A DECISION SUPPORT SYSTEM FOR SHELTER SITE SELECTION WITH GIS INTEGRATION: CASE FOR TURKEY

A THESIS
SUBMITTED TO THE DEPARTMENT OF INDUSTRIAL ENGINEERING
AND THE GRADUATE SCHOOL OF ENGINEERING AND SCIENCE OF BILKENT UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

by
Fırat Kılcı
June 2012

I certify that I have read this thesis and that in my opinion it is full adequate, in scope and in quality, as a dissertation for the degree of Master of Science.

Assoc. Prof. Bahar Y. Kara (Advisor)

I certify that I have read this thesis and that in my opinion it is full adequate, in scope and in quality, as a dissertation for the degree of Master of Science.

Assoc. Prof. Burçin Bozkaya (Co-Advisor)

I certify that I have read this thesis and that in my opinion it is full adequate, in scope and in quality, as a dissertation for the degree of Master of Science.

Assoc. Prof. Osman Alp

I certify that I have read this thesis and that in my opinion it is full adequate, in scope and in quality, as a dissertation for the degree of Master of Science.

Asst. Prof. Muhittin Hakan Demir

Approved for the Graduate School of Engineering and Science

Prof. Dr. Levent Onural
Director of the Graduate School of Engineering and Science

ABSTRACT

A DECISION SUPPORT SYSTEM FOR SHELTER SITE SELECTION WITH GIS INTEGRATION: CASE FOR TURKEY

Fırat Kılcı

M.S. in Industrial Engineering

Supervisor: Assoc. Prof. Bahar Y. Kara

Co-Supervisor: Assoc. Prof. Burçin Bozkaya

June 2012

In this study, a methodology for locating shelter sites after a disaster is developed. Currently, in Turkey, Turkish Red Crescent is responsible for selecting the location of shelter areas. First, they identify the candidate shelter site locations. Then, they rank those locations by using a weighted average function composed of eleven criteria and whenever there is an emergency, they utilize the locations with the highest ranking until there is enough space to house the affected population. To improve Turkish Red Crescent's methodology, a mathematical model that selects the best possible combination of shelter sites from a set of candidate locations, controls the utilization of those sites and assigns every district to its closest shelter site is developed. The mathematical model is implemented with a decision support system. The decision support system, which is developed in C#, is an ArcGIS extension that uses Gurobi optimization software. With the decision support system, the user is able to solve the problem, obtain an initial solution, edit the solution and view the solution on the map that is generated by ArcGIS. To test the model with a greater data set, a sample data based on the Asian side of Istanbul is used.

ÖZET

ÇADIRKENT LOKASYON SEÇİMİ İÇİN CBS İLE ENTEGRE BİR KARAR DESTEK SİSTEMİ: TÜRKİYE ÜZERİNDE UYGULAMA

Fırat Kılcı
Endüstri Mühendisliği Yüksek Lisans
Tez Yöneticisi: Doç Dr. Bahar Y. Kara
Eş-Tez Yöneticisi: Doç. Dr. Burçin Bozkaya
Haziran 2012

Bu çalışmada, afet sonrası çadırkent lokasyonlarının belirlenmesi için bir yöntem geliştirilmiştir. Mevcut durumda Türkiye'de çadırkent lokasyonlarının seçiminden Türk Kızılayı sorumludur. Bunun için, öncelikle çadırkent aday lokasyonları belirlenmektedir. Daha sonra, bu lokasyonlar on bir kriterden oluşan bir ağırlıklı ortalama fonksiyonu kullanarak sıralanmakta ve acil bir durum meydana geldiğinde, afetten etkilenmiş bütün nüfusa barınak sağlayacak yeterli alan oluşana kadar en iyi lokasyonlar kullanıma sokulmaktadır. Türk Kızılayı'nın bu çözüm yöntemini iyileştirmek için, bir aday lokasyon kümesi içinden mümkün olan en iyi çadırkent alanı kombinasyonunu seçen, bu alanların kullanımını kontrol eden ve her mahalleyi ona en yakın çadırkente atayan matematiksel bir model geliştirilmiştir. Bu matematiksel model, bir karar destek sistemi ile uygulamaya geçirilmiştir. C#'ta geliştirilen karar destek sistemi, Gurobi optimizasyon yazılımını kullanan bir ArcGIS eklentisidir. Bu karar destek sistemi ile kullanıcı problemi çözme, bir başlangıç çözümü elde etme, bu çözümü düzenleme ve ArcGIS tarafından oluşturulan harita üzerinde görme imkânına sahiptir. Modeli daha büyük bir veri grubu ile test etmek için, İstanbul'un Anadolu yakası baz alınarak elde edilen örnek veri kullanılmıştır.

