USING CONTAINERS AS ASTORAGE FACILITIES IN HUMANITARIAN LOGISTICS

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SEPTEMBER 2014

USING CONTAINERS AS ASTORAGE FACILITIES IN HUMANITARIAN LOGISTICS

A THESIS SUBMITTED TO

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES OF

ÇANKAYA UNIVERSITY

BY

AYŞENUR ŞAHİN ARSLAN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

THE DEPARTMENT OF

INDUSTRIAL ENGINEERING

SEPTEMBER 2014

Title of the Thesis : **Using Containers as Storage Facilities in Humanitarian Logistics.**

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

USING CONTAINERS AS ASTORAGE FACILITIES IN HUMANITARIAN LOGISTICS

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September 2014, 75 pages

In humanitarian logistics, relief supplies are pre-positioned in strategic locations near disaster-prone areas. The beneficiaries are supplied from pre-positioned inventory during the initial days after the disaster; therefore, having those supplies ready to dispatch is of critical importance in disaster response. Previous studies focused on operating a permanent warehouse building for storage of relief supplies.

The main objective of this thesis is to investigate how containers (e.g., 20 or 40 feet freight containers) could be used as storage facilities. Using containers as storage facilities is an appealing idea because of the ad-hoc nature of the disaster relief network. They can be shipped from unaffected locations to the disaster locations after the disaster strike. Containers can be stacked on top of each other occupying less land than warehouse buildings. Moreover, the containers that are used to store relief supplies can be used as accommodation places in the immediate aftermath of a disaster strike. In order to investigate the practicality of this idea in Turkey, a mathematical model is developed to determine the location and quantity of containers as well as the type and amount of relief supplies to store. The model is tested using earthquake risk data, estimates of population under risk, and distances between cities. To investigate how and at what cost freight containers could be used as an inventory holding mechanism instead of a transportation unit, the layout and cost comparison of two alternatives; (1) stocking in a warehouse or (2) storage in

containers, are performed. Leasing and purchasing option costs of these alternatives are compared using present worth (PW) analysis.

The results reveal that leasing option is not cost advantageous in the long run for both warehouse storage and container stockpiling area. Warehouse construction results with the least cost but it requires more area than a container stockpiling area and incurs more operating costs including lighting, ventilation, and maintenance as well as handling of the pallets. On the basis of the results of this research, it can be concluded that using containers for storage is cheaper than operating a warehouse building. The results of our thesis illustrate how to best use containers as storage facilities to achieve the most possible response-time benefit and also support the implementation of an ad-hoc pre-positioning strategy. The thesis is carried in conjunction with Turkish Prime Ministry Disaster and Emergency Management Presidency (AFAD) and the results of this thesis will help AFAD reach beneficiaries of a disaster in shorter time, with fewer disruptions, and in an efficient way.

Keywords: Humanitarian Logistics, Earthquake Risk, Pre-positioning, Containers, Warehouse Design, MIP Modeling

ÖZ

İNSANİ YARDIM LOJİSTİĞİNDE KONTEYNERLERİN DEPO OLARAK KULLANIMI

ŞAHİN ARSLAN, Ayşenur

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Tez Yöneticisi: Yrd. Doç. Dr. Mustafa Alp ERTEM

Eylül 2014, 75 sayfa

İnsani yardım lojistiğinde yardım malzemeleri afet riski olan alanlara yakın stratejik yerlerde önceden konumlandırılmaktadır. Afet sonrasındaki ilk günlerde afetzedeler bu önceden konumlandırılmış depolardan ihtiyaçlarını karşıladıkları için bu malzemelerin dağıtıma hazır olması afete müdahale etmede kritik öneme sahiptir. Daha önceki yapılmış çalışmalar yardım malzemelerinin saklanması için beton yapıların depo olarak kullanılması üzerinde durmuştur.

Bu tezin amacı konteynerlerin (20 ya da 40 feet yük konteynerleri) depolama ekipmanı olarak kullanılabilirliğini araştırmaktır. Afet yardım ağının afet sonrasında ortadan kalkması ve geçici yapıda olması sebebiyle konteynerlerde depolama fikri caziptir, çünkü konteynerler afet sonrasında afetten etkilenmeyen yerlere kolayca taşınabilir. Konteynerler üst üste üç kat konularak geleneksel betonarme depolardan daha az yer kaplayabilir. Ayrıca konteynerler afet sonrasında konaklama alanı olarak da kullanılabilir. Konteynerlerde depolama fikrinin Türkiye'de kullanılabilirliğini araştırmak amacıyla konteynerlerin yer ve sayısının yanı sıra içinde depolanacak yardım malzemelerinin miktarını belirleyen bir matematiksel model geliştirilmiştir. Bu model deprem risk verileri, risk altındaki nüfus tahminleri ve şehirlerarası mesafeler kullanılarak test edilmiştir. Konteynerların hangi maliyette ve ne şekilde depolama ünitesi olarak kullanılabileceğini araştırmak amacıyla insani yardım malzemelerinin konteynerlerin içinde depolanması ve beton yapılarda depolama seçenekleri maliyet ve tasarım açısından karşılaştırılmıştır. Konteynerlerin satınalma ve yıllık kiralama maliyetleri ile beton yapılarda depolamanın kiralama ve yapım maliyetleri güncel değer analiziyle karşılaştırılmıştır.

Çalışmadan varılan sonuç ile diyebiliriz ki kiralama seçeneği hem konteynerler hem de beton yapılarda depolama için uzun vadede maliyet avantajı getirmemektedir. Beton yapıların yapım maliyeti konteynerleri kiralamak ve satınalmaktan daha ucuz olsa da, beton yapıların konteyner yığma alanlarından daha fazla alanı kullanması ve aydınlatma, havalandırma, bakım ve malzemelerin elleçlemesi gibi daha fazla işletim giderlerine sahiptir. Buradan yola çıkarak diyebiliriz ki konteynerde depolama depo işletmekten daha az maliyetlidir. Sonuçlar konteynerlerin, depolama tesisi olarak hem geçici önceden konumlandırma stratejisinin uygulanabilirliğini hem de afete olası en hızlı müdahaleyi sağlamada nasıl en iyi şekilde depolama tesisi olarak kullanılabileceğini göstermektedir. Bu tez AFAD (T.C. Başbakanlık Afet ve Acil Durum Yönetimi Başkanlığı) ile bağlantılı olarak yürütülmüştür ve elde edilen sonuçlar afetzedelere en kısa zamanda, en az hasarla ve en etkili şekilde ulaşmasında AFAD’a yardımcı olacaktır.

Anahtar Kelimeler: İnsani Yardım Lojistiği, Deprem Riski, Önkonumlandırma, Depo Tasarımı, Konteyner, Karışık Tamsayılı Modelleme

ACKNOWLEDGEMENTS

I would like to thank my advisor Mustafa Alp ERTEM for his endless support and guidance in my thesis by encouraging me and being pleasure with my performance. The methodology of the thesis added richness to my background by enabling academic publishings and conference participations. I also thank for his attitude being an older brother always when I was depressed.

Special pleasures to Assoc. Prof. Dr. Serhan DURAN and Assist. Prof. Dr. Nureddin KIRKAVAK for their participation to my thesis committee and their valuable comments.

I would like to thank also Emel EMÜR for her support to research in Chapter 2.

I am grateful to Turkish Prime Ministry Disaster and Emergency Management Presidency (AFAD) personnel and the Scientific and Technological Research Council of Turkey (TUBITAK) who partially supported this thesis with the research Grant No. 113M493. I also would like to express our sincere thanks to the companies who were willing to disclose their cost figures.

I would like to express my appreciation to my family for their sincere love, support and positiveness at each stage of my life. I am proud of being a member of my family.

Lastly I would like to give my special thanks to my love, my husband, for his endless patient, optimisim, motivation and life energy.

Thank you everyone who gave me good or bad experiences...

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AFAD	Turkish Prime Ministry Disaster and Emergency Management Presidency
NAF	North Anatolian Fault
DRF	Disaster Response Facility
KGM	General Directorates for Highways
TUIK	Turkish Statistical Institute
LWO	Local Warehouse Opening
GWO	Global Warehouse Opening
WTO	World Trade Organization
MNDP	Minimum Normalized Destruction Power
CPU	Central Processing Unit
AW	Annual Worth
PW	Present Worth
FW	Future Worth
TCMB	Turkish Republic Central Bank
GIB	Revenue Administration
TUBITAK	The Scientific and Technological Research Council of Turkey

CHAPTER 1

INTRODUCTION

Turkey is located at one of the most active earthquake regions of the world. Turkey is the third in the world in terms of human loss, eighth in terms of the number of people affected by an earthquake [1]. The only unchanging reality of Turkey besides the political events and the changes of economic conditions that took place during the years is “the earthquake”.

Most of Turkey’s population can be considered as risky because of the North Anatolian Fault (NAF) line. Several earthquakes have been reported in this geographical region. In August 17, 1999, Marmara earthquake took place on the western portion of NAF line with a magnitude of 7.4 on the Richter scale [2]. This major earthquake marks a turning point in Turkey in the field of disaster management and coordination of disaster relief activities. This earthquake, that caused great loss of life and property, has revealed that the issue of disaster management in Turkey needed to be reconsidered [1].

In the nature of the disasters there are uncertainties because the timing and location of the disasters cannot be predicted beforehand. This uncertainty affects the proper management of disaster relief operations. It has been observed that in different locations of Turkey, the earthquakes show different destruction powers. The severity of the earthquake and building quality might be considered as the main source of this difference. On the other hand, when a particular fault line is taken into account, it can be inevitably seen that some locations in Turkey has more potential to experience devastating earthquakes than the others. In this thesis this potential is defined as “the Earthquake Risk”.

Humanitarian logistics is defined as “the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people”[3]. The purpose in this definition can be interpreted as taking measures to prevent the negative impacts of a disaster and effectively respond to the needs of beneficiaries. Pre-positioning of relief supplies near disaster-prone areas is applied in disaster relief to quickly respond to the immediate needs of beneficiaries in a short time after a disaster strike. In the classical approach, pre-positioning in disaster relief is mainly considered using permanent warehousing. Similar to the business supply chain and logistics activities, humanitarian logistics includes diverse activities like procurement and prepositioning. Before the disaster onset the relief items are procured from global or local sources and stored in the warehouses. Therefore prepositioning provides time and place utility since the time and location of the disasters cannot be predicted beforehand. Also after the disaster onset the warehouses are continued to be supplied from the suppliers because of the flow of relief items from warehouses to disaster locations. Therefore planning the storage locations of relief supplies and selecting these locations in terms of vulnerability is a crucial job before disasters for humanitarian relief organizations. As a new approach, pre-positioning of relief supplies in mobile (temporary) warehouses is proposed in this thesis. Temporary warehousing is realized by using freight containers instead of operating a warehouse building for storage of relief supplies.

Generally speaking, containers are defined as large boxes, which are used to transport goods from an origin to a destination. Compared to conventional bulk transportation, the use of containers has several advantages, such as less product packaging, less damage and higher productivity. Despite the advantages of containers in storage, containers have usually been considered as transportation units.

In humanitarian logistics, the beneficiaries are supplied from pre-positioned inventory during the initial days after the disaster; therefore, having those supplies ready to dispatch is of critical importance in disaster response. When deciding how to pre-position inventory, humanitarian organizations should consider the number of warehouse(s) and their locations, as well as the types and the amount of relief supplies to stock, which requires extensive investigation and managerial effort.

Previous studies focused on operating a permanent warehouse building for storage of relief supplies ([4], [5], [2], [6]). The objective of this thesis is to investigate how containers (e.g., 20 or 40 feet steel freight containers) could be used as storage facilities.

Using containers as storage facilities is an appealing idea because of the ad-hoc nature of the disaster relief network. First, containers can be shipped from unaffected locations to the disaster locations after the disaster strike. Second, containers can be stacked on top of each other occupying less land than warehouse buildings. Moreover, the containers that are used to store relief supplies can be used as accommodation places in the immediate aftermath of a disaster strike.

Supply chain risks are influenced by several external and internal factors that need to be identified, analysed and controlled. Risks result in disturbances that can cause deviations in the performance and can be mitigated by means of efficient supply chain designs. Risk mitigating designs often come with an additional cost [7]. Business continuity management tools can be employed to ensure that the outputs of processes and services can be delivered to the customers when risks are present [8]. In order to achieve business continuity; the source of the risks should be well analysed and eliminated where possible.

Holding inventory is one of the redundancy to achieve business continuity when customers request the items at a date different than their production date [7]. Thus, holding inventory adds “time” value to the product. For a simple two echelon supply chain, the inventory is hold either at the supplier side, at the customer side, or on the vehicles during transportation. The supplier is responsible for satisfying the demand in time at the right quantity and quality. However, the inventory might not be enough or might be damaged after a disruption. The customer initiates the ordering process which ends when the order is delivered. The risks related with an order might be withdrawing an order after shipment or customer being disrupted when the order is delivered. Transportation related risks might stem from damaged transportation infrastructure, malfunctioning vehicles or looting of goods during transportation. Inventory holding in either end of this supply chain is well studied by researchers, but inventory holding during transportation has not received much attention.

The purpose of this thesis is to determine the supply points and assignment of demand points to them with minimum total travelled distance as well as to investigate how and at what cost freight containers could be used as an inventory holding mechanism instead of a transportation unit.

In this thesis there are six chapters. In Chapter 1, motivation for the thesis is given and storage in humanitarian logistics topic is introduced. In Chapter 2, the assignment of demand points to pre-positioned disaster response facilities (DRFs) is made in terms of population to minimize the distance between demand points and DRFs considering the earthquake risk. In Chapter 3, the locations of supply points using relief supplies and limited number of containers given by AFAD is assigned to each supply point by satisfying the demand while traveling the minimum distance in order to quickly respond to the immediate needs of beneficiaries. Moreover in Chapter 3, the introduction of container storage and managerial/research implications are mentioned. In Chapter 4, how and at what cost freight containers could be used as an inventory holding mechanism instead of their regular use as transportation units is investigated. The layout and cost comparison of two methods; (1) stocking in a warehouse or (2) storage in containers, are performed to differentiate the storage in a warehouse and in containers. In Chapter 5, the enhnacements are made for the models in previous chapters. The similarities and differences between Chapter 2, 3, 4 and in Chapter 5 in terms of variables and parameters is presented in Table 1.

As seen in Table 1, between Chapter 2 and Chapter 3 there are similarities in all categories; namely model type used, decision variables and parameters. It is possible to say that Chapter 3 is an improved version of Chapter 2 since it covers assignment of relief items and containers. It also includes the normalized average destrcution powers of supply points to select the containers locations with minimum earthquake risks. Chapter 5 contains an enhancement for Chapter 2 adding a new case and making comparison with other cases. In that sense Chapter 2 and 5 have similarities in all three categories.

Chapter 5 has enhancements for Chapter 3. It makes assignment to proposed AFAD container locations and makes a new assignment for all potential cities changing objective function from minimization of total distance to minimization of total cost of distance and container locations. Chapter 5 covers the enhancement for cost comparison part of Chapter 4 performing sensitivity analyses of annual interest rate and warehouse leasing cost.

It is seen that there is no similarity between Chapter 4 and Chapter 2, and Chapter 4 and Chapter 3. While Chapter 2 and 3 use location-allocation type model Chapter 4 uses layout and cost model. Chapter 4 pays attention to layout of container locations and warehouse for the determined supply locations. Chapter 4 also discusses the importance of using containers for storage taking into account risk, uncertainty and business continuity management issues. Chapter 5 handles the enhancements made for the other chapters for performance measures and parameter analyses. The summary of the results and future work analyses which can be adapted to the thesis is discussed in Chapter 6.

Table 1 Similarities and Differences in Chapters 2, 3, 4 and 5

	Chapter 2 (Assignment Model)	**Chapter 3 (Location Model)**	**Chapter 4 (Cost Model)**	**Chapter 5**
Model type used				
location allocation	✓	✓		✓
layout and cost model			✓	✓
Decisison Variables				
assignment of demand points (binary)	✓	✓		✓
amount of relief items		✓		✓
number of storage spaces along a shelf			✓	
number of double shelves			✓	
number of containers along longitudinal dimension			✓	
number of containers along cross dimension			✓	
longitudinal dimension			✓	
cross dimension (width)			✓	
total cost			✓	✓
total travelled distance	✓	✓		✓
Parameters				
distance between supply point and demand point	✓	✓		✓
capacity of supply point	✓	✓		✓
average destruction power	✓	✓		✓
weight of relief supplies		✓		✓
volume of relief supplies		✓		✓
normalized destruction power		✓		✓
potential number of affected people		✓		✓

width of double shelf			✓	
width of container			✓	
length of a storage space			✓	
length of a container			✓	
number of storage levels in vertical direction			✓	
total capacity in storage spaces			✓	
total capacity in container storage			✓	
width of an aisle			✓	
width of aisles in front of doors			✓	
container loading department width			✓	
yearly throughput (demand) in storage units (pallets for warehouse, containers for container stockpiling area)			✓	
material handling cost, of moving a storage unit one length unit			✓	
annual cost per unit of warehouse area			✓	
annual cost per unit length of external walls			✓	
annual interest rate			✓	✓
container leasing cost			✓	
container purchasing cost			✓	
warehouse leasing cost			✓	✓
warehouse construction cost			✓	

CHAPTER 2

ASSIGNMENT OF DEMAND POINTS TO DISASTER RESPONSE FACILITIES

2.1 Literature Review

Despite humanitarian logistics' importance, the literature in this area is limited [9]. Altay and Green [10] survey the literature to identify potential research directions in disaster operations, discuss relevant issues, and provide a starting point for interested researchers.

In the fall of 2005, since hurricanes Katrina, Wilma and Rita caused more than $100 billion in damage, and highlighted the inadequacy of existing preparedness strategies, some research effort has been aimed at devising pre-positioning plans for emergency supplies [6]. Ukkusuri and Yushimoto [11] modeled the pre-positioning of supplies as a location routing problem. Their model incorporates the reliability of the ground transportation network in case of any destruction happened. They maximize the probability that all the demand points can be served by a service location given fixed probabilities of link/node failure and a specified budget constraint. This model is related to this thesis in terms of demand points and service locations. Balçık and Beamon [4] developed a model to design a pre-positioning system that balances the costs against the risks in the relief chain, which is a variant of the maximal covering location model, integrates facility location and inventory decisions, considers multiple item types, and captures budgetary constraints and capacity restrictions. It is revealed by the results of computational experiments that there are effects of pre- and post-disaster relief funding on relief system's performance, specifically on response time and the proportion of demand satisfied.

Duran et al. [5] developed a mixed-integer programming inventory-location model to find the optimal configuration while considering a set of typical demand instances given a specified upfront investment (in terms of the maximum number of warehouses to open and the total inventory available to allocate) to determine the configuration of the supply network that minimizes the average response time over all the demand instances in all over the world. The model obtains the typical demand instances from historical data; the supply network consists of the number and the location of warehouses and the quantity and type of items held in inventory in each warehouse. The basic differences between this study and the thesis are stock pre-positioning, response times and coverage area since the model of this thesis provides an emergency response by assigning demand points to the DRFs with minimum earthquake risk in Turkey. Görmez et al. [2] developed a mathematical model to determine the locations of DRFs for Istanbul with the objectives of minimizing the average-weighted distance between casualty locations and DRFs, and opening a small number of facilities, subject to distance limits and backup requirements under regional vulnerability considerations. They analyzed the trade-offs between these two objectives under various disaster scenarios and investigate the solutions for several modeling extensions. The main difference of this thesis is to aim covering all of Turkey and considering a single objective of minimizing total travelled distance. Dükkancı et al. [12] developed a model for Turkish Red Crescent Society (i.e., Kızılay in Turkish) that determined the DRF locations by evaluating demographic and past disasters' information to cover maximum number of people.

