supplier *i* ($/fixed agreement term),

*Buyer related parameters:*

$f_s^l$ = Minimum fill rate that the buyer wants to achieve at lead time level *l* in scenario *s* per unit (scalar),

$n_{min}, n_{max}$ = Minimum and maximum number of suppliers that the relief organization wants to choose (scalar),

*Demand related parameters:*

$d_s$ = Expected demand associated with scenario *s* (units),

*Pr{s}* = Probability of scenario *s* (scalar),

***Decision Variables:***

*First stage variables:*

$$Y_i = \begin{cases} 1, \text{if supplier } i \text{ is selected for an agreement} \\ 0, \text{otherwise} \end{cases}$$

$Q_i^{min}$ = Minimum quantity that the buyer commits to purchase from supplier *i* during a fixed agreement term, *Second stage variables:*

$$X_{is}^{lm} = \begin{cases} 1, \text{if the contract with supplier } i \text{ is executed at quantity interval } m \\ \text{and lead time interval } l \text{ in scenario } s \\ 0, \text{otherwise} \end{cases}$$

$Q_{is}^{lm}$= Amount of supplies bought from supplier *i* at quantity interval *m* and lead time interval *l* in scenario *s*,

$W_i$= Expected amount of supplies bought below minimum quantity during the contract term from supplier *i*,

The formulation of the supplier selection model by using quantity flexibility contract is as follows:

$$Min \sum_{i=1}^{I} F_i \; Y_i + \sum_{i=1}^{I} W_i \; \delta_i + \sum_{s=1}^{S} Pr\{s\} \sum_{i=1}^{I} \sum_{l=1}^{L} \sum_{m=1}^{M} P_{is}^{lm} \, Q_{is}^{lm} \qquad (1)$$

subject to

$$W_i \; \geq \; Q_i^{min} - \sum_{s=1}^{S} Pr\,\{s\} \sum_{l=1}^{L} \sum_{m=1}^{M} Q_{is}^{lm} \qquad \forall i \in \; I \qquad (2)$$

$$\sum_{l=1}^{L} \sum_{m=1}^{M} Q_{is}^{lm} \; \leq \; C_i Y_i \qquad \forall i \in I, \forall s \in S \qquad (3)$$

$$n_{min} \; \leq \; \sum_{i=1}^{I} Y_i \leq \; n_{max} \qquad (4)$$

$$Q_i^{min} \geq \sum_{s=1}^{S} \Pr\{s\} \sum_{l=1}^{L} \sum_{m=1}^{M} Q_{is}^{lm} \qquad \forall i \in I \qquad (5)$$

$$\sum_{i=1}^{I} \sum_{m=1}^{M} Q_{is}^{lm} \, / \;\; d_s \; \geq \; f_s^l \qquad \forall s \in S, \forall l \in L \qquad (6)$$

$$X_{is}^{lm} * \; q_{ilms}^{low} \leq \; Q_{lm}^{is} \; \leq \; q_{ilms}^{high} * \; X_{is}^{lm} \quad \forall i \in I, \forall s \in S, \forall l \in L, \forall m \in M \qquad (7)$$

$$\sum_{m=1}^{M} X_{is}^{lm} \leq \; Y_i \qquad \forall i \in I, \forall s \in S, \forall l \in L \qquad (8)$$

$$Y_i \in \{0,1\} \;\; \forall i \in I \; and \;\; X_{is}^{lm} \in \{0,1\} \;\; \forall i \in I, \forall s \in S, \forall l \in L, \forall m \in M \qquad (9)$$

$$W_i \geq 0 \; and \; Q_i^{min} \; \geq 0 \;\; \forall i \in I, \; Q_{is}^{lm} \geq 0 \;\; \forall i \in I, \forall s \in S, \forall l \in L, \forall m \in M \; (10)$$

The objective function (1) is a cost minimization function. The first term represents the supplier's fixed agreement fee. The second term is expected penalty cost of the buyer that incurs at the end of the contract term if the buyer buys under minimum quantity. The third term is the expected cost of purchasing the commodities. All costs incur over a fixed contract term. Expected amount below the committed quantity is represented by the variable $W_i$ , and constraint (2) is used to define the expected amount purchased below minimum committed quantity. Constraint (3) ensures that the capacity limit of each supplier is respected; that is, the total bought from a supplier for any scenario should be less than or equal to the available capacity of the supplier. Constraint (4) limits the number of selected suppliers to the agreement. Constraint (5) forces the minimum quantity commitment of a supplier to be greater than or equal to the expected amount bought from the supplier. Constraint (6) ensures that a minimum fill rate for each specified lead time interval is achieved for the purchases from the contracted suppliers for each scenario. Constraint (7) limits the amount of supplies that can be bought from each supplier for each scenario by the limits of the quantity breakpoints. Constraint (8) ensures that the relief organization can buy from a particular supplier to meet the demands of a scenario if an agreement is made with the supplier beforehand; the relief organization can buy supplies at one level of quantity interval for each lead time interval. Finally, constraint (9) defines binary variables and constraint (10) is non-negativity constraint.

# 6 Computational Results

In this chapter, we introduce a numerical example to illustrate the proposed model described in the previous chapter and present computational results. The model is applied using a data set developed based on available real world data about drinking water suppliers in Turkey. Specifically, we consider a supply chain network that includes five pre-approved suppliers and one relief organization as a buyer. The relief organization is interested in determining which suppliers to make agreements with, which suppliers to buy from, and how much to buy from each supplier at the minimum cost. The agreement we consider is exemplified in Appendix B. The agreement is a quantity flexibility agreement for Demijohn water.

It is known that clean drinking water is an essential nutrient for humans. A person can go several days without food but a short time without water. After disasters, providing clean drinking water is one of the biggest challenges because water sources can be damaged in the affected area. Therefore, it is important to have emergency water supply to meet needs during this situation. One method relief organizations use is purify untreated water. One way could be to buy bottled water. In this way logistic efficiency plays a significant role because transportation of large quantities of bottled water is costly.

## 6.1 Data Set

We develop a data set to test the proposed model. This section describes the data related to suppliers, demand scenario development and other parameters.

### 6.1.1 Suppliers

To illustrate our model, we consider a relief organization which is interested to purchase clean drinking water from water suppliers to be used in emergencies. A, B, C, D and E are reputable clean drinking water suppliers in Turkey, whose annual capacities are known and reachable from their websites. Each supplier sells the water in 19-liter demijohns. Table 4 shows capacities of suppliers (in liters) per year.

**Table 4** Capacities of suppliers (lt/ per year).

| SUPPLIERS | CAPACITIES |
|---|---|
| A | 4,000,000,000 |
| B | 1,000,000,000 |
| C | 1,500,000,000 |
| D | 1,300,000,000 |
| E | 1,000,000,000 |

We assume that the relief organization is interested in supplying water that will be sufficient for 10 days to the affected areas. Therefore, we find the capacities of suppliers for the period of 10 days, assuming that each supplier has uniform capacity during the year. For example, given the capacity of the supplier A as 4,000,000,000 lt/year, we divide the capacity by 365 days times 19lt (as we want to know the capacities in demijohns), and then we multiply the result with 10 to obtain the capacity of supplier for 10 days. That is, capacity of supplier A = (4000000000 / (365*19)) * 10 = 5,767,844, so the supplier A has 5,767,844 demijohn capacity for 10 days. Table 5 shows the capacity of all suppliers per 10 days.

**Table 5** Capacity of suppliers (demijohns/per 10 days).

| SUPPLIERS | CAPACITIES |
|---|---|
| A | 5,767,844 |
| B | 1,441,961 |
| C | 2,162,942 |
| D | 1,874,549 |
| E | 1,441,961 |

These suppliers operate in different parts of the Turkey. We consider taking 10 regions for Turkey as Turkish Red Crescent divides Turkey in 10 regions as seen in Figure 11. The market prices of suppliers are different in each of the regions. Table 6 shows the market prices of the suppliers to the regions in Turkey. We collect the market prices from the distributors of suppliers' websites.

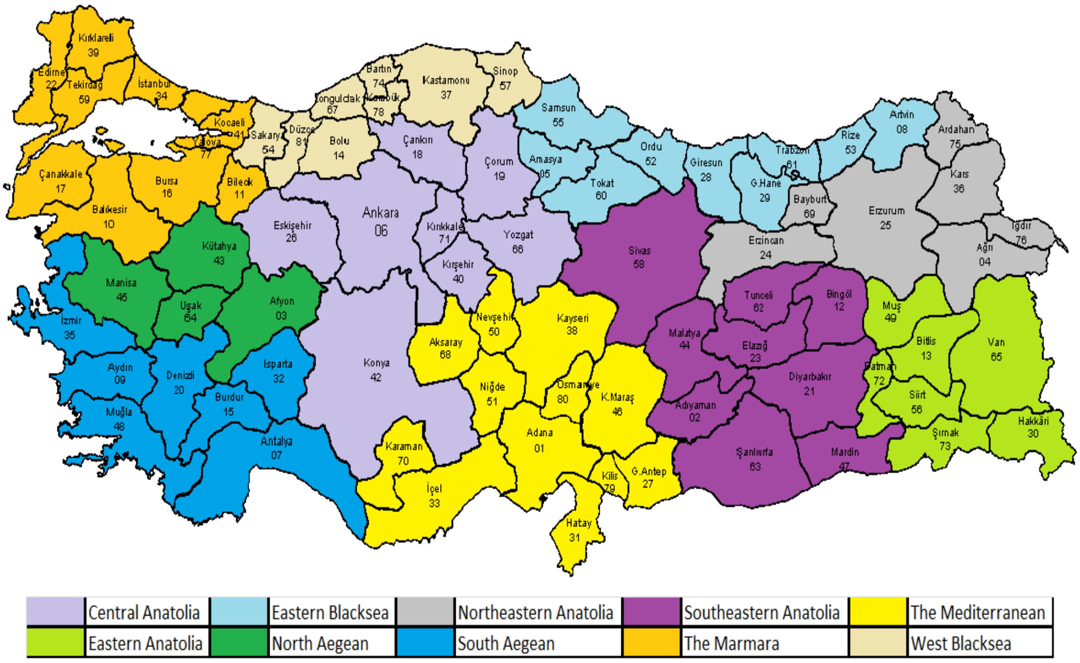


**Figure 11** Regions in Turkey according to provinces.

The regions shown in Figure 11:

1. The Marmara (TM)
2. West Black Sea (WBS)
3. Eastern Black Sea (EBS)
4. North Aegean (NA)
5. South Aegean (SA)
6. The Mediterranean (TMA)
7. Southeastern Anatolia (SEA)
8. Northeastern Anatolia (NEA)
9. Eastern Anatolia (EA)
10. Central Anatolia (CA)

**Table 6** Market prices of suppliers to the regions in Turkey.

| | SUPPLIERS | | | | |
|---|---|---|---|---|---|
| REGIONS | A | B | C | D | E |
| THE MARMARA | 7.70TL | 6.25TL | 6.50TL | 5.50TL | 6.50TL |
| WEST BLACK SEA | - | - | 6.00TL | 5.00TL | 6.50TL |
| EASTERN BLACK SEA | - | - | 6.00TL | 5.00TL | 6.50TL |
| NORTH AEGEAN | 7.00TL | - | - | 5.00TL | 5.50TL |
| SOUTH AEGEAN | 7.00TL | - | - | 5.00TL | 5.50TL |
| THE MEDITERRANEAN | 7.00TL | 5.50TL | 4.75TL | 6.50TL | 6.50TL |
| SOUTHEASTERN ANATOLIA | - | | 5.00TL | - | - |
| NORTEASTERN ANATOLIA | - | - | 5.00TL | - | - |
| EASTERN ANATOLIA | 7.00TL | - | 6.00TL | - | - |
| CENTRAL ANATOLIA | 7.70TL | 5.50TL | 6.50TL | 6.00TL | 6.50TL |

As seen in Table 6, these suppliers don't operate in every region because of their regional logistics capacities, and the regions which they operate and have facilities are reachable from their websites. Figure 12 and Table 7 shows which regions the suppliers operate and have facilities.

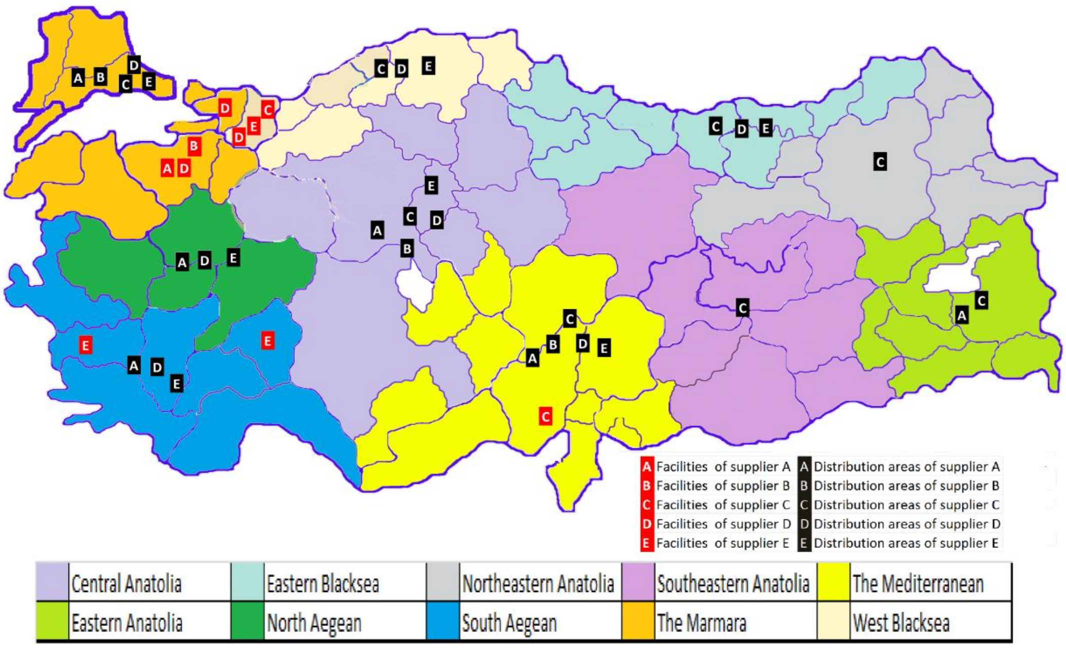


**Figure 12** The regions that the suppliers operate and have facilities.

**Table 7** The regions that the suppliers operate and have facilities**.**

| SUPPLIERS | REGIONS WITH FACILITIES | REGIONS SERVED |
|---|---|---|
| A | TM | TM, NA, SA, TMA, EA, CA |
| B | TM | TM, TMA, CA |
| C | WBS, TMA | TM, WBS, EBS, TMA, SEA, NEA, EA, CA |
| D | TM, WBS | TM, WBS, EBS, NA, SA, TMA |
| E | TMA, WBS | TM,WBS, EBS, NA, SA, TMA, CA |

Based on the market prices of the suppliers and the regions they operate, we create a price list which includes discounts for different quantity and lead time intervals. These quantity and lead time discounts are applied for one time purchases over the contract period. We generate the quantity discounts based on the data we found from a website of an online water distributor. That is, the supplier A drops 0.90 from the unit price for the quantities above 1000 demijohns of water. Accordingly, we define three quantity intervals: 1 to 1000, 1000 to 10000 and 10000 to 10-day capacities of each supplier. There is no discount applied for the quantities smaller than 1000. Each supplier drops 0.50 TL from the unit price for the quantities bought larger than 1000 and 1.00 TL for the quantities higher than 10000.

Next, we found that, a penalty of 1% is charged for every week delayed in delivery from a purchase agreement of a relief organization, the World Vision International. Related with the data, we assume that, there are three lead time intervals and all suppliers apply the same discount on their unit price; that is, no discount for 1-3 days, 10% discount for 4-6 days and 20% discount for 7- 10 days.

Table 8 is an example from the price list; full list is in Appendix C. For the lead time interval 1-3 days, there are three quantity intervals. Supplier A has a unit price 7.70 TL to the region Marmara for the quantity interval; 1 to 1000 and there is no discount applied in this interval. For the quantity interval; 1000 to 10000 the supplier drops 0.50 TL on the unit price and the unit price is 7.20. For the quantities higher than 10000, the supplier drops 1.00 TL on the unit price and the unit price decreases to 6.70. 4-6 days and 7-10 days, discounts are applied for the three quantity intervals. Let’s take the first interval, the unit price is 7.70, we have

10% discount for 4-6 days and the unit price becomes 7.70 - (7.70 * 0.10) = 6.93 TL. For 7-10 days, a 20% discount is applied and the unit price becomes 7.70 - (7.70 * 0.20) = 6.16 TL. The other intervals are calculated similarly.

**Table 8** Supplier A's unit prices for different quantity and lead time intervals to the region Marmara (TM).

| | | QUANTITY AND LEAD TIME INTERVALS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $1 \le Q \le 1000$ | | | $1000 < Q \le 10000$ | | | $10000 < Q \le C(i)$ | | |
| **SUPPLIER** | **REGION** | 1 -3 day | 4- 6 day | 7- 10 day | 1 -3 day | 4- 6 day | 7- 10 day | 1 -3 day | 4- 6 day | 7- 10 day |
| A | TM | 7.70TL | 6.93TL | 6.16TL | 7.20 TL | 6.48TL | 5.76 TL | 6.70TL | 6.03TL | 5.36TL |

According to our model, the relief organization agrees to commit some liters of demijohn water as a minimum quantity to purchase from the seller. When the relief organization purchases under the agreed minimum quantity, supplier will apply a percentage penalty to the relief organization on the quantity which remains below the minimum quantity. Therefore, if the relief organization doesn't want to pay any penalties for this quantity to the supplier at the end of a contract term, the minimum quantity can be bought and kept in stock. For this reason, we set unit penalty cost parameters considering unit inventory holding costs, which can be found by multiplying an interest rate (i) with supplier's average unit price ($P_{avg}$), that is, $\delta_i = i * P_{avg}$. We assume an annual interest rate of 0.08.

Afterwards, we calculate unit penalty costs for each supplier. For example; the supplier E has different costs to regions in Turkey. The average unit price of the supplier E is 5.50 TL (according to the market prices in Table 6) and the unit penalty cost is 5.50 * 0.08= 0.44. Average unit prices of suppliers A, B, C, D, E are 7.23 TL, 5.75 TL, 5.71 TL, 5.43 TL and 5.50 TL, respectively. After multiplying with 0.08, we found the unit penalty costs shown in Table 9.

**Table 9** Penalty costs of suppliers.

| SUPPLIERS (i) | PENALTY COSTS ($\delta_i$) |
|---|---|
| A | 0.58 |
| B | 0.46 |
| C | 0.46 |
| D | 0.43 |
| E | 0.44 |

### 6.1.2 Demand Scenario Development

To develop disaster scenarios, we process historical disaster data. Specifically, we find disasters that happened in Turkey from 1900 to 2010 from the International Disaster Database, EM-DAT. Table 10 shows an example of the disaster list. The available data involve the timing, location, and type of the disasters along with the number of people killed/ total affected. These data are reachable from the web-site of EM-DAT (EM-DAT, 2009).

**Table 10** Example disaster list from EM- DAT.

| DISASTER TIME | COUNTRY | LOCATION | DISASTER TYPE | KILLED | TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|
| 08/03/2010 | Turkey | Elazig | Earthquake (seismic activity) | 51 | 3600 |
| 06/06/2005 | Turkey | Near Karliova (Bingol province) | Earthquake (seismic activity) | | 354 |
| 14/03/2005 | Turkey | Karliova (Bingol province) | Earthquake (seismic activity) | | 2268 |
| 24/01/2005 | Turkey | Van city (Adana and Hakkari province) | Earthquake (seismic activity) | 2 | 422 |
| 02/07/2004 | Turkey | Dogubeyazit (Agri province) | Earthquake (seismic activity) | 18 | 356 |
| 28/03/2004 | Turkey | Askale, Ilica, Cat, Erzurum | Earthquake (seismic activity) | | 32530 |
| 25/03/2004 | Turkey | Askale, Cat, Buyukgecit, … | Earthquake (seismic activity) | 9 | 4030 |

We create demand scenarios for Turkey using these data. There are 151 entries in the disaster list but some of the data (such as total affected people) are missing. That’s why we eliminate the missing data and process the remaining 114 entries. Initially, we organize the data which we find from EM-DAT according to a regional base. Table 11 shows a part from the disaster list, the entire disaster list arranged according to the regions is available in Appendix D.