ACKNOWLEDGEMENT

I would like to express my gratitude to Assoc. Prof. Bahar Yetiş Kara and Assoc. Prof. Burçin Bozkaya for their guidance and support during my graduate study. They have supervised me with everlasting patience and encouragement throughout this thesis. I can consider myself lucky to have a chance to work with them.

I am also grateful to Assoc. Prof. Osman Alp and Asst. Prof. Muhittin Hakan Demir for accepting to read and review this thesis. Their comments and suggestions have been invaluable.

I also would like to express my deepest gratitude to my mother Nilgün Kılcı and my father Serdar Kılcı for their love, support and trust at all stages of my life and especially during my graduate study. I can consider myself very lucky to be their child.

I am also grateful to Emre Uzun, who has always been like a brother to me and my beloved Bengisu Ilgıt for their morale support, patience, and encouragement.

Also, I would like to thank to my precious friends and officemates Feyza Güliz Şahinyazan, Görkem Özdemir, Serasu Duran, Sertalp Bilal Çay, Pelin Çay, İrfan Mahmutoğulları, Haşim Özlü, Okan Dükkancı, Bengisu Sert, Başak Yazar, Gizem Özbaygın, Nur Timurlenk, Meltem Peker, Halenur Şahin, Kumru Ada, Hatice Çalık and Ece Demirci for their moral support and for making my graduate life bearable and enjoyable.

Finally, I would like to acknowledged financial support of The Scientific and Technological Research Council of Turkey (TUBITAK) for the Graduate Study Scholarship Program.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

Introduction

Humanitarian logistics is a sub topic of logistics that focuses on providing relief goods, such as food, shelter, blankets to individuals or to the temporary shelters that are built after the disaster, evacuating the affected people from the disaster area, selecting the location of temporary shelter areas and optimizing the supply chain of relief materials. According to Aslanzadeh et al. [1], as large amounts of cash are spent in the disaster relief and the number of disaster victims increase from year to year, it is imminent to plan the humanitarian operations.

Tomasini and Wassenhove [2] define the three principles of humanitarian logistics. They are defined as humanity, neutrality and impartiality where humanity implies it should not matter where the disaster occurs and relief should be provided wherever the human suffering is, neutrality suggests that operations should be done without bias to a group of people, party or any nation and impartiality indicates that discrimination should not be made in relief operations and priority should be given to the ones who have relatively urgent needs.

Shelter areas are established to house the affected population after a disaster such as tornados and earthquakes. Since they are related to the relief of the society, the problem of choosing the location of shelter areas can be pointed out as a branch of humanitarian logistics.

In this study, the problem of selecting location of the temporary shelter areas is addressed. Selecting the location of such areas is a multi-criteria problem as they need to be close to the affected population, health institutions, roads and they should be established on areas that are suitable for construction. The aim of this thesis is to develop a mathematical model that decides on the location of the temporary shelter areas and construct a decision support system that implements the mathematical model.

In the next chapter, disasters and their types are defined, the historical data on the disasters in Turkey are provided. In Turkey, the Turkish Red Crescent is responsible for choosing the shelter sites after a disaster. Thus, Chapter 2 is concluded by providing brief information about the Turkish Red Crescent

In Chapter 3, the role and the standards of temporary shelter areas are defined. Then, the implementation of these standards by the Turkish Red Crescent and their methodology on choosing the shelter sites are explained. Chapter 3 is concluded by defining the problem which is addressed in this study.