Risk is a widely used term in everyday life and businesses. Knight [13] defined risk as "if you don't know the for sure what will happen, but you know the odds, that's risk, and if you don't even know the odds, that's uncertainty". The concept of resilience is closely related with the capability and ability of an element to return to a pre-disturbance state after a disruption [14]. After the disaster there might be risks related with the disruption of transportation roads, and long delivery times and they should be well analyzed. In this thesis an earthquake risk map is used including destruction powers to integrate risk concept into the model. Destruction power is stated as *g* which is the acceleration due to earth's gravity (peak ground acceleration) and measured with Mercalli scale as a-cm/sn^2 in logarithmic scale in e base and they are increasing exponentially as given in Figure 1. Destruction power is generally used to define build hazard risks and damage of infrastructure and buildings being related with ground motion. It is different than the magnitude of earthquake and ensures ground shake as intensity [15].

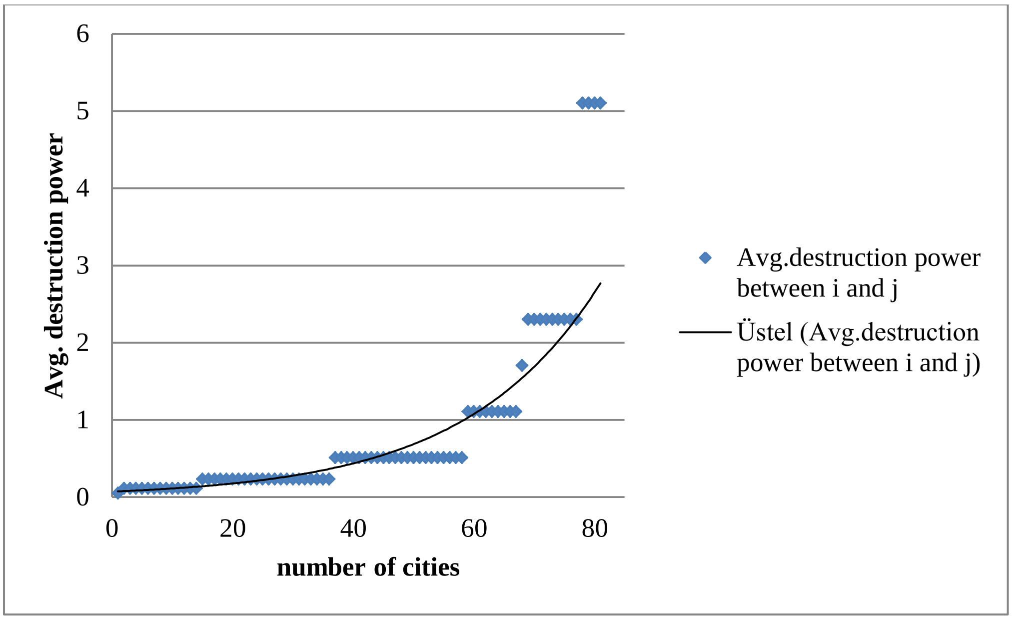

Figure 1 The distribution of average destruction power for 81 cities of Turkey (derived from [16])

To the best of our knowledge, assignment of demand points to pre-positioned DRF locations (in terms of cities) throughout Turkey considering the earthquake risk has not been analyzed thoroughly. The next section presents an Integer Programming model for assigning city demand points to pre-positioned DRF locations in Turkey considering the earthquake risk.

2.2 Solution Methodology

When the prepositioning literature is analyzed it is seen that either the travelled distance between the DRFs and affected areas or elapsed time is minimized by considering the closeness of the DRFs to the disaster prone areas. In this thesis the affected areas by the disaster are called as "demand points". The assumptions used in the problem are given in the following:

- The DRFs can serve a maximum 15,000,000 population, because the service level with the population sizes of the cities those have DRFs are limited.
- The DRFs can satisfy their own requirements from an infinite supply.

2.2.1 Mathematical model

The objective is to minimize the distances between demand points and DRFs in order to quickly respond to the requirements of beneficiaries. The following notation is used for the DRF assignment model:

Sets

C set of DRF locations; $i \in C$

T set of demand points; $j \in T$

Parameters

D_{ij} : Distance between DRF *i* and demand point *j*

K_j : Population of demand point *j*

P_i : Capacity of DRF *i* in terms of population

R_{ij} : Average destruction power based on the magnitude of the earthquake for DRF *i* and demand point *j*

Decision Variables

$$x_{ij} = \begin{Bmatrix} 1 & if\ demand\ point\ j\ is\ assigned\ to\ DRF\ i \\ 0 & otherwise \end{Bmatrix}$$

The mathematical model for the problem is as follows:

$$min \sum_{i \in C} \sum_{j \in T} D_{ij} x_{ij} \qquad (2.0)$$

subject to

$$\sum_{j \in T} K_j x_{ij} \leq P_i \qquad \forall i \in C \qquad (2.1)$$

$$\sum_{i \in C} x_{ij} \geq 1 \qquad \forall j \in T \qquad (2.2)$$

$$\sum_{j \in T} R_{ij} x_{ij} \geq 1 \qquad \forall i \in C \qquad (2.3)$$

$$x_{ij} \in \{0,1\} \qquad \forall i \in C, \forall j \in T \qquad (2.4)$$

The objective function (2.0) minimizes the distance between the DRFs and demand points. Constraint set (2.1) ensures that a DRF can serve the population of a demand point j up to its population capacity. Constraint set (2.2) ensures that every demand point must be served by at least one facility. Constraint set (2.3) satisfies that the total average destruction power between DRFs and demand points must be greater than or equal to one. Thus the DRFs serve the demand points which have large destruction powers. Constraint set (2.4) ensures that the location assignment variables are binary.

2.3 Experimental Studies

The proposed mathematical model is tested for DRFs of the new container warehouses proposed by AFAD, Turkish Red Crescent warehouses and AFAD Civil Defense Search and Rescue City Directorates in the following subsections. Only the data set and computational results of the first case will be given in detail and the visual representation of the results will be given for the others. The data set (i.e., risk, population, distance) used for all these cases are the same.

2.3.1 First case

This experiment is conducted for 27 container warehouse locations proposed by AFAD recently. Earthquake Risk data is taken from the earthquake risk map in city- and town-level, which was prepared by Prof. Dr. Ahmet ERCAN [16]. The distances between cities are taken from KGM [17]. Demographic information of cities and towns (populations) are taken from TUIK [18].

The average destruction powers given in Table 2 are derived from the minimum and maximum destruction powers in the earthquake map [16]. The first column of the table shows cities, the second column shows the populations and the third column shows the corresponding risk regions. Fourth and fifth columns show minimum and maximum destruction powers corresponding to risk regions. The sixth column is the average destruction power value calculated by taking average of minimum and maximum destruction powers. This is taken as the average to have a moderate representation of the destruction power. According to Table 2 the maximum average destruction power is 7.1g for Düzce in the most risky area (XII). The minimum average destruction power is 0.051g for Kilis in the least risky area (VI).

Table 2 A Sample from The Data Set

City	2012 Population	Risk Region	Min. Destruction Power (a-cm/sn^2)	Max. Destruction Power (a-cm/sn^2)	Avg. Destruction Power (a-cm/sn^2)
Adana	2,125,635	IX	0.31	0.71	0.51
Adıyaman	595,261	IX	0.31	0.71	0.51
Afyon	703,948	IX	0.31	0.71	0.51
Ağrı	552,404	XI	1.50	3.10	2.30
Amasya	322,283	X	0.71	1.50	1.10
Ankara	4,965,542	VIII	0.15	0.31	0.23
Antalya	2,092,537	IX	0.31	0.71	0.51
Artvin	167,082	VIII	0.15	0.31	0.23
Aydın	1,006,541	X	0.71	1.50	1.10
Balıkesir	1,160,731	X	0.71	1.50	1.10
			…		
Kilis	124,320	VI	0.03	0.07	0.05
Osmaniye	492,135	VII	0.07	0.15	0.11
Düzce	346,493	XII	3.10	7.10	5.10

The proposed mathematical model was solved using GAMS 23.7 with CPLEX 11 Solver. The total traveled distance is 10,778 km with 59 (i,j) pairs. The (i,j) pair stands for the assignment of demand point j to DRF i. They are identified as pair since the model determines the (i,j) pair and the comparison is made among each cases by the pair assignments. The total average destruction power between (i,j) pairs is 60.92.

The assignment of demand points to DRFs is given in Table 3 for this case. In the first and fifth columns the prepositioned DRFs are listed. In the second and sixth columns the assigned demand points to DRFs are listed. In the third and seventh columns the distances between the DRFs and the demand points are given as (i,j) pairs. In the fourth and eighth columns the average destruction power between (i,j)

pairs are given. The results show that demand points are assigned to DRFs with an ability to serve the demand points in at most four hours by highways in normal conditions except for Elazığ-Rize assignment with 570 km. It can be concluded that each DRF serves at least one demand point and at most five demand points such as Bursa and Erzurum DRFs. The demand points receive relief supplies from one facility since the facility sizes are limited with their population sizes. Few demand points receive relief supplies from more than one facility like Kütahya, Aydın, Uşak and Bingöl.

Table 3 Assignment of Demand Points to DRFs for Container Warehouses Proposed by AFAD

DRFs	Assigned Demand Points	Distance between *(i,j)* pairs	Avg. Destruction Power between *(i,j)* pairs	DRFs	Assigned Demand Points	Distance between *(i,j)* pairs	Avg. Destruction Power between *(i,j)* pairs
Adana	Mersin	69	0.37	Manisa	Aydın	156	0.81
	Niğde	205	0.31		Uşak	195	0.51
	Karaman	289	0.37	Kahramanmaraş	Gaziantep	80	0.17
Adıyaman	Bingöl	349	0.81		Tokat	415	0.67
	Şanlıurfa	110	0.31		Osmaniye	100	0.17
Afyon	Eskişehir	144	0.37	Muğla	Aydın	99	0.81
	Kütahya	100	1.41		Isparta	292	0.51
Ankara	İstanbul	453	1.27	Muş	Bitlis	83	0.51
Antalya	Burdur	122	0.51		Siirt	180	0.31
	Isparta	130	0.51		Şırnak	275	0.51
Balıkesir	Kütahya	224	1.70	Samsun	Giresun	196	1.27
Bursa	İzmir	322	2.00		Ordu	152	1.27
Denizli	Aydın	126	0.81		Sinop	163	1.27
	Uşak	150	0.51	Sivas	Amasya	222	1.11
Diyarbakır	Bingöl	144	0.81		Kayseri	195	0.67
	Mardin	95	0.31	Tekirdağ	Çanakkale	188	1.41
	Batman	100	0.31		Edirne	140	1.27
Elazığ	Malatya	98	0.37		Kırklareli	121	1.27
	Rize	570	2.67	Van	Hakkari	202	1.41
Erzincan	Gümüşhane	131	2.61		Iğdır	225	1.27
	Trabzon	231	2.67	Aksaray	Çorum	326	0.61
	Tunceli	130	2.81		Kırşehir	110	0.17
Erzurum	Ağrı	184	1.41		Konya	148	0.17
	Artvin	226	0.37		Nevşehir	75	0.11
	Kars	203	0.51	Kırıkkale	Çankırı	105	0.37

	Bayburt	125	0.31		Çorum	167	0.67
	Ardahan	230	0.37		Yozgat	141	0.23
Hatay	Kilis	147	1.18	Yalova	Bilecik	129	1.21
Kastamonu	Bartın	181	0.67	Düzce	Bolu	45	3.10
	Karabük	114	0.67		Zonguldak	114	2.67
Kocaeli	Sakarya	37	5.10				

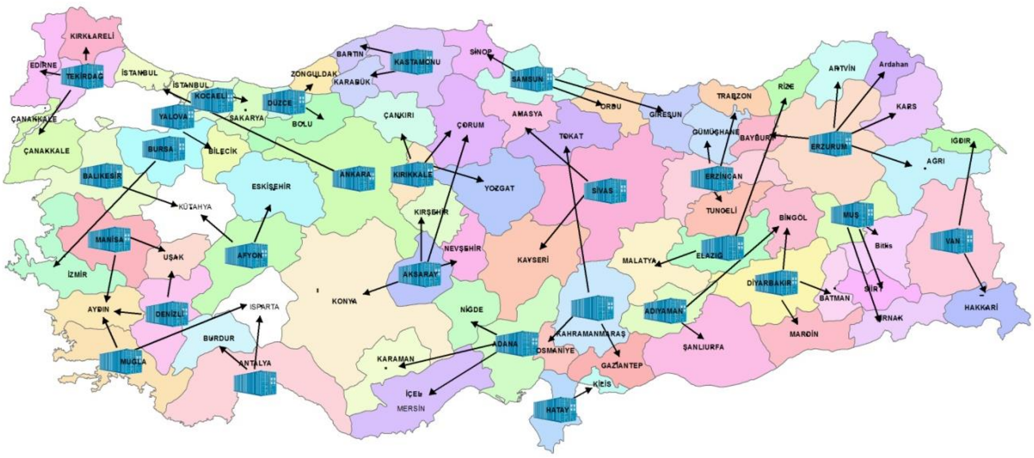

Figure 2 Assignment of cities for container warehouses proposed by AFAD

The demonstration of the assignments for (*i*,*j*) pairs is given in Figure 2. It shows the assignment of demand points to DRFs which are symbolized by a container. The assignments are demonstrated with black arrows. For example Adana DRF has three arrows goes to Mersin, Niğde and Karaman. Few demand points receive relief supplies from more than one facility like Kütahya, Aydın, Çorum, Isparta and Uşak. Moreover few demand points are assigned to far DRFs in order to ensure the balance of average destruction power and service level of DRFs in terms of population. As it is seen in Figure 2 İstanbul is assigned to Ankara which has 453 km distance. The nearest and the farest distance between demand points and DRFs are 37 km and 570 km, occurred in between Elazığ-Rize and Kocaeli-Sakarya, respectively.

2.3.2 Second case

This experiment is conducted for 30 Turkish Red Crescent warehouses. The proposed mathematical model was solved using GAMS 23.7 with CPLEX 11 Solver. The total traveled distance is 10,617 km with 59 (*i*,*j*) pairs. The total average destruction power between (*i*,*j*) pairs is 47, which is less than the observed value in the first case. The visual representation of the assignment of demand points to DRFs is given in Figure 2 for the second case. As seen from Figure 2 that the demand points are assigned to DRFs with an ability to serve the demand points in at most four hours by highways in normal conditions except for Gaziantep-Çorum and Rize-Amasya assignments with 630 and 535 km, respectively. Each DRF serves at least one demand point and at most five demand points such as Ağrı and Gaziantep DRFs. The demand points receive relief supplies from one facility since the facility sizes are limited with their population sizes. Few demand points receive relief supplies from more than one facility like Kütahya, Çankırı, Aydın, Bitlis and Bingöl.

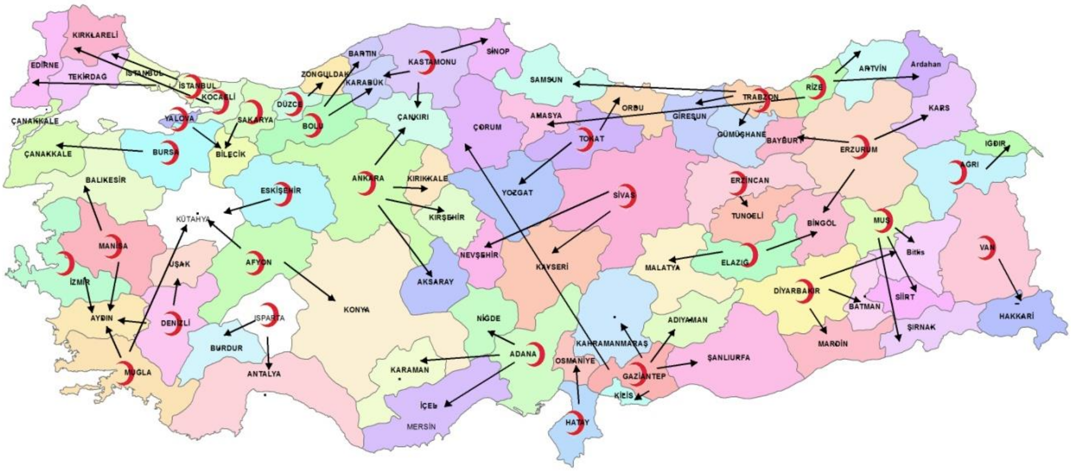

Figure 3 Assignment of cities for Turkish Red Crescent warehouses

As it is seen in Figure 3 Çorum is assigned to Gaziantep which has 630 km distance. The nearest and the farest distance between demand points and DRFs are 51 km and 630 km, occurred in between Isparta-Burdur and Gaziantep-Çorum, respectively. The assignment dispertion is better than container warehouses generally since the demand points are assigned to closer DRFs to themselves. For instance Elazığ was serving further demand point, Rize, in the first case but in this case it serves closer points which are Malatya and Bingöl.

2.3.3 Third case

This experiment is conducted for eleven DRFs of AFAD Civil Defense Search and Rescue City Directorates. The total traveled distance is 13,997 km with 71 (*i*,*j*) pairs. The total travelled distance is higher than the first and second case studies because the number of DRFs is fewer. The total average destruction power between (*i*,*j*) pairs is 72.71, which is more than the observed value in the first and second case studies. The visual representation of the assignment of demand points to DRFs is given in Figure 4 for this case. As seen from Figure 4 that the demand points are assigned to DRFs with an ability to serve the demand points in at most four hours by highways in normal conditions except for Van-Erzincan assignment with 602 km. Only one point, Erzinceni is assigned to a further DRF, Van, the others are assigned to the closer points to them. The nearest and the farest distance between demand points and DRFs are 37 km and 602 km, occurred in between Kocaeli-Sakarya and Van-Erzincan, respectively. Each DRF serves at least one demand point and at most twelve demand points such as Diyarbakır DRF. The demand points receive relief supplies from one facility since the facility sizes are limited with their population sizes. The assignment dispertion is better than the other cases generally since the demand points are assigned to closer DRFs to themselves. And the DRFs are not scattered so much. In the first and second cases Adana was serving Mersin, Niğde and Karaman demand points but in this case it serves six more demand points. Kütahya is the only demand points taking service from more than one DRFs, Afyon and İzmir.

Figure 4 Assignment of cities for AFAD civil defence and rescue city directorates

The set of the warehouses used in the first, second and third cases are given in Figure 5 by displaying the overlapping DRFs among them. There are twelve overlapping cities for container warehouses and Turkish Red Crescent warehouses, three overlapping cities for AFAD warehouses and Turkish Red Crescent warehouses, one overlapping city for container warehouses and AFAD warehouses. Eight cities belong to only Turkish Red Crescent warehouses and seven cities belong to only container warehouses. Seven DRFs are common in all cases: Adana, Diyarbakır, Afyon, Erzurum, Ankara, Van and Bursa. The demonstration of the warehouses on Turkey map is shown also in Figure 6. The container image is used for container warehouses proposed by AFAD, the crescent image is used for Turkish Red Crescent warehouses and the AFAD image is used for the AFAD directorates. The green shapes are for the common DRFs of each case and there are two images for the dual common DRFs.

The summary of three cases is depicted in Table 4 for comparison. In the first column of the table three cases are given for container warehouses, Turkish Red Crescent warehouses and AFAD warehouses, respectively. In the second and third columns the number of DRFs belong to each case and the number of (i,j) pair by the assignment model, are shown respectively. In the fourth column the number of demand points served by more than one DRF is given. In the results of the model for three cases it is observed that there are five, eight and one demand points are served by two DRFs. The serving by two DRFs is induced by the model parameters and could be increased when the capacity limits of the DRFs are increased. The fifth and sixth columns are for the total travelled distance and total average destruction powers obtained by the assignment model. In the last column of Table 4 the average destruction power of (i,j) pair for each cases is calculated by dividing the total average destruction power to number of (i,j) pair obtained in the result of the assignment model. Thus the average destruction power is found per (i,j) pair. This value could be compared with the situation when it is thought as there are 81 DRFs (i.e., one warehouse in each city) and 81 demand points. If each demand point is assigned to each DRF then there are 81x81 assignment and the overall average destruction power per assignment is found as 0.85 by dividing the average destruction powers of each (i,j) pair to the number of demand points, which is 81. This means that when all cities behave like DRFs and are able to serve to all cities, the average destruction value of any assignment is 0.85. However the population capacity of each DRF as well as destruction powers are taken into account. It can be said that the assignment of demand points to the pre-positioned DRFs are less risky when the obtained value is less than 0.85 value, so 0.85 is taken as a "moderate value”. When considered from this point of view the second case is superior to the other cases and it has the least average destruction power per (*i*,*j*) pair.