**Table 11** An example table from the organized disaster list according to regions.

| DISASTER TIME | COUNTRY | REGION | LOCATION | DISASTER TYPE | TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|
| 08/03/2010 | Turkey | Southeastern Anatolia | Elazig | Earthquake (seismic activity) | 3600 |
| 06/06/2005 | Turkey | Southeastern Anatolia | Near Karliova (Bingol province) | Earthquake (seismic activity) | 354 |
| 14/03/2005 | Turkey | Southeastern Anatolia | Karliova (Bingol province) | Earthquake (seismic activity) | 2268 |
| 24/01/2005 | Turkey | Eastern Anatolia and the Mediterranean | Van city (Adana and Hakkari province) | Earthquake (seismic activity) | 422 |
| 02/07/2004 | Turkey | Northeastern Anatolia | Dogubeyazit (Agri province) | Earthquake (seismic activity) | 356 |
| 28/03/2004 | Turkey | Northeastern Anatolia | Askale, Ilica, Cat, Erzurum | Earthquake (seismic activity) | 32530 |
| 25/03/2004 | Turkey | Northeastern Anatolia | Askale, Cat, Buyukgecit, … | Earthquake (seismic activity) | 4030 |
| 10/04/2003 | Turkey | South Aegean | Izmir | Earthquake (seismic activity) | 170 |

We generate demands for demijohns for each scenario based on the total affected people: Most of the data related to total affected people are from past years; therefore, we process those data to adapt it to current year 2011. To adapt it, we find the total affected people percentage of population and multiply with the current population of regions. We reach the population of provinces from TUIK (TUIK, 2011), and calculate the population of regions accordingly. Specifically, we find the *total affected people percentage* by proportioning total affected people to population of region at the time of the disaster and then multiply it with hundred. By this way, we find the percentage of the population that is affected by the disaster. Later, we multiply the percentages with present population of regions and divide by hundred. The results gave us the normalized total affected people that are adapted to year 2011. Before 1965, only the general country population is available, so we use it to find the total affected people percentage. Table 12 shows an example of the data obtained. The rest of disaster list including total affected people percentage and normalized total affected people is provided in Appendix E.

**Table 12** An example of disasters list including total affected people percentage and normalized affected people.

| DISASTER TIME | COUNTRY | REGION | LOCATION | DISASTER TYPE | TOTAL AFFECTED PEOPLE | POPULATION OF REGION | TOTAL AFFECTED PEOPLE PERCANTAGE | NORMALIZED TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|---|---|---|
| 24/11/1976 | Turkey | Eastern Anatolia | Muradiye | Earthquake (seismic activity) | 216,000 | 1,379,361 | 15.6594249 | 514,222 |

According to Table 12, an earthquake happened in 1976, in Muradiye and 216,000 people were affected. Muradiye is in Eastern Anatolia and the population of that region was 1,379,361 in 1976, the total affected people percentage can be found as: (216,000 / 1,379,361) *100 = 15.6594249, so the total affected people constituted 15.6594249% of the population of that region. The present population of Eastern Anatolia is 3,283,783 and the normalized total affected people can be found by: (3,283,783 * 15.7) /100 = 514,222. The normalized total affected people for the 2011 of Eastern Anatolia are 514,222.

The disaster list available from EM-DAT includes multiple regions for specific disasters. Table 13 shows an example disaster that affected both the Eastern Anatolian and the Mediterranean regions, and hence the total affected people are for both regions.

**Table 13** Disaster data involving multiple regions.

| DISASTER TIME | COUNTRY | REGION | LOCATION | DISASTER TYPE | TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|
| 24/01/2005 | Turkey | Eastern Anatolia and the Mediterranean | Van city (Adana and Hakkari province) | Earthquake (seismic activity) | 422 |

In these cases, we process the data as follows. We first divide the total affected people to the total population of these regions and multiply with hundred to obtain the percentage of total affected people with respect to the population. Then, we multiply the total affected people percentage with the current population of the regions and divide by hundred to find the normalized total affected people for each region; shown in Table 14.

**Table 14** Organized data of disaster that happened in multiple regions.

| DISASTER TIME | COUNTRY | REGION | LOCATION | DISASTER TYPE | TOTAL AFFECTED PEOPLE | POPULATION OF REGION | TOTAL AFFECTED PEOPLE PERCENTAGE | NORMALIZED TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|---|---|---|
| 24/01/2005 | Turkey | Eastern Anatolia | Van city (Adana and Hakkari province) | Earthquake (seismic activity) | 422 | 13,257,247 | 0.00318316 | 105 |
| 24/01/2005 | Turkey | The Mediterranean | Van city (Adana and Hakkari province) | Earthquake (seismic activity) | | | | 317 |

To generate demand scenarios that consider different disaster impacts, we determine 4 impact levels according to the normalized total affected people. These are mild, medium, severe and very severe. For example, a disaster that has less than 1000 total affected people is a mild level disaster. Table 15 shows the impact levels.

**Table 15** Impact levels.

| IMPACT LEVEL | INTERVAL |
|---|---|
| MILD | 1- 1000 |
| MEDIUM | 1000 - 8000 |
| SEVERE | 12000 - 100000 |
| VERY SEVERE | 100000 - 800000 |

For every region, we calculate average of normalized total affected people for every impact level. For example in Table 16, for the region of North Aegean, there are two values for the normalized affected people: 535 and 601 for the mild impact level. Average of these values is 568. There are no disasters that correspond to the medium and the severe impact levels, while there are three disasters in the fourth impact level.

**Table 16** Disasters list including total affected people percentage and normalized total affected people for the region of North Aegean.

| DISASTER TIME | COUNTRY | REGION | LOCATION | DISASTER TYPE | TOTAL AFFECTED PEOPLE | POPULATION OF REGION | TOTAL AFFECTED PEOPLE PERCANTAGE | NORMALIZED TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|---|---|---|
| 28/03/1969 | Turkey | North Aegean | West Alasehir | Earthquake (seismic activity) | 350 | 1995240 | 0.0175417 | 535 |
| 16/11/2007 | Turkey | North Aegean | Thracian and Aegean regio … | Flood | 2250 | 11429016 | 0.0196867 | 601 |
| 28/03/1970 | Turkey | North Aegean | Gediz | Earthquake (seismic activity) | 83448 | 1995240 | 4.182354 | 127637 |
| 01/10/1995 | Turkey | North Aegean | Dinar, Evciler (Afyon province) | Earthquake (seismic activity) | 160240 | 2761944 | 5.8017107 | 177057 |
| 03/02/2002 | Turkey | North Aegean | Bolvadin (Afyon province) | Earthquake (seismic activity) | 252327 | 3051801 | 8.2681341 | 252327 |

Assuming one person drinks 2 lt per day, we find how much demijohn is needed for 10 days, considering the capacity of one demijohn is 19lt. For example; for the mild impact level of the North Aegean region, we multiply 568 (average total affected people) with 2 liters and 10 days and divide the result by 19 liters. Therefore, the demand for demijohns in North Aegean region in the event of a mild-level disaster is found as: (568*2*10) /19 = 598.

After finding demand of demijohn for every region, we find the probabilities of occurrences of mild, medium, severe and very severe disasters. According to previous example, we have two mild disasters and four very severe disasters. For each region we find the number of disasters happened in each impact level. We proportion this number by the total number of disasters. For instance, the probability of a mild disaster in the North Aegean region is: 2/112= 0.017. As a result, we obtain 32 scenarios. If there were mild, medium, severe and very severe disasters in every region, there would be 40 scenarios. Appendix F presents the demands and probabilities for the 32 scenarios we consider.

### 6.1.3 Other Parameters

There is fixed agreement fee, and we assume that, it is set to 500 TL. In the event of termination of the agreement by the relief organization, the agreement fee remains to the supplier.

The relief organization can impose fill rate constraints for different lead time intervals; we assume it 10% for each lead time interval. So, at least 30% of total demand is considered for purchase from the suppliers with agreements.

We refer to the problem instance created with the parameter values described in this section as the base case problem instance. In the next section, we discuss the solution of the base case problem.

### 6.2 Base Case Results

In order to solve the two-stage mixed integer linear programming model, GAMS 23.6 and ILOG Cplex is used. The base case problem instance is solved about in 2 seconds on a Toshiba Intel(R) Core (TM) i3 CPU M350 2.27GHz laptop. The GAMS model is provided in Appendix G.

According to the results for the base case, which are shown in Table 17, supplier C and D are selected to the agreement. Detailed results are provided in Appendix H. As explained before (also presented in Figure 11) these suppliers can operate almost all regions in the country and have lower unit prices.

**Table 17** Base case solutions.

| Selected Suppliers | Total Cost | Committed Quantity (Qmin) | # of scenarios served by suppliers |
|---|---|---|---|
| C and D | 105,330TL | Supplier C: 15,111<br>Supplier D: 12,662 | Supplier C: 15<br>Supplier D: 17 |

Each supplier serves different scenarios. Supplier C responds to 15 scenarios, while supplier D responding to 17 scenarios out of 32 scenarios. Each scenario is satisfied by only one supplier, as the supplier capacity is sufficient enough. Also, to reach discount levels, there is no other motivation to buy from multiple suppliers. Minimum quantity commitment for the supplier C is 15,111 demijohns, and for supplier D is 12,662 demijohns over the contract term. Expected total cost is 105,330 TL over the contract term and there is no penalty paid. Figure 13 illustrates the expected total cost. As seen, the fixed agreement fee is 1000 TL (two suppliers are selected), and the expected purchasing cost is 104,330 TL.

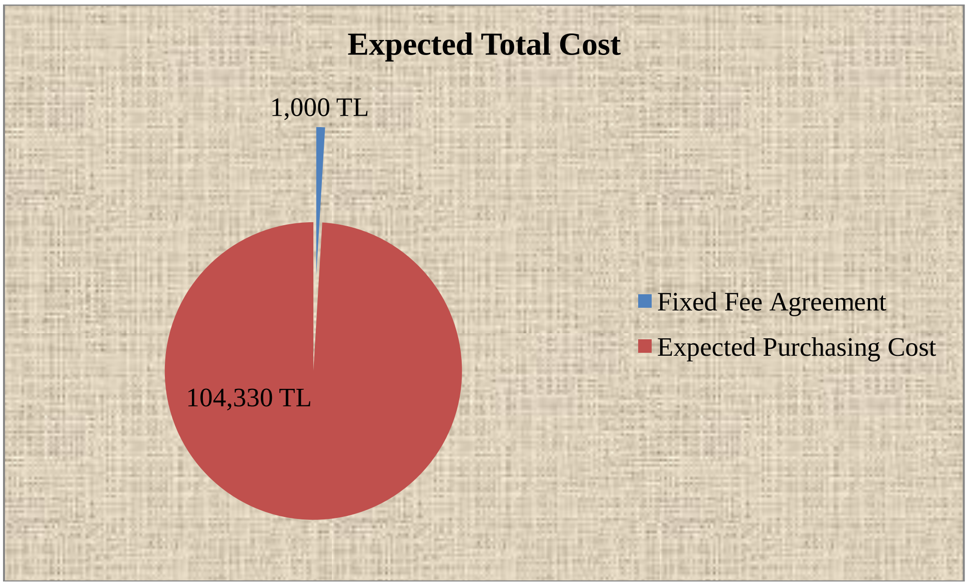


**Figure 13** Expected total cost.

Supplier C and D commits to supplying about 1% of their capacities (ten-day capacity). Purchases are made mostly at the third quantity interval to each supplier to obtain more discounts. Figure 14 depicts the percentage of the capacities used from the suppliers for a single scenario. The percentage of a maximum amount ever bought from the suppliers (across all scenarios that the supplier serves) to suppliers' capacity is as follows: 23% from the supplier C for the scenario 17 and 22.89% from the supplier D for the scenario 4.

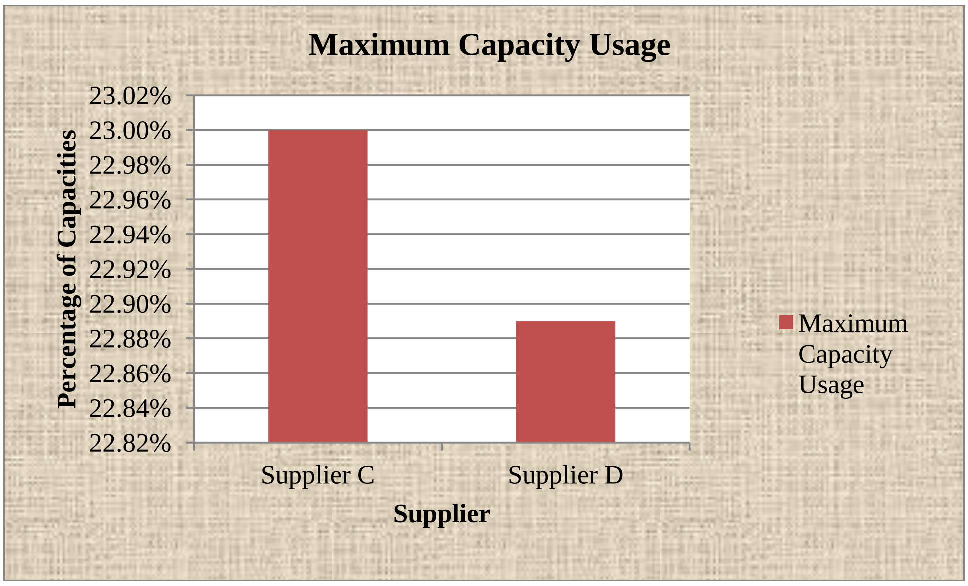


**Figure 14** Percentage of capacities used from the suppliers for a single scenario.

Results show that, supplier C and D are complementary (generally) as shown in Figure 15; supplier C operates in the regions that supplier D doesn’t operate (Southeastern Anatolia, Northeastern Anatolia and Eastern Anatolia) and supplier D operates in the regions that supplier C doesn’t operate ( North and South Aegean).

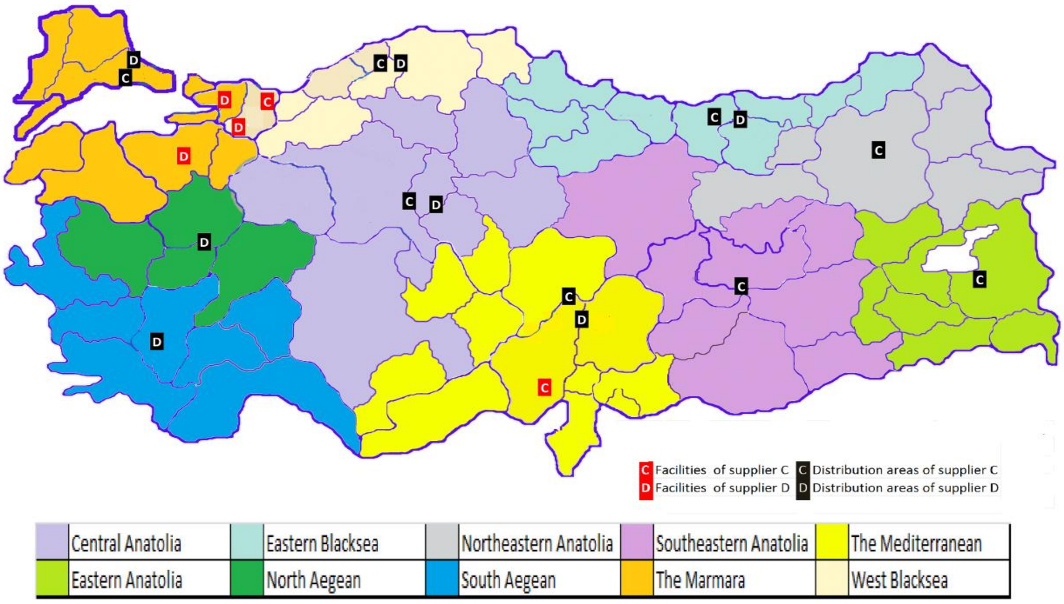


**Figure 15** The Regions that supplier C and D operate.

In Figure 15, the Marmara, West Black Sea, Eastern Black Sea, the Mediterranean and Central Anatolia are in operational zones of the supplier C and D. Each supplier can operate in these regions. However, in the results, the supplier D serves the Marmara, West Black Sea, Eastern Black Sea, Central Anatolia, and the supplier C serves the Mediterranean. That is, because of unit prices of the suppliers. Supplier C has a lower unit price to the Mediterranean, and vice versa for the supplier D.

Results of the quantity bought from suppliers show that, quantities bought for the mild and medium level of disasters are made from the first quantity interval; from the second quantity interval for the severe, and from the third quantity interval for very severe. So, the relief organization can achieve higher levels of quantity discounts as disaster impact is more severe.

Table 18 further reports the results for the base case problem instance.  Impact level of scenarios (mild-medium, severe, and very severe) represents the percentage of scenarios responded by the suppliers C and D at the different impact levels to all 32 scenarios. For example; the supplier C responds to 8 scenarios at the mild and medium level in 32 scenarios. So, [(8 / 32) * 100] gives that, the supplier C responds in 25% of the scenarios to the mild and medium level. According to the results, the supplier C and D respond to every impact level of disasters. There is no relation like, the supplier C responds to severe level disasters, and the supplier D responds to mild level disasters, etc.

**Table 18** Analysis of results.

| | | Supplier C | Supplier D |
|---|---|---|---|
| Impact Level of Scenarios | Mild/Medium | 25% | 31% |
| | Severe | 9% | 9% |
| | Very Severe | 13% | 13% |
| Scenarios Served | - | 47% | 53% |
| Quantity Discount Interval | m1 | 25% | 31% |
| | m2 | 9% | 9% |
| | m3 | 13% | 13% |
| Lead Time Discount Interval | l1 | 16% | 18% |
| | l2 | 16% | 18% |
| | l3 | 16% | 18% |

Scenarios served shows what percent of the scenarios are responded by the supplier C and D. Such as the supplier D responds to 17 scenarios in 32 scenarios. That is, [(8/32)*100] = 53% of the scenarios are responded by the supplier D.  Supplier C responds to 47% of the scenarios. Supplier D responds to more scenarios than the supplier C related to lower price of the supplier D for specific regions.

In Table 18, quantity discount interval represents what percent of scenarios are responded by the supplier C and D from the first (m1), second (m2) and third (m3) quantity intervals. The percentages are same with the results of the impact level of scenarios because mild and medium impact levels are consistently accomplished at the first quantity interval, severe in the second, and very severe in the third quantity interval as mentioned before. From the table, we can conclude results like that; the relief organization buys 25% of the scenarios from the supplier C in the m1 interval without discount (there is no discount applied for the m1 interval). Likewise, the relief organization buys 9% of the scenarios from the supplier C in the m2 interval and 13% of the scenarios from the m3 interval with discounted prices. Also, 31% of the scenarios are bought from the supplier D in the m1 interval without discount, 9%

of the scenarios from the supplier D in the m2 interval, and 13% of the scenarios from the m3 interval with discounted prices.

In the same way, lead time discount interval shows what percent of scenarios are responded by the supplier C and D from the first (l1), second (l2) and third (l3) lead time intervals. In every scenario, the suppliers must buy from each lead time interval. That's why, the percentage of scenarios responded by a supplier for each lead time interval is equal. For example; the supplier C responds to 47% of the scenarios, so we can find the percentage of scenario responded in each lead time interval for the supplier C by this way: [(47% ÷ 3) =15.67%]. That means, the supplier C responds to 47% of the scenarios and accomplish 15.67% of it from l1, 15.67% from l2 and 15.67% from l3.

## 6.3 Sensitivity Analysis

In this section, we perform additional analysis by using different parameters to verify the model and understand the effects of parameters on output variables. Specifically, we consider changing the parameters related to fill rate requirements, fixed agreement fee, minimum and maximum number of suppliers selected to the agreement, capacity of the suppliers, impact levels, demand (number of days that the service will be provided), and scenario probabilities. With the parameters specified above, we performed a total of 12 tests. Table 19 shows the parameters we use in our computational tests.

**Table 19** Parameters to be tested.

| PARAMETERS | | BASE CASE VALUES | ADDITIONAL VALUES |
|---|---|---|---|
| **Fill Rate Requirement** | | 10%, 10%, 10% | Increasing: 10%, 20%, 30%<br>Decreasing: 30%, 20%, 10% |
| **Fixed Agreement Fee** | | 500 TL | No fee |
| **Minimum and Maximum Suppliers** | | nmin:1<br>nmax: 2 | nmin:1 and nmax: 5<br>nmin:3 and nmax: 5 |
| **Capacity of Suppliers** | | A: 5,767,844<br>B: 1,441,961<br>C:2,162,942<br>D:1,874,549<br>E:1,441,961 | Decreasing the base case capacities to 25% and 10%. |
| | **Impact Level** | 4 levels | 2 and 3 levels |
| **Demand** | **Number of days** | 10 days | 3 and 7 days |
| | **Probability of Scenarios** | Rounded to 10 decimal points | Rounded to decimal points |

- As shown in the table, in the base case, we assume fill rate requirements of 10% for each lead time interval. We varied the fill rate requirements by considering two cases: an increasing fill rate: 10%, 20%, 30% and a decreasing fill rate: 30%, 20%, 10%.
- In the base case 500 TL paid as a fixed agreement fee. We evaluate the case when there is no agreement fee paid.
- Minimum (nmin) and maximum (nmax) number of suppliers selected to the agreement are set as nmin: 1 and nmax: 2 in the base case. We examine the cases in which nmin: 1 and nmax: 5, and also nmin: 3 and nmax: 5.
- We decrease the base case capacity of suppliers to 25% and 10%.
- Expected demand is calculated in different ways by considering different impact levels, days to provide a service and probability of scenarios. Specifically,
    - We define four impact levels (low, medium, high, extreme) in the base case. We consider the two (low and high) and three (low, medium, high) impact levels in generating demand scenarios for further analysis.
    - We determine 10 days to provide a service in the base case. We test for 3 days and one week to provide service.
    - In the base case the scenario probabilities are rounded to 10 decimal points, and we test the case in which probabilities are rounded to 2 decimal points.