In Chapter 4, the literature on the location problems in disaster relief, namely i) emergency medical center location problem, ii) relief material warehouse location problem, iii) shelter site location problem, and the contributions of this study is discussed.

In Chapter 5, a mathematical model that addresses the problem is developed. The mathematical model is a mixed integer linear programming model that selects the best combination of shelter areas, assigns population to those areas and controls their utilization.

In Chapter 6, results of the experiments that are conducted using the mathematical model posed in Chapter 5 are discussed. For the experiments, a real data set based on Istanbul, Kartal is used and the behavior of the mathematical model is observed by varying the parameters.

In Chapter 7, a decision support system that implements the mathematical model that is posed in Chapter 5 is explained. The intended user of this decision support system is the Turkish Red Crescent and with this decision support system, the user is able to solve the problem with a set of parameters of his/her choice, view the solution on a map, edit the solution and compare a set of solutions.

In Chapter 8, the performance of the mathematical model is discussed. In Chapter 6, computational studies are performed with a relatively small dataset. Thus, in Chapter 6, the performance of the mathematical model is tested on a dataset based on the Asian side of Istanbul and results are presented. In Chapter 9, the thesis is concluded by briefly summarizing the work performed in this thesis.

Chapter 2

Disasters in Turkey and Turkish Red Crescent

2.1. Disasters

Throughout the literature, several different definitions of disaster are made. In 2005, Landesmann defined disaster as "an emergency of such severity and magnitude that the resultant combination of deaths, injuries, illnesses, and property damages cannot be effectively managed with routine procedures of resources. These events can be caused by nature, equipment malfunction, human error, or biological hazards and diseases." [1].

Also, United Nations Department of Humanitarian Affairs (UNDHA) defined disaster as "a serious disruption of the functioning of the society, causing widespread human, material, or environmental losses that exceed the ability of affected society to cope using only its own resources." [1].

On the other hand, International Federation of Red Cross and Red Crescent Societies (IFRC) defined disaster as "a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community's or society's ability to cope using its own resources." [3]

Another disaster definition is made by Wassenhove [4], that is, "a disruption that physically affects a system as a whole and threatens its priorities and goals".

No matter how it is defined, it is obvious from those definitions that a disaster results a malfunction in a society's mechanism. One of the main components of a society is the people that live in that society. Thus, disaster is an occurrence that affects people. So, any recovery process from a disaster can be classified as human related, or humanitarian.

According to International Federation of the Red Cross and the Red Crescent (IFRC) there are two main types of disasters. These are "natural hazards" and "technological or man – made hazards".

Natural hazards are naturally occurred phenomena which can be caused by slow or rapid onsets. Geophysical activities (earthquakes, landslides, tsunamis and volcanic activities), hydrological activities (avalanches and floods), climatological activities (extreme temperatures, drought and wildfires), meteorological activities (cyclones and storms/wave surges) and biological activities (disease epidemics and insect/animal plagues) can be classified as natural hazards.

Technological or man – made hazards are events that are caused by humans and they usually occur in or near urban zones. Complex emergencies/conflicts, famine, displaced populations, industrial accidents and transport accidents lies in this category.

Wassenhove [4] makes another classification of disasters which is based on the occurrence of the disaster (slow or sudden) and the source of the disaster (natural or man-made). The classification can be found in the figure below.