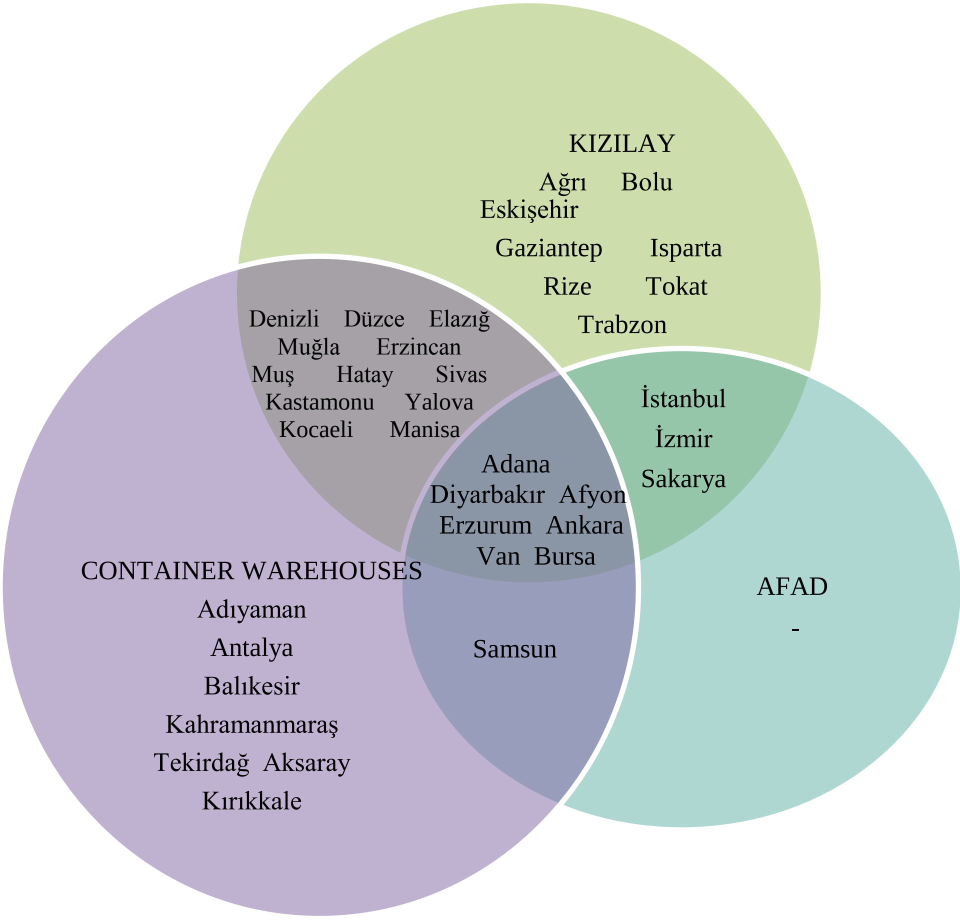

Figure 5 The set of the warehouses used in the case studies

Table 4 Comparison of The Cases According to Numerical Results

Case	(a) # of DRFs	(b) # of (*i*,*j*) pair	(c) # of Demand Points Served by Two DRFs	(d) Total Travelled Distance (km)	(e) Total Avg. Destruction Power	(f) = (e) / (b) Avg. Destruction Power of (*i*,*j*) pair
First Case	27	59	5	10,778	60.92	1.033
Second Case	30	59	8	10,617	47.00	0.797
Third Case	11	71	1	13,997	72.71	1.024

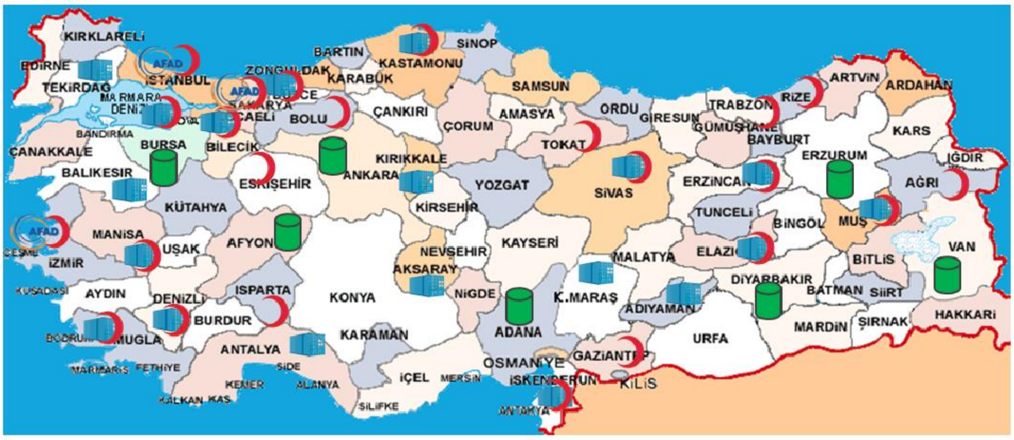

Figure 6 The visual representation of the warehouses

2.3.4 Distance limitation for the model

In this part a new constraint is added to limit the distance between each demand point and supply point. In the results of the best case which is for Turkish Red Crescent Warehouses the maximum distance was obtained in between Gaziantep and Çorum as 630 km. In order to obtain shorter distances a new constraint is added and limited with 200, 300 and 400 km, respectively by adding Eq. (3.1) and holding other constarints and the objective function as the same. The distance limit is changed between 200 and 300 km and the total minimum travelled distance is obtained at 289 km.

$$D_{ij}x_{ij} \leq 289 \qquad (3.1)$$

The result of this case is given in Table 5. The assignments of demand points are changed as being the distance in between lower than 289 km. The total travelled distance is obtained as 10629 km where it was 10617 km in the second case. The total average destruction power is obtained as 39.52 a-cm/sn^2 where it was 47 a-cm/sn^2. The number of (i,j) pair is increased from 59 to 64. The maximum distance is in between Adana and Karaman. The assignments of Ankara, Elazığ, Erzurum, Gaziantep, Muğla, Muş, Tokat and Trabzon are changed. Two new demand points are added to Ankara, one new to Elazığ, one new to Gaziantep, one new to Muğla and two new to Trabzon whereas Erzurum, Muş and Tokat has one less demand points.

Table 5 Assignment Result of Distance Limited Model for The Second Case

Disaster Response Facilities	Covered Demand Points	Distance between (*i*,*j*) pairs	Avg. Destruction Power between (*i*,*j*) pairs	Total Number of Covered Demand Points	Disaster Response Facilities	Covered Demand Points	Distance between (*i*,*j*) pairs	Avg. Destruction Power between (*i*,*j*) pairs	Total Number of Covered Demand Points
Adana	Mersin	69	0.37	3	Hatay	Osmaniye	127	1.21	1
	Niğde	205	0.31		Isparta	Antalya	130	0.51	2
	Karaman	289	0.37			Burdur	51	0.51	
Afyon	Konya	223	0.37	2	İstanbul	Edirne	230	1.27	2
	Kütahya	100	1.41			Kırklareli	211	1.27	
Ağrı	Iğdır	143	1.27	1	İzmir	Aydın	126	1.40	2
						Balıkesir	173	0.67	
Ankara	Çankırı	131	0.37	6	Kastamonu	Çorum	195	1.11	2
	Kırşehir	184	0.23			Sinop	183	0.67	
	Nevşehir	275	0.17		Kocaeli	Bilecik	136	2.61	1
	Aksaray	225	0.17		Manisa	Aydın	156	0.81	2
	Yozgat	216	0.17			Balıkesir	137	0.81	
	Kırıkkale	75	0.23		Muğla	Aydın	99	0.81	2
Bolu	Bartın	174	0.67	2		Burdur	241	0.51	
	Karabük	134	0.67		Muş	Bitlis	83	0.51	2
Bursa	Çanakkale	271	1.41	1		Bingöl	114	0.81	
Denizli	Aydın	126	0.81	2	Rize	Artvin	159	0.23	3
	Uşak	150	0.51			Gümüşhane	174	0.31	
Diyarbakır	Siirt	187	0.31	3		Ardahan	268	0.23	
	Batman	100	0.31		Sakarya	Tekirdağ	280	1.41	1
	Şırnak	282	0.51		Sivas	Kayseri	195	0.67	2
Elazığ	Bingöl	142	0.37	3		Amasya	222	1.11	
	Malatya	98	0.37		Tokat	Samsun	230	1.70	1
	Mardin	248	0.37		Trabzon	Artvin	233	0.23	5
Erzincan	Tunceli	130	2.81	1		Giresun	137	0.23	
Erzurum	Bingöl	180	0.81	2		Gümüşhane	100	0.17	
	Kars	203	0.51			Ordu	181	0.23	
						Bayburt	178	0.17	
Eskişehir	Kütahya	78	1.27	1	Van	Hakkari	202	1.41	1
Gaziantep	Adıyaman	150	0.31	6	Yalova	Bilecik	129	1.21	1
	Malatya	247	0.31		Düzce	Zonguldak	114	2.67	1
	Kahramanmaraş	80	0.17						
	Şanlıurfa	137	0.11						
	Kilis	63	0.08						
	Osmaniye	120	0.11						
	Total						**10,629**	**39.52**	

The visual representation of the new assignment limiting distances is given in Figure 7.

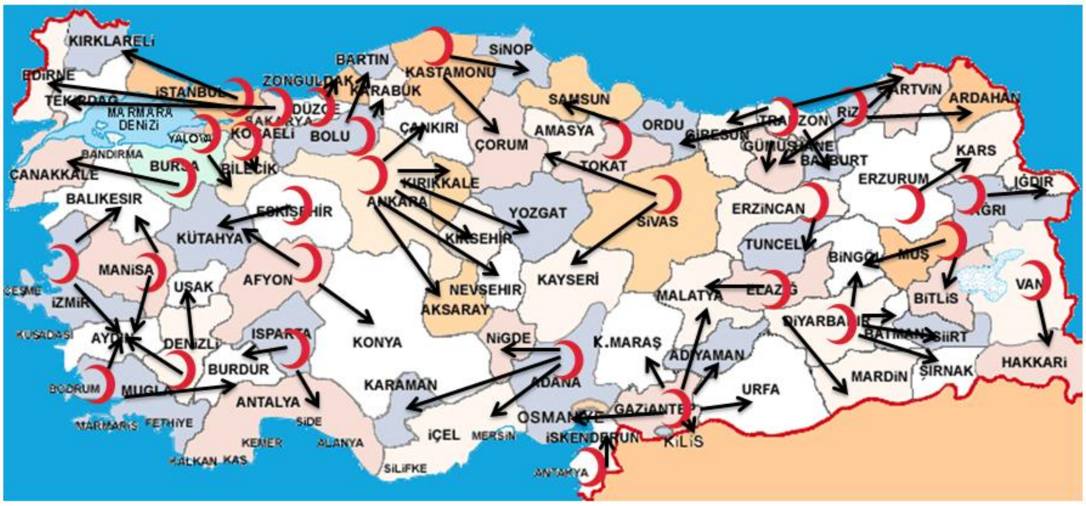

Figure 7 The visual representation of the results for the distance limited second case

As given in Figure 7 the assignment of the demand points are made to closer demand points than the second case. For example Gaziantep was serving Çorum in 630 km distance but in this assignment Çorum is assigned to Sivas and Gaziantep serves other five demand points which are its border neighbors. Moreover Muğla was serving Kütahya in 430 km distance but in this assignment Kütahya is served by Eskişehir and Afyon.

CHAPTER 3

USING CONTAINERS AS STORAGE FACILITIES FOR PREPOSITIONING INVENTORY

3.1 Literature Review

Despite the importance of humanitarian logistics, the academic studies in this area are limited [9]. Altay and Green [10] survey the literature to identify potential research directions in disaster operations, discuss relevant issues, and provide a starting point for interested researchers. Kovács and Spens ([19] give an overview of the research in humanitarian logistics and highlight several research gaps. Galindo and Batta [20] made the review of recent developments in Operations Research/Management Science (OR/MS) research as a continuation of the work of Altay and Green [10] by giving some neglected topics in humanitarian logistics. Overstreet et al. [21] created a framework for identification and categorization of the literature about humanitarian logistics as a guide of existing research for future efforts.

The operations of disaster management can be separated into four major phases: mitigation, preparedness, response and recovery [10]. Pre-positioning of containers as disaster response facilities is a new approach for the preparedness phase, and to the best of our knowledge, this approach has not been addressed in the humanitarian logistics literature. Therefore, the literature is reviewed under warehousing, pre-positioning in disaster relief, and containerization sub-topics as can be seen in Figure 8.

Traditional definition of a warehouse, where it is defined as a place to store, reconfigure, and shorten lead times, has become much more complex and technology driven.

All warehouse opportunities such as order picking, cross-docking, productivity, space utilization, and value added services allow warehouses to process more effectively [22]. The ad-hoc nature of relief chain makes permanent warehousing more cumbersome and does not allow for effective processing.

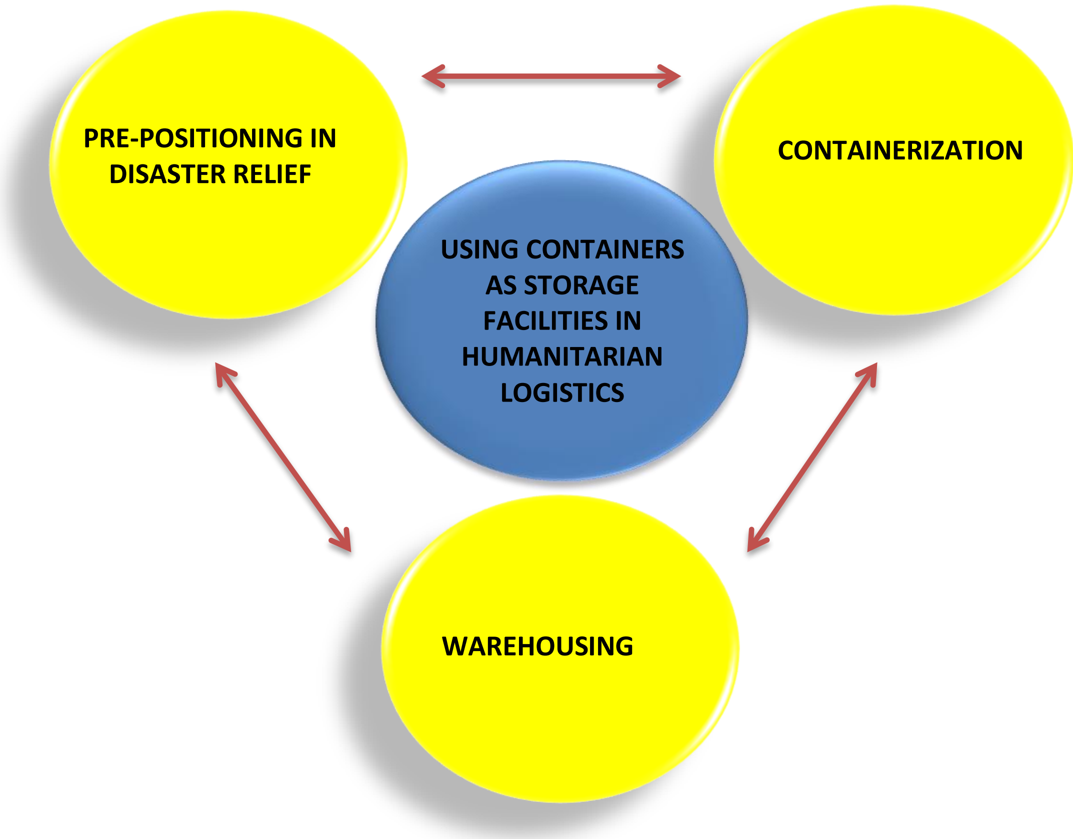

Figure 8 Literature review sub-topics

Activities in humanitarian logistics include preparedness, planning, procurement, transport, warehousing, tracking and tracing, and customs clearance [3]. Warehousing is part of an overall effort to add place and time utility to the relief supplies. That is to say, by pre-positioning inventory in warehouses, humanitarian practitioners have access to relief supplies at another place than the original production point (place utility) and at another time than the original production date (time utility). In one of the seminal studies in warehousing and inventory management in humanitarian logistics, a multi-supplier inventory model was developed by Beamon and Kotleba [23] for the South Sudan relief operations to obtain optimal order quantities and reorder points for a long-term emergency relief response.Warehousing is usually envisaged using permanent structures. The idea of using temporary facilities or storage units, having ability to move for warehousing, has not been analyzed thoroughly. Some research effort has been aimed at devising pre-positioning plans for emergency supplies since 2005 [6]. Caunhye et al. [24] stated that the stock prepositioning, evacuation and relief distribution aims are brought together in location analysis in most of the facility location optimization models in humanitarian logistics. The decisions are varied such as commodity prepositioning, facility selection among potential local and global distribution centers, and optimizing facility size. Frequently used objective functions in the prepositioning literature are: minimizing costs of setting up relief centers, transportation and commodity purchase, average or maximum response time, unfilled demand and expected number of casualties left behind or maximizing coverage of beneficiaries. The prepositioning literature is analyzed here by addressing whether a local warehouse opening (LWO) or a global warehouse opening (GWO) approach is suggested and the type of objective function used.

Balçık and Beamon [4] developed a model to design a pre-positioning system balancing the costs against the risks in the relief chain by integrating facility location and inventory decisions under a GWO approach. Duran et al. [5] developed an inventory-location model to find the location of warehouses, the amount of inventory by minimizing the response time with a GWO approach. Görmez et al. [2] developed a multi-objective model determining the locations of new disaster response facilities for Istanbul considering regional vulnerability to minimize the average-weighted distance under LWO approach. Ukkusuri and Yushimoto [11] developed a model for prepositioning disaster relif supplies considering the routing of vehicles to find optimum location and number of the warehouses. Chang et al. [25] developed a two-stage stochastic programming model to group the rescue centers by miminizing the distance and then determine the location allocation of rescue centers by minimizing the set up cost. Bemley et al. [26] developed a two- stage stochastic pre-positioning model providing short-term port recovery with respect to weather events to maximize expected amount of repaired ports under a LWO approach.

Mete and Zabinsky [27] developed a two-stage stochastic programming model for determining the storage locations and amounts of medical supplies to minimize warehouse operation costs, the response time and unfilled demand rate under a LWO approach. Döyen et al. [28] developed a two-stage stochastic programming model determining the locations for pre- and post-disaster rescue centers, and the amount of relief items to minimize the cost of facility location, stock holding, transportation and shortage. Davis et al. [29] developed a stochastic programming model for pre- and post-disaster periods determining the number of supplies and distribution network similar to Döyen et al. [28] to minimizine relevant costs under a LWO approach. Salmerón and Apte [30] developed a two stage stochastic programming model pre-positioning the relief assets and locations to minimize the expected number of casualties and warehouse operating cost, then the allocation and transportation costs.
Containers were used for the first time in the mid-fifties. Through the years, the proportion of cargo handled with containers has steadily increased [31]. The overwhelming major ity of general cargo is nowadays containerized [32]. There are two billion containers used for cargo transportation according to World Trade Organization (WTO) summaries [33]. Use of containers for transportation is cost effective when large amount of emergency relief is transported. Hu [33] developed a container multimodal path selection model for container supply chain in emergency relief by minimizing the relevant costs for transportation. Kim et al. [34] developed a container multimodal transportation model for transportation flow to minimize shipping and inland transportation costs.