In the following subsections, the results of the tests are provided.

### 6.3.1 Effect of Fill Rate Requirements

Our first observation is related to fill rate. We increased the total satisfied demand by the agreements from 30% to 60%. In this case, we consider fulfilling the demand according to an increasing fill rate (10%, 20%, 30%) and decreasing fill rate (30%, 20%, 10%) with respect to lead time. Results show that, the number of selected suppliers and scenarios responded by the suppliers doesn’t change in any case related to the fill rate. The minimum quantity commitments and the expected total cost increase when the total satisfied demand is increased. Buying according to the increasing fill rate or the decreasing fill rate doesn't change the decisions related to the minimum quantity commitments. However, the amount of supplies bought from the suppliers at the lead time intervals change and in this situation fulfilling the demand according to an increasing fill rate is advantageous in terms of cost. Because in a decreasing fill rate, the relief organization buys less from the third lead time interval where there are more discounts applied according to other lead time intervals. In an increasing fill rate, the relief organization buys more quantity from the third lead time interval and so obtain more discounts. So, the expected total cost decreases from decreasing case to increasing case. Figure 16 illustrates the effect of fill rate requirements on the expected total cost for three different fill rates: the base case fill rate (10%, 10%, 10%), the decreasing fill rate (30%, 20%, 10%), and the increasing fill rate (10%, 20%, 30%). The expected total cost decreases by 7% from the decreasing fill rate to the increasing fill rate. Also, the expected total cost increases by 51% when the total percentage of fill rate requirements are increased from 30% (base case) to 60% (decreasing case).

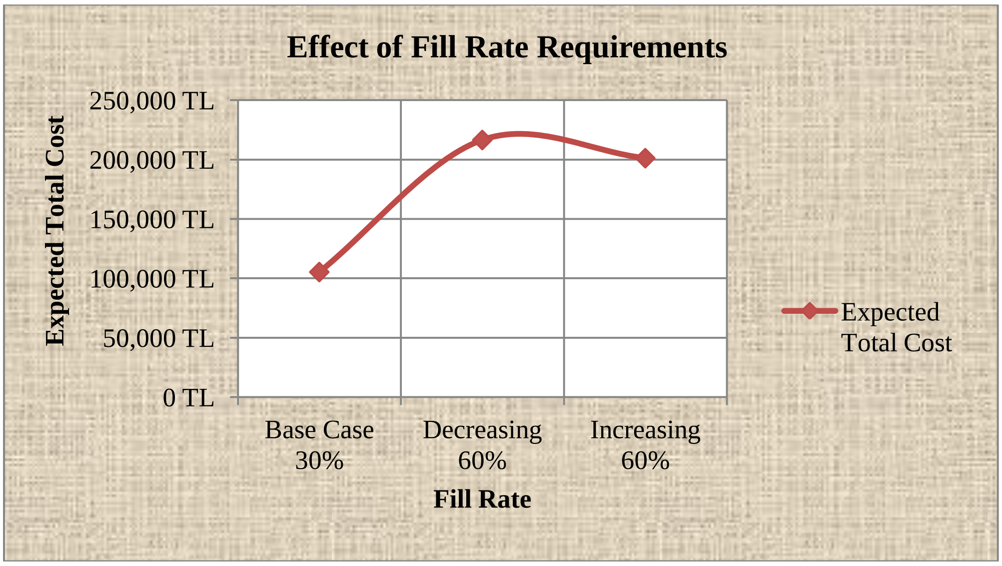


**Figure 16** Effect of the fill rate requirements on the expected total cost.

Minimum quantity commitments with respect to fill rate requirements are shown in Figure 17. The minimum commitments of the suppliers change in the same way for the increasing and decreasing fill rates. Minimum quantity commitments change when there is an increase in the total percentage of fill rate. For example, in Figure 17 the minimum quantity commitments of both suppliers increase by 50% from the base case (30%) to the decreasing case (60%).

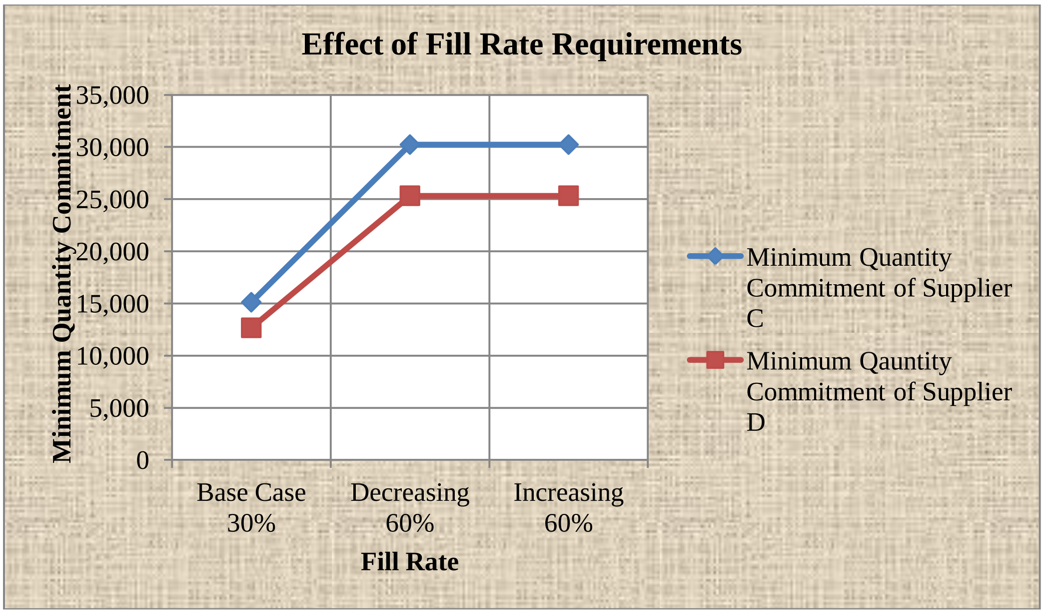


**Figure 17** Effect of the fill rate requirements on the minimum quantity commitment of suppliers.

Relief organizations can satisfy the demand according to an increasing fill rate with a cost advantage. They can purchase a small portion of the demand in a shorter lead time and then larger amounts within discounted lead time intervals for the later periods. However, it may take long time to satisfy the demand. In this situation, they should consider whether they need higher amounts in a shorter time period and if so, then they can satisfy the demand according to a decreasing fill rate which makes possible buying large amounts in a shorter lead time.

### 6.3.2 Effect of Fixed Agreement Fee

Next, we observed the results without fixed agreement fee, because relief organizations may not want to pay the agreement fee because of limited funds. When the fixed agreement is not considered (that is, $F_i$ is set to 0 for all suppliers), the decisions (minimum quantity commitment, amount of supplies bought from suppliers at quantity and lead time intervals, number of suppliers selected to the agreement, and scenarios responded by the suppliers) don't change. Only the expected total cost decreases. Figure 18 shows the effect of the fixed agreement fee on the expected total cost. There is a 0.95% decrease from the base case (500 TL) to the case when there is no agreement fee (0TL) is paid.

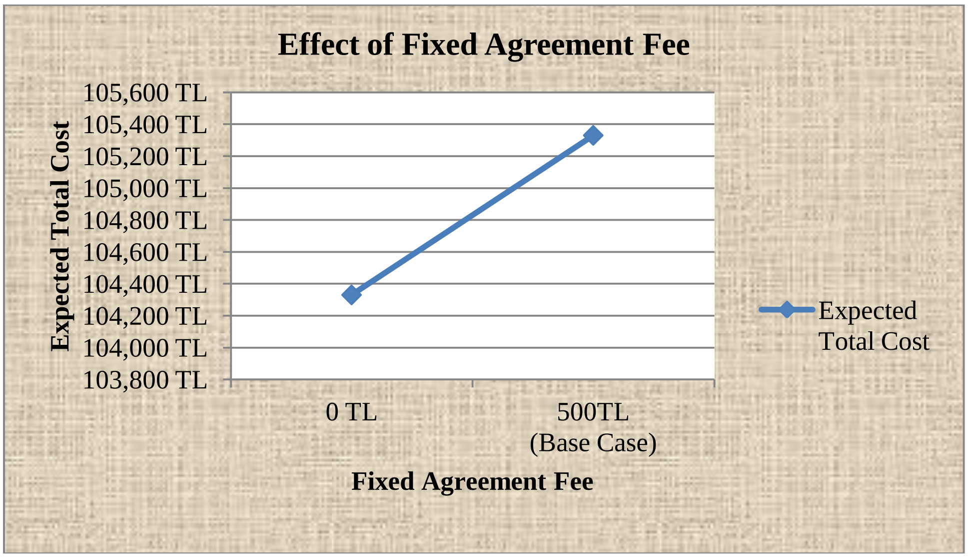


**Figure 18** Effect of the fixed agreement on the expected total cost.

When a relief organization doesn't pay a fixed agreement fee, it may seem advantageous in terms of total costs incurred through the contract term. However, a fixed agreement provides the supplier to be compliant on the terms and conditions of the agreement which may be more important than the cost advantages to the relief organization.

### 6.3.3 Effect of Minimum and Maximum Suppliers Selected to the Agreement

Later, we observed the changes in results with respect to the number of suppliers to choose for an agreement. We set the minimum number of supplier (nmin) to choose an agreement to 1, and the maximum number of suppliers (nmax) to 5. According to the results, we observe that the supplier selection decisions stay the same with the base case; that is, two suppliers are selected for the agreement. Additionally, when we set nmin as 3 and nmax as 5, three suppliers are selected in the solution; the supplier B, C and D. Different than the base case, the supplier B serves to Central Anatolia as the unit prices are lower. In the base case, the supplier D serves this region, so the minimum quantity commitment of supplier D changes, a little commitment from supplier B is made. The expected total cost increases, although supplier B has lower unit prices because an agreement fee is paid for every selected supplier. From Figure 19, we see that the expected total cost increases when the minimum number of suppliers (nmin) is increased because of the agreement fees.

There is 0.35% increase in the expected total cost for the case with nmin: 3 and nmax: 5.

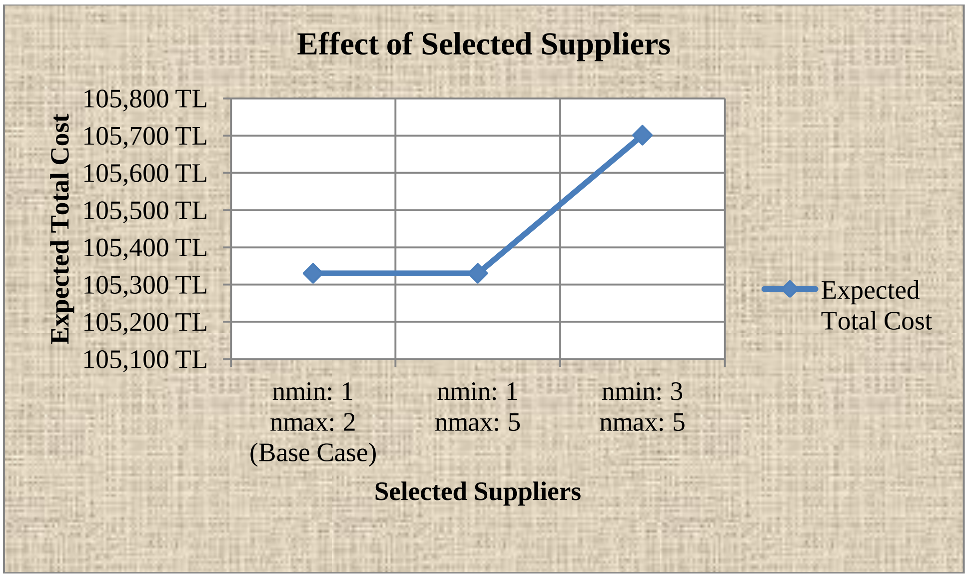


**Figure 19** Effect of the selected suppliers on the expected total cost.

Figure 20 illustrates the effect of selected suppliers on the minimum quantity commitment of the suppliers. There is no change for nmin: 1 and nmax: 5. For nmin: 3 and nmax: 5, there is a 2.26% decrease in the minimum quantity commitment of the supplier D, and no change in the minimum quantity commitment of the supplier C.

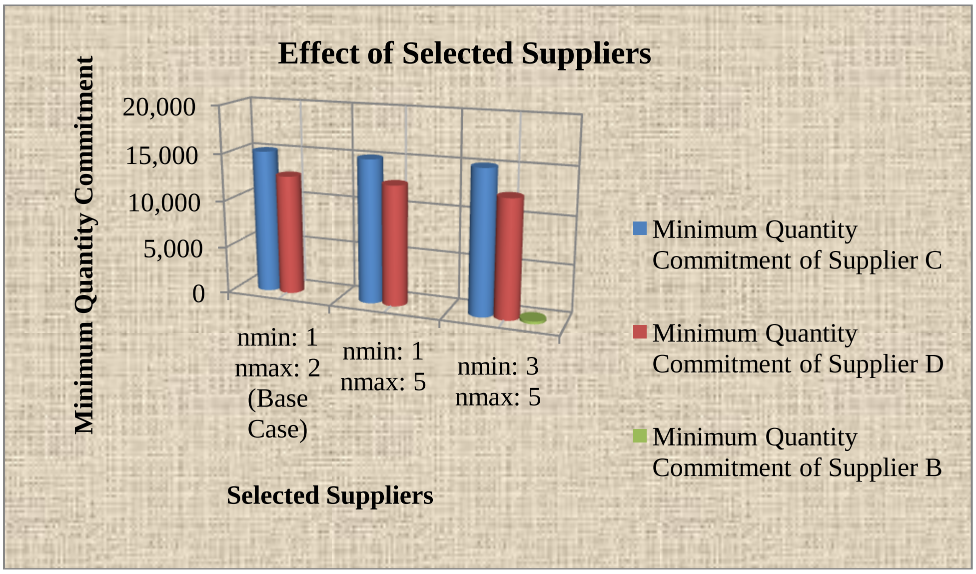


**Figure 20** Effect of the selected suppliers on the minimum quantity commitment of suppliers.

Relief organizations should consider the supplier selection limits (minimum and maximum) carefully, because the minimum number of suppliers selected to an agreement increases the expected total cost of the agreement related to the fixed agreement fee paid. Also, there might be costs that we have not considered explicitly (e.g., managing too many suppliers may be difficult).

### 6.3.4 Effect of Supplier Capacity

In this case, we decrease the base case capacities of suppliers to 25% and 10%. Results show that, the decisions (supplier selection, the scenarios responded by the suppliers, the amount of supplies bought at the quantity and lead time intervals and the minimum quantity commitment) change when the capacity of the suppliers cannot meet the demand.

When we decrease the capacity of the suppliers to 25%, there is no change occurs in the decisions. But, for the 10% case, all the decisions and the expected total cost change. When the capacities are reduced to 10%, suppliers A and C are selected to the agreement. Supplier C responds to 78% of scenarios and the supplier A responds to 22% of the scenarios. Minimum quantity commitment of the supplier C increases by 27% compared to the base case, and the supplier A commits 7,144 demijohns. Suppliers respond to some scenarios together when their capacities are not sufficient to meet the demand. Accordingly, amount of supplies bought at the lead time intervals change. Figure 21 shows the changes related to the expected total cost. There is no change in the expected total cost for the 25% capacity case. The expected total cost increase by 16% when the capacity is reduced to 10%. This is related to higher unit prices of the supplier A. Supplier A is selected although the higher unit prices because the supplier A has also the highest capacity among the suppliers.

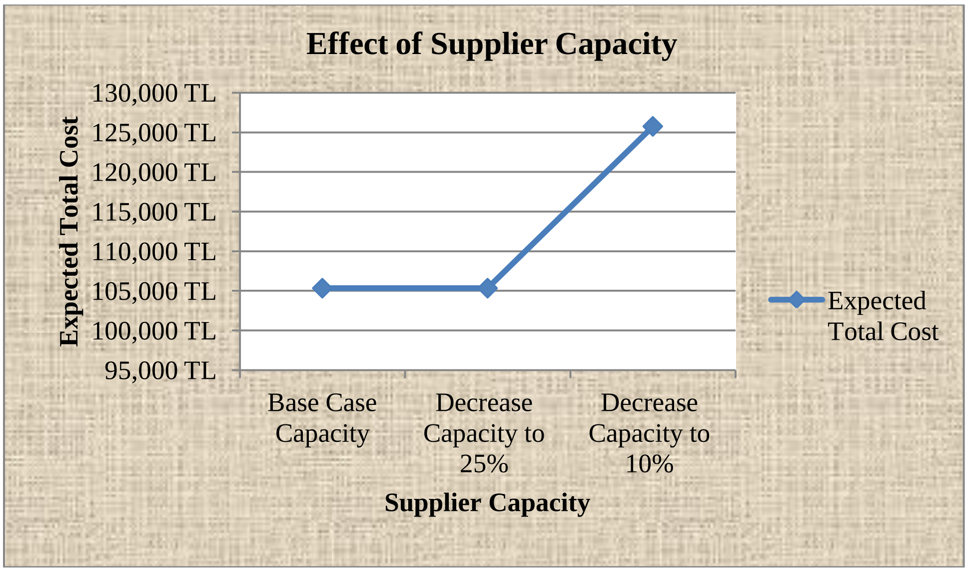


**Figure 21** Effect of the supplier capacity on the expected total cost.

Figure 22 illustrates the changes on the minimum quantity commitment. As mentioned before, there is no change for the 25% capacity case. In the 10% capacity case, there is no commitment from the supplier D because the supplier A is selected instead of the supplier D. Minimum quantity commitment for the supplier C increases according to the base case.

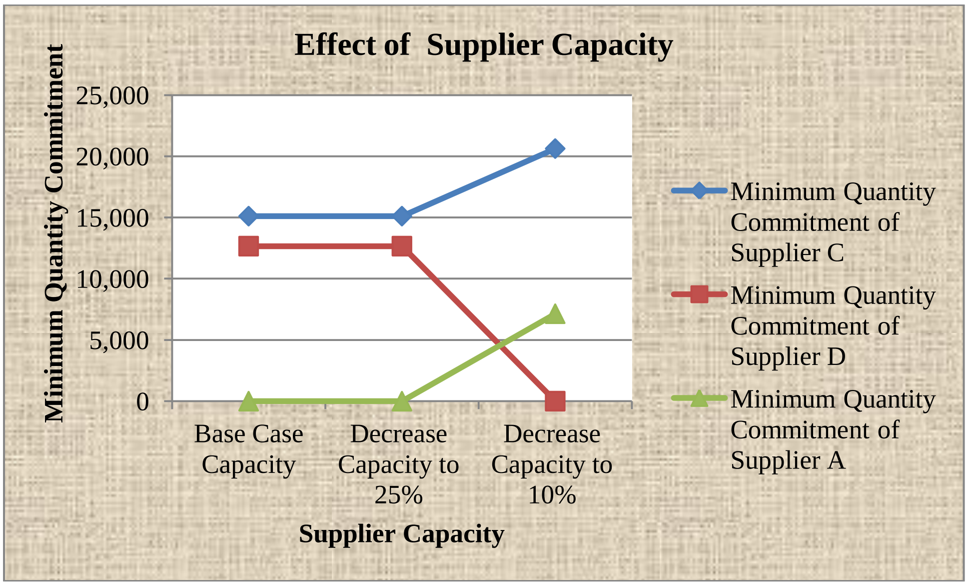


**Figure 22** Effect of the supplier capacity on the minimum quantity commitment.

The scenarios responded by the supplier C increases by 40% in the 10% capacity reduction case as shown in Figure 23. Supplier C responds to more scenarios compared to the base case because supplier C has lowest prices and has the second highest capacity among the suppliers. Supplier A is selected in the 10% capacity reduction case and responds to 22% of the scenarios (responds to fewer scenarios) because the supplier A has high unit prices.