	Natural	Man-made
Sudden-onset	Earthquake Hurricane Tornadoes	Terrorist Attack Coup d'Etat Chemical leak
Slow-onset	Famine Drought Poverty	Political Crisis Refugee Crisis

Figure 2-1 The Types of Disasters [4]

Furthermore, another classification is made by Siroya and Joshi. They classified disasters according to the relief operations after it occurs. This classification is often referred to as "supply chain based classification" and is as follows;

- Evacuation and rescue: Disasters which need taking people away from affected area to a safer place after the occurrence are in this category. Cases of this category can be a localized disaster with short impact time, pre-disaster evacuation, transfer of people from an area that a disaster occurred and prone to further damage and quick hospitalization of victims.
- Relief related resource deployment: This category includes disasters that need sending supplies and skilled manpower to the affected area in order to keep area quarantined or until the recovery is completed. This category includes disasters such as epidemics, tsunamis, pandemics and quarantines. [1]

2.2 Disasters in Turkey

Turkey is among the countries that are vulnerable to natural disasters. Throughout the history, many destructive disasters have occurred in the geography where Turkey is located. Because of this, disaster is considered as a significant issue in the society and can be counted as one of the main fears of Turkish people.

Although disasters are high frequency occurrences in Turkey, its type is mainly limited to earthquakes, landslides, floods, rock falls and avalanches. According to Ozmen et. al [5], 650.654 households were destroyed because of disasters since the beginning of the 20th century. The total destruction that is caused in terms of the number of households destroyed by the disasters can be found in Table 2-1.

Type of Disaster	# of households destroyed	Percentage (%)
Earthquake	495.000	79
Landslide	63.000	10
Flood	61.000	9
Rock Fall	26.500	4
Avalanche	5.154	1
	650.654	100

Table 2-1 Number of Households Destroyed [5]

Landslides, floods, rock falls and avalanches are usually caused by excessive rainfall or snowfall. Among those disasters, floods occur more frequently and are usually with no or small death tolls. However, there are around 10 recorded earthquakes with casualties 1000 or more since the beginning of the 20th century. In this section, some recent occurrences of flood and information about major earthquakes are presented.

2.2.1 Floods

Floods occur several times nearly in all parts of Turkey every year. Although not many lives are lost during floods, many small shops and homes that are located in the ground floor of the buildings and cars that are parked on the streets become unusable. There is no systematic data on floods, thus, information can be found only from newspaper articles. Below, some examples of floods that occurred in the summer of 2011 can be found.

On 24.09.2011, a flood occurred in Rize, Turkey because of the enormous amount of rainfall. According to the journal Hürriyet's report on 25.09.2011, rainfall caused rivers to overflow and caused water to flow into the streets of Rize. The reason for this overflow is a road built on stream beds which could not handle the increased amount of water flow after the rainfall because of the blockage that is caused by the road build. As a result, three buildings were collapsed, ten buildings were severely damaged, about 100 homes were evacuated and about sixty vehicles were covered with water. Also, there is one recorded death. [6]

On 22.09.2011, a flood occurred in Tekirdag. The reason of this flood was, again, excessive rainfall. There was no recorded loss of life, however, streets were covered with water, lots of homes, small shops and summer houses were flooded and became unusable and lots of people were stuck in their homes because of the flood. Firefighters were deployed in order to evacuate the ones that are stuck and to help people dump the water in their homes or shops. [7]

On 22.07.2011, a flood occurred in Giresun because of massive rainfall. According to the journal Hürriyet, a person who was carried away with the flood died. As a consequence of the disaster, many homes and shops were flooded and Karadeniz highway was closed to the vehicle traffic because of the water overflow. Also, blackouts in Giresun and surrounding regions were reported. [8]

On 16.07.2011, a flood occurred in Özalp and Çaldıran, two districts of Van, because of excessive rainfall and storm. As a result of the thunderstorm, two people in Çaldıran got struck by lightning and lost their lives. In Özalp, two people were carried away by flood, and they were eventually found dead. [9]

Although floods are not limited to mentioned examples, the consequences are all similar. Their death tolls are not great in number when compared to earthquakes, which is the topic of the next section. However, almost in every heavy rain, streets, houses and shops are flooded, and there are severe power shortages because of the flood.

2.2.2 Earthquakes

Earthquake is the most feared type of disaster in Turkey because of the high frequency of seismic activities. There are several fault lines, and among these lines North Anatolian Fault Line, which lies in the northern part of the Anatolia, from Thrace to Northeast of Turkey, is the most active one. The danger exposed by this fault line can be considered as important since nearly one third of Turkey's population lives in regions that are close to this faulty line.