Intermodal freight transportation is used to describe the movement of goods in one loading unit or vehicle, which uses successive, various modes of transport (road, rail, water) without any handling of the goods themselves during transfers between modes [35]. Container-based transportation services are an important part of intermodal transportation and the backbone of international trade [36]. Since 1990, a substantial number of analytical publications specifically addressing intermodal transportation issues have appeared [35]. The studies   concerning container, multimodal and intermodal transportation mainly focus on stowage planning, transshipment of containers and bottlenecks of transportation ([31], [37]). Use of containers is observed in real life as shipping units or for housing aims. Morgan et. al [38] used refrigerated containers in mass fatality management after South Asian Tsunami as shipping units of dead bodies to protect them from high temperatures. Peña and Schuzer [39] presented a solution to the temporary housing by using shipping containers as a shelter.

Thanks to its myriad advantages, containerization entered its peak growth years [40]. The main advantage of using a container is to be transshipped directly from one mode of transportation to another. Another advantage is that containers can remain in a storage area while preserving the stored goods for a certain period of time before they are transferred to another mode. Moreover, the developments in logistics in the last decades give a new meaning to the temporary storage on terminals. "Instead of using the stacking area as a facilitator for a smooth synchronization between transport modes, shippers and logistics service providers started to use terminals as places for the cheap storage of goods" [40]. This implies using containers as storage units. In addition to many advantages of using containers, this change in the functional use of terminals awakens the idea of using containers as a storage unit in humanitarian logistics.

To the best of our knowledge, following the literature review, there is no such study at the intersection of the three sub-topics: warehousing, pre-positioning in disaster relief, and containerization. Therefore, pre-positioning of disaster response facilities as containers and using containers as a storage facility seems to be a viable research topic.

3.2 Problem and Model Description

When pre-positioning studies in the literature are analyzed, it is observed that exposure to disaster risk has to be considered together with minimizing the distance between beneficiaries and warehouses. A warehouse location far from a disaster-prone location might be more suitable than a nearer location having lower risk location to satisfy the demand of beneficiaries. Without loss of generality, the problem in consideration focuses on earthquake risks. Each potential relief location faces different destruction powers in terms of earthquake risks, so location of warehouses and pre-positioning of the relief supplies in the warehouse should be balanced against the effect of destruction. Here, relief supplies are prepositioned in containers located at some potential sites. The number of containers and their locations are important to satisfy the needs of demand points. It is referred the container locations as '*supply points*' and the population concentrated areas (i.e., cities, towns) as '*demand points*'. The assumptions are given in the following.

Assumptions

- The supply points are located in city centers to reach the population easily.
- One tent covers a limited number of people.
- A container can store a limited number of relief supplies.
- Overall supply amount is enough to serve some percent of potentially affected people.
- The supply points can satisfy their own requirements.
- Vehicle routing decisions are left out of scope.

Objective

The objective is determining the locations of supply points using a limited number of containers and relief supplies assigned to each supply point by satisfying the demand while traveling the minimum distance in order to quickly respond to the immediate needs of beneficiaries.

Model Formulation

The following notations are used for the model.

Sets

C set of supply points; $i \in C$

T set of demand points; $j \in T$

S set of relief supplies; $k \in S$

Parameters

E_j : Potential number of affected people in demand point *j* in an earthquake

D_{ij}: Distance between supply point *i* and demand point *j* in Kilometers

W_k: Weight of the relief supply *k* in Kilograms

V_k: Volume of the relief supply *k* in Meters-cubed

B_k: Unit usage coefficient of relief supplies corresponding to one tent unit

R_{ij}: Average destruction power between supply point *i* and demand point *j*

F_i: Normalized destruction power for supply point *i*

M : Total available tent amount

A : Total allowable average destruction power between supply point *i* and demand point *j*

P: Allowable minimum normalized destruction power (MNDP)

β : The percentage of served affected people for total tent amount

Constants

N: Maximum number of people a tent can accommodate

W^T : Total weight capacity of a container in Kilograms

V^T : Total volume capacity of a container in Meters-cubed

Decision Variables

$$x_{ij} = \begin{Bmatrix} 1 & \text{if demand point } j \text{ is covered by supply point } i \\ 0 & \text{otherwise} \end{Bmatrix}$$

$y_{ik} = \text{amount of relief supply } k \text{ assigned to supply point } i$

$a_i = \text{number of containers assigned to supply point } i$

The mathematical model for the problem is as follows:

$$\min z = \sum_i \sum_j D_{ij}\, x_{ij} \tag{3.0}$$

subject to

$$\sum_j E_j x_{ij} \beta \leq N y_{i1} \qquad \forall i \in C \tag{3.1}$$

$$\sum_{i} y_{i1} \leq M \qquad (3.2)$$

$$\sum_{k} W_k y_{ik} \leq W^T a_i \qquad \forall i \in C \qquad (3.3)$$

$$\sum_{k} V_k y_{ik} \leq V^T a_i \qquad \forall i \in T \qquad (3.4)$$

$$NB_k y_{i1} = y_{ik} \qquad \forall i \in C, \forall k \in S \text{ and } k > 1 \qquad (3.5)$$

$$\sum_{j} R_{ij} x_{ij} \leq A \qquad \forall i \in C \qquad (3.6)$$

$$\sum_{i} F_i x_{ij} \geq P \qquad \forall j \in T \qquad (3.7)$$

$$x_{ij} = 0 \text{ or } 1, \qquad y_{ik} \geq 0, a_i \geq 0 \qquad \forall i \in T, \forall j \in C \qquad (3.8)$$

The objective function (3.0) minimizes the total distance travelled between the supply and demand points. Constraint set (3.1) ensures that the supply points provide some percentage of served potential number of affected people with a limited tent amount. Constraint set (3.2) ensures that total assigned tents to the supply points must be lower than or equal to the total available tent amount. Constraints (3.3) and (3.4) require total weight and total volume of the relief items to be lower than or equal to the total weight and volume of container quantities, respectively. Constraint set (3.5) provides the unit usage coefficient of relief supplies in terms of one unit of tent. Constraint set (3.6) ensures that the total average destruction power between supply and demand points must be lower than or equal to total allowable average destruction power. Constraint set (3.7) ensures that for every demand point, the sum of normalized destruction power of assigned cities must be greater than or equal to allowable minimum normalized destruction power (MNDP). Constraint set (3.8) is the sign restriction for decision variables.

3.3 Experimental Study

The proposed mathematical model is tested with a real life data set for all the cities of Turkey. The computational results are given for the assignment of demand points, containers and relief supplies to supply points. The main governmental organization in Turkey for disaster relief is the Prime Ministry Disaster and Emergency Management Presidency (abbreviated as *AFAD* in Turkish). AFAD is working on locating some relief supplies and tents to select cities of Turkey, and these cities (i.e., supply points) will supply the remainder cities (i.e., demand points). AFAD currently has 80,000 tents and plans to increase this amount to 120,000. The required number and location of containers to store relief supplies at each supply point is found by a mathematical model. The mathematical model is solved by changing some parameters and the system behavior is observed.

3.3.1 The data set

The earthquake risk data are taken from the earthquake risk map at city- and town-level [16]. These data include the risk regions of cities and destruction powers corresponding to the risk regions. The intercity distances are obtained from General Directorates for Highways [17]. The potential number of affected people in each city is obtained from AFAD earthquake scenarios [1]. AFAD analyzed an earthquake database between 1894 – 2011 years and generated the potential number of affected people in each city. Table 1 shows a sample from the relevant data. The first column of the table shows cities, while the second and third columns show the potential number of injured people and risk regions of these cities. The fourth and fifth columns show minimum and maximum destruction powers corresponding to risk regions. The sixth column is the average destruction power value calculated with the minimum and maximum destruction powers. The average is used to provide a moderate representation of the destruction power, and the normalized to give better results for comparison in the model. The last column represents the normalized values of average destruction powers computed between 0.051 and 1 with the following Eq. (3.9).

$$Normalized\ Destruction\ Power\ of\ city = \frac{(5.1 - Avg.Destruction\ Power\ of\ city) \times (1 - 0.051)}{(5.1 - 0.051)}$$

(3.9)

For instance, according to Table 6, the corresponding maximum and minimum destruction powers are 0.31g and 0.15g for Ankara which takes place in the VIII. risk area. The average destruction power is 0.23g and the corresponding normalized value is 0.085.

Table 6 A Sample from The Data Source

#	City	Injured people population	Risk region	Min. destruction power (a-cm/sn^2)	Max. destruction power (a-cm/sn^2)	Avg. destruction power (a-cm/sn^2)	Normalized Avg. destruction power
1	Adana	28,458	IX	0.31	0.71	0.51	0.137
2	Adıyaman	10,017	IX	0.31	0.71	0.51	0.137
3	Afyon	11,772	IX	0.31	0.71	0.51	0.137
4	Ağrı	7,479	XI	1.50	3.10	2.30	0.474
5	Amasya	5,427	X	0.71	1.50	1.11	0.249
6	Ankara	66,015	VIII	0.15	0.31	0.23	0.085
				…			
79	Kilis	2,079	VI	0.031	0.071	0.051	0.051
80	Osmaniye	8,181	VII	0.07	0.15	0.11	0.062
81	Düzce	5,751	XII	3.10	7.10	5.10	1.000

The relief supplies to be stored in each container are taken from AFAD scenarios as a tent, blanket, bed, electric heater and a kitchen set as illustrated in Table 7. The list and the quantities of products are taken from AFAD. The weight and volume of the relief supplies are given on the third and fourth column of the table. Each measure is given for one unit of supply. On the last column of the table, the unit usage coefficient of each supply corresponding to one unit of tent is given. For instance, if one unit of tent is stored, two units of blanket, one unit of bed, one unit of electric heater and one unit of kitchen set must be stored.

Table 7 Relief Supply Dimensions

Item no. (k)	Relief supply (Unit)	Weight W_k(Kg)	Volume V_k (m^3)	Unit coefficient usage (B_k)
1	Tent	105	0.4639	1
2	Blanket	3	0.0200	2
3	Bed	6	0.1368	1
4	Electric Heater	10	0.0475	1/5
5	Kitchen Set	15	0.0288	1/5

3.3.2 Experimental setting

A full experimental design is constructed by changing the parameters of total tent amount, total allowable average destruction power between supply and demand points, and allowable MNDP for supply points. By using three parameters, twelve experiments (i.e., scenarios) are generated and presented in Table 8. In Table 8, total tent quantity takes two different values; 80,000 and 120,000 as AFAD currently has 80,000 tents available, and they plan to increase the available number of tents to 120,000 in the near future. Total allowable average destruction powers take three different values; three, four and five because each supply point is restricted up to a total amount of average destruction power for the demand points it serves. Total MNDP (represented by P) take two different values; 0.1 and 0.2, since F_j values are between 0.062 and 1 each demand point should be served by either one supply point with high MNDP or more than one supply points with low MNDP.

Table 8 Experimental Study Scenarios

Scenario no.	Tent amount	Total allowable Avg. dest. power	Min. Normalized dest. power
1	80000	3	0.1
2	80000	4	0.1
3	80000	5	0.1
4	80000	3	0.2
5	80000	4	0.2

6	80000	5	0.2
7	120000	3	0.1
8	120000	4	0.1
9	120000	5	0.1
10	120000	3	0.2
11	120000	4	0.2
12	120000	5	0.2

3.3.3 Computational results

Twelve scenarios for the developed model were solved by using the GAMS 22.6 optimization tool with CPLEX 11 Solver and run on a PC with a Pentium Dual-Core CPU, 3.00 GB, and 2.00 Ghz. Three of the generated scenarios had infeasible solutions (Scenario 4, 10 and 11) due to changes in the allowable MNDP parameter for supply points. The summary of the results for the scenarios which have feasible solutions are presented in Table 9.

Table 9 Results Summary of Feasible Scenarios

Scenario no.	Objective function value (z)	# of Container assigned city (Supply point)	Quantity of assigned containers	CPU time (sec.)
1	11,683	50	2,053	7.609
2	10,770	49	2,065	8.953
3	10,702	47	2,049	7.531
5	20,343	36	2,061	8.203
6	16,751	34	2,062	7.078
7	12,182	45	3,088	9.312
8	11,066	41	3,079	8.094
9	11,044	41	3,079	5.813
12	17,994	30	3,080	9.547

In Table 9, the first column represents the total travelled distance between demand and supply points. The second column shows the total number of containers assigned to cities in terms of supply points. The total quantity of assigned containers to supply points is given in the third column of the table. On the last column, the execution time of the scenarios is given in seconds. As seen in Table 9, the lowest objective function values result from Scenario 3 using 80,000 tent amounts and Scenario 9 using 120,000 tent amounts. Scenario 3 assigned 2,049 containers to 47 supply points while Scenario 2 has the second lowest objective function with 2,065 containers assigned to 49 supply points. Scenario 2 has two supply points, 16 containers and 68 km travelled distance more than Scenario 3. Scenario 1 uses 12 containers fewer than Scenario 2, but the total travelled distance is higher. In Scenario 6, the total travelled distance is higher than Scenario 3, but the supply points number assigned is fewer than Scenario 3. The largest objective function appears in Scenario 5 with fewer supply points and higher container amounts with regard to Scenario 3. However, the total travelled distance is almost twofold. Destruction power affects the results in such a way that higher destruction power demand points (e.g. risky locations) should be supported by several cities, thus have backup supply points. When minimum normalized destruction power (MNDP) is doubled, the objective function almost doubles (i.e., from Scenario 2 to Scenario 5) leading to a higher total distance.

Scenario 9 assigns 3,079 containers to 41 supply points for 120,000 planned tent amounts when all other experimental design variables are the same with Scenario 3. The second lowest objective function is very close to Scenario 9 and is obtained from Scenario 8 with the same amounts of supply points and containers. However Scenario 9 is superior to Scenario 8 in terms of total travelled distance. Scenario 7 has about 1,100 km travelled distance, four supply points and nine containers more than Scenario 9. The largest objective function appears in Scenario 12 with fewer supply points and almost the same container amounts when compared to Scenario 9. However, the total travelled distance is unacceptable in terms of response time. The comparison between the scenarios is depicted in Figure 9 according to total travelled distance and the number of supply points for 80,000 and 120,000 tents.

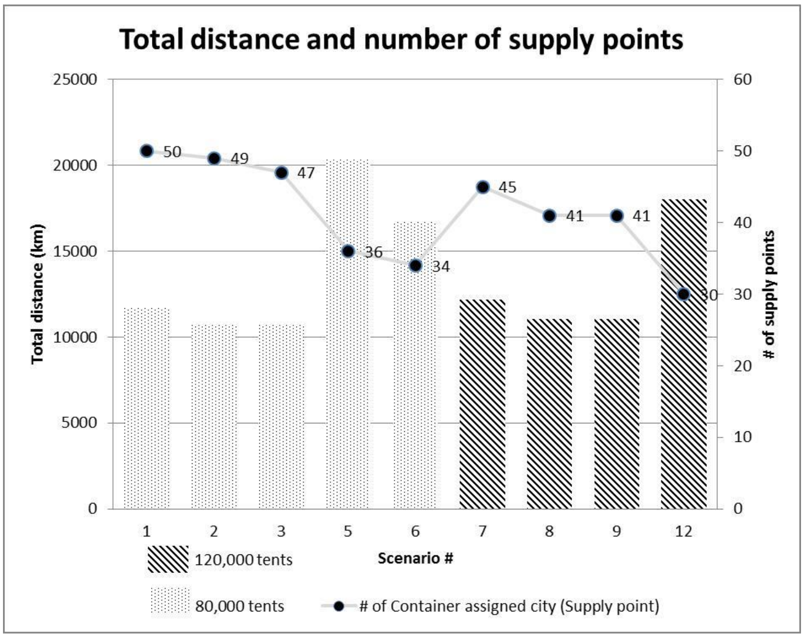

Figure 9 Comparison between the scenarios for 80,000 and 120,000 tent amounts

In Figure 9, the number of container-assigned cities is demonstrated above the bars. The lowest objective function value arises from Scenario 3 and Scenario 9 for 80,000 and 120,000 tent amounts, respectively. The details of Scenario 3 for on hand tent amount are depicted in Table 10.

Table 10 Assignment of Demand Points to Supply Points of Scenario#3

Plate code	Supply points	Normalized dest. Power	# of Assigned container	Served demand points	Distance between supply and demand point	Avg. dest. power between supply and demand point
				Hatay	191	1.41
				Mersin	69	0.37
1	Adana	0.137	85	Niğde	205	0.31
				Karaman	289	0.37
				Osmaniye	85	0.31
				Gaziantep	150	0.31
2	Adıyaman	0.137	113	Kahramanmaraş	164	0.37
				Şanlıurfa	110	0.31
				Konya	223	0.37
3	Afyon	0.137	87	Kütahya	100	1.41
				Uşak	116	0.51
5	Amasya	0.249	53	Çorum	92	1.11
				Samsun	131	1.70
8	Artvin	0.085	4	Rize	159	0.23
				...		

62	Tunceli	0.137	7	Elazığ	130	2.81
68	Aksaray	0.062	12	Kırşehir	110	0.17
				Nevşehir	75	0.11
73	Şırnak	0.137	18	Hakkari	189	0.51
				Siirt	95	0.31
77	Yalova	0.474	47	Kocaeli	65	3.70
81	Düzce	1.000	9	Bolu	45	3.10
		Total	**2,049**		**10,702**	**81.61**

In Table 10, the first and second columns show the city plate codes and the cities as being supply points. The third column is the corresponding normalized destruction powers of supply points. The fourth and fifth columns depict the assigned container quantity and demand points to the supply points, respectively. On the sixth and seventh columns, the distance and average destruction powers are given between demand and supply points, respectively. For instance, Adana serves five demand points, namely Hatay, Mersin, Niğde, Karaman and Osmaniye, which are its neighbors. The nearest and the furthest demand points are Mersin and Karaman, respectively. Adana has 85 containers to supply one of these demand points after an earthquake. The maximum numbers of containers (i.e., 400) in a city is stored in Sakarya to supply İstanbul after an earthquake. The minimum number of containers (i.e., four) in a city is stored in Artvin and Elazığ. The total travelled distance between supply points and demand points is 10,702 km and the total average destruction power is 81.61 a-cm/sn^2.

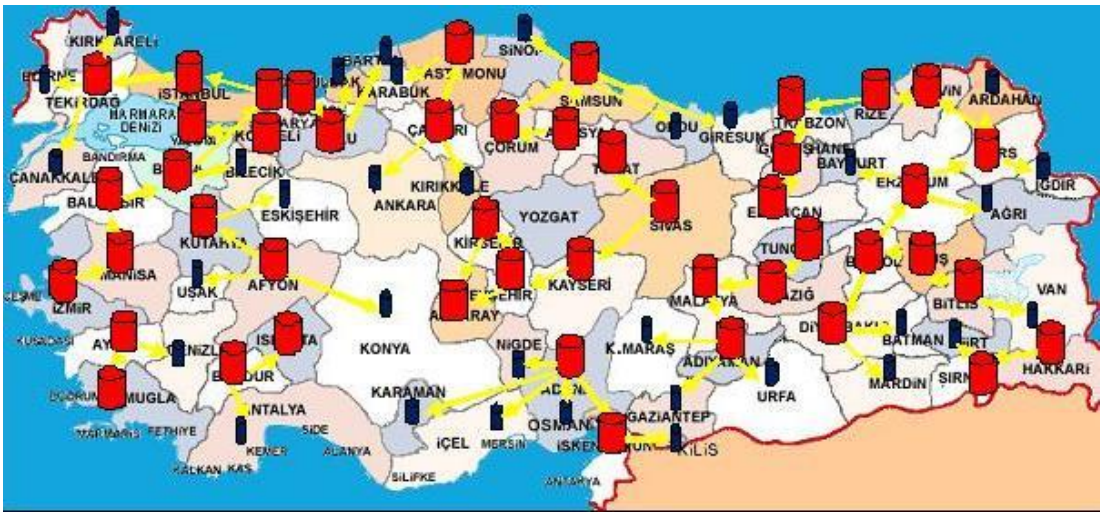

Figure 10 Graphical representation of scenario 3

The visual presentation of the results of Scenario 3 is given in Figure 10. As illustrated in Figure 107, the red marked points are the supply points, and the blue marked points are the demand points seen on the cities. Each supply point acts as both a supply and a demand point, and can be supported by another supply point. However, the supply points without support are considered self-sufficient.