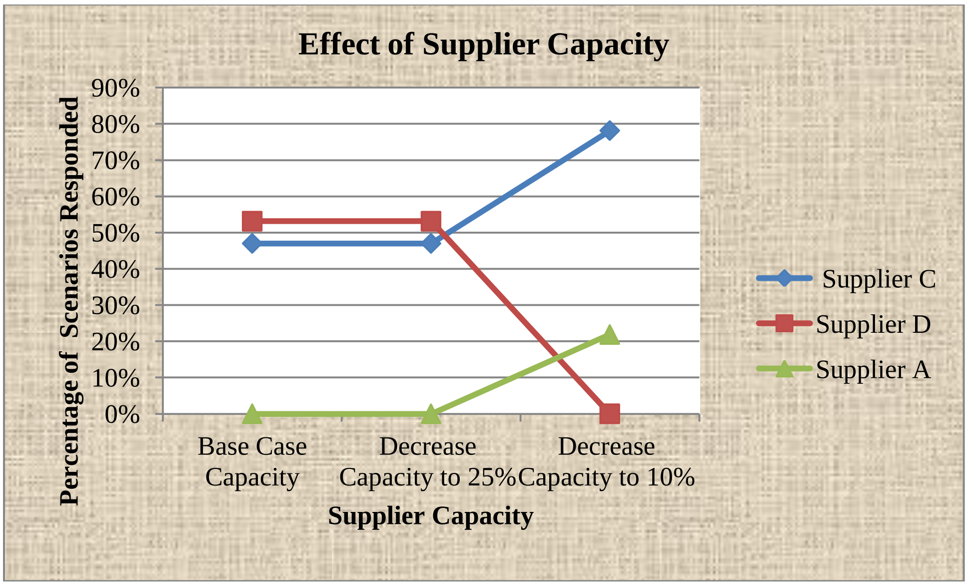


**Figure 23** Effect of the supplier capacity on the percentage of scenarios responded.

The results show that, capacity of the suppliers plays an important role in the supplier selection process. A supplier with high unit prices can be selected to the agreement because of a high capacity. If all the suppliers have higher capacities then the cost becomes important. In this case, suppliers are selected according to the lower unit prices. The relief organizations may consider the suppliers that have almost same capacities in order to have lower costs. On the other hand, if there is no fixed agreement fee and capacity of the suppliers are small, and then the relief organizations should consider to work with multiple suppliers (or maximum suppliers) in order to increase the supplier availability regardless the high unit prices.

### 6.3.5 Generation of Demand Scenarios

In general, there is no way that one can be sure about demand amounts and probabilities in advance in disaster situations. We processed the historical data, but there can also be different ways to process data depending on the assumptions made. In other words, the scenario demands and probabilities will be affected by the assumptions one makes in processing the raw data. Therefore, we test our model by using different parameters related to scenario development:

a. Disaster impact levels

b. Number of days for service
c. Scenario probabilities

**a) Disaster Impact Levels**

In the base case, we consider different disaster impacts and determine four impact levels; mild, medium, severe and very severe according to the total affected people (see Table 15). In this case, we define two impact levels; mild and severe, and three impact levels; mild, medium and severe. Table 20 and Table 21 show two impact levels and three impact levels according to the interval that are defined based on the total affected people.

**Table 20** Two impact levels.

| IMPACT LEVEL | INTERVAL |
|---|---|
| MILD | 1-12000 |
| MEDIUM | 12000-800000 |

**Table 21** Three impact levels.

| IMPACT LEVEL | INTERVAL |
|---|---|
| MILD | 1-12000 |
| MEDIUM | 12000- 100000 |
| SEVERE | 100000-800000 |

We create two scenario lists based on the two and three impact levels; they are available at Appendix I. We obtain 19 scenarios for the two impact levels, and 25 scenarios for the three impact levels. Demand and probabilities of the scenarios change. We arrange the data related to probabilities, demand, and scenarios and run the model for the cases two impact levels and three impact levels.

Results show that, the minimum quantity commitments, the amounts of supplies bought at the quantity intervals and the expected total cost change. Number of suppliers selected to the agreement, and the regions responded by suppliers don't change although the number of scenarios decreased. Figure 24 shows the change in the expected total cost. The expected total cost decreases by 30% from the 2 impact level to the base case, and decrease by 4% from the 3 impact level to the base case. This shows the expected total cost is higher for the 2 impact levels.

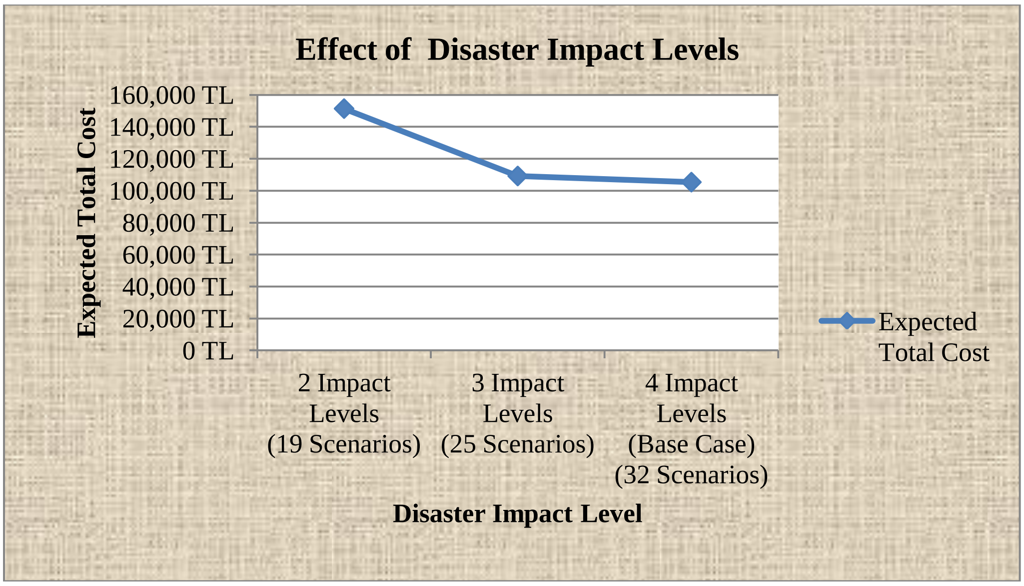


**Figure 24** Effect of the disaster impact levels on the expected total cost.

Figure 25 demonstrates the minimum quantity commitments of the selected suppliers. For example, the minimum quantity of the supplier C decreases by 3% in the 2 impact level case, and increases by 7% in the 3 impact level case compared to the base case. Likewise, the minimum quantity of the supplier D increases by 48% in the 2 impact level case, and decreases by 0.07% in the 3 impact level case with respect to the base case.

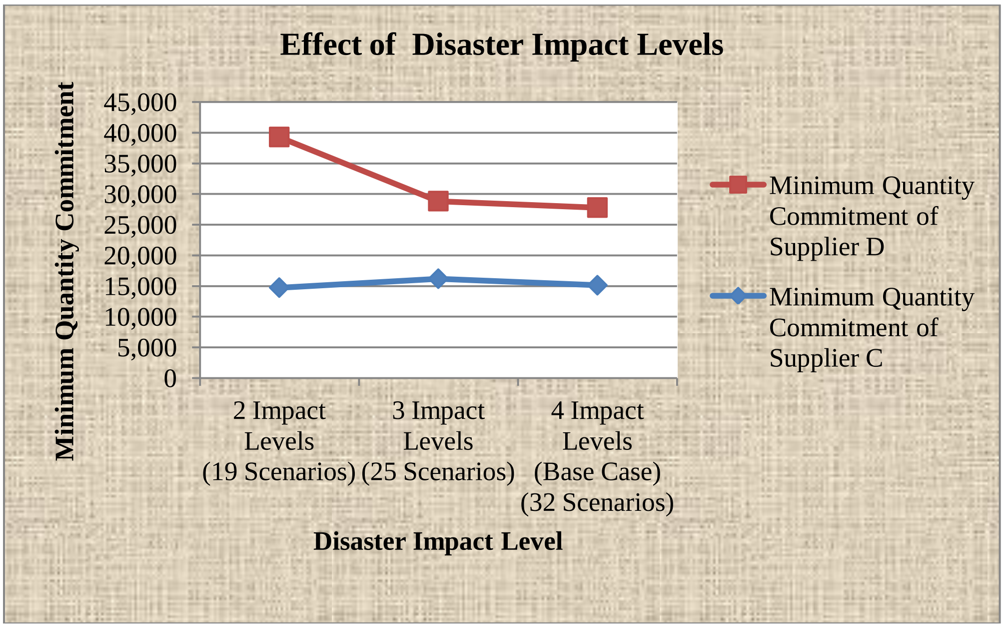


**Figure 25** Effect of the disaster impact levels on the minimum quantity commitment.

Figure 26 illustrates the changes in the percentage of scenarios responded in the quantity intervals. For example, the percentage of scenarios responded in the first (m1) quantity interval decreases by 6% in the 2 impact level case and 29% in three impact level case. In the second (m2) quantity interval, the percentage of scenarios responded decreases by 72% in the 2 impact level case, while increases by 33% in the 3 impact level case. Lastly, there is a 41% increase in the 2 impact level case for the third (m3) quantity interval and 22% increase in the 3 impact level case with respect to the base case.

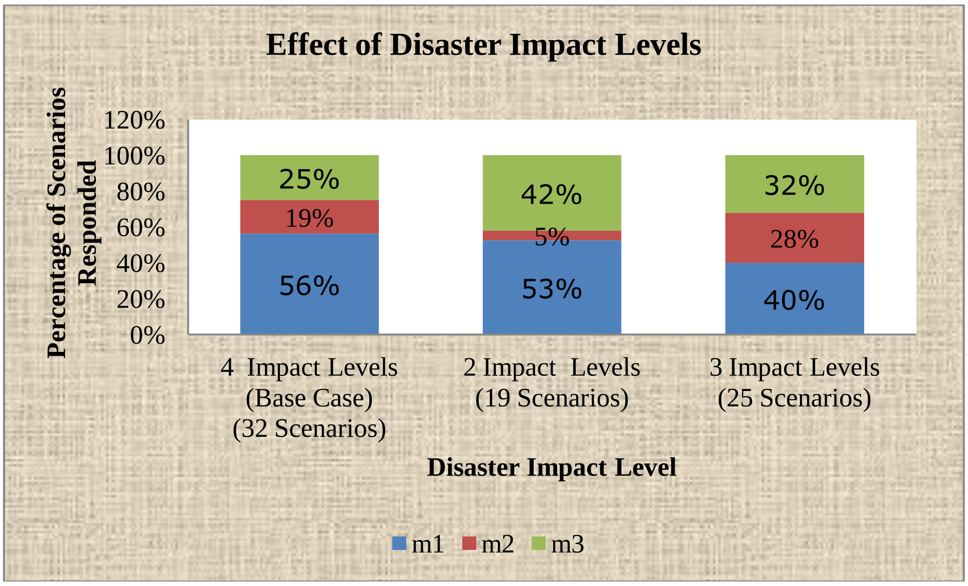


**Figure 26** Effect of the disaster impact levels on the percentage of scenarios responded in the quantity intervals.

Relief organizations must process historical data carefully in creating demand scenarios. For instances, how disaster impact levels are defined may affected decisions. In general, defining more impact levels may be helpful to manage demand uncertainty better.

### b) Number of Days that the Service will be provided

When demand is uncertain, different conditions have to be considered to determine the demand. In the base case, we assume ten days for providing service to beneficiaries in an emergency. The relief organization may be interested in considering a smaller number of days for service in designing the agreement. Therefore, we present results for providing three and seven days of service. Results show that, the minimum quantity commitments, and the expected total cost increase when the days for providing service are increased. There is no change in the number selected suppliers and scenarios responded by the suppliers. Figure 27 shows the increase in the minimum quantity commitment. According to the base case (10 days), supplier C and D have 30% decreases in the minimum quantity commitments when the service reduced to 7 days. Also, both suppliers have 70% decreases in the minimum quantity commitments when the service is reduced from 10 days to 3 days.

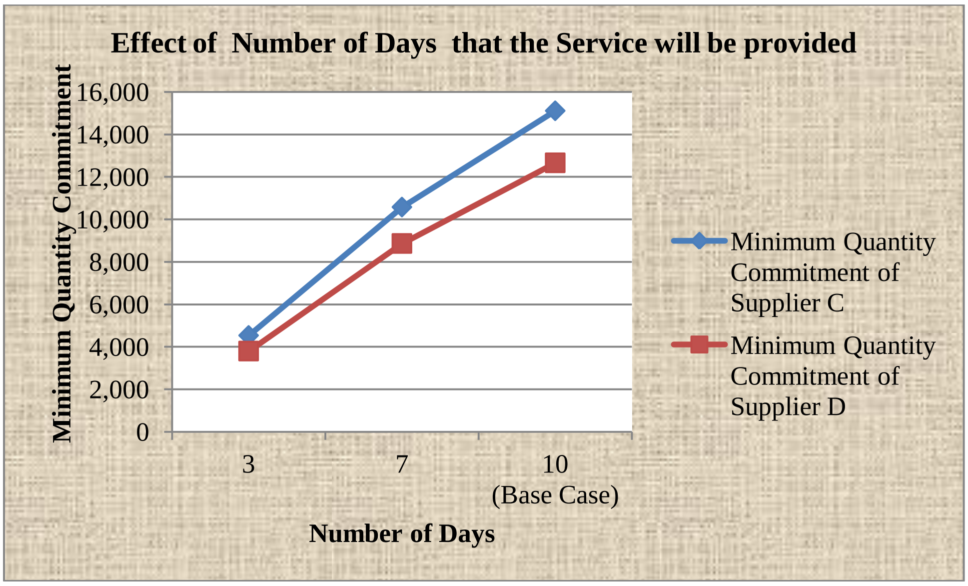


**Figure 27** Effect of number of days that the service will be provided on the minimum quantity commitment.

Figure 28 illustrates the increase in the expected total cost from 3 days to 10 days (base case). According to the base case, there is a 30% decrease in the expected total cost compared to 7 days and a 69% decrease compared to 3 days.

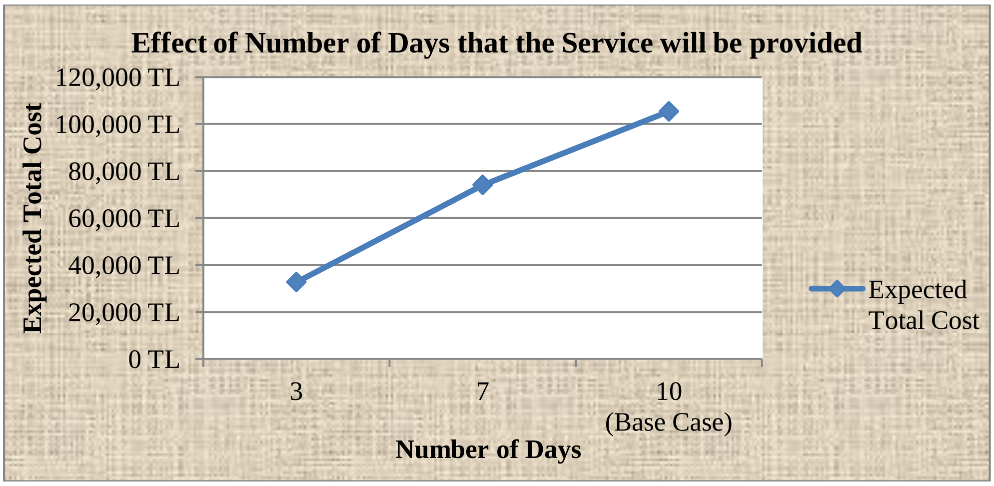


**Figure 28** Effect of the number of days that the service will be provided on the expected total cost.

Relief organizations can decide number of days to provide service according to their budgets and capacities to stock (if exists) because it is difficult to estimate demand due to nature of disasters.

**c) Scenario Probabilities**

It is no doubt that, data rounding has an impact on the estimation of parameters. In the base case study, probabilities of scenarios are rounded to 10 decimals. Generally, when probabilities are rounded to a smaller number of decimal points, the decisions may be affected. To get a better feel for how the small changes in probability parameter affect the contract decisions, we round to 2 decimal places and test the rounded case. When we round the probabilities to 2 decimal places and run the base case model again, the minimum quantity commitment increases, because it is dependent on the expected bought through the scenarios. In this case, expected total cost increases, while the number of suppliers selected to the agreement, scenarios responded by the suppliers, and the amount of supplies bought from the quantity and lead time intervals don't change. Figure 29 shows the changes on the minimum quantity commitment, as seen the minimum quantity commitment of the suppliers' increases by 10.70% in the rounded to 2 decimal case.

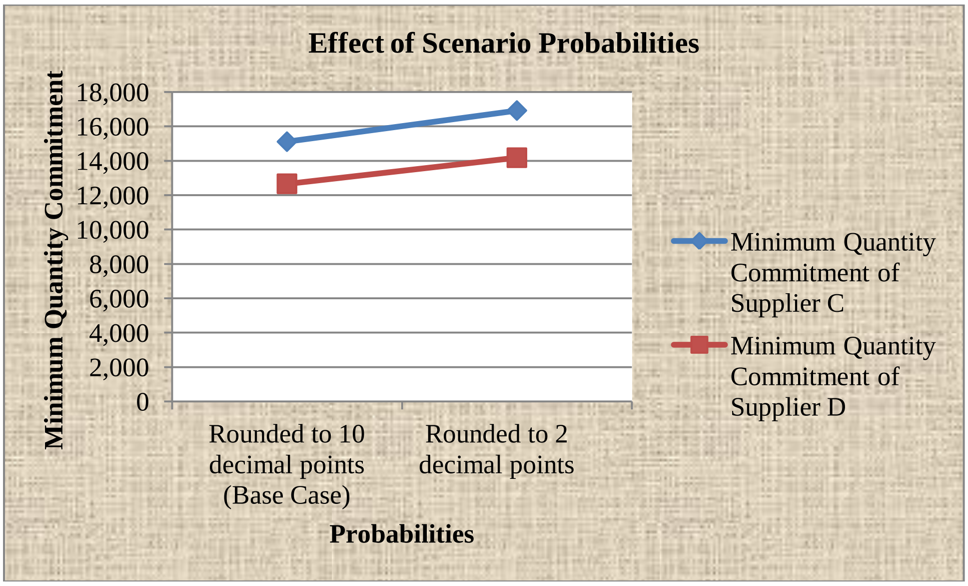


**Figure 29** Effect of the scenario probabilities on the minimum quantity commitment.

Figure 30 demonstrates the changes on the expected total cost. Expected total cost increases by 10.60% in the rounded to 2 decimal case as shown in the figure.

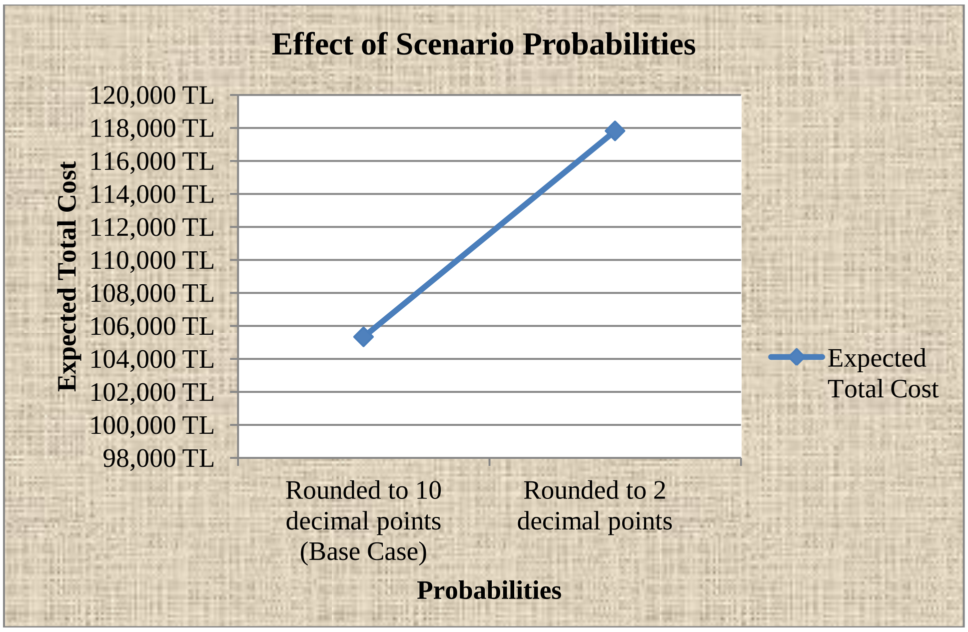


**Figure 30** Effect of the scenario probabilities on the expected total cost.

In summary, the results show that the calculation of scenario probabilities requires precision for the accuracy in the contract decision (minimum quantity commitment) and affects the expected total cost of the agreement.