According to seismologist, there are five categories of earthquake zones. These are;

- First degree earthquake zones: An earthquake of magnitude 9 Richter or greater is very likely to occur in the future, or has already occurred in this zone.
- Second degree earthquake zones: An earthquake of magnitude between 8 Richter and 9 Richter is very likely to occur in the future, or has already occurred in this zone.
- Third degree earthquake zones: An earthquake of magnitude between 7 Richter and 8 Richter is very likely to occur in the future, or has already occurred in this zone.
- Fourth degree earthquake zones: An earthquake of magnitude between 6 Richter and 7 Richter is very likely to occur in the future, or has already occurred in this zone.

- Fifth degree earthquake zones: These zones are exposed to no or little earthquake risk.

Earthquake Zone	Population	%Population	Area (km2)	%Area
Degree 1	10,877,245	21.5	122,592	16.8
Degree 2	15,924,284	31.4	208,596	26.9
Degree 3	11,084,823	21.9	225,989	29.2
Degree 4	10,174,184	20.1	150,000	19.4
Degree 5	2,603,922	5.1	67,638	8.7

Table 2-2 The distribution of population and surface area of Turkey in 1972 [10]

As seen from the Tables 2-2 and 2-3, the surface area of first degree earthquake zone is increased in a great amount between 1972 and 1990 because of the movements in the fault lines. Because of this fact, and the population increase in Turkey, there are now more people living in the first degree earthquake zones. This means that there is a great possibility that nearly half of the population is under the threat of a destructive earthquake.

Earthquake Zone	Population	%Population	Area (km2)	%Area
Degree 1	25,052,683	44	328,995	42
Degree 2	14,642,950	26	186,411	24
Degree 3	8,257,582	15	139,594	18
Degree 4	7,534,083	13	97,894	12
Degree 5	985,737	2	32,051	4

Table 2-3 The distribution of population and surface area of Turkey in 1990. [11]

Starting from 20^{th} century, thousands of earthquakes occurred in Turkey. Most of them were small scaled and did not cause any destruction or loss of life. However, there are also lots of them that have death tolls. The important ones are mentioned below [12].

The complete list of the earthquakes, their death tolls and number of damaged buildings after the earthquake can be found in Appendix 1.

- **26 December 1939 Erzincan earthquake**

  This earthquake was the most devastating earthquake in the history of Turkey. The magnitude of the earthquake was 7.8 Richter and caused approximately 33,000 people to lost their lives. Also, hundreds of thousands of people became homeless as their homes were damaged. The earthquake was so strong that it was felt in Larnaca, Cyprus, and caused a small tsunami in Black Sea, near Fatsa, Turkey.

- **28 March 1970 Gediz earthquake**

  This earthquake occurred in Gediz, Kütahya with a magnitude of 6.9 Richter, killed over 1,000 people and left thousands of people homeless. After the earthquake, communication with the region was disrupted because of the broken phone lines. Also, there was no electricity in the area as power generating facilities stopped working after the earthquake.

  Relief efforts began on 29th of March. There was generous aid from countries all over the world. However, the relief could not be sent to all the affected people since some roads were blocked because of the landfall and made some towns or villages unreachable.

- **12 May 1971 Burdur earthquake**

  It occurred in the early morning with a magnitude of 6.3 Richter. It had a death toll of over 100. Also, thousands of buildings were damaged because of the earthquake. Thus, thousands of people became homeless after it occurred.

  Also, the area suffered from some strong aftershocks. Some additional damage occurred due to these aftershocks; however there is no official report about this damage.

- **22 May 1971 Bingöl earthquake**

  An earthquake with a magnitude of 6.9 Richter occurred in Bingöl. According to reports, more than a thousand people died, 15,000 people became homeless and 90% of the buildings were damaged.

  Despite the heavy rain after the disaster, Turkish Red Crescent initiated relief immediately. However, since the relief goods were mostly sent to Burdur, where an earthquake took place 10 days before the Bingöl earthquake, additional help was asked from other countries.