The earthquake risk map of Turkey is given in Figure 11 [16]. As demonstrated in Figure 11, it can be concluded that the dispersion of the supply points are determined according to the earthquake risks of the cities. The supply points determined with the optimization tool are clustered in the riskiest areas, which are marked by dark and light orange colors on the earthquake risk map. However, after some discussion with AFAD, it is considered that the supply points do not serve all the AFAD Provincial Directorates given in Figure 12. These directorates have a crucial role in the provinces in assignment of relief supplies and manpower after any disaster. For this reason, Ankara and Van should be accounted as supply points. Çankırı and Kırşehir supply points are combined, and Ankara is formed as a new supply point. Bitlis and Hakkari supply points are combined, and Van is formed as a new supply point. After these changes, some demand points are swapped from previous supply points and assigned to the new supply points.

Figure 11 Earthquake risk map prepared by Prof. Dr. Ahmet Ercan

Figure 12 AFAD province directorates

The resulting assignment of demand points to supply points after swapping is given in Table 11. As seen on Table 11, the old supply points, which are Çankırı and Kırşehir, are assigned to the new supply point Ankara. Nevertheless, the old supply points Bitlis and Hakkari are assigned to new supply point Van. Thus, all the AFAD Province Directorates are served by swapping, and the integrity of the supply points are provided with supply points added in the post-processing. Consequently, the total travelled distance decreased from 10,702 km to 9,440 km, and the total average destruction power decreased from 81.61 a-cm/sn^2 to 81.31 a-cm/sn^2. For the case in Scenario 3, the total assigned container quantity did not change and distributed to new supply points by taking from combined supply points. The visual representation of the resulting assignment after post-processing of the current scenario (i.e., Scenario 3) is given in Figure 13. A similar analysis can be done for the future scenario (i.e., Scenario 9) for 120,000 tents.

Table 11 Assignment of Demand Points to Supply Points After Post-processing

Plate code	Supply points	Normalized dest. power	# of Assigned container	Assigneded demand points	Distance between supply and demand point	Avg. dest. power between supply and demand point
1	Adana	0.137	85	Hatay	191	1.41
				Mersin	69	0.37
				Niğde	205	0.31
				Karaman	289	0.37

				Osmaniye	85	0.31
				Gaziantep	150	0.31
2	Adıyaman	0.137	113	Kahramanmaraş	164	0.37
				Şanlıurfa	110	0.31
				Konya	223	0.37
3	Afyon	0.137	87	Kütahya	100	1.41
				Uşak	116	0.51
5	Amasya	0.249	53	Çorum	92	1.11
				Samsun	131	1.70
6	Ankara	0.085	143	Kastamonu	245	0.67
				Kırıkkale	75	0.23
				Aksaray	334	0.17
				…		
62	Tunceli	0.137	7	Elazığ	130	2.81
65	Van	0.474	52	Muş	223	1.41
				Şırnak	360	1.41
68	Aksaray	0.062	12	Kırşehir	110	0.17
				Nevşehir	75	0.11
73	Şırnak	0.137	18	Hakkari	189	0.51
				Siirt	95	0.31
77	Yalova	0.474	47	Kocaeli	65	3.70
81	Düzce	1.000	9	Bolu	45	3.10
		Total	**2,049**		**9,440**	**81.31**

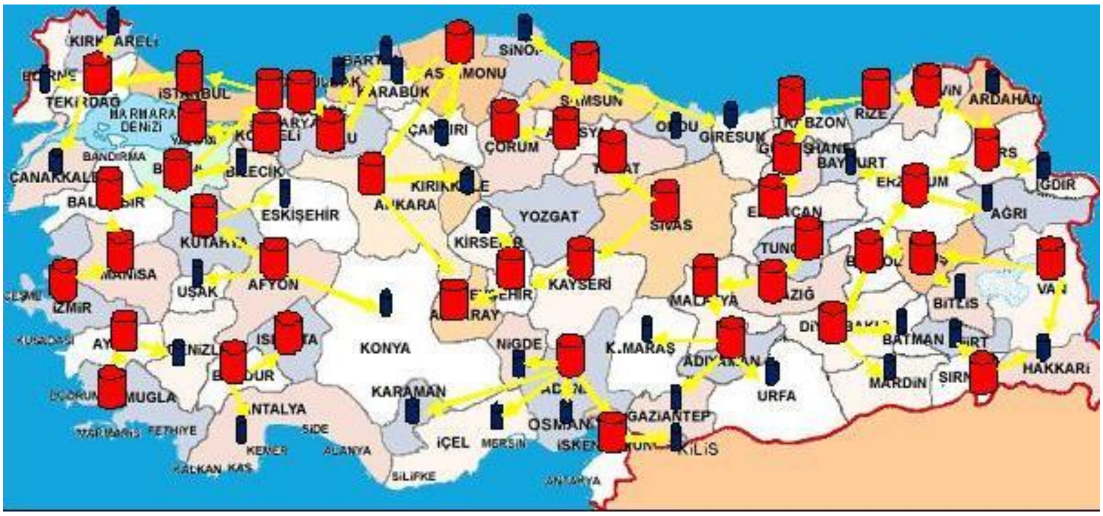

Figure 13 Graphical representation of supply and demand points after post-processing

As seen from Figures 10 and 13, the supply points are in scattered locations but have advantages in terms of both response time and closeness. For instance, if there is a disruption between the demand point and supply point connection, the second closer supply point is activated during the response. Life-saving and quick response to disasters is prioritized in this work despite the coordination challenges of these scattered supply points.

3.4 Managerial and Research Implications

The proposed model helps managers and researchers in determining the locations of supply points and the quantity of containers and relief supplies assigned to each supply point. This is accomplished by satisfying the demand while travelling the minimum distance to quickly respond to the immediate needs of beneficiaries. The results of the model can be used in both tactical and strategic decisions by the practitioners. Upon retrieving results from the model, the implementation procedure can be summarized under three issues: (1) selection of the container locations within the supply points (cities), (2) managerial operations of the supply points, and (3) environmental planning and security.

Selection of the container locations within the supply points. Many criteria arise while determining the locations of the containers within a city region. The selection of the container locations should be planned by considering the climate characteristics, such as the raining rate, moisture, temperature and wind. Also geological availability of the selected location should be considered in terms of endurance. It should be considered that the road infrastructure could collapse in case of a disaster. It would be better if the container locations are positioned closer to the railway and highway connections to provide alternative means to reach to container locations.

Managerial operations in supply points. The operation and maintenance of the containers will be the main pursuit. The containers can be stacked as much as three containers high to save more land for operations. In case of any disaster, the containers will be loaded to the trucks with a mobile crane, reach stacker or overhead crane and dispatched to the disaster area. The containers can be transported by one of the transport modes available near that location. After the procurement and stacking of the containers, the humanitarian logistician should decide how many items to procure from suppliers. The model presented in this thesis ties tent quantity with the capacity of a tent and the required relief items are calculated. Humanitarian logisticians can use these quantities to determine how many to order. The procured relief items will be transported according to the terms of agreement. The items arrived at the container locations will be loaded to the containers with a material handling equipment such as pallet trucks. A first-in-first-out (FIFO) system could be used to keep inventory up-to-date, and the tracking of the products could be performed using a radio-frequency identification (RFID) barcode system. The containers could be covered with a material like polyurethane for the insulation and could be ventilated on a biannual basis. It is recommended that the ventilations are made for two or three containers monthly for each city. Visual inspection of the supplies could be done during the ventilation process and should be reported to the decision maker.

Environmental planning and security. The current scenario tries to allocate 80,000 tents to 81 candidate locations (i.e., all cities of Turkey). This type of large data can lead to light scatter of containers and difficult management of them. Some precautions should be taken in order to better conduct the management of containers and ensure the security of supply points. The environmental planning for the maneuver area of trucks and parking area are the foremost aspects in terms of loading/unloading operations. The containers would be located on a concrete floor and there would be one mobile crane for the movement of the containers. A wire fence around the container location could be used as a security precaution. A fire alarm and camera system can also be recommended to the practitioners and managers. Security personnel can be hired for 24 hours to ensure the security of the containers in case of any theft or looting.

In this thesis, a first step is taken in mobile pre-positioning strategy using freight containers. In future work, transportation and routing decisions of containers used for storage can be considered. This thesis can be extended by considering towns instead of cities to be supply points.

CHAPTER 4

COMPERATIVE ANALYSIS OF WAREHOUSE AND CONTAINER STORAGE IN TERMS OF LAYOUT AND COST

4.1 Literature Review

Supply chain literature lacks a common risk related terminology [41]. Here, some highly cited definitions for uncertainty, risk, disturbance, disruption, vulnerability, resilience and business continuity terms are given. *Uncertainty* is a term used for the events that have potential results either good or bad. Ritchie and Brindley [42] relates the uncertainty with the unawareness of the potential outcomes of any event and lack of information about it whether the outcome is positive or negative. *Risk* is a widely used term in everyday life and business, and is broadly defined in the decision making perspective as “variation in the distribution of possible outcomes, their likelihoods and their subjective values” by March and Shapira [43]. Here, it isreferred to risk’s negative meaning (as in [44]) seeing it as a source of disruption in supply chains.

Svensson [45] defines *disturbance* as the deviation that causes a negative or undesired result. Melynk, Rodrigues and Ragatz [46] define disturbance in a holistic approach as the output of any supply chain occurred by an unexpected event in one part of the chain affecting the other parts. Disturbances imply *disruption* if not properly managed. Disruption is defined by Wilson [47] as a rapid disconnection on the supply chain suspending the ‘material flows’. They think that “natural disaster, labour dispute, dependence on a single supplier, supplier bankruptcy, terrorism, war, and political instability” cause supply chain disruptions.

Vulnerability can be defined as ‘sensitivity’ in its literal meaning. Christopher and Peck [48] define the supply chain vulnerability as ‘‘an exposure to serious disturbance'' [44]. A decrease in vulnerability results as a decrease in probability of a disruption and an increase in *resilience* [49].

Resilience can be defined as the capability and ability of an element to return to a pre-disturbance state after a disruption [14]. *Business continuity* efforts happen in an enterprise before a disruption occurs and ensures the persistence of the organization after the disruption [8]. Resilient organizations can be said to have properly employed business continuity management tools.

Inventory is held to create a buffer for uncertainties in supply chains. A transportation chain is formed between the sender warehouse and the receiver warehouse. Chopra [50] states that when a customer of Amazon.com places an order, the order processing takes one day or less, however it takes much time in transportation and distribution points before reaching to the customer. Thus, the goods spend more time in *transportation warehouse* than the sender warehouse or the receiver warehouse. Today, companies aiming for resilience need to consider alternative methods of storage rather than traditional warehousing.

Containers are used frequently [40] in international transportation for movement of goods from one transportation mode to another at container terminals [37]. Containers are loaded and unloaded at these terminals for shipping [31]. Container terminals have been studied in terms of performance and efficiency [51], manpower planning ([52], [53]), ship routing and scheduling ([54], [55]), material handling ([56], [57]). One advantage of using containers is that containers can stay in a storage area while keeping the goods in a preserved place for some time. The advances in supply chain management provided a new meaning to the temporary storage on terminals. "Instead of using the stacking area as a facilitator for a smooth synchronization between transport modes, shippers and logistics service providers started to use terminals as places for the cheap storage of goods" [40]. This change in the use of terminals awakens the idea of using containers as a storage unit to mitigate supply chain disruptions.

4.2 Problem and Model Description

Literature review revealed that previous studies focus mostly on warehouse inventory policies and management, thus the use of containers for longer terms to store products is a novel idea. This idea is useful when demanded products are slow moving and more durable. Container stockpiling areas are more resilient than a warehouse building against natural disasters. Gu et al. [58] reviewed the warehouse design related studies and discussed them in terms of major decisions and objectives. According to their framework the problem handled in this thesis can be classified under the subtopic of determining the warehouse structure and dimension to increase space utilization at the least cost.

The methodology that is followed to investigate how and at what cost freight containers could be used as an inventory holding mechanism is composed two parts. First, the optimum warehouse layout and container stockpiling area layout is determined (i.e., layout analysis). Then, two methods are compared in terms of total annual worth (AW) value by using the present worth (PW) values in terms of years and interest rates (i.e., cost comparison analysis).

4.2.1 Layout analysis

Optimum layouts for warehouse and container stockpiling area alternatives are presented in this section. An optimum layout provides the peripheral dimensions of the designated area, the number of shelves and the number of storage spaces on a shelf for a given demand quantity. Material handling cost, perimeter cost and area cost are utilized to find the optimum warehouse layout as described in Bassan, Roll and Rosenblatt [59]. The assumptions for the design of the warehouse and container stockpiling area layout are given in the following.

<u>Assumptions</u>

(1) The demand for the warehouse and the container stockpiling area is the same.
(2) Warehouse construction time is neglected, items are stored on double shelves and a reach truck is used as the handling equipment.
(3) The container stockpiling area is on a concreted floor, items are stored in containers on pallets and a gantry crane is used as handling equipment.

(4) There is only one item type on each pallet and in each container.

(5) The warehouse and container layouts are rectangular to give the optimum geometrical shape to store palletized items [60].

(6) The aisle widths and container loading department width are large enough to provide easy manoeuvre of material handling equipment.

(7) There are two doors for both design alternatives. One is for entrance and the other is for exit. The doors are placed at the middle of crosswise walls. The widths of doors are neglected.

(8) The height of the shelves and pallets are independent of the floor layout [59].

A typical layout for the warehouse is given in Figure 14. This type of layout is chosen because it is used frequently in practice. The warehouse building is composed of concrete floor and walls together with an appropriate roofing structure. The items are handled in the warehouse by reach trucks and stored on the shelves using pallets.

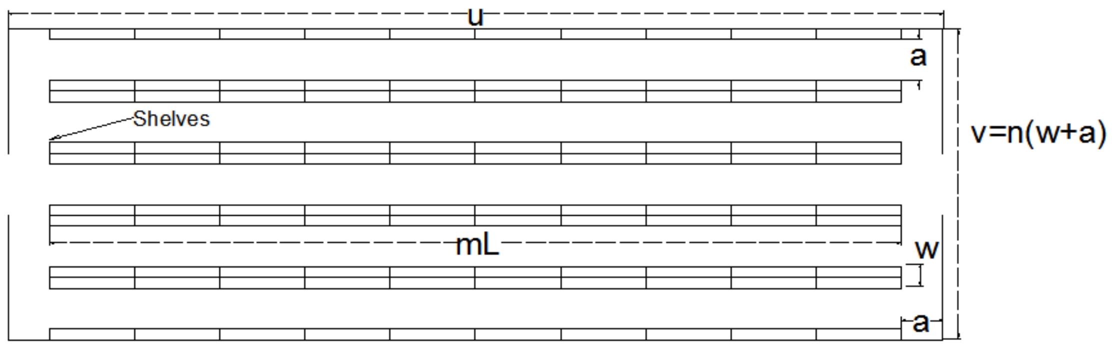

Figure 14 Typical drawing for the warehouse

The layout design for the container stockpiling area is presented in Figure 15. The area is on a concreted floor and wire fenced. There is one door for receipt and one for shipment of the containers on trucks. When a container arrives, the trucks arrive from the entrance door, park at the space in between containers; a crane unloads the container and places in either side of the container stacks. Then the trucks leave from the exit door.

The notation given in Table 12 is used for warehouse layout and container stockpiling area analysis. (See Figure 14 and Figure 15 for details)

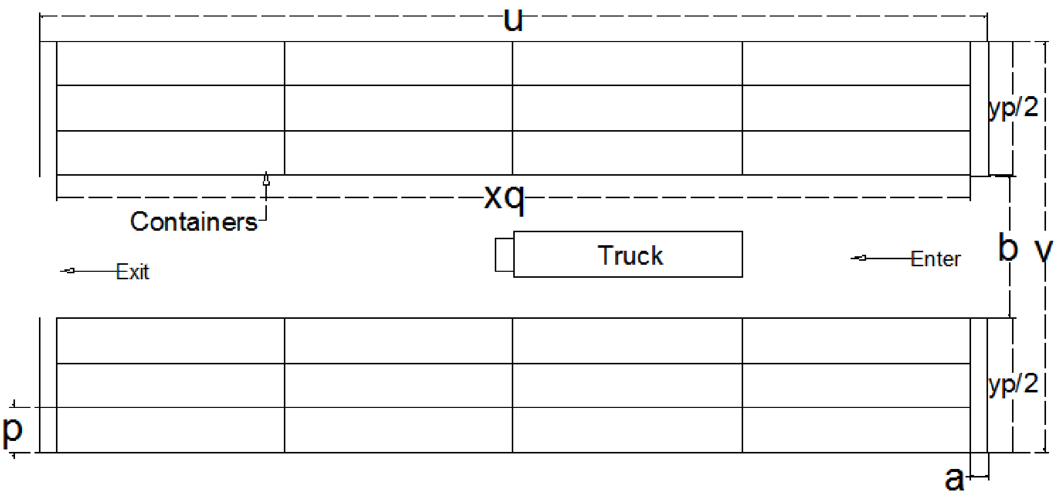

Figure 15 Typical drawing for the container stockpiling area

Table 12 Notations Used for Warehouse Layout and Container Stockpiling Area Layout

Notations	Warehouse	Container Stockpiling Area
width of double shelf	*W*	-
width of container	-	*P*
length of a storage space	*L*	-
length of a container	-	*Q*
number of storage spaces along a shelf	*M*	-
number of containers along longitudinal dimension	-	*X*
number of storage levels in vertical direction	*H*	*H*
number of double shelves	*N*	-
number of containers along cross dimension	-	*Y*
total capacity in storage spaces	*K*(2*mnh*)	-
total capacity in container storage	-	*Cap*(*xyh*)
width of an aisle	*A*	-
width of aisles in front of doors	-	*A*
container loading department width	-	*B*
longitudinal dimension	*U*	*U*

cross dimension (width)	V	V
yearly throughput (demand) in storage units (pallets for warehouse, containers for container stockpiling area)	D	D
material handling cost, of moving a storage unit one length unit	$C_h{}^w$	$C_h{}^c$
annual cost per unit of warehouse area	$C_s{}^w$	$C_s{}^c$
annual cost per unit length of external walls	$C_p{}^w$	$C_p{}^c$

Total annual cost, $C_1{}^w$ is calculated in Bassan, Roll and Rosenblatt [59] as

$$C_1^w = d[4a + 2mL + n(w + a)]C_h^w + [(n(w + \alpha)(mL + 2a)]C_s^w + 2[(n(w + \alpha) + (mL + 2a)]C_p^w \quad (4.1)$$

By some algebraic manipulation and taking the derivative of equation (1) according to m and substituting n with ($n = K/2mh$), optimal (m^*, n^*) pair is calculated as in Eq.s (4.2) and (4.3).

$$m^* = \frac{1}{L}\sqrt{\frac{(dC_h^w + 2\alpha C_s^w + 2C_p^w)}{2(dC_h^w + C_p^w)}S} \quad (4.2)$$

$$n^* = \frac{1}{w+\alpha}\sqrt{\frac{2(tC_h^w + C_p^w)}{(tC_h^w + 2\alpha C_s^w + 2C_p^w)}S} \quad (4.3)$$

where $S = K(w+a)L / 2h$ is the minimal "operative" area which is needed for a capacity of K and h storage level [59].