To sum up, the relief organizations can consider the following issues before they enter into an agreement to improve their performances in terms of costs and supply availability.

1. Relief organizations can satisfy the demand according to an increasing fill rate with a cost advantage. They can purchase a small portion of the demand in a shorter lead time and then larger amounts within discounted lead time intervals for the later periods. However, it may take long time to satisfy the demand. In this situation, they should consider whether they need higher amounts in a shorter time period and if so, then they can satisfy the demand according to the decreasing fill rate which makes possible buying large amounts in a shorter lead time.
2. When a relief organization doesn't pay a fixed agreement fee, it may seem advantageous in terms of total costs incurred through the contract term. However, a fixed agreement provides the supplier to be compliant on the terms and conditions of the agreement which is more important than the cost advantage of the relief organization.

3. Relief organizations should consider the supplier selection limits (minimum and maximum) carefully, because the minimum number of suppliers selected to an agreement increases the expected total cost of the agreement related to the fixed agreement fee paid.
4. Capacity of the suppliers plays an important role in the supplier selection process. A supplier with high unit prices can be selected to the agreement because of a high capacity. If all the suppliers have higher capacities then the cost becomes important. In this case, the suppliers are selected according to the lower unit prices. The relief organizations may consider the suppliers that have almost same capacities in order to have lower costs. On the other hand, if there is no fixed agreement fee and capacity of the suppliers are small, and then the relief organizations should consider to work with multiple suppliers in order to increase the supplier availability regardless the high unit prices.
5. Relief organizations must process historical data carefully in creating demand scenarios. For instances, how disaster impact levels are defined may affected decisions. In general, defining more impact levels may be helpful to manage demand uncertainty better.
6. Relief organizations can decide the number of days to provide service according to their budgets and capacities to stock (if exists) because it is difficult to estimate demand due to nature of disasters.
7. Calculation of scenario probabilities requires precision for the accuracy in the contract decision (minimum quantity commitment) and affects the expected total cost of the agreement.

# 7 Conclusion

This thesis focuses on improving procurement in emergency situations for relief organizations. The purpose of this thesis is twofold. First, the characteristics of the contracts that are applied in relief chains and traditional supply chains are examined, and the applicability of supply chain contracts as framework agreements (which allows relief organizations to guarantee availability and fast procurement of relief supplies) in relief chains are explored. Second, a model for contract design and supplier selection is developed. In the first part, we examine two types of contracts in the supply chain: Contracts under demand uncertainty and cost uncertainty. In these contracts, both the supplier and the buyer share the potential risks of cost or demand uncertainty in order to improve their profits. We mainly focus on the contracts under demand uncertainty because while we are examining the contracts in the relief chains, we observe that relief organizations apply contracts under cost uncertainty mostly for the development activities because demand is generally more predictable at that stage. We evaluate the applicability of the contracts under the category of demand uncertainty. Contracts we consider include the buyback, revenue-sharing, quantity flexibility, and quantity discount contracts. We find that, quantity flexibility contract is more applicable to the relief chain according to the other contracts because it is possible to manage demand uncertainty with this contract by setting minimum commitments for supplies in a pre-disaster stage and allowing maximum purchases according to capacity of the suppliers at the post-disaster stage. Therefore, we consider designing a quantity flexibility contract as a framework agreement by integrating it with supplier selection decision.

In the second part, we present a two-stage stochastic mixed integer programming model for contract design and supplier selection decisions of a relief organization (buyer) under stochastic demand scenarios with the objective of minimizing cost. In this model, the relief organization wishes to satisfy a product or good in the emergency situation as quick as possible. That’s why an agreement between the supplier(s) and the relief organization is made before disaster occurrence. A quantity flexibility contract is applied. Accordingly, the relief organization commits a minimum quantity and guarantees to buy that amount in a given contract period to satisfy the demand in the event of disaster. To design the contract, we assume that the relief organization has a pool of pre-approved suppliers, and sets minimum and maximum limits for the number of suppliers to be selected an agreement. Each supplier applies quantity and lead time discounts. The relief organization pays a fixed agreement fee as a representative of the commitment. For each supplier, the minimum quantity commitment should be greater than the total expected amount of supplies bought from the supplier during the contract term. A scenario approach is used to characterize the uncertainty of disaster demands and the amount of demand due to a scenario is affected by the impact level of the disaster. A probability is associated with the occurrence of a scenario. The relief organization wants to ensure a minimum fill rate for each scenario and can impose fill rate constraints for different lead time intervals. The purchased volume amount from a supplier in a time period under a given scenario can’t exceed the capacity of that supplier in that time period under that scenario.

With these assumptions, the decisions of the model include: supplier selection, minimum quantity commitment, and the level of quantity and lead time intervals to procure from and the amount of supplies to procure. To test the model, we generate a data set based on historical disaster data and based on water suppliers in Turkey. The two-stage stochastic programming model is solved by Gams/Cplex optimally. Numerical results show that our model helps to assess which supplier(s) to make an agreement and how much to commit in the first stage, and amount of supplies purchased at which level of quantity and lead time interval in the second stage. Using a sensitivity analysis, we show the effects of different parameters on the contract design decisions. Results of the sensitivity analysis give useful tips for the relief organization in terms of performance measures such as cost and supply availability. For instances, we show that higher amounts can be supplied in a short time period if the relief organization satisfies the demand according to a decreasing fill rate. Paying a fixed agreement fee increases the expected total cost but provides the supplier to be compliant on the terms and conditions of the agreement. Minimum number of suppliers selected to an agreement increases the expected total cost. Capacity of the suppliers plays an important role in the supplier selection process. A supplier with high unit prices can be selected to the agreement because of a high capacity. While generating demand scenarios, defining more impact levels can be helpful to supply more supplies with lower costs. Furthermore, organizations must decide the number of days to provide service according to their budgets and capacities to stock (if exists). Lastly, they should calculate the scenario probabilities with precision for the accuracy of the expected total cost.

As a future research, the model can be extended in a way that, benefits (profit) of the supplier increases; in our model we just consider the total benefit of the relief organization. Also, further research problems include the cases with multiple products, and financial constraints due to logistical and budgetary considerations. The solvability of the model can be tested for larger scenarios and heuristic approaches can be developed to solve the model if the solution times increase. Finally, a user-friendly interface can be designed to enable relief organizations to use the proposed model for practical decision making effectively.

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## Appendix A An Example of Framework Agreement for Medium and Lower Thermal Resistance Blankets

THIS FRAMEWORK AGREEMENT ("Agreement"), entered into on _________ 2010, by and between:

Company Name                                        Contact:

Hereinafter referred to as the Seller

AND

***(Name Of Organisation)***
***Location***

Hereinafter referred to as the Buyer

**WITNESSETH**

***Whereas,*** the Buyer has tendered, as a member of an inter-agency initiative, for a Framework Agreement for the provision of relief blankets to be used in emergency operations primarily in East and Central Africa, but also possibly in order locations;

***Whereas***, this Agreement is for the potential purchase of Lower and Medium Thermal Blankets as per attached specifications and in accordance with samples submitted to the Buyer (the "Goods");

***Whereas,*** based on the Seller's quotation and price dated ……………. and subsequent response to re-tender, reference ………………… dated …………………, and based on the quality of the Seller's blankets, the Seller has been selected to be *primary vendor for the Buyer*

***Whereas,*** the Buyer wishes to purchase blankets at a fixed price and fixed specification for a fixed duration.

**NOW, THEREFORE,** the Parties hereby agree as follows:

**Article 1 Commodity**

1.1 Primary stock: The seller agrees to manufacture and hold in stock, in their warehouse, for the first ………… months of this agreement 25,000 blankets of 50% wool content and 25,000 blankets of 30% wool content (*according to the attached detailed specifications*). As a member of the inter-agency initiative, the Buyer will draw down on the stock if and when required. In such case, the Seller will ensure that such stock is replenished. At the end of the ………… month, of the agreement, the Buyer (in collaboration with inter-agency members) will advise the Seller of their requirement for further stocks and their intention to renew this agreement. Should the agreement not be renewed the Seller shall have the right to dispose of any remaining stocks.

1.2 Reserve stock: The seller agrees to stock sufficient raw material to manufacture up to an additional 100,000 blankets within a maximum of three weeks of a confirmed purchase order from the Buyer.

**Article 2 Term**

2.1 The Term of this Agreement shall be from ……/……/09 to ……/……/09. It may be extended with prior agreement of the Parties.

**Article 3 Price**

3.1 Fixed price: Throughout the Term of this Agreement the maximum price of the Goods shall be fixed at the following amount:

Medium thermal resistance – 50% wool content: US$3.62 each
Lower thermal resistance – 30% wool content: US$3.32 each

Prices are FCA vendor's warehouse (exclusive of VAT)

3.2 Variation: The above prices can be re-negotiated if there is a sustained change (positive or negative) in the value of the US Dollar against the Euro (currency in which raw materials are valued) by 15% or more. The exchange rate at date of signing is: Euro1.00 = US$_______

**Article 4 Purchase of Goods**

4.1 As a member of the inter-agency initiative, the Buyer shall purchase the Goods individually as and when required. It shall be the responsibility of the Buyer to issue purchase orders accordingly. Such orders shall be in accordance with the terms of this Agreement and shall identify the number of Goods required, delivery terms, packaging and marking requirements (as defined below) and other applicable conditions. The purchase order shall also state whether the Goods are to be purchased out of the Primary or the Reserve stock or otherwise.

**Article 5 Conditions of Purchase**

5.1 Inspection: the Buyer or their representatives may inspect the purchased goods before loading at the Seller's premises with 24 hours prior notice. The cost of such inspection will be for the account of the Buyer; the Seller will cover the cost of any re-inspection.

5.2 Warranty: The Seller will be responsible for the quantity and quality delivered according to the agreed specifications. In case of delivery of non-conforming merchandise, the Buyer shall reserve the right to reject the consignment. Furthermore, the Buyer reserves the right to conduct random testing of Goods in stock to ensure compliance with the specifications hereto attached.

5.3 Marking: Standard markings (unless otherwise advised)
- Commodity: Blankets
- Type: Medium, or Lower, thermal resistance. Wool content 50% or 30% (as appropriate)
- 25 pieces/bale
- Size (cms) 150 x 200 cm
- Gross weight per bale: 40 kgs
- Wt/pc: min 1.5kgs (approx)
- Made by ………………., Country

5.4 Delivery date: To be defined at each Purchase Order

5.5 Packing instructions: 25 blankets packed in a strong plastic sheet and closed by tape. Top and bottom of package to be reinforced with cardboard sheets. The plastic must be pierced to allow breathing and to avoid condensation. The bale is packed into a heavy-duty polypropylene sack to protect the contents against damage and wear and tear during handling and transportation, then compressed and strapped with nylon bands (3 length and 2 width wise). The polypropylene bag should be marked/printed with indelible ink, as per order instructions, with logo (if required by the Buyer). Markings (above) to be on both sides of the bale.

(Note: It shall be understood that markings and logos will add 4 to 5 days to delivery times unless polypropylene bags are pre-printed).

5.6 Penalty clause – Late Deliveries: For deliveries that are beyond the agreed due date there will be a penalty of 0.1% per day of the total FCA value of the order subject to a maximum of 2% of the total order value.

5.7 Consignee: To be confirmed on each Purchase Order

5.8 Delivery Terms: Delivery terms for each purchase order are to be specified according to INCOTERMS 2000 (normally either CIF or C&F). The Buyer will advise the Seller, at time of order, of the type and scope, if any, of any freight forwarding and/or transport service required. Clearance at the country of destination / import will be arranged by the Buyer's representatives.

5.9 Post Order: All orders must be deemed equally important unless the Buyer indicates priority. If delivery times agreed with the Buyer at time of order are not going to be met, the Seller will contact the concerned organization (named on the Purchase Order) at least 24hrs in advance of the initial delivery time and agree another date.

5.10 Price: as defined above.

5.11 Insurance: arranged by the Buyer member concerned unless included as part of delivery terms (Article 5.8)

5.12 Payment terms: By bank transfer or cheque within 30 days after invoicing, receipt of shipping documents and confirmation that Goods are in good order.

5.13 Address for Invoice: To be stated on purchase order.

5.14 Documents required for each Delivery:

The following documents are to be completed by the Seller within 24 hours of receipt of a confirmed order (for primary blanket stock) from the Buyer:

- Export Invoice (VAT exempt) in triplicate – unless Goods are for use within Kenya, in which case a standard invoice inclusive of VAT shall be prepared.
- Packing List in triplicate
- Signed delivery note by the Carrier, Certificate of Analysis (when requested), Copy of the Certificate of Quality and Quantity established by the Survey company (if performed)
- Other documents according to each Purchase Order

5.15 Dispatch of documents: One full set of originals to be sent to the Buyer undertaking the purchase.

**Article 6 Purchase of Goods by other than an inter-agency member**

6.1 Purchase orders will be made by either: X, Y, Z, or , P. Blanket and raw material stocks (as indicated in Article 1) are collectively for all members of inter-agency initiative.

6.2 The Seller agrees that other National offices related to any of the above organizations may also benefit from the terms and conditions of this Agreement as described herein but that all orders shall only be accepted from the Buyer offices that are party to this agreement.

6.3 Any purchases by any party other than a member of the inter-agency initiative or their associated Office (see 6.1 above), are not in any way the responsibility of the Buyer. Such purchases will be made directly by the third party and be invoiced directly to them.

**Article 7 Exclusivity**

7.1 In cases of extreme urgency or need for larger quantities than available with the Seller, the Buyer reserves the right, after consultation with the Seller, to procure Goods from secondary sources.

**Article 8 Breach**

8.1 If the Seller breaches any term or condition of this Agreement, or the conditions set out in any given purchase order, including but not limited to quality of the goods, price and delivery requirements, the Buyer shall be entitled to immediately purchase goods from any other source, in addition to any other remedy available in law or equity.

**Article 9 General Terms and Conditions**

9.1 Acceptance of this agreement entails the waiving by the Seller of its General Conditions of Sales.

9.2 All terms and conditions not mentioned herein shall be governed by the Buyer's general purchasing conditions.

9.3 Termination: Should Seller or the Buyer wish to terminate this agreement they should give 3 months written notice detailing their reasons for such a request.

9.4 Applicable Laws & Arbitration: This agreement and any subsequent purchase contract(s) shall be governed by the laws of Kenya.

9.5 Disputes: In the event that a dispute cannot be resolved through negotiations, the parties to this agreement and any subsequent purchase contracts(s) agree to be bound by the arbitration procedures of the International Chamber of Commerce and accept the arbitration decision as the final adjudication of a dispute.

9.6 Service Measurements & Performance: The Seller is required to demonstrate their performance. Failure to meet the targets contained herein will be deemed to be a failure in servicing the agreement. The professional and timely provision of the services purchased is of paramount importance to the Buyer and if the Seller subsequently fails to meet these expectations the Buyer reserves the right to find a suitable alternative supplier for blankets, in addition to any other remedy available in law or equity.

**Article 10 <u>Final Provisions</u>**

This contract is produced in three original copies, whereby the Seller shall keep one and the Buyer shall keep two original copies after signature.

This agreement comes into force with signature and stamps of all parties.

| | | | |
|---|---|---|---|
| The Buyer | | …………………………………… | |
| Name of Signatory: | ____________________ | Name of Signatory: | ………………, Director, Finance |
| Signature: | ____________________ | Signature: | ____________________ |
| Date: | ____________________ | Date: | ____________________ |

## Appendix B Quantity Flexibility Agreement for Demijohn Water

This Quantity Flexibility Agreement entered into on .................. 2011, by and between: ........................... (Company name) referred as seller and................................ (Name of organization) referred as buyer.

This agreement is for the potential purchase of demijohn water to be used in emergency operations.

Based on the Seller's lead time, price and the quality of the water, the Seller has been selected to be *primary vendor for the Buyer.*

The Buyer wishes to purchase at a flexible interval and volume discount for the quantities.

**THEREFORE,** the Parties hereby agree as follows:

**Commodity:**

The buyer agrees to commit ………………………. demijohn water as a minimum quantity to purchase from the seller.

The buyer can alter up the quantity to the capacity of the supplier.

**Purchase of Goods:**

The buyer can purchase the goods when it is required.

**Conditions of Purchase:**

Delivery Date**:** It will be determined when a purchase order is given.
**Payment and Contract Price:**

………… a fixed agreement fee will be pay to the seller.

Payment will be made when a purchase occurs from the buyer.

Payment includes both transportation and purchasing price

**Delivery:**

The seller must deliver the goods within …… days in the presence of emergency.

If the seller fails to deliver the goods within the time promised, the buyer has the right to take an additional discount for the late delivery.

**Termination:**

In the event of termination of agreement by the buyer, he will lose the contract price and a penalty cost is incurred for the committed quantity.

# Appendix C Supplier Unit Prices

| | | QUANTITY AND LEAD TIME INTERVALS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1≤Q≤1000 | | | 1000<Q≤10000 | | | 10000<Q≤C(i) | | |
| **SUPPLIERS** | **REGIONS** | 1 -3days | 4- 6days | 7- 9days | 1 -3 days | 4- 6 days | 7- 9days | 1 -3 days | 4- 6 days | 7- 9days |
| | TM | 7.70TL | 6.93TL | 6.16TL | 7.20 TL | 6.48TL | 5.76 TL | 6.70TL | 6.03TL | 5.36TL |
| | WBS | - | - | - | - | - | - | - | - | - |
| | EBS | - | - | - | - | - | - | - | - | - |
| | NA | 7.00TL | 6.30TL | 5.60TL | 6.50 TL | 5.85TL | 5.20TL | 6.00 TL | 5.40TL | 4.80TL |
| A | SA | 7.00TL | 6.30TL | 5.60TL | 6.50 TL | 5.85TL | 5.20TL | 6.00 TL | 5.40TL | 4.80TL |
| | TMA | 7.00TL | 6.30TL | 5.60TL | 6.50 TL | 5.85TL | 5.20TL | 6.00 TL | 5.40TL | 4.80TL |
| | SEA | - | - | - | - | - | - | - | - | - |
| | NEA | - | - | - | - | - | - | - | - | - |
| | EA | 7.00TL | 6.30TL | 5.60TL | 6.50 TL | 5.85TL | 5.20TL | 6.00 TL | 5.40TL | 4.80TL |
| | CA | 7.70TL | 6.93TL | 6.16TL | 7.20 TL | 6.48TL | 5.76 TL | 6.70TL | 6.03TL | 5.36TL |
| | TM | 6.25TL | 5.63TL | 5.00TL | 5.75TL | 5.18TL | 4.60TL | 5.25TL | 4.73TL | 4.20TL |
| | WBS | - | - | - | - | - | - | - | - | - |
| | EBS | - | - | - | - | - | - | - | - | - |
| | NA | - | - | - | - | - | - | - | - | - |
| B | SA | - | - | - | - | - | - | - | - | - |
| | TMA | 5.50TL | 4.95TL | 4.40TL | 5.00TL | 4.50 TL | 4.00TL | 4.50TL | 4.05TL | 3.60TL |
| | SEA | - | - | - | - | - | - | - | - | - |
| | NEA | - | - | - | - | - | - | - | - | - |
| | EA | - | - | - | - | - | - | - | - | |
| | CA | 5.50TL | 4.95TL | 4.40TL | 5.00TL | 4.50 TL | 4.00TL | 4.50TL | 4.05TL | 3.60TL |
| | TM | 6.50TL | 5.85TL | 5.20TL | 6.00TL | 5.40TL | 4.80TL | 5.50TL | 4.95TL | 4.40TL |
| | WBS | 6.00TL | 5.40TL | 4.80TL | 5.50TL | 4.95TL | 4.40TL | 5.00TL | 4.50TL | 4.00TL |
| | EBS | 6.00TL | 5.40TL | 4.80TL | 5.50TL | 4.95TL | 4.40TL | 5.00TL | 4.50TL | 4.00TL |
| | NA | - | - | - | - | - | - | - | - | - |
| C | SA | - | - | - | - | - | - | - | - | - |
| | TMA | 4.75TL | 4.28TL | 3.80TL | 4.25TL | 3.83TL | 3.40TL | 3.75TL | 3.38TL | 3.00TL |
| | SEA | 5.00TL | 4.50TL | 4.00TL | 4.50TL | 4.05TL | 3.60TL | 4.00TL | 3.60TL | 3.20TL |
| | NEA | 5.00TL | 4.50TL | 4.00TL | 4.50TL | 4.05TL | 3.60TL | 4.00TL | 3.60TL | 3.20TL |
| | EA | 6.00TL | 5.40TL | 4.80TL | 5.50TL | 4.95TL | 4.40TL | 5.00TL | 4.50TL | 4.00TL |
| | CA | 6.50TL | 5.85TL | 5.20TL | 6.00TL | 5.40TL | 4.80TL | 5.50TL | 4.95TL | 4.40TL |
| | TM | 5.50TL | 4.95TL | 4.40TL | 5.00TL | 4.50 TL | 4.00TL | 4.50TL | 4.05TL | 3.60TL |
| | WBS | 5.00TL | 4.50TL | 4.00TL | 4.50TL | 4.05TL | 3.60TL | 4.00TL | 3.60TL | 3.20TL |
| | EBS | 5.00TL | 4.50TL | 4.00TL | 4.50TL | 4.05TL | 3.60TL | 4.00TL | 3.60TL | 3.20TL |
| | NA | 5.00TL | 4.50TL | 4.00TL | 4.50TL | 4.05TL | 3.60TL | 4.00TL | 3.60TL | 3.20TL |
| D | SA | 5.00TL | 4.50TL | 4.00TL | 4.50TL | 4.05TL | 3.60TL | 4.00TL | 3.60TL | 3.20TL |
| | TMA | 6.50TL | 5.85TL | 5.20TL | 6.00TL | 5.40TL | 4.80TL | 5.50TL | 4.95TL | 4.40TL |
| | SEA | - | - | - | - | - | - | - | - | - |
| | NEA | - | - | - | - | - | - | - | - | - |
| | EA | - | - | - | - | - | - | - | - | - |
| | CA | 6.00TL | 5.40TL | 4.80TL | 5.50TL | 4.95TL | 4.40TL | 5.00TL | 4.50TL | 4.00TL |
| | TM | 6.50TL | 5.85TL | 5.20TL | 6.00TL | 5.40TL | 4.80TL | 5.50TL | 4.95TL | 4.40TL |
| | WBS | 6.50TL | 5.85TL | 5.20TL | 6.00TL | 5.40TL | 4.80TL | 5.50TL | 4.95TL | 4.40TL |
| | EBS | 6.50TL | 5.85TL | 5.20TL | 6.00TL | 5.40TL | 4.80TL | 5.50TL | 4.95TL | 4.40TL |
| | NA | 5.50TL | 4.95TL | 4.40TL | 5.00TL | 4.50 TL | 4.00TL | 4.50TL | 4.05TL | 3.60TL |
| E | SA | 5.50TL | 4.95TL | 4.40TL | 5.00TL | 4.50 TL | 4.00TL | 4.50TL | 4.05TL | 3.60TL |
| | TMA | 6.50TL | 5.85TL | 5.20TL | 6.00TL | 5.40TL | 4.80TL | 5.50TL | 4.95TL | 4.40TL |
| | SEA | - | - | - | - | - | - | - | - | - |
| | NEA | - | - | - | - | - | - | - | - | - |
| | EA | - | - | - | - | - | - | - | - | - |
| | CA | 6.50TL | 5.85TL | 5.20TL | 6.00TL | 5.40TL | 4.80TL | 5.50TL | 4.95TL | 4.40TL |