- **6 September 1975 Diyarbakır earthquake**

  This earthquake, which had a magnitude of 6.7 Richter, caused more than 2,000 deaths and more than 3,400 injuries. Also, lots of buildings were damaged. Hazro, Hani, Kulp and Lice districts were almost totally destroyed. There were many strong aftershocks, which collapsed the buildings that had already suffered damage due to the previous earthquakes.

- **17 August 1999 Marmara earthquake**

  1999 Marmara earthquake is the second biggest earthquake that occurred in Turkey in terms of death toll. It had a magnitude of 7.6 Richter and killed about 17,000 people, injured nearly 50,000 people, left about 500,000 people homeless. The recorded financial damage was about 3 to 6.5 billion US dollars.

  Aftershocks of this earthquake lasted several months. The greater aftershock occurred in Düzce, with a magnitude of 7.2 and killed about 1,000 people, while leaving thousands of homes damaged and thousands of people homeless.

- **3 August 2010 Bingöl earthquake**

  As a result of this earthquake with a magnitude of 6.1 Richter, nearly 50 people were killed, 100 people were injured, 5000 people were displaced, 300 buildings were destroyed and 700 buildings were heavily damaged. It was felt in most of the Eastern part of Turkey and also northern parts of Iran, Iraq and Syria.

- **23 October 2011 Van earthquake**

  With a magnitude 7.1, it caused the death of nearly 550 people, left around 2,300 people injured and destroyed nearly 14,000 buildings, thus leaving hundreds of thousands people homeless. It was felt through eastern Turkey and also Armenia, Georgia, Iran, Iraq, Syria, Lebanon, Jordan and Israel.

  Aftershocks continued after the earthquake. Most notable aftershock occurred on November 9th and caused 7 additional deaths and destroyed 25 additional buildings. One of the destroyed buildings was a hotel where journalist and foreign aid workers were staying.

Among these earthquakes, the most notable ones are the 1932 Erzincan and the 1999 Kocaeli earthquakes. Although the 1932 Erzincan earthquake has the greatest death toll, most studies were conducted on the aftermath of the 1999 Kocaeli earthquake. Because of this reason, this chapter will continue with focusing on the 1999 Kocaeli earthquake.

As mentioned above, on 17th August 1999, an earthquake hit the Marmara region of Turkey, where approximately one third of the Turkish population lives. As a consequence, 17,480 people lost their lives and about 600,000 people were direct victims. In addition to homes, many commercial buildings were also damaged and infrastructure of the region was highly damaged. [1]

There were hundreds of thousands of victims who are in need of relief and more than 200 national and international agencies were trying to reach the area and help people. However, there were some major operational challenges which prevented agencies from providing efficient relief to those in need. The most important challenge for the agencies was Turkish bureaucracy. While providing relief, most of the time was wasted because of the bureaucratic processes such as clearing relief materials from customs and the process of obtaining permission to use vehicles and equipment that belong to the state.

Moreover, a disaster response plan didn't exist. This lack of plan resulted in a chaos and therefore slowed down the relief providing process.

Also, lack of communication was an issue. Apart from the absence of related equipment, there were limited numbers of Turkish officials who can speak English, which made it even harder for international aid workers.

To overcome these effects in the future, many operational and structural changes in Turkish laws and institutions those are responsible for disaster management. Most notable ones are as follows;

- Turkish Red Crescent (TRC) initiated a restructuring process following the earthquake. AFOM (disaster operations center), regional and local disaster response and logistics centers were founded. Stock levels and standards were revised and technological infrastructure was renewed.
- Obstacles that were occurred by the laws were addressed.
- Disaster trainings became more important, individualism during the survival process was brought front.
- Every institution that is responsible for disaster relief started to form their own disaster plan.
- Number of non-governmental organizations working towards disaster relief increased.
- New law codes for state administration and regional and local municipalities were determined.
- Plans for the cooperation of civilians and military in case of a disaster were developed.
- Housing standards were revised.
- In eleven provinces, search and rescue teams were located.