The cost calculation of Bassan, Roll and Rosenblatt [59]is followed to determine the costs for warehouse design. Here, the formulation for the container stockpiling area is proposed by adopting the warehouse calculations in Bassan, Roll and Rosenblatt [59] given in Table 13. The lengthwise dimension of the container stockpiling area is found as;

$$u = xq + 2\alpha \quad (4.4)$$

The crosswise dimension is;

$$v = yp + b \quad (4.5)$$

The perimeter and the area of the container stockpiling area are;

Perimeter: $2[(yp + b) + (xq + 2\alpha)]$ (4.6)

Area: $[(yp + b)(xq + 2\alpha)]$ (4.7)

When the utilization rate of doors is taken as equal, the average travelling distance in the container stockpiling area along lengthwise dimension and crosswise dimension would be (xq+2a) / 2 and (yp+b) / 4, respectively. Then, the expected annual travelling (EAT) distance for the demanded amount of items is calculated as,

$$EAT = d[4\alpha + 2xq + yp + b] \quad (4.8)$$

It is assumed that the cost parameters; perimeter, material handling and area costs are linearly related to the travelled distance, perimeter and area [59]. Then, the total annual cost for the container stockpiling area, C_1^c, will be

$$C_1^c = b[4\alpha + 2xq + yp + b]C_h^c + [(yp + b)(xq + 2\alpha)]C_s^c + 2[(yp + b) + (xq + 2\alpha)]C_p^c \quad (4.9)$$

By grouping the same parameters and letting new notations, the following equations are obtained:

$$\theta = 4\alpha\left(dC_h^c + C_p^c\right) + MC_s^c \quad (4.10)$$

$$\delta = 2q\left(dC_h^c + C_p^c\right) \quad (4.11)$$

$$\mu = \left(dC_h^c + 2\alpha C_s^c + 2C_p^c\right)\frac{M}{q} \quad (4.12)$$

where M = $Cap(p+a)q$ / 2h is the minimal “operative” area which is needed for a capacity of Cap and z storage level. The abbreviated version of C_1^c can be written in terms of x and y.

$$C_1^c(x) = \theta + \delta x + \frac{\mu}{x} \quad (4.13)$$

By taking the derivative of Eq. (4.12) according to x and substituting y with (y = Cap / 2xz) the optimal (x*, y*) pair is obtained as in Eq.s (4.14) and (4.15).

$$x^* = \frac{1}{p}\sqrt{\frac{(dC_h^c + 2\alpha C_s^c + 2C_p^c)}{2(dC_h^c + C_p^c)}M} \tag{4.14}$$

$$y^* = \frac{1}{q}\sqrt{\frac{b}{b - \sqrt{(dC_h^c + 2\alpha C_s^c + 2C_p^c)M}}} \tag{4.15}$$

Substituting (x^*, y^*) pair, the optimal lengthwise and crosswise dimensions of the container stockpiling area can be calculated by Eq.s (4.4) and (4.5). Similarly, the area and perimeter can be calculated by Eq.s (4.6) and (4.7).

4.2.2 Cost comparison analysis

A present worth analysis with Present Worth (PW) values of the cost items is calculated here to compare the alternatives based on the present worth under the assumption of each alternative provide the same service which is storage. Here a concrete floor is assumed as given and can either be used to construct a warehouse or to stockpile containers. Lease option is also investigated for the warehouse storage and containers in addition to warehouse construction and container purchasing. The warehouse and container storage cost items are given in Table 13. Costs that are not applicable are shown with N/A.

PW value of the warehouse leasing and container leasing costs are calculated by Eq. (4.16) [61] to compare with leasing option. In Eq. (4.16), i is the interest rate. Other costs such as operating, handling and personnel costs are assumed to be the same for both alternatives.

Table 13 Cost Items Used in PW Analysis

Cost Type	Warehouse		Container Stockpiling Area	
	Purchase	Lease	Purchase	Lease
Construction	Construction cost of the warehouse	Leasing cost of the warehouse (monthly)	N/A (no construction in the area)	N/A (no construction in the area)
Storage	Purchasing cost of shelves	N/A (included in the leasing cost)	Purchasing cost of containers	Leasing cost of containers (monthly)

$$PW = AW\ \frac{(1+i)^n - 1}{i(1+i)^n} \tag{4.16}$$

Duration (n) in years is determined as the common variable for warehouse and container stockpiling area to make the comparison. Then the PW value is used to express the present worth of each alternative. The alternative having the least PW value is determined as the best. In the analysis, the purchasing option and leasing option for the warehouse and container stockpiling area are evaluated separately and then an overall comparison is performed for these options.

4.3 An Application for Humanitarian Logistics

An application of the proposed model is done in the humanitarian logistics field. Humanitarian logistics is a good ground for test of the model because of the ad-hoc nature of the relief chain network. When a disaster happens, the immediate needs of beneficiaries have to be transported from prepositioned inventory. If the prepositioned inventory is stored in containers, it reduces the time for handling in both ends of the relief chain. The idea of using containers as a storage unit is in the planning phase for application in Turkey by AFAD.

4.3.1 Layout analysis application

In the warehouse, the shelves are perpendicular to the entrance and exit doors (See Figure 14). There is a reach truck for handling of the pallets. In container stockpiling area, the containers are perpendicular to the entrance and exit doors (See Figure 15). Stockpiling area is fenced with a wire for security reasons. A gantry crane handles the containers since this is a type of suitable cranes used in open land to handle heavy materials. There is 10 m space in the middle of the stockpiling area for loading and unloading of the containers to/from trucks. The parameters used in the layout analysis are given in Table 14.

The items are stored on euro pallets in the warehouse; therefore the width and length dimensions of the double shelves are determined according to euro pallet sizes. The width of the shelf for two pallets is 2.7 m, the height is 2.025 m and the depth is 0.7 m.

Table 14 Parameters Used in the Layout Analysis Application

Parameters	Warehouse	Container Stockpiling Area
width of double shelf	1.80 m	-
width of container	-	2.35 m
length of a storage space	1.35 m	-
length of a container	-	12.03 m
number of storage levels in vertical direction	3	3
total capacity in storage spaces	1200 pallets	-
total capacity in container storage	-	48 containers
width of an aisle	3 m	-
width of aisles in front of doors	-	3 m
container loading department width	-	10 m
yearly throughput (demand) in storage units (pallets for warehouse, containers for container stockpiling area)	1000 pallets	40 containers
material handling cost, of moving a storage unit one length unit	0.0011 m.u $pallet^{-1}$	0.00064 m.u $container^{-1}$
annual cost per unit of warehouse area	37.60 TL m^{-2}	19.95 TL m^{-2}
annual cost per unit length of external walls	10 TL m	4.3 TL m

The stored items in the containers are also on euro pallets and one 40 ft dry container takes up to 25 euro pallets as seen in Figure 16. The number of storage levels is assumed as 3 levels high for both warehouse and container stockpiling area. The capacity of the warehouse and container stockpiling area is the same in terms of pallets assuming 1200 pallets for the warehouse and 48 containers (25 pallets in each container) for stockpiling area since it is considered that this amount would be enough for the first response in case of an average magnitude earthquake – which is the most common disaster type in Turkey.

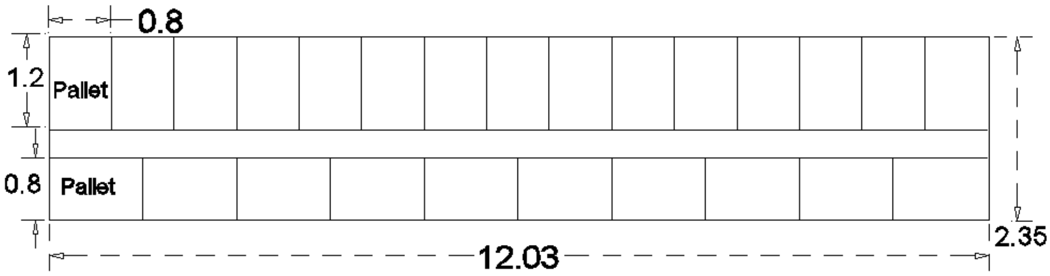

Figure 16 Top view drawing of a 40 ft dry container loaded with pallets

The cost parameters for handling equipment are obtained from Maerskline™ Turkey Company as lower and upper values. Euro (€) costs are converted to monetary units by a coefficient because of the confidentiality rules of the companies that the costs are obtained from. The cost of working with a reach truck is 0.04 monetary unit (m.u) per hour including the operator cost. The reach truck takes one pallet and moves for one unit distance (as meter) within 60 and 140 seconds. Cost of working with a gantry crane including the operator cost is 0.24 m.u per hour. The crane moves one container for one unit distance within 180 and 300 seconds. The average of given upper and lower values of moving time and costs are taken to obtain the handling cost of one container for one unit distance. Other cost intervals are shown in Table 15. The cost of handling for reach truck and gantry crane is calculated as in Eq. (4.17).

Table 15 Costs Related with Handling and Purchasing

	Reach Truck		Gantry Crane	
	Lower Bound	*Upper Bound*	*Lower Bound*	*Upper Bound*
Purchasing cost of handling equipment	250	480	1817	1833.70
Cost of handling one hour	0.00067	0.00156	0.00048	0.0008

$$Cost\ of\ handling\ of\ one\ pallet\ (m.u.)/meter\ =$$
$$Cost\ of\ handling\ one\ hour\ (m.u.360\ sec.^{-1})\ x\ Handling\ time\ (sec.)/meter$$
(4.17)

Thus the cost of handling one pallet for one unit distance with a reach truck is between 0.00067 and 0.00156 m.u per meter according to Eq. (4.17). The cost of handling of one container for one meter changes between 0.012 and 0.02 m.u per meter. This cost is 0.012/25 = 0.00048 m.u per pallet for the lower limit and 0.02/25=0.0008 m.u per pallet for the upper limit since one container takes 25 pallets (See Figure 15). The cost of container handling is taken in terms of pallet to provide a common ground for comparison. Then the cost of handling one pallet for warehouse (C_h^w) is taken as 0.0011 m.u/meter and the cost of handling one pallet for the container stockpiling area (C_h^c) is taken as 0.00064 m.u/meter by taking the average of lower and upper limits.

By using the Eq.s (4.2) and (4.3) the optimal (m^*, n^*) pair is found as (24.49, 8.19). The (m^*, n^*) pair should be integer so m^* is taken as 25 and n^* is taken as 8. For the optimal (x^*,y^*) parameters Eq.s (4.14) and (4.15) are used and found as (2.98, 5.37). The pair is rounded to integer values considering the capacity of container stockpiling area, so x^* is taken as 3 and y^* is taken as 6. The variables and their values are shown in Table 16.

Table 16 Variables and Their Optimum Values

Variables	Warehouse	Container Stockpiling Area
m^*	25	-
x^*	-	3
n^*	8	-
y^*	-	6
U	39.75	42.09
V	38.4	24.1
Area (m^2)	1,526.4	1,014.4
Perimeter (m)	156.3	132.4
Total Cost (m.u)	327.506	138.652

As seen in Table 16, container stockpiling area uses less area to stock the same amount of pallets than the warehouse. The total cost of storing the same amount of pallet is much less in container stockpiling area than the warehouse.

4.3.2 Cost comparison analysis application

In this section a present worth analysis for leasing and purchasing options of two alternatives is performed. First, leasing and purchasing options for warehouse alternative are compared. Then a similar analysis is performed for container stockpiling area. Finally four alternatives (i.e., warehouse-construct, warehouse-lease, container-purchase, container-lease) are compared simultaneously.

The cost of leasing option for warehouse and container stockpiling area is 366.34 and 345.60 m.u, respectively. The warehouse construction cost is 229.91 m.u and the purchasing costs of 48 containers is 1,321.60 m.u. The purchasing costs of handling equipment (reach truck and gantry crane) is not included in the PW analysis because in humanitarian logistics the stocks are used whenever a disaster occurs so the handling of the stocks is a rare event that can be neglected. The leasing cost of warehouse for total used area and leasing cost of containers; purchasing cost of containers and construction cost of the warehouse are included in the analysis. The construction cost of the warehouse also includes the shelf and roof costs.

4.3.1.1 Analysis for warehouse

The warehouse construction option is compared with leasing option to find the better option in terms of cost. The interest rate is taken as mutuation interest rate which is 5% as given by TCMB [62]. By using Eq. (4.16) the PW value is calculated for the annual payments of warehouse leasing cost. The lifetime of the warehouse is taken as 50 years since it is a concrete building [63] and the lifetime of a container is taken as 25 years since they will be used as storage units.

The leasing cost is used as 0.24 m.u per m^2 each year and calculated as 366.34 m.u for the calculated warehouse area which is 1526.4 m^2. The warehouse construction cost, 229.91 m.u is taken as the PW value directly for construction option.

$$PW_{Wh\ leasing}\ (m.u.) = 366.34/(1+0{,}05)^n \tag{4.18}$$

By making the necessary calculations in Eq. (4.18) for 50 year- lifetime, the PW of leasing option is obtained as 6,687.80 m.u. By looking at these values PW value of the warehouse construction less than PW value of leasing. Note that warehouse construction cost does not include the land cost, but warehouse leasing includes both the building and the land cost.

The annual payments and the present worth values of the alternatives are given as cash flow diagrams in Figure 17. It is assumed that there will be no salvage value of the warehouse at the end of its lifetime.

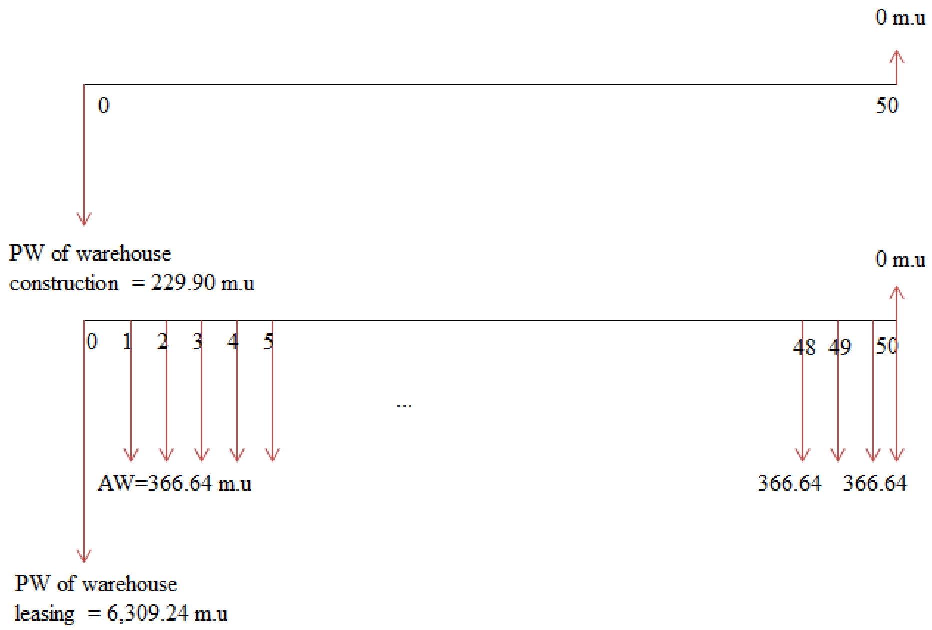

Figure 17 Cash flow diagram for warehouse leasing and construction alternatives

4.3.1.2 Analysis for container stockpiling area

The container purchasing option is compared with container leasing option. The interest rate is taken as 5% as given by TCMB [62]. By using Eq. (4.16) the PW value is calculated for container leasing for 25 year-lifetime.

$$PW_{Container\ leasing}\ (m.u.) = 345.60\,\frac{(1+0{,}05)^{50}-1}{0{,}05(1+0{,}05)^{50}} \quad (4.19)$$

Solving Eq. (4.19) for 50 year-lifetime, the PW of leasing option is obtained as 6,309.24 m.u. Since the usage life of warehouse is 50 years, the containers are replenished one time after 25 years the replenishment cost of containers added to the analysis as future worth (FW) so the calculations are made according to Eq. (4.20) and (4.21) to find the PW of container purchasing.

$$PW_{Container\ purchasing}\ (m.u.) = PW + FW\frac{1}{(1+i)^{25}} \tag{4.20}$$

$$PW_{Container\ purchasing}\ (m.u.) = 1{,}321.60 + 1{,}321.60\frac{1}{(1+0{,}05)^{25}} \tag{4.21}$$

By looking at the PW values of the container purchasing for 50 years (1,711.78 m.u) is less than the leasing PW value of containers. The annual payments and the present worth values of the alternatives are given as cash flow diagram in Figure 18. It is assumed that there will be no salvage value of the containers at the end of their lifetime.

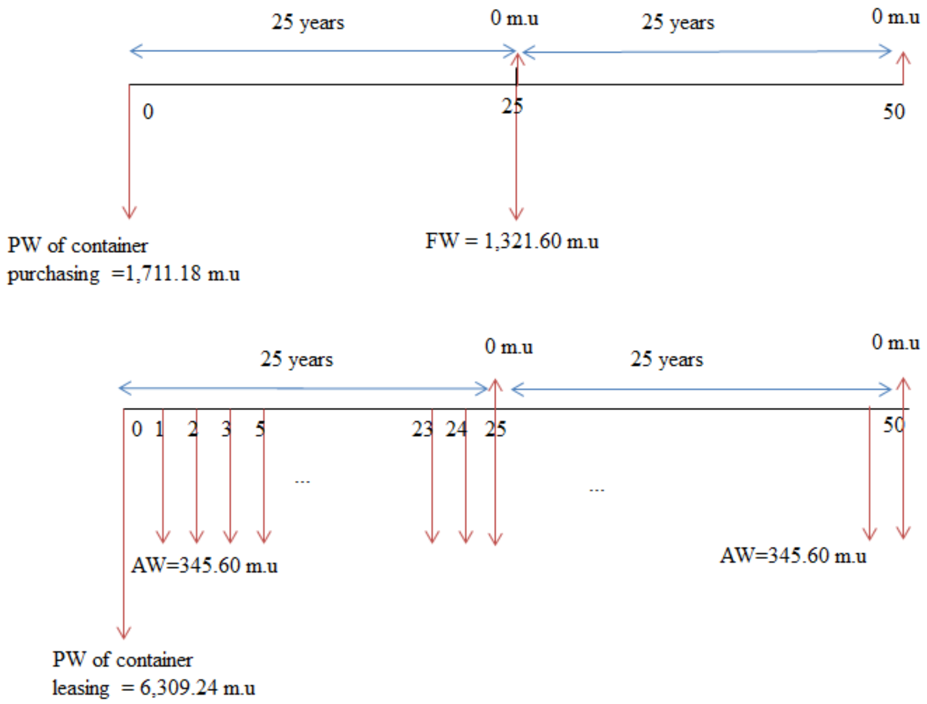

Figure 18 Cash flow diagram of container purchasing and leasing alternatives

CHAPTER 5

ENHANCEMENTS FOR PROPOSED MODELS

In this chapter some enhancements are presented in order to see the effects of changes in some parameters and experimental design for Chapters two, three and four. The results of the enhancements are presented by making comparisons with proposed models.

5.1 Enhancements for Assignment Model

In Chapter two the aim was to assign the demand points in Turkey to the pre-determined (i.e., pre-positoned) DRFs by considering the earthquake risks in terms of destruction powers. Within this context, a DRF assignment model was developed and solved for three experimental studies which are; (1) the container warehouses proposed by AFAD (Turkish Prime Ministry Disaster and Emergency Management Presidency), (2) Turkish Red Crescent warehouses, and (3) AFAD Civil Defense Search and Rescue City Directorates. Results showed the effect of earthquake risks on the assignment of demand points to the DRFs with minimum distances. In the results comparisons are made in terms of the total average destruction powers, total travelled distance and average destruction power for three cases and obserdved that Turkish Red Crescent assignments are better than the other two cases in terms of all performance measures namely total travelled distance, total average destruction power and average destruction power of (i,j) pair.

In section 5.1.1 the assignment model introduced in Chapter 3 is compared with the experimental studies. In section 5.1.2 the objective function of the assignment model is weighted with demands of demand points.

5.1.1 Enhancement for assignment model in comparison

The result of the assignment model introduced in Chapter 3 is added to comparison. The result of the model (i.e., fourth case) and the three cases are comparatively analyzed. Table 17 shows the performance measures. In the last row of the table the results of the model developed in Chapter 3 is represented as ‘fourth case’ in comparison with other experiments. As comparing with the first casethe number of DRFs are the same as it should be and the number of (*i*,*j*) pair and number of demand points served by two DRFs are less. Moreover the assignment model minimized the total travelled distance more than the first case by giving 8,819 km travelled distance which is less than also the value of 10,617 km obtained in the best case (second case) in terms of average destruction power of (*i*,*j*) pair. The total average destruction power and average destruction power of (*i*,*j*) pair values are less than the first case but more than the best case when the container locations proposed by AFAD is solved with the assignment model developed in Chapter 3.