# Appendix D Historical Disaster List Arranged According to Regions

| DISASTER TIME | COUNTRY | REGION | LOCATION | DISASTER TYPE | TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|
| 27/01/2003 | Turkey | Southeastern Anatolia | Pulumur (Tunceli province) | Earthquake (seismic activity) | 2 |
| 00/00/2006 | Turkey | Central Anatolia | Agri, Ankara, Van, Kastam … | Epidemic | 8 |
| 00/00/2006 | Turkey | Eastern Anatolia | Agri, Ankara, Van, Kastam … | Epidemic | 8 |
| 00/00/2006 | Turkey | Northeastern Anatolia | Agri, Ankara, Van, Kastam … | Epidemic | 8 |
| 00/00/2006 | Turkey | West Black Sea | Agri, Ankara, Van, Kastam … | Epidemic | 8 |
| 25/01/2009 | Turkey | Eastern Black Sea | Zigana region (Gumushane … | Mass Movement Wet | 6 |
| 08/12/1991 | Turkey | Eastern Anatolia | Van, Bitlis, Hakkari Prov … | Storm | 3 |
| 17/03/2005 | Turkey | Southeastern Anatolia | Sivas province | Mass Movement Wet | 9 |
| 22/09/1939 | Turkey | South Aegean | Dikili | Earthquake (seismic activity) | 68 |
| 28/04/1957 | Turkey | South Aegean | Fethiye | Earthquake (seismic activity) | 100 |
| 26/05/1957 | Turkey | West Black Sea | Abant (Bolu province) | Earthquake (seismic activity) | 119 |
| 16/08/2004 | Turkey | The Marmara | Alibeykoy and Esenler dis … | Flood | 100 |
| 19/08/1976 | Turkey | South Aegean | Denizli | Earthquake (seismic activity) | 28 |
| 13/08/1951 | Turkey | Central Anatolia | Kursunlu:Ilgaz | Earthquake (seismic activity) | 150 |
| 31/08/1999 | Turkey | The Marmara | Izmit | Earthquake (seismic activity) | 166 |
| 03/01/1952 | Turkey | Northeastern Anatolia | Hasankale (Erzurum province | Earthquake (seismic activity) | 250 |
| 05/10/1999 | Turkey | South Aegean | Marmaris | Earthquake (seismic activity) | 103 |
| 30/03/1928 | Turkey | South Aegean | Torbah:Izmir | Earthquake (seismic activity) | 209 |
| 17/08/1949 | Turkey | Southeastern Anatolia | Karliova (Anatolia) | Earthquake (seismic activity) | 355 |
| 10/07/2009 | Turkey | Eastern Black Sea | Savsat city, Bogazski vil … | Flood | 111 |
| 10/04/2003 | Turkey | South Aegean | Izmir | Earthquake (seismic activity) | 170 |
| 12/08/1985 | Turkey | Eastern Black Sea | Gumushane,Erzincan | Earthquake (seismic activity) | 165 |
| 12/08/1985 | Turkey | Northeastern Anatolia | Gumushane,Erzincan | Earthquake (seismic activity) | 165 |
| 01/01/2006 | Turkey | Southeastern Anatolia | Tokat, Sivas, Gümüshane, … | Epidemic | 222 |
| 01/01/2006 | Turkey | West Black Sea | Tokat, Sivas, Gümüshane, … | Epidemic | 222 |
| 13/09/1999 | Turkey | The Marmara | Kocaeli, Bursa, Istanbul, … | Earthquake (seismic activity) | 422 |
| 00/08/1987 | Turkey | South Aegean | Southern | Epidemic | 150 |
| 21/11/2004 | Turkey | Central Anatolia | Istanbul, Ankara, Yozgat, … | Storm | 721 |
| 21/11/2004 | Turkey | The Marmara | Istanbul, Ankara, Yozgat, … | Storm | 721 |
| 26/07/2003 | Turkey | South Aegean | Buldan (Western Turkey) | Earthquake (seismic activity) | 240 |
| 24/01/2005 | Turkey | Eastern Anatolia | Van city (Adana and Hakkari province) | Earthquake (seismic activity) | 422 |

| DISASTER TIME | COUNTRY | REGION | LOCATION | DISASTER TYPE | TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|
| 24/01/2005 | Turkey | The Mediterranean | Van city (Adana and Hakkari province) | Earthquake (seismic activity) | 422 |
| 27/08/2010 | Turkey | Eastern Black Sea | Gündogdu (Rize province, … | Mass Movement Wet | 206 |
| 00/05/1984 | Turkey | Southeastern Anatolia | SouthEast | Flood | 200 |
| 19/04/1938 | Turkey | Central Anatolia | Kirsehir | Earthquake (seismic activity) | 800 |
| 27/05/2007 | Turkey | Eastern Anatolia | Agri, Ban, Bitlis, Gazian … | Flood | 750 |
| 27/05/2007 | Turkey | Northeastern Anatolia | Agri, Ban, Bitlis, Gazian … | Flood | 750 |
| 27/05/2007 | Turkey | The Mediterranean | Agri, Ban, Bitlis, Gazian … | Flood | 750 |
| 25/06/2001 | Turkey | The Mediterranean | Osmaniye province | Earthquake (seismic activity) | 480 |
| 10/07/2001 | Turkey | Northeastern Anatolia | Erzurum area | Earthquake (seismic activity) | 131 |
| 06/06/2005 | Turkey | Southeastern Anatolia | Near Karliova (Bingol province) | Earthquake (seismic activity) | 354 |
| 02/12/2001 | Turkey | The Mediterranean | Adana, Icel provinces | Flood | 570 |
| 11/11/1999 | Turkey | West Black Sea | Sakarya Province | Earthquake (seismic activity) | 200 |
| 08/03/2001 | Turkey | Southeastern Anatolia | Sanliurfa province | Flood | 450 |
| 14/12/1998 | Turkey | The Mediterranean | Kayseri | Earthquake (seismic activity) | 690 |
| 03/08/2007 | Turkey | Northeastern Anatolia | Aliceyrek, Akkeran, Danis … | Flood | 186 |
| 00/00/1962 | Turkey | Southeastern Anatolia | Pulumur | Earthquake (seismic activity) | 267 |
| 02/05/1995 | Turkey | Eastern Anatolia | Bitlis (Eastern Turkey) | Flood | 201 |
| 16/05/1991 | Turkey | Southeastern Anatolia | Diyarbakir, Malatya, Adiyaman | Flood | 500 |
| 19/06/2004 | Turkey | Central Anatolia | Sunlu | Storm | 915 |
| 04/07/1998 | Turkey | The Mediterranean | Geyhan, Adana area | Earthquake (seismic activity) | 1,016 |
| 10/11/2001 | Turkey | Eastern Black Sea | Camlihemsin, Cayeli, Ardesen … | Mass Movement Wet | 600 |
| 23/06/1988 | Turkey | Eastern Black Sea | Catak (Trabzon province) | Mass Movement Wet | 620 |
| 01/01/1992 | Turkey | Eastern Anatolia | Sirnak, Siirt, Elazig, Batm ... | Mass Movement Dry | 1,069 |
| 01/01/1992 | Turkey | Southeastern Anatolia | Sirnak, Siirt, Elazig, Batm ... | Mass Movement Dry | 1,069 |
| 02/07/2004 | Turkey | Northeastern Anatolia | Dogubeyazit (Agri province) | Earthquake (seismic activity) | 356 |
| 08/05/2000 | Turkey | Southeastern Anatolia | Puturge | Earthquake (seismic activity) | 1,000 |
| 04/07/2005 | Turkey | The Marmara | Istanbul, Duzce, Sakarya … | Flood | 3,000 |
| 04/07/2005 | Turkey | West Black Sea | Istanbul, Duzce, Sakarya … | Flood | 3,000 |
| 07/05/2001 | Turkey | Central Anatolia | Antakya (Konya provinces) | Flood | 1,500 |
| 11/10/1986 | Turkey | South Aegean | Aydin area | Earthquake (seismic activity) | 1,003 |
| 28/03/1969 | Turkey | North Aegean | West Alasehir | Earthquake (seismic activity) | 350 |
| 27/05/2000 | Turkey | Eastern Black Sea | Samsun and Tokat province … | Flood | 1,000 |
| 10/08/1998 | Turkey | Eastern Black Sea | Beskoy (Trabzon province) | Flood | 1,000 |
| 13/06/1988 | Turkey | Central Anatolia | Ankara | Flood | 1,500 |
| 16/11/2007 | Turkey | North Aegean | Thracian and Aegean regio … | Flood | 2,250 |
| 16/11/2007 | Turkey | South Aegean | Thracian and Aegean regio … | Flood | 2,250 |
| 07/11/1985 | Turkey | Northeastern Anatolia | Erzurum area | Earthquake (seismic activity) | 579 |
| 26/11/1943 | Turkey | Eastern Black Sea | Ladik | Earthquake (seismic activity) | 5,000 |
| 14/03/2005 | Turkey | Southeastern Anatolia | Karliova (Bingol province) | Earthquake (seismic activity) | 2,268 |
| 15/02/1978 | Turkey | Northeastern Anatolia | Pulumur, Erzincan | Earthquake (seismic activity) | 2,645 |

| DISASTER TIME | COUNTRY | REGION | LOCATION | DISASTER TYPE | TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|
| 15/02/1978 | Turkey | Southeastern Anatolia | Pulumur, Erzincan | Earthquake (seismic activity) | 2,645 |
| 08/03/2010 | Turkey | Southeastern Anatolia | Elazig | Earthquake (seismic activity) | 3,600 |
| 23/07/2002 | Turkey | Eastern Black Sea | Rize province (Black sea) | Flood | 3,000 |
| 00/02/1964 | Turkey | The Mediterranean | Adana Province | Epidemic | 2,500 |
| 10/03/1964 | Turkey | Central Anatolia | Western:Eskisehir | Flood | 3,000 |
| 14/02/1994 | Turkey | Eastern Anatolia | Eastern and North East | Extreme temperature | 8,000 |
| 14/02/1994 | Turkey | Eastern Black Sea | Eastern and North East | Extreme temperature | 8,000 |
| 14/02/1994 | Turkey | Northeastern Anatolia | Eastern and North East | Extreme temperature | 8,000 |
| 10/07/1995 | Turkey | Central Anatolia | Ankara, Istanbul, Senirke … | Mass Movement Wet | 12,046 |
| 10/07/1995 | Turkey | South Aegean | Ankara, Istanbul, Senirke … | Mass Movement Wet | 12,046 |
| 10/07/1995 | Turkey | The Marmara | Ankara, Istanbul, Senirke … | Mass Movement Wet | 12,046 |
| 18/06/1990 | Turkey | Eastern Black Sea | Giresun, Gumushane, Trazb … | Flood | 4,500 |
| 25/03/2004 | Turkey | Northeastern Anatolia | Askale, Cat, Buyukgecit, … | Earthquake (seismic activity) | 4,030 |
| 14/08/1996 | Turkey | Central Anatolia | Corum, Amasya | Earthquake (seismic activity) | 26,006 |
| 14/08/1996 | Turkey | Eastern Black Sea | Corum, Amasya | Earthquake (seismic activity) | 26,006 |
| 07/09/2009 | Turkey | The Marmara | Silivri, Catalca district … | Flood | 35,020 |
| 18/03/1953 | Turkey | The Marmara | Canakkale, Balikesir | Earthquake (seismic activity) | 50,000 |
| 06/10/1964 | Turkey | The Marmara | Bursa & Balikesir provinc … | Earthquake (seismic activity) | 13,100 |
| 06/06/2000 | Turkey | Central Anatolia | Cubuk (Cankiri province) | Earthquake (seismic activity) | 23,080 |
| 05/05/1986 | Turkey | Southeastern Anatolia | Malatya, Adiyaman province | Earthquake (seismic activity) | 20,100 |
| 05/03/2004 | Turkey | Eastern Anatolia | Erzurum, Batman, Bitlis, … | Flood | 50,000 |
| 05/03/2004 | Turkey | Northeastern Anatolia | Erzurum, Batman, Bitlis, … | Flood | 50,000 |
| 27/10/2006 | Turkey | Southeastern Anatolia | Cinar, Bismil (Sanliurfa, … | Flood | 63,015 |
| 06/09/1975 | Turkey | Southeastern Anatolia | Lice | Earthquake (seismic activity) | 53,372 |
| 28/03/2004 | Turkey | Northeastern Anatolia | Askale, Ilica, Cat, Erzurum | Earthquake (seismic activity) | 32,530 |
| 22/05/1971 | Turkey | Northeastern Anatolia | Bingol, Erzincan | Earthquake (seismic activity) | 88,665 |
| 22/05/1971 | Turkey | Southeastern Anatolia | Bingol, Erzincan | Earthquake (seismic activity) | 88,665 |
| 28/03/1970 | Turkey | North Aegean | Gediz | Earthquake (seismic activity) | 83,448 |
| 01/05/2003 | Turkey | Southeastern Anatolia | Diyarbakir region (Bingol … | Earthquake (seismic activity) | 290,520 |
| 04/11/1995 | Turkey | South Aegean | Izmir, Antalaya, Isparta | Flood | 306,617 |
| 01/10/1995 | Turkey | North Aegean | Dinar, Evciler (Afyon province) | Earthquake (seismic activity) | 160,240 |
| 12/11/1999 | Turkey | West Black Sea | Duzce, Bolu, Kaynasli | Earthquake (seismic activity) | 224,948 |
| 17/08/1999 | Turkey | The Marmara | Izmit, Kocaeli, Yalova, Golcuk | Earthquake (seismic activity) | 1,358,953 |
| 03/02/2002 | Turkey | North Aegean | Bolvadin (Afyon province) | Earthquake (seismic activity) | 252,327 |
| 19/08/1966 | Turkey | Eastern Anatolia | Varto | Earthquake (seismic activity) | 109,500 |
| 13/03/1992 | Turkey | Northeastern Anatolia | Erzican province | Earthquake (seismic activity) | 348,850 |
| 22/07/1967 | Turkey | West Black Sea | (1) West Turkey : (2) Eas … | Earthquake (seismic activity) | 326,073 |
| 24/11/1976 | Turkey | Eastern Anatolia | Muradiye | Earthquake (seismic activity) | 216,000 |
| 28/06/1998 | Turkey | The Mediterranean | Adana, Ceyhan, Hatay | Earthquake (seismic activity) | 1,589,600 |
| 18/10/1984 | Turkey | Northeastern Anatolia | Erzurum:Senkaya area | Earthquake (seismic activity) | 375,035 |
| 18/09/1984 | Turkey | Northeastern Anatolia | Olur:Senkaya area | Earthquake (seismic activity) | 375,038 |
| 30/10/1983 | Turkey | Northeastern Anatolia | Horasan, Pasinler, Narma … | Earthquake (seismic activity) | 834,137 |
| 20/05/1998 | Turkey | West Black Sea | Zonguldak, Karabuk, Bartin | Flood | 1,240,047 |