- The Ministry of Health initiated new disaster response standards, such as forming national medical rescue teams.
- Reception centers for international relief aids were established in airports.
- Communication problems were addressed. [1]

Seven months after the 1999 Marmara earthquake, on 16th March 2000, the daily journal Radikal [13] published an article that provides numerical data on the number of residents in temporary shelter areas. According to the article, in the affected zone, around 91,000 people were still living in 20,000 tents. 18,500 of them were living in Kocaeli and in there, the shelter areas where at capacity. In Sakarya, 906 people were living in tents and utilization of the shelter area was 20%. In Yalova, 2,547 people were living in 6 shelter areas, and the combined utilization of those areas was 74%. In Bolu, 16,648 people were living in 11 shelter areas and those areas were at capacity.

The situation was even worse than other cities in Düzce. Düzce was the city that had the highest destruction after the earthquake. At that time, 11,278 tents were in use in Düzce and around 53000 people were living in those tents. There were 24 shelter areas and there were only a total of 206 showers and 345 bathroom facilities in those shelter areas. The utilization was around 90%.

The daily journal Milliyet [14] published a series of articles between 11th and 16th August 2000, which is exactly one year after the disaster. According to their series of articles, people were still homeless and living in those temporary shelter areas. However, the number of people living in the tents had decreased when compared to the Radikal's report. In Kocaeli, 9,865 people still were living in the tents after one year has passed from the occurrence. The number of people living in tents one year after the earthquake for Bolu, Düzce and Sakarya were 10,591, 8,232 and 229 respectively. In the article series, it is also mentioned that although pre – fabricated houses were established, people were forcing their way into staying in the tents because pre–fabricated housing areas were very far from city centers. The total number of people living in pre–fabricated houses was around 160,000, where 55,399 of them were living in prefabricated houses in Kocaeli, 38,131 of them were living in prefabricated houses in Sakarya, 14,296 of them were in prefabricated houses in living Bolu, 22,822 of them were living in prefabricated houses in Düzce and 15,946 of them were in prefabricated houses in Yalova.

In the most recent case, which is the 23 October 2011 Van earthquake, tents arrived to the area two days after the disaster. According to Turkish journal Akşam's article [15], there were 3,013 tents on 25th October 2011. 232 of them were used in shelter areas and the remaining was given to the citizens so that they can set them up in front of their apartments.

There were initially three shelter areas in Van and its surroundings. However, since a lot of people did not want to live in their houses because of the aftershocks, five new shelter areas were established.

The above discussion points to the fact that temporary areas are important components of the recovery phase of disaster management and the significant problems related with temporary shelters can be observed. In Turkey, Turkish Red Crescent (TRC) is the main responsible authority for establishing temporary shelter areas. After a disaster occurs, managers of TRC determine the locations for temporary shelters and provide necessary amount of tents in order to reside all the people that became homeless of cannot yet live in their houses after the occurrence. TRC is also responsible for supplying enough food and non–food items for all the people that are living in the temporary shelter areas and ensuring the security of the shelters.

Turkish Red Crescent was founded on June 11, 1868 with the name "Community for Helping Wounded and Sick Ottoman Soldiers". It was initially found to bring assistance without discrimination to the wounded and sick soldiers on the battlefield. The name

“Red Crescent” was given in 1935 by Mustafa Kemal Atatürk. Although it was initially founded to provide health services for military, today, the main purpose of TRC is to prevent and reduce human suffering, to protect life and health, and to ensure respect for the human being. TRC is a non–governmental and voluntary foundation. [16]

Turkish Red Crescent has several service and activity areas. These can be listed as;

- Disaster Preparedness and Response
    - In the event of war
    - During natural disasters
    - In ordinary periods
- Cash and In-kind Relief Services
- Health and Social Support Services
    - Medical Centres
    - Psychosocial Support Services
    - First Aid Courses
- Youth and Volunteer Services
    - Youth Camps
    - Scholarships
    - Dormitories
    - Volunteer Services
- Blood Services
- International Relations

Chapter 3

Shelter Areas, Turkish Red Crescent's Methodology and Problem Definition

3.1 The Sphere Project and Shelter Areas

After a large scale disaster occurs, many houses become damaged and a notable number of residents will be homeless. These people have to reside in temporary places until the disaster recovery process is completed. Because of this, shelter areas are established. In order to better address the needs of the affected population, these areas need to be set up with respect to some quality measurements which are defined by *The Sphere Project.* This project is explained next.