Table 17 Comparison of The Cases According to Numerical Results After Enhancement

	(a)	(b)	(c)	(d)	(e)	(f) = (e) / (b)
Case	# of DRFs	# of (*i*,*j*) pair	# of Demand Points Served by Two DRFs	Total Travelled Distance (km)	Total Avg. Destruction Power	Avg. Destruction Power of (*i*,*j*) pair
First Case	27	59	5	10,778	60.92	1.033
Second Case	30	59	8	10,617	47.00	0.797
Third Case	11	71	1	13,997	72.71	1.024
Fourth Case	27	56	3	8,819	48.69	0.869

5.1.2 Enhancement in the objective function of assignment model

In this section the objective function is weighted with the demand amounts of demand points as

$$min \sum_{i \in C} \sum_{j \in T} K_j D_{ij} x_{ij} \quad (5.1)$$

K_j is 2012 population of each city as given in Chapter 2 and on Table 6. That is taken as the demand of the cities. The results are obtained for the second case is shown in Table 18.

Table 18 The Obtained Results After The Enhancement in the Objective Function of The Assignment Model

Disaster Response Facilities	Covered Demand Points	Distance between (*i*,*j*) pairs	Avg, Destruction Power between (*i*,*j*) pairs	Total Number of Covered Demand Points	Disaster Response Facilities	Covered Demand Points	Distance between (*i*,*j*) pairs	Avg, Destruction Power between (*i*,*j*) pairs	Total Number of Covered Demand Points
Adana	Mersin	69	0.37	4	Hatay	Kilis	147	1.21	1
	Nevşehir	287	0.31		Isparta	Antalya	130	0.51	2
	Niğde	205	0.31			Burdur	51	0.51	
	Kilis	223	0.37		İstanbul	Edirne	230	1.27	2
Afyon	Bilecik	210	0.31	3		Tekirdağ	132	2.3	
	Konya	223	0.37		İzmir	Aydın	126	1.4	2
	Karaman	336	0.37			Çanakkale	325	0.37	
Ağrı	Iğdır	143	1.27	1	Kastamonu	Çorum	195	1.11	2
Ankara	Çankırı	131	0.37	4		Sinop	183	0.67	
	Kırşehir	184	0.23		Kocaeli	Bilecik	136	2.61	1
	Aksaray	225	0.17		Manisa	Balıkesir	137	0.81	2
	Kırıkkale	75	0.23			Bilecik	381	0.31	
Bolu	Bilecik	213	0.61	2	Muğla	Burdur	241	0.51	2
	Karabük	134	0.67			Uşak	295	0.51	
Bursa	Bilecik	95	1.21	1	Muş	Bitlis	83	0.51	3
Denizli	Burdur	150	0.51	2		Siirt	180	0.31	
	Uşak	150	0.51			Şırnak	275	0.51	
Diyarbakır	Bingöl	144	0.81	3	Rize	Artvin	159	0.23	3
	Mardin	95	0.31			Bayburt	252	0.31	
	Batman	100	0.31			Ardahan	268	0.23	
Elazığ	Artvin	544	0.67	2	Sakarya	Bilecik	99	2.61	3
	Malatya	98	0.37			Kırklareli	359	0.37	
Erzincan	Bayburt	153	2.61	1		Bartın	272	0.37	
Erzurum	Gümüşhane	203	2.61	3	Sivas	Kayseri	195	0.67	2
	Kars	203	0.51			Yozgat	224	0.61	
	Bayburt	125	0.31		Tokat	Amasya	114	1.11	1

Eskişehir	Kütahya	78	1.27	1		Giresun	137	0.23	
	Adıyaman	150	0.31		Trabzon	Ordu	181	0.23	3
	Kahramanmaraş	80	0.17			Samsun	333	1.27	
Gaziantep	Tunceli	480	0.31	5	Van	Hakkari	202	1.41	1
	Şanlıurfa	137	0.11		Yalova	Bilecik	129	1.21	1
	Osmaniye	120	0.11		Düzce	Zonguldak	114	2.67	1
	Total						**12,048**	**47.91**	

The total travelled distance is found as 12,048 km and the total average destruction power is found as 47.91 a-cm/sn^2. Few DRFs which are Kilis, Burdur, Uşak, Artvin, and Bayburt are served by two DRFs and also Bilecik is served by six DRFs since it has lower demand with respect to others. The minimum and maximum distances are 51 and 544 kms seen in between Isparta-Burdur and Elazığ Artvin. The total travelled distance has increased with respect to the result obtained in Chpater 2 and the total average destruction power has remained almost the same.

5.2 Enhancements for the Location Model

In Chapter 3 the aim was to investigate the use of containers in freight transportation by developing a mathematical model to determine the location and quantity of containers as well as the type and amount of relief supplies to store by minimizing the total travelled distance between supply and demand points. In section 5.2.1 the enchanced model determines the container and relief amounts for the proposed container locations by AFAD. In section 5.2.2 the objective function of the previous model is changed as minimizing the transportation and land costs.

5.2.1 Enhancement for container locations proposed by AFAD

AFAD selected 27 container locations to store the relief items in containers. In this part the developed model in Chapter 3 is run given the selected container locations and the the amounts of containers and relief items are obtained. The results are presented in Table 19.

Table 19 Assignment of Demand Points to Supply Points After Enhancement

Plate code	Supply points	Normalized dest. power	# of Assigned container	Assigned demand points	Distance between supply and demand point	Avg. dest. power between supply and demand point
1	Adana	0.137	76	Hatay	191	1.41
				Mersin	69	0.37
				Niğde	205	0.31
				Nevşehir	287	0.31
2	Adıyaman	0.137	88	Gaziantep	150	0.31
				Kahramanmaraş	164	0.37
				Yalova	1162	1.41
3	Afyon	0.137	99	Eskişehir	144	0.37
				Konya	223	0.37
				Kütahya	100	1.41
7	Antalya	0.137	56	Burdur	122	0.51
				Isparta	130	0.51
				Samsun	954	1.41
10	Balıkesir	0.249	117	Bursa	151	1.70
				Manisa	137	0,81
			…			
68	Aksaray	0.062	6	Kırşehir	110	0.17
71	Kırıkkale	0.085	6	Kırşehir	113	0.23
77	Yalova	0.474	47	Kocaeli	65	3.70
81	Düzce	1	8	Bolu	45	3.10
		Total	**2003**		**34327**	**74.37**

In Table 19, the first and second columns show the city plate codes and 27 container locations (i.e., supplier cities). The third column is the corresponding normalized destruction powers of supply points. The fourth and the fifth columns depict the assigned container quantity and demand points to the supply points, respectively. On the sixth and seventh columns, the distance and average destruction powers are given between demand and supply points, respectively. For instance, Adana servs five demand points, namely Hatay, Mersin, Niğde, Gaziantep and Nevşehir, which are its neighbors. The nearest and the furthest demand points are Mersin and Nevşehir, respectively. Adana has 76 containers to supply one of these demand points after an earthquake. The maximum numbers of containers (i.e., 399) in a city is stored in Kocaeli to supply İstanbul after an earthquake. The minimum number of container (i.e., 0) in a city is stored in Kahramanmaraş. The total travelled distance between supply points and demand points is 34,327 km and the total average destruction power is 74.37 a-cm/sn^2.

The number of containers, number of (*i*,*j*) pairs, total travelled distance increased and the total average destruction power between supply points and demand points decreased as compared to the results presented in Chapter 3 as given in Table 20. The number of containers remains almost the same as in Chapter 3. Decreased number of container locations increases the management and security performance of container locations but in this assignment few supply points are assigned to far cities because of the average destruction power constraint. This situation can be reorganized by making swapping in the assignments.

Table 20 Comparison of Results Obtained in Chapter 3 and Enhancement

	# of container locations	# of (*i*,*j*) pairs	# of Assigned container	Total travelled distance	Total avg. dest. power
Chapter 3	47	86	2,049	10,702	81.61
Enhancement	27	83	2,003	34,327	74.37

5.2.2 Enhancement for the objective function of the location model

In Chapter 3 the objective is determining the locations of supply points using certain number of containers and relief supplies assigned to each supply point by satisfying the demand while traveling the minimum distance in order to quickly respond to the immediate needs of beneficiaries. The objective function of the mixed-integer programming model is minimizing the total distance travelled between the supply and demand points.

Here, the objective function is changed as the minimization of transportation and land costs. The land cost of per meter square for each city is taken from GIB (Revenue Administration) for barren land by taking the average of each distinct's per meter square cost in order to obtain a weighted cost for city center [63]. The barren lands are chosen especially because the containers will be only stocked on the lands that are not convenient for agriculture. Table 21 shows the calculated land costs of each city.

Table 21 Average Land Costs of Each Cities

Plate Code	City	Average land cost (TL/m^2)	Plate Code	City	Average land cost (TL/m^2)
1	Adana	0.64	42	Konya	0.25
2	Adıyaman	0.25	43	Kütahya	0.52
3	Afyon	0.58	44	Malatya	0.16
4	Ağrı	0.18	45	Manisa	0.61
5	Amasya	0.43	46	Kahramanmaraş	0.42
6	Ankara	1.25	47	Mardin	0.36
7	Antalya	0.70	48	Muğla	0.69
8	Artvin	2.25	49	Muş	0.25
9	Aydın	0.11	50	Nevşehir	0.21
10	Balıkesir	0.68	51	Niğde	0.78
11	Bilecik	0.28	52	Ordu	0.38
12	Bingöl	0.29	53	Rize	1.70
13	Bitlis	0.41	54	Sakarya	1.93
14	Bolu	0.48	55	Samsun	0.36
15	Burdur	0.37	56	Siirt	0.22
16	Bursa	0.56	57	Sinop	0.56
17	Çanakkale	0.53	58	Sivas	0.19
18	Çankırı	0.52	59	Tekirdağ	0.51
19	Çorum	0.46	60	Tokat	0.26
20	Denizli	0.24	61	Trabzon	0.05
21	Diyarbakır	0.25	62	Tunceli	0.14
22	Edirne	0.83	63	Şanlıurfa	0.68
23	Elazığ	0.56	64	Uşak	0.20
24	Erzincan	0.27	65	Van	0.41
25	Erzurum	0.06	66	Yozgat	0.08
26	Eskişehir	0.40	67	Zonguldak	1.71
27	Gaziantep	0.05	68	Aksaray	0.35
28	Giresun	1.20	69	Bayburt	0.24
29	Gümüşhane	0.27	70	Karaman	0.35
30	Hakkari	1.55	71	Kırıkkale	0.18
31	Hatay	0.21	72	Batman	0.52
32	Isparta	0.44	73	Şırnak	0.29
33	Mersin	0.31	74	Bartın	0.37
34	İstanbul	2.10	75	Ardahan	0.10
35	İzmir	2.20	76	Iğdır	0.36
36	Kars	0.15	77	Yalova	0.96
37	Kastamonu	0.60	78	Karabük	0.33

38	Kayseri	0.04	79	Kilis	0.36
39	Kırklareli	0.33	80	Osmaniye	0.68
40	Kırşehir	0.16	81	Düzce	0.71
41	Kocaeli	2.90			

In the first and fourth columns of the table the plate codes are given and the potential supply point names are in the second and fifth columns. In the third and sixth columns the land costs in TLs are given per one meter square land. Kayseri has the least land cost whereas Kocaeli has the most land cost for per meter square land. The land cost is added as the new parameter for the model as;

$\boldsymbol{L_i}$: Land cost of supply point *i* to stack containers

The transportation cost is determined based on diesel fuel price of the tractor-trailer since the containers would be transported via tractor-trailers. On 14.04.2014, diesel fuel price was between 4 and 5 TL per liter so the price is taken 4,5 TL/lt as the average of 4 and 5. A trailer can take 100 km with 24 liter diesel fuel. Then for to travel one km a trailer will cost on average:

$$Average\ transportation\ cost\ for\ 1\ km = \frac{1}{100\ km} * 24\ lt * 4{,}5\ TL/lt = 1{,}08\ TL/km \tag{5.1}$$

The distances between potential supply and demand points are converted to transportation cost using Eq. (5.1). The transportation cost is added as the new parameter for the model as;

$\boldsymbol{C_{ij}}$**:** Transportation cost between supply point *i* and demand point *j*

The containers are stacked on land as much as three containers high, so all of the container number covers one-third of land. One container covers 30 m^2 land and 20 m^2 land is saved. Therefore the number of assigned container is multiplied with 10 instead of 30.

After adding the new parameters the objective function of the mathematical model is updated as

$$\min z\ \sum_i \sum_j C_{ij} x_{ij} + L_i (a_i * 10) \tag{5.2}$$

where

$$x_{ij} = \begin{cases} 1 & if\ demand\ point\ j\ is\ covered\ by\ supply\ point\ i \\ 0 & otherwise \end{cases}$$

$$a_i = number\ of\ containers\ assigned\ to\ supply\ point\ i$$

The objective function Eq.(5.2) minimizes the total transportation cost and land costs of potential supply points. The constraints of the mathematical model remain the same as the model developed in Chapter 3. The assignment result of the model is given in Table 22.

Table 22 Assignment Result of The Model After Changing The Objective Function

Plate code	Supply points	Normalized dest. Power	# of Assigned container	Assigned demand points	Distance between supply and demand point	Cost of transportation between supply and demand point	Avg. dest. power between supply and demand point
1	Adana	0.137	42	Mersin	69	74.52	0.37
				Niğde	205	221.40	0.31
				Karaman	289	312.12	0.37
2	Adıyaman	0.137	82	Osmaniye	85	91.80	0.31
				Gaziantep	150	162	0.31
				Şanlıurfa	110	118.80	0.31
3	Afyon	0.137	214	Ankara	256	276.48	0.37
				Eskişehir	144	155.52	0.37
				Konya	223	240.84	0.37
				Kütahya	100	108	1.41
5	Amasya	0.249	52	Çorum	92	99.36	1.11
				Samsun	131	141.48	1.70
8	Artvin	0.085	4	Rize	159	171.72	0.23
9	Aydın	0.249	64	Manisa	156	168.48	0.81
				Muğla	99	106.92	0.81
10	Balıkesir	0.249	92	Bursa	151	163.108	1.70
				Çanakkale	200	216	0.81
				...			
71	Kırıkkale	0.085	6	Kırşehir	320	345.60	0.23
73	Şırnak	0.137	17	Hakkari	189	204.12	0.51
				Siirt	95	102.60	0.31
77	Yalova	0.474	47	Kocaeli	65	70.20	3.70
78	Karabük	0.085	5	Bartın	87	93.96	0.23
81	Düzce	1.000	8	Bolu	45	48.60	3.10
				Total	**11,491**	**13,745.16**	**70.08**

In Table 22, the first and second columns show the city plate codes and the cities as being supply points. The third column is the corresponding normalized destruction powers of supply points. The fourth and fifth columns depict the assigned container quantity and demand points to the supply points, respectively. On the sixth and seventh columns, the distance and average destruction powers are given between demand and supply points, respectively. For instance, Adana servs four demand points, namely Mersin, Niğde, Karaman and Osmaniye, which are its neighbors. Over 81 potential supply points the model opens 48 supply points assigning 2034 containers to 88 demand points and servs five demand points two times and two demand points three times. The total travelled distance, 11,491 km, and the total average destruction power between supply and demand points, 70,08 m/sn^2 are fewer than the objective function value of the previous model in Chapter 3. The total cost of transportation and land is found as 22,975.79 TL with Eq. (5.2). If the land cost is calculated for the result in Chapter 3, it is found as 16,408.2 TL and the total transportation cost for Chapter 3 is calculated as 11,558.16 TL. The total cost for Chapter 3 is found as 27,966.36 TL. The total number of containers and the supply points are very close to the results obtained in Chapter 3. The supply point locations are different since the model minimizes the land costs of supply points and chooses the locations with minimum land costs as possible. The cities having less land cost are chosen by the model in order to minimize total cost.

5.2.3 Multiobjective location model using weighted sums method

In this part of the analysis the objective function of the location model proposed in chapter three is changed as multiobjective considering minimization of total average destruction power as well as total distance between supply and demand points. The new objective function takes place as in Eq. (5.3) where $0 < w_1 < 1$ and $0 < w_2 < 1$ are the weights ensuring $w_1 + w_2 = 1$.

$$\min z \ \sum_i \sum_j (w_1 D_{ij} + w_2 R_{ij}) x_{ij} \tag{5.3}$$

Two different objective values are minimized in one objective function using weights. Table 24 illustrates the results for some different combinations of weights. When the weight of the first objective function decreases the total travelled distance increases. In all of the alternative solutions there are 81 (i,j) pairs because each demand point assigned to one supply point. The number of supply points change in [46-59] range and the number of containers assigned to each supply point is the same, 1645.

Table 23 Different Combinations of Weights and The Corresponding Results

Run #	Weight		Total Distance Travelled	Total Average Dest. Power	# of (*i,j*) pair	# of supply points
	w1	w2				
1	0.4	0.6	7,624	69.79	81	58
2	0.2	0.8	7,566	62.35	81	57
3	0.083	0.917	7,567	62.15	81	57
4	0.039	0.961	7,749	57.06	81	59
5	0.007	0.993	8,344	46.14	81	51
6	0.003	0.997	9,402	40.72	81	46

Total travelled distance achieves its worst value on the efficient frontier when total average destruction power achieves its best value, and total average destruction power achieves its smallest value on the efficient frontier when total travelled distance achieves its best value. The best values of each objective are obtained by solving model for each objective separately, and calculate the value of both objective functions in each point.

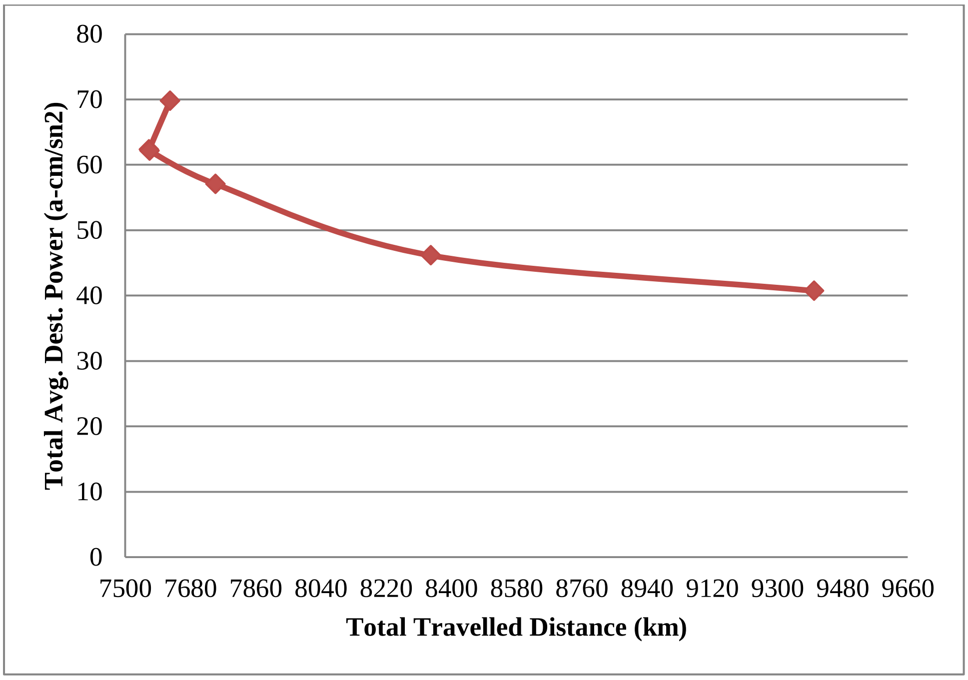

Figure 19 Efficient frontier for the solutions

An optimal solution to a multiobjective problem comes from the efficient frontier that includes the set of all efficient solutions. The efficient frontier for this model is given in Figure 19.