# Appendix E Disaster List with the Normalized Total Affected People

| DISASTER TIME | COUNTRY | REGION | LOCATION | DISASTER TYPE | TOTAL AFFECTED PEOPLE | POPULATION OF REGION | TOTAL AFFECTED PEOPLE PERCANTAGE | NORMALIZED TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|---|---|---|
| 16/08/2004 | Turkey | The Marmara | Alibeykoy and Esenler dis … | Flood | 100 | 16,608,859 | 0.0006020880 | 100 |
| 31/08/1999 | Turkey | The Marmara | Izmit | Earthquake (seismic activity) | 166 | 16,608,859 | 0.0009994670 | 166 |
| 13/09/1999 | Turkey | The Marmara | Kocaeli, Bursa, Istanbul, … | Earthquake (seismic activity) | 422 | 16,608,859 | 0.0025408130 | 422 |
| 21/11/2004 | Turkey | The Marmara | Istanbul, Ankara, Yozgat, … | Storm | 721 | 25,701,980 | 0.0028052310 | 466 |
| 4/7/2005 | Turkey | The Marmara | Istanbul, Duzce, Sakarya … | Flood | 3,000 | 19,575,876 | 0.0153249850 | 2,545 |
| 10/7/1995 | Turkey | The Marmara | Ankara, Istanbul, Senirke … | Mass Movement Wet | 12,046 | 14,357,544 | 0.0839001430 | 13,935 |
| 6/10/1964 | Turkey | The Marmara | Bursa & Balikesir provinc … | Earthquake (seismic activity) | 13,100 | 5,348,069 | 0.2449482230 | 40,683 |
| 7/9/2009 | Turkey | The Marmara | Silivri, Catalca district … | Flood | 35,020 | 16,608,859 | 0.2108513290 | 35,020 |
| 18/03/1953 | Turkey | The Marmara | Canakkale, Balikesir | Earthquake (seismic activity) | 50,000 | 22,569,000 | 0.2215428240 | 36,796 |
| 17/08/1999 | Turkey | The Marmara | Izmit, Kocaeli, Yalova, Golcuk | Earthquake (seismic activity) | 1,358,953 | 16,608,859 | 8.1820972770 | 1,358,953 |
| 00/00/2006 | Turkey | West Black Sea | Agri, Ankara, Van, Kastam … | Epidemic | 8 | 17,851,659 | 0.0000448000 | 1 |
| 26/05/1957 | Turkey | West Black Sea | Abant (Bolu province) | Earthquake (seismic activity) | 119 | 25,250,000 | 0.0004712870 | 14 |
| 11/11/1999 | Turkey | West Black Sea | Sakarya Province | Earthquake (seismic activity) | 200 | 2,967,017 | 0.0067407770 | 200 |
| 1/1/2006 | Turkey | West Black Sea | Tokat, Sivas, Gümüshane, … | Epidemic | 222 | 9,627,744 | 0.0023058360 | 68 |
| 4/7/2005 | Turkey | West Black Sea | Istanbul, Duzce, Sakarya … | Flood | 3,000 | 19,575,876 | 0.0153249850 | 455 |
| 12/11/1999 | Turkey | West Black Sea | Duzce, Bolu, Kaynasli | Earthquake (seismic activity) | 224,948 | 2,967,017 | 7.5816215410 | 224,948 |
| 22/07/1967 | Turkey | West Black Sea | (1) West Turkey : (2) Eas … | Earthquake (seismic activity) | 326,073 | 2,145,915 | 15.1950566500 | 450,840 |
| 20/05/1998 | Turkey | West Black Sea | Zonguldak, Karabuk, Bartin | Flood | 1,240,047 | 2,967,017 | 41.7944015800 | 1,240,047 |

| DISASTER TIME | COUNTRY | REGION | LOCATION | DISASTER TYPE | TOTAL AFFECTED PEOPLE | POPULATION OF REGION | TOTAL AFFECTED PEOPLE PERCENTAGE | NORMALIZED TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|---|---|---|
| 25/01/2009 | Turkey | Eastern Black Sea | Zigana region (Gumushane … | Mass Movement Wet | 6 | 5,533,941 | 0.0001084220 | 6 |
| 10/7/2009 | Turkey | Eastern Black Sea | Savsat city, Bogazski vil … | Flood | 111 | 5,533,941 | 0.0020058040 | 111 |
| 12/8/1985 | Turkey | Eastern Black Sea | Gumushane,Erzincan | Earthquake (seismic activity) | 165 | 7,382,291 | 0.0022350790 | 124 |
| 27/08/2010 | Turkey | Eastern Black Sea | Gündogdu (Rize province, … | Mass Movement Wet | 206 | 5,533,941 | 0.0037224830 | 206 |
| 10/11/2001 | Turkey | Eastern Black Sea | Camlihemsin, Cayeli, Ardesen … | Mass Movement Wet | 600 | 5,533,941 | 0.0108421830 | 600 |
| 23/06/1988 | Turkey | Eastern Black Sea | Catak (Trabzon province) | Mass Movement Wet | 620 | 4,591,780 | 0.0135023890 | 747 |
| 27/05/2000 | Turkey | Eastern Black Sea | Samsun and Tokat province … | Flood | 1,000 | 5,533,941 | 0.0180703050 | 1,000 |
| 36076 | Turkey | Eastern Black Sea | Beskoy (Trabzon province) | Flood | 1,000 | 5,533,941 | 0.0180703050 | 1,000 |
| 23/07/2002 | Turkey | Eastern Black Sea | Rize province (Black sea) | Flood | 3,000 | 5,533,941 | 0.0542109140 | 3,000 |
| 18/06/1990 | Turkey | Eastern Black Sea | Giresun, Gumushane, Trazb … | Flood | 4,500 | 5,090,867 | 0.0883935880 | 4,892 |
| 26/11/1943 | Turkey | Eastern Black Sea | Ladik | Earthquake (seismic activity) | 5,000 | 18,337,000 | 0.0272672740 | 1,509 |
| 14/02/1994 | Turkey | Eastern Black Sea | Eastern and North East | Extreme temperature | 8,000 | 9,811,577 | 0.0815363320 | 4,512 |
| 14/08/1996 | Turkey | Eastern Black Sea | Corum, Amasya | Earthquake (seismic activity) | 26,006 | 12,793,253 | 0.2032790250 | 11,249 |
| 28/03/1969 | Turkey | North Aegean | West Alasehir | Earthquake (seismic activity) | 350 | 1,995,240 | 0.0175417000 | 535 |
| 16/11/2007 | Turkey | North Aegean | Thracian and Aegean regio … | Flood | 2,250 | 11,429,016 | 0.0196867000 | 601 |
| 28/03/1970 | Turkey | North Aegean | Gediz | Earthquake (seismic activity) | 83,448 | 1,995,240 | 4.1823540000 | 127,637 |
| 34709 | Turkey | North Aegean | Dinar, Evciler (Afyon province) | Earthquake (seismic activity) | 160,240 | 2,761,944 | 5.8017107000 | 177,057 |
| 37317 | Turkey | North Aegean | Bolvadin (Afyon province) | Earthquake (seismic activity) | 252,327 | 3,051,801 | 8.2681341000 | 252,327 |
| 19/08/1976 | Turkey | South Aegean | Denizli | Earthquake (seismic activity) | 28 | 4,460,485 | 0.0006277340 | 53 |
| 22/09/1939 | Turkey | South Aegean | Dikili | Earthquake (seismic activity) | 68 | 17,429,000 | 0.0003901540 | 33 |
| 28/04/1957 | Turkey | South Aegean | Fethiye | Earthquake (seismic activity) | 100 | 25,250,000 | 0.0003960400 | 33 |
| 36290 | Turkey | South Aegean | Marmaris | Earthquake (seismic activity) | 103 | 8,377,215 | 0.0012295260 | 103 |
| 00/08/1987 | Turkey | South Aegean | Southern | Epidemic | 150 | 5,737,011 | 0.0026146020 | 219 |
| 37898 | Turkey | South Aegean | Izmir | Earthquake (seismic activity) | 170 | 8,377,215 | 0.0020293140 | 170 |

| DISASTER TIME | COUNTRY | REGION | LOCATION | DISASTER TYPE | TOTAL AFFECTED PEOPLE | POPULATION OF REGION | TOTAL AFFECTED PEOPLE PERCANTAGE | NORMALIZED TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|---|---|---|
| 30/03/1928 | Turkey | South Aegean | Torbah:Izmir | Earthquake (seismic activity) | 209 | 13,843,000 | 0.0015097880 | 126 |
| 26/07/2003 | Turkey | South Aegean | Buldan (Western Turkey) | Earthquake (seismic activity) | 240 | 8,377,215 | 0.0028649140 | 240 |
| 31726 | Turkey | South Aegean | Aydin area | Earthquake (seismic activity) | 1,003 | 5,737,011 | 0.0174829720 | 1,465 |
| 16/11/2007 | Turkey | South Aegean | Thracian and Aegean regio … | Flood | 2,250 | 11,429,016 | 0.0196867340 | 1,649 |
| 34979 | Turkey | South Aegean | Ankara, Istanbul, Senirke … | Mass Movement Wet | 12,046 | 14,357,544 | 0.0839001430 | 7,028 |
| 34800 | Turkey | South Aegean | Izmir, Antalaya, Isparta | Flood | 306,617 | 6,655,158 | 4.6072084240 | 385,956 |
| 24/01/2005 | Turkey | The Mediterranean | Van city (Adana and Hakkari province) | Earthquake (seismic activity) | 422 | 13,257,247 | 0.0031831650 | 317 |
| 25/06/2001 | Turkey | The Mediterranean | Osmaniye province | Earthquake (seismic activity) | 480 | 9,973,464 | 0.0048127710 | 480 |
| 36934 | Turkey | The Mediterranean | Adana, Icel provinces | Flood | 570 | 9,973,464 | 0.0057151660 | 570 |
| 14/12/1998 | Turkey | The Mediterranean | Kayseri | Earthquake (seismic activity) | 690 | 9,973,464 | 0.0069183590 | 690 |
| 27/05/2007 | Turkey | The Mediterranean | Agri, Ban, Bitlis, Gazian … | Flood | 750 | 15,764,985 | 0.0047573780 | 474 |
| 00/02/1964 | Turkey | The Mediterranean | Adana Province | Epidemic | 2,500 | 3,971,554 | 0.0629476520 | 6,278 |
| 35892 | Turkey | The Mediterranean | Geyhan, Adana area | Earthquake (seismic activity) | 1,016 | 9,973,464 | 0.0101870320 | 1,016 |
| 28/06/1998 | Turkey | The Mediterranean | Adana, Ceyhan, Hatay | Earthquake (seismic activity) | 1,589,600 | 9,973,464 | 15.9382938600 | 1,589,600 |
| 27/01/2003 | Turkey | Southeastern Anatolia | Pulumur (Tunceli province) | Earthquake (seismic activity) | 2 | 6,660,727 | 0.0000300268 | 2 |
| 17/03/2005 | Turkey | Southeastern Anatolia | Sivas province | Mass Movement Wet | 9 | 6,660,727 | 0.0001351200 | 9 |
| 00/05/1984 | Turkey | Southeastern Anatolia | SouthEast | Flood | 200 | 5,127,523 | 0.0039005190 | 260 |
| 38718 | Turkey | Southeastern Anatolia | Tokat, Sivas, Gümüshane, … | Epidemic | 222 | 9,627,744 | 0.0023058360 | 154 |
| 00/00/1962 | Turkey | Southeastern Anatolia | Pulumur | Earthquake (seismic activity) | 267 | 3,377,115 | 0.0079061570 | 527 |
| 38509 | Turkey | Southeastern Anatolia | Near Karliova (Bingol province) | Earthquake (seismic activity) | 354 | 6,660,727 | 0.0053147350 | 354 |
| 17/08/1949 | Turkey | Southeastern Anatolia | Karliova (Anatolia) | Earthquake (seismic activity) | 355 | 20,350,000 | 0.0017444720 | 116 |
| 37106 | Turkey | Southeastern Anatolia | Sanliurfa province | Flood | 450 | 6,660,727 | 0.0067560190 | 450 |
| 16/05/1991 | Turkey | Southeastern Anatolia | Diyarbakir, Malatya, Adiyaman | Flood | 500 | 5,519,179 | 0.0090593180 | 603 |

| DISASTER TIME | COUNTRY | REGION | LOCATION | DISASTER TYPE | TOTAL AFFECTED PEOPLE | POPULATION OF REGION | TOTAL AFFECTED PEOPLE PERCANTAGE | NORMALIZED TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|---|---|---|
| 36743 | Turkey | Southeastern Anatolia | Puturge | Earthquake (seismic activity) | 1,000 | 6,660,727 | 0.0150133760 | 1,000 |
| 33604 | Turkey | Southeastern Anatolia | Sirnak, Siirt, Elazig, Batm ... | Mass Movement Dry | 1,069 | 7,885,859 | 0.0135559110 | 903 |
| 14/03/2005 | Turkey | Southeastern Anatolia | Karliova (Bingol province) | Earthquake (seismic activity) | 2,268 | 6,660,727 | 0.0340503370 | 2,268 |
| 15/02/1978 | Turkey | Southeastern Anatolia | Pulumur, Erzincan | Earthquake (seismic activity) | 2,645 | 6,650,150 | 0.0397735390 | 2,649 |
| 40393 | Turkey | Southeastern Anatolia | Elazig | Earthquake (seismic activity) | 3,600 | 6,660,727 | 0.0540481540 | 3,600 |
| 31537 | Turkey | Southeastern Anatolia | Malatya, Adiyaman province | Earthquake (seismic activity) | 20,100 | 5,127,523 | 0.3920021420 | 26,110 |
| 27554 | Turkey | Southeastern Anatolia | Lice | Earthquake (seismic activity) | 53,372 | 4,224,679 | 1.2633385870 | 84,148 |
| 27/10/2006 | Turkey | Southeastern Anatolia | Cinar, Bismil (Sanliurfa, … | Flood | 63,015 | 6,660,727 | 0.9460678990 | 63,015 |
| 22/05/1971 | Turkey | Southeastern Anatolia | Bingol, Erzincan | Earthquake (seismic activity) | 88,665 | 5,742,403 | 1.5440400130 | 102,844 |
| 37626 | Turkey | Southeastern Anatolia | Diyarbakir region (Bingol … | Earthquake (seismic activity) | 290,520 | 6,660,727 | 4.3616860440 | 290,520 |
| 00/00/2006 | Turkey | Northeastern Anatolia | Agri, Ankara, Van, Kastam … | Epidemic | 8 | 17,851,659 | 0.0000448138 | 1 |
| 37171 | Turkey | Northeastern Anatolia | Erzurum area | Earthquake (seismic activity) | 131 | 2,507,738 | 0.0052238310 | 131 |
| 31389 | Turkey | Northeastern Anatolia | Gumushane,Erzincan | Earthquake (seismic activity) | 165 | 7,382,291 | 0.0022350790 | 56 |
| 38024 | Turkey | Northeastern Anatolia | Dogubeyazit (Agri province) | Earthquake (seismic activity) | 356 | 2,507,738 | 0.0141960600 | 356 |
| 31239 | Turkey | Northeastern Anatolia | Erzurum area | Earthquake (seismic activity) | 579 | 2,299,722 | 0.0251769560 | 631 |
| 27/05/2007 | Turkey | Northeastern Anatolia | Agri, Ban, Bitlis, Gazian … | Flood | 750 | 15,764,985 | 0.0047573780 | 119 |
| 15/02/1978 | Turkey | Northeastern Anatolia | Pulumur, Erzincan | Earthquake (seismic activity) | 2,645 | 6,650,150 | 0.0397735390 | 997 |
| 25/03/2004 | Turkey | Northeastern Anatolia | Askale, Cat, Buyukgecit, … | Earthquake (seismic activity) | 4,030 | 2,507,738 | 0.1607025930 | 4,030 |
| 14/02/1994 | Turkey | Northeastern Anatolia | Eastern and North East | Extreme temperature | 8,000 | 9,811,577 | 0.0815363320 | 2,045 |
| 28/03/2004 | Turkey | Northeastern Anatolia | Askale, Ilica, Cat, Erzurum | Earthquake (seismic activity) | 32,530 | 2,507,738 | 1.2971849530 | 32,530 |
| 38110 | Turkey | Northeastern Anatolia | Erzurum, Batman, Bitlis, … | Flood | 50,000 | 5,791,521 | 0.8633310660 | 21,650 |
| 22/05/1971 | Turkey | Northeastern Anatolia | Bingol, Erzincan | Earthquake (seismic activity) | 88,665 | 5,742,403 | 1.5440400130 | 38,720 |

| DISASTER TIME | COUNTRY | REGION | LOCATION | DISASTER TYPE | TOTAL AFFECTED PEOPLE | POPULATION OF REGION | TOTAL AFFECTED PEOPLE PERCANTAGE | NORMALIZED TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|---|---|---|
| 13/03/1992 | Turkey | Northeastern Anatolia | Erzican province | Earthquake (seismic activity) | 348,850 | 2,354,030 | 14.8192673800 | 371,628 |
| 18/10/1984 | Turkey | Northeastern Anatolia | Erzurum:Senkaya area | Earthquake (seismic activity) | 375,035 | 2,299,722 | 16.3078406900 | 408,958 |
| 18/09/1984 | Turkey | Northeastern Anatolia | Olur:Senkaya area | Earthquake (seismic activity) | 375,038 | 2,299,722 | 16.3079711400 | 408,961 |
| 30/10/1983 | Turkey | Northeastern Anatolia | Horasan, Pasinler, Narma … | Earthquake (seismic activity) | 834,137 | 2,152,078 | 38.7596081600 | 971,989 |
| 08/12/1991 | Turkey | Eastern Anatolia | Van, Bitlis, Hakkari Prov … | Storm | 3 | 2,369,527 | 0.0001266100 | 4 |
| 00/00/2006 | Turkey | Eastern Anatolia | Agri, Ankara, Van, Kastam … | Epidemic | 8 | 17,851,659 | 0.0000448100 | 1 |
| 02/05/1995 | Turkey | Eastern Anatolia | Bitlis (Eastern Turkey) | Flood | 201 | 2,366,680 | 0.0084929100 | 279 |
| 24/01/2005 | Turkey | Eastern Anatolia | Van city (Adana and Hakkari province) | Earthquake (seismic activity) | 422 | 13,257,247 | 0.0031831600 | 105 |
| 27/05/2007 | Turkey | Eastern Anatolia | Agri, Ban, Bitlis, Gazian … | Flood | 750 | 15,764,985 | 0.0047573800 | 156 |
| 01/01/1992 | Turkey | Eastern Anatolia | Sirnak, Siirt, Elazig, Batm ... | Mass Movement Dry | 1,069 | 7,885,859 | 0.0135559100 | 445 |
| 14/02/1994 | Turkey | Eastern Anatolia | Eastern and North East | Extreme temperature | 8,000 | 9,811,577 | 0.0815363300 | 2,677 |
| 05/03/2004 | Turkey | Eastern Anatolia | Erzurum, Batman, Bitlis, … | Flood | 50,000 | 5,791,521 | 0.8633310700 | 28,350 |
| 19/08/1966 | Turkey | Eastern Anatolia | Varto | Earthquake (seismic activity) | 109,500 | 968,394 | 11.3073810900 | 371,310 |
| 24/11/1976 | Turkey | Eastern Anatolia | Muradiye | Earthquake (seismic activity) | 216,000 | 1,379,361 | 15.6594249100 | 514,222 |
| 00/00/2006 | Turkey | Central Anatolia | Agri, Ankara, Van, Kastam … | Epidemic | 8 | **17,851,659** | 0.0000448138 | 4 |
| 13/08/1951 | Turkey | Central Anatolia | Kursunlu:Ilgaz | Earthquake (seismic activity) | 150 | 21,351,000 | 0.0007025430 | 64 |
| 21/11/2004 | Turkey | Central Anatolia | Istanbul, Ankara, Yozgat, … | Storm | 721 | 25,701,980 | 0.0028052310 | 255 |
| 19/04/1938 | Turkey | Central Anatolia | Kirsehir | Earthquake (seismic activity) | 800 | 16,926,000 | 0.0047264560 | 430 |
| 19/06/2004 | Turkey | Central Anatolia | Sunlu | Storm | 915 | 9,093,121 | 0.0100625520 | 915 |
| 13/06/1988 | Turkey | Central Anatolia | Ankara | Flood | 1,500 | 7,702,386 | 0.0194744850 | 1,771 |
| 07/05/2001 | Turkey | Central Anatolia | Antakya (Konya provinces) | Flood | 1,500 | 9,093,121 | 0.0164959860 | 1,500 |
| 10/03/1964 | Turkey | Central Anatolia | Western:Eskisehir | Flood | 3,000 | 4,553,017 | 0.0658903760 | 5,991 |
| 10/07/1995 | Turkey | Central Anatolia | Ankara, Istanbul, Senirke … | Mass Movement Wet | 12,046 | 14,357,544 | 0.0839001430 | 7,629 |
| 06/06/2000 | Turkey | Central Anatolia | Cubuk (Cankiri province) | Earthquake (seismic activity) | 23,080 | 9,093,121 | 0.2538182430 | 23,080 |
| 14/08/1996 | Turkey | Central Anatolia | Corum, Amasya | Earthquake (seismic activity) | 26,006 | 12,793,253 | 0.2032790253 | 18,484 |

# Appendix F Base Case Scenario List

| SCENARIO # | IMPACT LEVEL | LOCATION | DEMAND FOR DEMIJOHN | COUNT | PROBABILITY | TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|---|
| 1 | MILD | THE MARMARA | 304 | 4 | 0.0357142857 | 289 |
| 2 | MEDIUM | THE MARMARA | 2,679 | 1 | 0.0089285714 | 2,545 |
| 3 | SEVERE | THE MARMARA | 33,272 | 4 | 0.0357142857 | 31,608 |
| 4 | VERY SEVERE | THE MARMARA | 1,430,477 | 1 | 0.0089285714 | 1,358,953 |
| 5 | MILD | WEST BLACK SEA | 155 | 5 | 0.0446428571 | 147 |
| 6 | VERY SEVERE | WEST BLACK SEA | 672,222 | 3 | 0.0267857143 | 638,611 |
| 7 | MILD | EASTERN BLACK SEA | 499 | 7 | 0.0625000000 | 474 |
| 8 | MEDIUM | EASTERN BLACK SEA | 3,661 | 4 | 0.0357142857 | 3,478 |
| 9 | SEVERE | EASTERN BLACK SEA | 11,841 | 1 | 0.0089285714 | 11,249 |
| 10 | MILD | NORTH AEGEAN | 598 | 2 | 0.0178571429 | 568 |
| 11 | VERY SEVERE | NORTH AEGEAN | 195,446 | 3 | 0.0267857143 | 185,674 |
| 12 | MILD | SOUTH AEGEAN | 128 | 7 | 0.0625000000 | 122 |
| 13 | MEDIUM | SOUTH AEGEAN | 3,558 | 3 | 0.0267857143 | 3,380 |
| 14 | VERY SEVERE | SOUTH AEGEAN | 406,268 | 1 | 0.0089285714 | 385,955 |
| 15 | MILD | THE MEDITERRANEAN | 533 | 5 | 0.0446428571 | 506 |
| 16 | MEDIUM | THE MEDITERRANEAN | 3,839 | 2 | 0.0178571429 | 3,647 |
| 17 | VERY SEVERE | THE MEDITERRANEAN | 1,673,263 | 1 | 0.0089285714 | 1,589,600 |
| 18 | MILD | SOUTHEASTERN ANATOLIA | 419 | 11 | 0.0982142857 | 398 |
| 19 | MEDIUM | SOUTHEASTERN ANATOLIA | 2,988 | 3 | 0.0267857143 | 2,839 |
| 20 | SEVERE | SOUTHEASTERN ANATOLIA | 60,797 | 3 | 0.0267857143 | 57,757 |
| 21 | VERY SEVERE | SOUTHEASTERN ANATOLIA | 207,034 | 2 | 0.0178571429 | 196,682 |
| 22 | MILD | NORTEASTERN ANATOLIA | 293 | 9 | 0.0803571429 | 278 |
| 23 | MEDIUM | NORTEASTERN ANATOLIA | 3,198 | 2 | 0.0178571429 | 3,038 |
| 24 | SEVERE | NORTEASTERN ANATOLIA | 32,596 | 3 | 0.0267857143 | 30,966 |
| 25 | VERY SEVERE | NORTEASTERN ANATOLIA | 568,825 | 4 | 0.0357142857 | 540,384 |
| 26 | MILD | EASTERN ANATOLIA | 174 | 6 | 0.0535714286 | 165 |
| 27 | MEDIUM | EASTERN ANATOLIA | 2,818 | 1 | 0.0089285714 | 2,677 |
| 28 | SEVERE | EASTERN ANATOLIA | 29,841 | 1 | 0.0089285714 | 28,349 |
| 29 | VERY SEVERE | EASTERN ANATOLIA | 466,068 | 2 | 0.0178571429 | 442,765 |
| 30 | MILD | CENTRAL ANATOLIA | 351 | 5 | 0.0446428571 | 333 |
| 31 | MEDIUM | CENTRAL ANATOLIA | 4,445 | 4 | 0.0357142857 | 4,223 |
| 32 | SEVERE | CENTRAL ANATOLIA | 43,752 | 2 | 0.0178571429 | 41,564 |

# Appendix G Gams Model

The Gams model is as follows:

```
Set i    preapproved suppliers /A, B, C, D, E/;
Set m    quantity intervals /m1, m2, m3/;
Set l    lead time intervals /l1, l2, l3/;
Set s    scenarios /1*32/;

Parameter gama(s) probability of occurrence for scenario s
/
1       0.035714286
2       0.008928571
3       0.035714286
.
.
.
31      0.035714286
32      0.017857143 /;

Parameter d(s) expected demand of scenario s
/
1       304
2       2679
3       33272
.
.
31      4445
32      43752 /;
```

Parameter C (i) Capacity of supplier i per 10 days

/

A 5767844

B 1441961

C 2162941

D 1874549

E 1441961

/;

Parameter delta (i) per unit penalty for purchases under the minimum quantity

/

A 0.58

B 0.46

C 0.46

D 0.43

E 0.44

/;

Parameter qlow (i, l, m, s) lower quantity limit

/

A.l1.m1.1= 1

A.l1.m2.1= 1001

A.l1.m3.1= 10001

A.l1.m1.2= 1

A.l1.m2.2= 1001

A.l1.m3.2=10001

.