As depicted in Figure 19 the total travelled distance is increasing when the total average destruction power decreases. As the average destruction power is given greater relative weight, activity shifts to the longer total distances. Using weighted sum method ensures an efficient solution. From Table 24 and Figure 19 it is decided that the result obtained as the second run is selected as the best multiobjective solution for our problem. The visual representation of the results on Turkey map is given in Figure 20. By looking the map it can be said that the dispersion of the supply points is smoother than the result obtained in Chapter 3. The distances between supply and demand points are closer. However there were demand points in Chapter 3 taking service from more than one supply points in previous result.

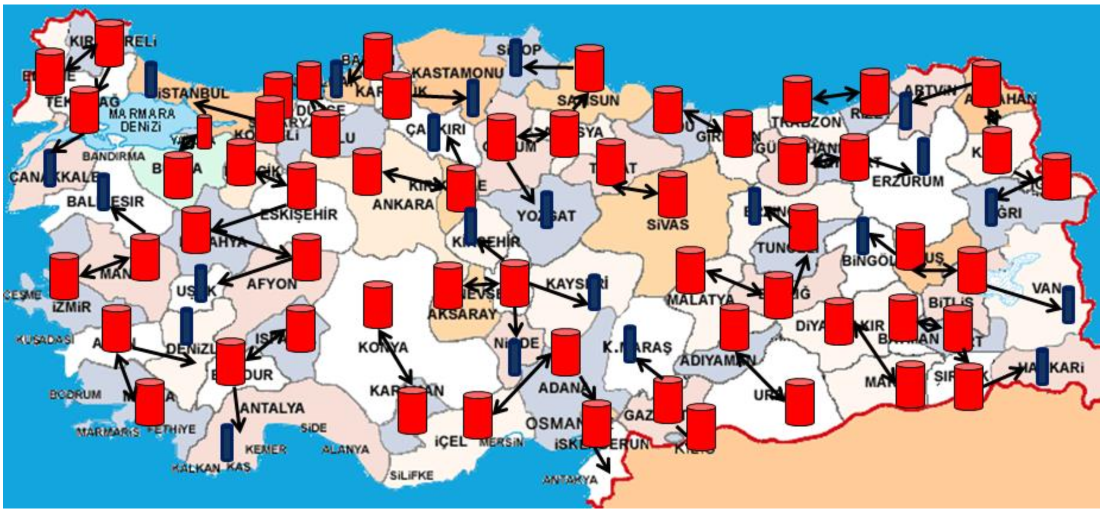

Figure 20 Visual representation of the results for multiobjective problem

The nearest and the furthest assignments are Şırnak-Hakkari and Kocaeli-Sakarya, respectively. The maximum numbers of containers (i.e., 350) in a city is stored in Kocaeli to supply İstanbul and Sakarya after an earthquake. The minimum number of container (i.e., four) in a city is stored in Gümüşhane. The total travelled distance between supply points and demand points is 7,566 km and the total average destruction power is 62.35 a-cm/sn^2 which are less than the results obtained in Chapter 3. The result obtained in this part is better than the previous model's results since it minimizes both total travelled distance and total average destruction power.

5.3 Enhancements for Cost Model

Here, sensitivity analyses are made for warehouse leasing cost and interest rate using the model in Chapter 4. In Chapter 4 the interest rate is taken as 5% to use in PW analysis. Using Eq. 16 the PW value of the warehouse leasing, container purchasing and container leasing are calculated and compared with eachother.

In Chapter 4 the leasing cost was taken as 0.24 m.u each year for per m^2 area as an average value of given information from various storage firms. In this part the leasing cost is taken as 0.48 and 0.72 m.u and the PW of warehouse leasing cost is calculated as 13,375.61 and 20,063.41 m.u respectively. As expected, an increase in the leasing cost per m^2 lead to an increase in the total cost of leasing option for the warehouse. In Figure 21 the PW values of each alternative is depicted when the warehouse leasing cost is changed. As it is depicted on Figure 21 when the leasing cost is 0,24 m.u per m2 per year the PW value is close to PW value of container leasing but when it is increased it moves away and becomes a disadvantage in terms of cost. The best alternative is warehouse construction and then container purchasing and then container leasing and the worst alternative is warehouse leasing by looking their PW values.

When the interest rate used in PW analysis is changed as 10% the PW values of the alternatives are depicted as given in Figure 22. When the interest rate increased the PW value of each alternative decreased except PW of warehouse construction. This means that each alternative is cost advantageous when the interest rates are high. Altough warehouse construction option is again the best alternative, container purchasing alternative can be thought as the second best alternative since its cost is less than warehouse and container leasing. For the long term the leasing alternative for container and warehouse options is not cost advantageous.

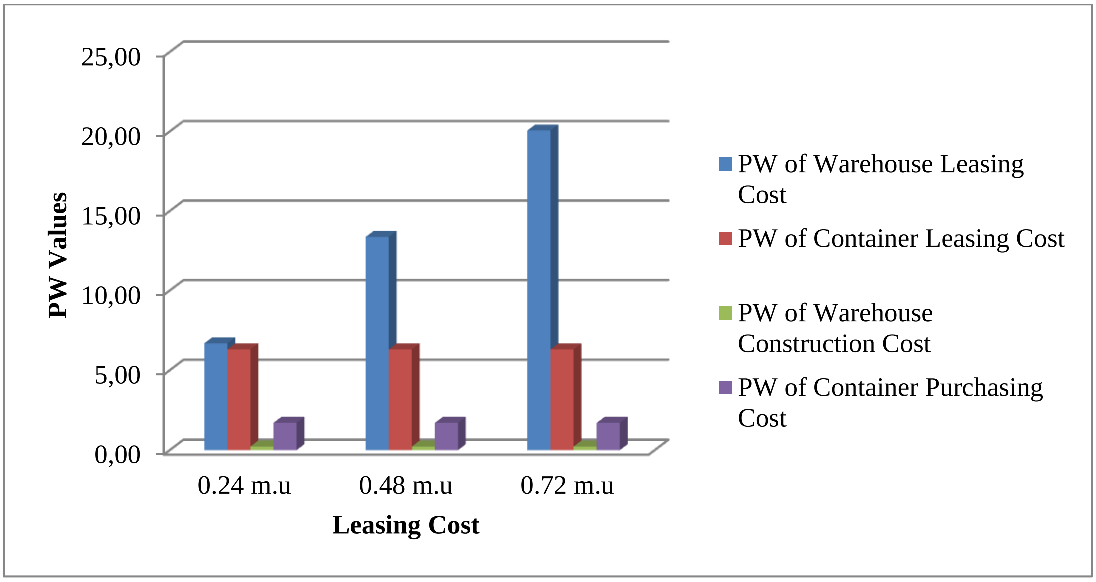

Figure 21 PW values of the alternatives according to leasing cost change

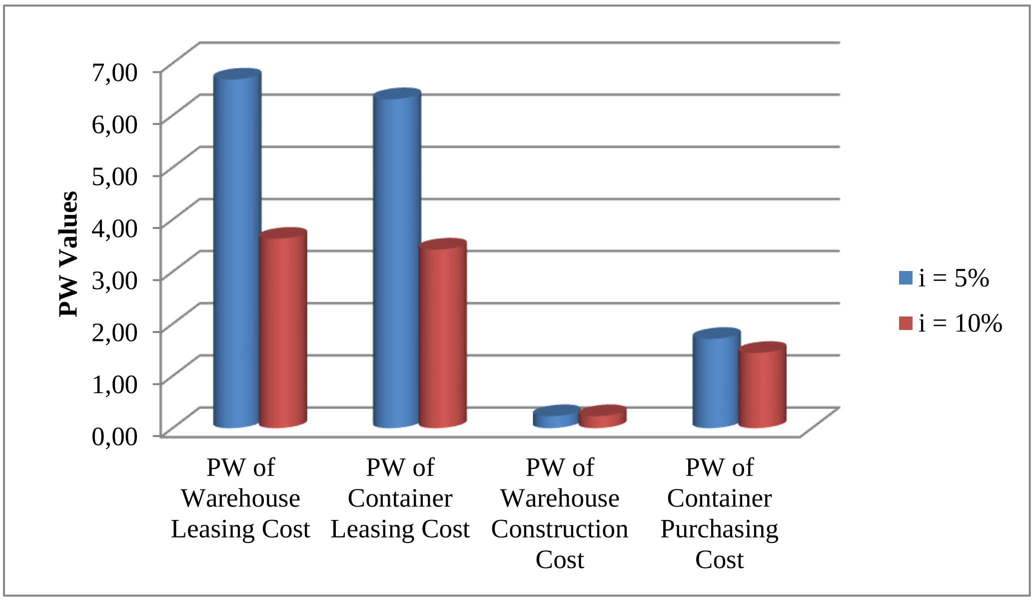

Figure 22 PW values for the alternatives in different interest rates

Figure 23 shows that the PW value of warehouse leasing cost changes when the interest rate increases from 5% to 10% and the leasing cost changes between 0,24 and 0,72 m.u. There are tangible changes in the PW value of the costs since they halved when the interest rate shifts slightly.

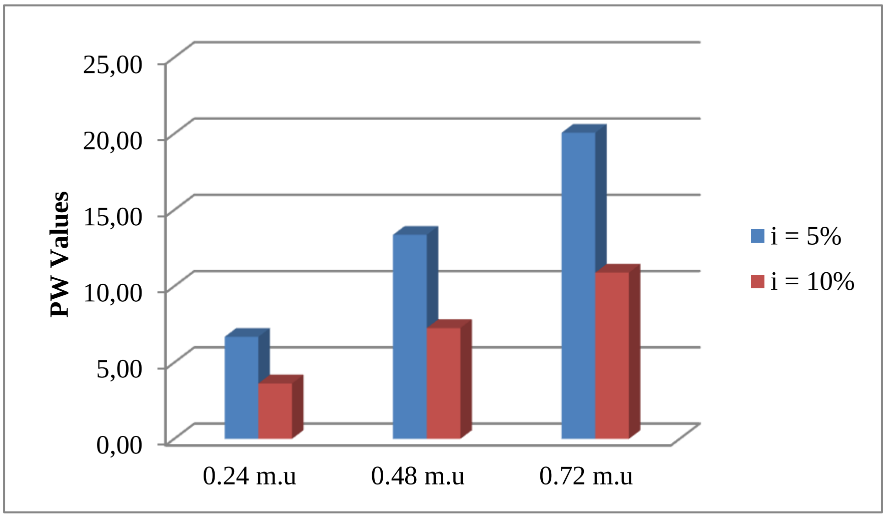

Figure 23 PW value of the warehouse leasing alternative according to different leasing costs and interest rates

As it is seen from the basic sensitivity analysis of leasing cost and interest rate there is worthwile result in PW analysis but still the most attractive alternative is constructing the warehouse if the land cost of it is not too much high.

In the PW analyses the land cost for warehouse construction, container leasing and container purchasing alternatives are not included. In order to see the effect of land cost on the PW values the land cost is valued between 1 m.u and 10 m.u and the intersection of the costs is given in Figure 24.

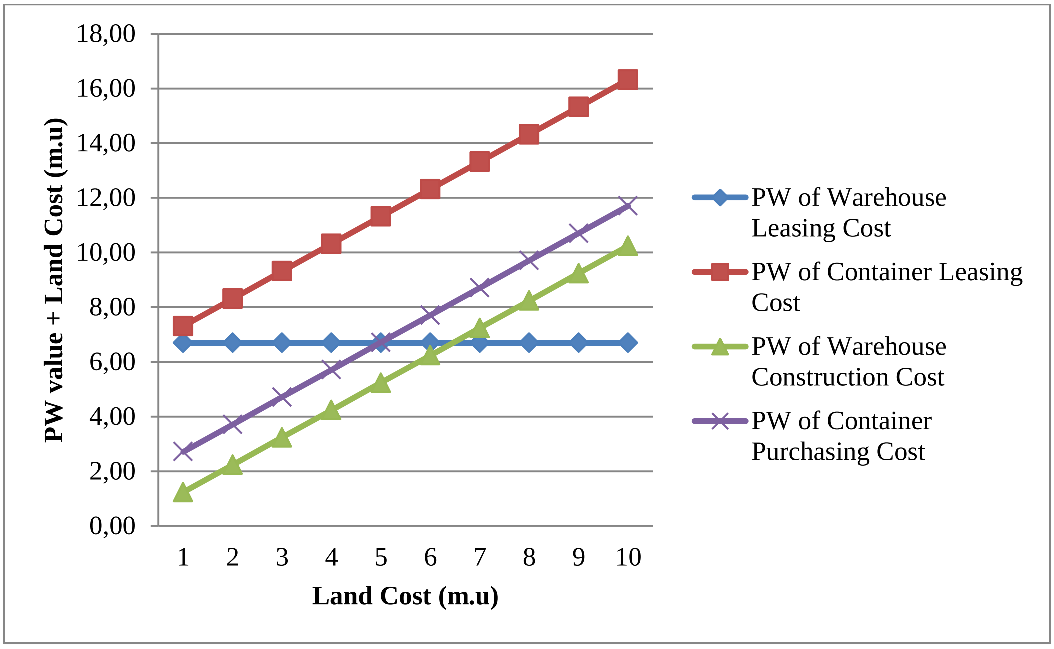

Figure 24 The intersection of the alternatives by land cost addition

As it is depicted on Figure 24, when the land cost is 5 m.u the container purchasing and when the land cost is between 6 and 7 m.u the warehouse construction alternatives have the same cost with warehouse leasing alternative. Actually the cost advantageous alternatives are firstly warehouse construction then container purchasing alternatives and after five m.u land cost the container purchasing and after almost six m.u land cost warehouse construction alternatives are not cost advantageous and warehouse leasing alternative can be benefited. Container leasing is not intersected with other cost since it has so much cost than the other alternatives.

CHAPTER 6

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

In this thesis, the objective was to determine the supply points and assignment of demand points to them with minimum total travelled distance as well as to investigate how and at what cost freight containers could be used as an inventory holding mechanism instead of a transportation unit. The pre-positioning of supply points and the assignments of demand points to these supply points is analyzed while taking into account the earthquake risks. Moreover the layout and cost structures are examined and comparative analysis of the container storage and warehouse is made.

An integer programming model is developed for the assignment problem and tested for container warehouses proposed by AFAD, Turkish Red Crescent warehouses and AFAD Civil Defense Search and Rescue City Directorates. In the results the total travelled distance, the number of served demand points by each DRF and the total average earthquake destruction power is obtained. It is observed that humanitarian relief organizations considered in experimental studies have common cities to store the relief items being unaware of the warehouse decisions of each other. It shows that those common cities are suitable to have DRFs. This also reveals that some of the factors they consider in selecting the DRF locations are the same. The assignment for Turkish Red Crescent warehouses is the best in terms of all performance measures which are total travelled distance, total average destruction powers and average destruction power per (i,j) pair.

A mixed-integer programming model is developed to determine the locations of supply points over eighty one cities, quantity of containers and relief supplies assigned to each supply point by satisfying the demand while traveling minimum distance to achieve a temporary warehousing strategy. Managerial and research implications are proposed in three aspects: selection of the container locations within the supply points, managerial operations, and the environmental planning and security of thesupply points. Since the model has not been implemented in real-life disaster relief operations, some guidelines for the practitioners and researchers for implementation is discussed. Guidelines for the practitioners and researchers for implementation can be given as follows. In any case of a disaster, some portion of the beneficiaries' needs will be available in containers, so the practitioners will not be negatively affected from price increases of the relief items in the chaotic environment of the disaster aftermath. Moreover, if the containers are located closer to the intermodal hubs, the movements of the containers would be easier. Quick mobilization of products decreases the lead time, resulting with more responsive supply chains.

The temporary warehouse idea will be advantageous if the container cost is low and the material handling requirement is less. In order to investigate how and at what cost freight containers could be used as an inventory holding mechanism instead of their regular use as transportation units, the comparison of the use of traditional warehouse alternative and the use of containers as storage units alternatives. Layout and PW analysis are used to compare leasing and purchasing options for these alternatives. Optimum layout configuration for the container stockpiling area is proposed. A comparative analysis has been made between storage in warehouses and in container stockpiling area alternatives. For this reason layout and PW analysis are made to compare leasing and purchasing options for these alternatives. In the layout analysis, it is seen that container stockpiling area uses less area to stock the same amount of pallets than the warehouse. The total cost of storing the same amount of pallet is much less in container stockpiling area than the warehouse. In the PW analysis for the container stockpiling area alternative is tested with two options one is leasing containers the other is purchasing containers. When these two options are compared, it is seen that the managers should purchase containers if they are used long years. When the leasing option of containers is compared with warehouse construction option it is inferred that the managers should construct the warehouse instead of leasing if they will use for long years. For the container purchasing option it is deduced that the managers may choose container purchasing if they want to be more resilient against disruptions and quicker in transportation, despite container purchasing is more expensive than warehouse construction. However the warehouse construction does not include the land cost so if the land cost added the container purchasing option may be more cost advantageous. Nevertheless it can be concluded that leasing option is not cost advantageous in the long run for both options. Warehouse construction results with the least cost but it requires more area than a container stockpiling area. Moreover, a traditional warehouse incurs more operating costs including lighting, ventilation, and maintenance as well as handling of the pallets. In the stockpiling area, operating costs such as lighting is also incurred, but roof maintenance is not needed. The handling of pallets within containers using crane is cheaper than the warehouse handling since the container takes 25 pallets and they are handled at once.

Proposed methodology is tested with real life data and some enhancements are made. The mixed-integer programming model developed for the location model is solved for 27 container locations proposed by AFAD and it is seen that the total travelled distance and average destruction power is decreased when compared with other experimental studies. The objective function of the mixed-integer model is changed as minimizing total cost and the model is solved. It is remarked that when the total cost decreased the total average destruction power increased. It should be noted that PW values in this analysis can change slightly with respect to the cost figures in different countries, but relative comparisons of different alternatives would not change significantly. Different interest rates and warehouse leasing cost figures are tested to check the robustness of these conclusions. It can be concluded from these experiments that these factors made a tangible difference on PW values.

In this thesis, a first step is taken in mobile pre-positioning strategy using freight containers. In future work, transportation and routing decisions of containers can be considered. This thesis can be extended by considering towns instead of cities to be supply points and the selection of storage locations within the cities can be studied. In the future, to compare the warehouse and container stockpiling area alternatives, operating cost of each alternative can be included in the total cost. Moreover the thesis can be extended by adding the replenishment strategies of available inventory in humanitarian logistics or the objective function can be weighted by amount of relief supplies transported. If it is applied this thesis will be a guide and contribution to the researchers and practitioners in operating with containers to response in shorter time and on warehouse design problem with a novel idea of using containers as storage units instead of transportation unit.

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APPENDICES A

CURRICULUM VITAE

PERSONAL INFORMATION

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EDUCATION

Degree	**Institution**	**Year of Graduation**
B.Sc.	Çankaya Univ., Industrial Engineering	2011
High School	Sinop Anatolian Teacher High School	2007

WORK EXPERIENCE

Year	**Place**	**Enrollment**
2012- 2014	Çankaya Univ. Industrial Engineering Department	Expert
2011-2012	KOÇSİSTEM-Callus	Expert

FOREIN LANGUAGES

Advanced English, Beginner German

PUBLICATIONS

1. Elevli B., Ak B. Şahin A. "Sandalye Üretimi Yapan Bir Kobi'nin İş Süreçlerini Belirleme ve İyileştirme Çalışması", YAEM 2012, Dogus University, İstanbul
2. Şahin A., Ertem M.A., Emür E., "Using Containers as Storage Facilities in Humanitarian Logistics", Journal of Humanitarian Logistics and Supply Chain Management (JHLSCM), 2014 (in press)
3. Şahin-Arslan., Ertem M.A., "İnsani Yardım Lojistiğinde Konteyner Kullanımı", YAEM 2014, Uludağ University, Bursa

PROJECTS

1. İntermodal Yük Taşımacılığı Ile Sürdürülebilir İnsani Yardım Lojistiği, Project Number: 113M493, Tubitak 3501 Career Project, 2013-2015.

HONOURS AND AWARDS

1. Graduate High Honor Student 2011
   Çankaya University

HOBBIES

Travelling, reading, technology, cinema and art