.

E.l3.m1.32= 1

E.l3.m2.32= 1001

E.l3.m3.32=10001/; /;

Parameter qhigh (i, l, m, s) upper quantity limit

/

A.l1.m1.1= 1000

A.l1.m2.1= 10000

A.l1.m3.1= 5767844

A.l1.m1.2= 1000

A.l1.m2.2= 10000

A.l1.m3.2=5767844

.

.

.

E.l3.m1.31= 1000

E.l3.m2.31= 10000

E.l3.m3.31=1441961

E.l3.m1.32= 1000

E.l3.m2.32= 10000

E.l3.m3.32=1441961/;

Parameter p (i, s, l, m) unit price offered by supplier i for the region of scenario s for the lead time interval l and quantity interval m

/

A.1.l1.m1 = 7.70

A.1.l2.m1 = 6.93

A.1.l3.m1 = 6.16

A.1.l1.m2 = 7.20

A.1.l2.m2 = 6.48

A.1.l3.m2 = 5.76

A.1.l1.m3 = 6.70

A.1.l2.m3 = 6.03

A.1.l3.m3 = 5.36

.

.

.

E.32.l1.m1 = 6.50

E.32.l2.m1 = 5.85

E.32.l3.m1 = 5.20

E.32.l1.m2 = 6.00

E.32.l2.m2 = 5.40

E.32.l3.m2 = 4.80

E.32.l1.m3 = 5.50

E.32.l2.m3 = 4.95

E.32.l3.m3 = 4.40 /;

Parameter F (i) Fixed agreement fee with supplier i

/ A 500

B 500

C 500

D 500

E 500/;

Scalar nmin minimum limit of the contracts that the buyer chooses /1/;

Scalar nmax maximum limit of the contracts that the buyer chooses /2/;

Parameter fill(s, l) fill rate at lead time interval l in scenario s

/

1.l1 = 0.10

1.l2 = 0.10

1.l3 = 0.10

.

.

.

32.l1 = 0.10

32.l2 = 0.10

32.l3 = 0.10 /;

**Variables**

Y (i) if supplier i is selected for a contract

Qmin (i) minimum quantity that the buyer commits to purchase from supplier i during a fixed contract term

X (i, s, l, m) if the contract with supplier i is executed at quantity interval m and lead time interval l in scenario s

Q (i, s, l, m) amount of supplies bought from supplier i at quantity interval m and lead time interval l in scenario s

W (i) how much bought under min quantity

A cost;

Positive Variable Q min (i)

Positive Variable Q (i, s, l, m)

Positive Variable W (i)

Binary Variable Y (i)

Binary Variable X (i, s, l, m) ;

**Equation**

Cost expected cost

Undermin (i) how much bought under min quantity

Capacity (i, s) capacity of supplier

Agreementmax maximum number of suppliers to have agreements with

Agreementmin minimum number of suppliers to have agreements with

Expectedbuy (i) total expected bought through the contract

Fillrate (s, l) fill rate at lead time interval l in scenario s

Limitbuymin (s, l, m, i) we have limits for buying from supplier i for scenario s

Limitbuymax(s, l, m, i) we have limits for buying from supplier i for scenario s

Onelevelbuy (i, s, l) we can buy from supplier i for scenario s at one level of quantity and lead time interval;

Cost.. A =e= Sum ((i), F (i)* Y (i)) + Sum [(s), gama(s) * Sum ((i, l, m), p (i, s, l, m) * Q(i, s, l, m))] + Sum ((i), W(i) * delta(i));

```
undermin (i)..   W (i) =g= Qmin (i) - sum ((s), gama(s) * Sum ((l, m), Q (i, s, l, m)));

Capacity (i, s)..  C (i) * Y (i) =g= Sum ((l, m), Q (i, s, l, m));

Agreementmax..   nmax =g=  Sum((i), Y(i));

Agreementmin..   Sum ((i), Y (i)) =g=   nmin;

Expectedbuy (i).. Sum ((s, l, m), gama(s)* Q (i, s, l, m)) =l= Qmin (i);

Fillrate(s, l)..  Sum ((i, m), Q (i, s, l, m)) =g= d(s) * fill(s, l);

Limitbuymin(s, l, m, i).. X (i, s, l, m) * qlow (i, l, m, s) =l= Q (i, s, l, m);

Limitbuymax(s, l, m, i).. Q (i, s, l, m) =l= X (i, s, l, m) * qhigh (i, l, m, s);

Onelevelbuy (i, s, l).. Sum ((m), X (i, s, l, m)) =l= Y (i);

Model Selection /all/ ;

option MIP = cplex;

option optcr=0.00;

Solve Selection using MIP minimizing A;

Display Y.l, A.l, Qmin.l, Q.l, X.l, W.l;
```

# Appendix H Gams Result for the Base Case Problem

Results of the Gams for the amount of supplies bought from supplier C for the given scenarios, lead time and quantity intervals.

| | m1 | m2 | m3 |
|---|---|---|---|
| 15.(l1 The Mediterranean. mild) | 53.30 | | |
| 15.(l2 The Mediterranean. mild) | 53.30 | | |
| 15.(l3 The Mediterranean. mild) | 53.30 | | |
| 16.(l1 The Mediterranean. medium) | 383.90 | | |
| 16.(l2 The Mediterranean. medium) | 383.90 | | |
| 16.(l3 The Mediterranean. medium) | 383.90 | | |
| 17.(l1 The Mediterranean. very severe) | | | 167326.30 |
| 17.(l2 The Mediterranean. very severe) | | | 167326.30 |
| 17.(l3 The Mediterranean. very severe) | | | 167326.30 |
| 18.(l1 Southeastern Anatolia. mild) | 41.90 | | |
| 18.(l2 Southeastern Anatolia. mild) | 41.90 | | |
| 18.(l3 Southeastern Anatolia. mild) | 41.90 | | |
| 19.(l1Southeastern Anatolia. medium) | 298.80 | | |
| 19.(l2 Southeastern Anatolia. medium) | 298.80 | | |
| 19.(l3 Southeastern Anatolia. medium) | 298.80 | | |
| 20.(l1Southeastern Anatolia. severe) | | 6079.70 | |
| 20.(l2 Southeastern Anatolia. severe) | | 6079.70 | |
| 20.(l3 Southeastern Anatolia. severe) | | 6079.70 | |
| 21.(l1Southeastern Anatolia. very severe) | | | 20703.40 |
| 21.(l2 Southeastern Anatolia. very severe) | | | 20703.40 |
| 21.(l3 Southeastern Anatolia. very severe) | | | 20703.40 |
| 22.(l1Northeastern Anatolia. mild) | 29.30 | | |
| 22.(l2 Northeastern Anatolia. mild) | 29.30 | | |
| 22.(l3 Northeastern Anatolia. mild) | 29.30 | | |
| 23.(l1 Northeastern Anatolia. medium) | 319.80 | | |
| 23.(l2 Northeastern Anatolia. medium) | 319.80 | | |
| 23.(l3 Northeastern Anatolia. medium) | 319.80 | | |
| 24.(l1 Northeastern Anatolia. severe) | | 3259.60 | |
| 24.(l2 Northeastern Anatolia. severe) | | 3259.60 | |
| 24.(l3 Northeastern Anatolia. severe) | | 3259.60 | |
| 25.(l1 Northeastern Anatolia. very severe) | | | 56882.50 |
| 25.(l2 Northeastern Anatolia. very severe) | | | 56882.50 |
| 25.(l3 Northeastern Anatolia. very severe) | | | 56882.50 |
| 26.(l1 Eastern Anatolia. mild) | | | |
| 26.(l2 Eastern Anatolia. mild) | 17.40 | | |
| 26.(l3 Eastern Anatolia. mild) | 17.40 | | |
| 27.(l1 Eastern Anatolia. medium) | 281.80 | | |
| 27.(l2 Eastern Anatolia. medium) | 281.80 | | |
| 27.(l3 Eastern Anatolia. medium) | 281.80 | | |
| 28.(l1 Eastern Anatolia. severe) | | 2984.10 | |
| 28.(l2 Eastern Anatolia. severe) | | 2984.10 | |
| 28.(l3 Eastern Anatolia. severe) | | 2984.10 | |
| 29.(l1 Eastern Anatolia. very severe) | | | 46606.80 |
| 29.(l2 Eastern Anatolia. very severe) | | | 46606.80 |
| 29.(l3 Eastern Anatolia. very severe) | | | 46606.80 |

Results of the Gams for the amount of supplies bought from the supplier D for the given scenarios, lead time and quantity intervals.

| | m1 | m2 | m3 |
|---|---|---|---|
| 1.(l1 Marmara. mild) | 30.40 | | |
| 1.(l2 Marmara. mild) | 30.40 | | |
| 1.(l3 Marmara. mild) | 30.40 | | |
| 2.(l1 Marmara. medium) | 267.90 | | |
| 2.(l2 Marmara. medium) | 267.90 | | |
| 2.(l3 Marmara. medium) | 267.90 | | |
| 3.(l1 Marmara. severe) | | 3327.20 | |
| 3.(l2 Marmara. severe) | | 3327.20 | |
| 3.(l3 Marmara. severe) | | 3327.20 | |
| 4.(l1 Marmara. very severe) | | | 143047.70 |
| 4.(l2 Marmara. very severe) | | | 143047.70 |
| 4.(l3 Marmara. very severe) | | | 143047.70 |
| 5.(l1 West Black Sea. mild) | 15.50 | | |
| 5.(l2 West Black Sea. mild) | 15.50 | | |
| 5.(l3 West Black Sea. mild) | 15.50 | | |
| 6.(l1 West Black Sea. very severe) | | | 67222.20 |
| 6.(l2 West Black Sea. very severe) | | | 67222.20 |
| 6.(l3 West Black Sea. very severe) | | | 67222.20 |
| 7.(l1 Eastern Black Sea. mild) | 49.90 | | |
| 7.(l2 Eastern Black Sea. mild) | 49.90 | | |
| 7.(l3 Eastern Black Sea. mild) | 49.90 | | |
| 8.(l1 Eastern Black Sea. medium) | 366.10 | | |
| 8.(l2 Eastern Black Sea. medium) | 366.10 | | |
| 8.(l3 Eastern Black Sea. medium) | 366.10 | | |
| 9.(l1 Eastern Black Sea. severe) | | 1184.10 | |
| 9.(l2 Eastern Black Sea. severe) | | 1184.10 | |
| 9.(l3 Eastern Black Sea. severe) | | 1184.10 | |
| 10.(l1 North Aegean. mild) | 59.80 | | |
| 10.(l2 North Aegean. mild) | 59.80 | | |
| 10.(l3 North Aegean. mild) | 59.80 | | |
| 11.(l1 North Aegean. very severe) | | | 19544.60 |
| 11.(l2 North Aegean. very severe) | | | 19544.60 |
| 11.(l3 North Aegean. very severe) | | | 19544.60 |
| 12.(l1 South Aegean. mild) | 12.80 | | |
| 12.(l2 South Aegean. mild) | 12.80 | | |
| 12.(l3 South Aegean. mild) | 12.80 | | |
| 13.(l1 South Aegean. medium) | 355.80 | | |
| 13.(l2 South Aegean. medium) | 355.80 | | |
| 13.(l3 South Aegean. medium) | 355.80 | | |
| 14.(l1 South Aegean. very severe) | | | 40626.80 |
| 14.(l2 South Aegean. very severe) | | | 40626.80 |
| 14.(l3 South Aegean. very severe) | | | 40626.80 |
| 30.(l1 Central Anatolia. mild) | 35.10 | | |
| 30.(l2 Central Anatolia. mild) | 35.10 | | |
| 30.(l3 Central Anatolia. mild) | 35.10 | | |
| 31.(l1 Central Anatolia. medium) | 444.50 | | |
| 31.(l2 Central Anatolia. medium) | 444.50 | | |
| 31.(l3 Central Anatolia. medium) | 444.50 | | |
| 32.(l1 Central Anatolia. severe) | | 4375.20 | |
| 32.(l2 Central Anatolia. severe) | | 4375.20 | |
| 32.(l3 Central Anatolia. severe) | | 4375.20 | |

# Appendix I Scenario List According to Different Impact Levels

Scenario list based on two impact levels:

| SCENARIO # | IMPACT LEVEL | LOCATION | DEMAND FOR DEMIJOHN | COUNT | PROBABILITY | AVERAGE TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|---|
| 1 | MILD | THE MARMARA | 779 | 5 | 0.0462962963 | 740 |
| 2 | SEVERE | THE MARMARA | 1,430,477 | 4 | 0.0370370370 | 1,358,953 |
| 3 | MILD | WEST BLACK SEA | 155 | 5 | 0.0462962963 | 147 |
| 4 | SEVERE | WEST BLACK SEA | 672,222 | 3 | 0.0277777778 | 638,611 |
| 5 | MILD | EASTERN BLACK SEA | 2,344 | 12 | 0.1111111111 | 2,227 |
| 6 | MILD | NORTH AEGEAN | 598 | 2 | 0.0185185185 | 568 |
| 7 | SEVERE | NORTH AEGEAN | 195,446 | 3 | 0.0277777778 | 185,674 |
| 8 | MILD | SOUTH AEGEAN | 128 | 7 | 0.0648148148 | 122 |
| 9 | SEVERE | SOUTH AEGEAN | 104,236 | 4 | 0.0370370370 | 99,024 |
| 10 | MILD | THE MEDITERRANEAN | 1,478 | 7 | 0.0648148148 | 1,404 |
| 11 | SEVERE | THE MEDITERRANEAN | 1,673,263 | 1 | 0.0092592593 | 1,589,600 |
| 12 | MILD | SOUTHEASTERN ANATOLIA | 969 | 13 | 0.1203703704 | 921 |
| 13 | SEVERE | SOUTHEASTERN ANATOLIA | 119,292 | 5 | 0.0462962963 | 113,327 |
| 14 | MILD | NORTEASTERN ANATOLIA | 821 | 10 | 0.0925925926 | 780 |
| 15 | SEVERE | NORTEASTERN ANATOLIA | 339,013 | 6 | 0.0555555556 | 322,062 |
| 16 | MILD | EASTERN ANATOLIA | 552 | 7 | 0.0648148148 | 524 |
| 17 | SEVERE | EASTERN ANATOLIA | 320,659 | 3 | 0.0277777778 | 304,626 |
| 18 | MILD | CENTRAL ANATOLIA | 2,171 | 9 | 0.0833333333 | 2,062 |
| 19 | SEVERE | CENTRAL ANATOLIA | 21,876 | 2 | 0.0185185185 | 20,782 |

Scenario list based on three impact levels:

| SCENARIO # | IMPACT LEVEL | LOCATION | DEMAND FOR DEMIJOHN | COUNT | PROBABILITY | AVERAGE TOTAL AFFECTED PEOPLE |
|---|---|---|---|---|---|---|
| 1 | MILD | THE MARMARA | 779 | 4 | 0.0360360360 | 740 |
| 2 | MEDIUM | THE MARMARA | 33,272 | 4 | 0.0360360360 | 31,608 |
| 3 | SEVERE | THE MARMARA | 1,430,477 | 1 | 0.0090090090 | 1,358,953 |
| 4 | MILD | WEST BLACK SEA | 155 | 5 | 0.0450450450 | 147 |
| 5 | SEVERE | WEST BLACK SEA | 672,222 | 3 | 0.0270270270 | 638,611 |
| 6 | MILD | EASTERN BLACK SEA | 1,554 | 11 | 0.0990990991 | 1,476 |
| 7 | MEDIUM | EASTERN BLACK SEA | 11,841 | 1 | 0.0090090090 | 11,249 |
| 8 | MILD | NORTH AEGEAN | 598 | 2 | 0.0180180180 | 568 |
| 9 | SEVERE | NORTH AEGEAN | 195,446 | 3 | 0.0270270270 | 185,674 |
| 10 | MILD | SOUTH AEGEAN | 128 | 7 | 0.0630630631 | 122 |
| 11 | MEDIUM | SOUTH AEGEAN | 3,558 | 3 | 0.0270270270 | 3,380 |
| 12 | SEVERE | SOUTH AEGEAN | 406,268 | 1 | 0.0090090090 | 385,955 |
| 13 | MILD | THE MEDITERRANEAN | 1,478 | 6 | 0.0540540541 | 1,404 |
| 14 | SEVERE | THE MEDITERRANEAN | 1,673,263 | 1 | 0.0090090090 | 1,589,600 |
| 15 | MILD | SOUTHEASTERN ANATOLIA | 13,569 | 13 | 0.1171171171 | 12,891 |
| 16 | MEDIUM | SOUTHEASTERN ANATOLIA | 60,798 | 3 | 0.0270270270 | 57,758 |
| 17 | SEVERE | SOUTHEASTERN ANATOLIA | 119,292 | 5 | 0.0450450450 | 113,327 |
| 18 | MILD | NORTEASTERN ANATOLIA | 821 | 10 | 0.0900900901 | 780 |
| 19 | MEDIUM | NORTEASTERN ANATOLIA | 32,597 | 3 | 0.0270270270 | 30,967 |
| 20 | SEVERE | NORTEASTERN ANATOLIA | 568,825 | 4 | 0.0360360360 | 540,384 |
| 21 | MILD | EASTERN ANATOLIA | 552 | 7 | 0.0630630631 | 524 |
| 22 | MEDIUM | EASTERN ANATOLIA | 29,841 | 1 | 0.0090090090 | 28,349 |
| 23 | SEVERE | EASTERN ANATOLIA | 466,068 | 2 | 0.0180180180 | 442,765 |
| 24 | MILD | CENTRAL ANATOLIA | 2,171 | 9 | 0.0810810811 | 2,062 |
| 25 | MEDIUM | CENTRAL ANATOLIA | 21,876 | 2 | 0.0180180180 | 20,782 |