In 1997, several humanitarian organizations and International Federation of Red Crescent and Red Cross initiated a project in order to improve the quality of post – disaster humanitarian operations. Their philosophy is based on two principles; the affected population has the right to live with dignity and receive necessary assistance and whenever there is human suffering that is caused by disaster or such conflict, any necessary action should be taken in order to suppress it. [17]

Given the two principles, a set of minimum standards were identified in four imminent areas: water supply, sanitation and hygiene promotion; food security and nutrition; shelter, settlement and non-food items; and health action. These standards are based on past experiences of the organizations as well as a consensus between involved organizations. The standards are organized in a book called "*The Sphere Handbook*" and are updated periodically. *The Sphere Handbook* [17] is considered as a very important source of information in humanitarian sector as it is the most comprehensive document that defines the standards of humanitarian relief operations and is compiled by the most experiences of organizations in the area.

As described in *The Sphere Handbook* [17], establishing shelter areas is a crucial stage in disaster recovery. Beyond recovery, shelter areas have an important role in sustaining security, ensuring personal safety and protecting people from differing weather conditions and epidemic diseases. For people who are left homeless and dispirited because of the disaster, finding a safe and secure place to pursue their lives is important for them to feel better and humane even under such inhumane conditions.

Moreover, as shelter areas are more likely to guarantee a certain level of life standard, they are important for preserving human dignity, sustaining daily family and community life and enabling affected people to recover from the effects of the disaster. People become vulnerable mentally and psychologically after a disaster. Because of this, establishing a shelter area and forming a small community will trigger a socialization process among those who are affected. As a result of this socialization process, affected people will be able to support each other in hard times, which will eventually speed up the recovery process of the society.

To ensure that shelter areas are built and established and operated in a manner that it satisfies basic human needs, several standards and guidelines are introduced in *The Sphere Handbook* [17]. As temporary shelter areas are crucial because of the above mentioned reasons, one should strategically plan those settlements. Strategic planning refers to the planning of the location of shelter areas, ensuring the existence of safe routes to those areas and to the homes of the affected people and making sure that there will be enough relief materials such as tents, shelter kits and construction kits, for the whole population.

Firstly, needs of shelter areas must be surveyed and a settlement response plan should be formed by the authorities and relevant organizations. These authorities and organizations should be in coordination with each other, and also with the affected population.

After the disaster, when the danger has been relieved of, some affected people may be able to return to their homes. In this case, the responsible organization should be able and willing to assist those people. On the other hand, some people may not be able to return to their homes even after the danger has been relieved of. These people have to live in a temporary shelter area until their homes are recovered. Because of this, responsible organization should take care of these people and guide them to their shelter areas.

After the shelter areas are established, the people living in those areas need some items such as non–food items and shelter solutions such as tents, shelter kits, construction kits, cash and technical assistance. These items are important for the affected population and because of this; responsible organizations should ensure that enough of the above mentioned items are supplied to those in need.

As mentioned above, affected population that resides in temporary shelter areas is vulnerable and needs to feel safe. Because of this responsible organization should make sure that established shelter areas are located as far as possible from threat zones.

After disasters such as earthquakes, debris blocks the roads and prevents people to reach their homes, public facilities, temporary shelter areas and other routes. Moreover, water, sanitation, health facilities and schools are daily needs of a person and they need to be reachable from shelter areas. Because of this, the debris should be cleared and a safe and debris–free route should be determined from shelter areas to such facilities.

Potential shelter areas should be selected in a fashion such that settlement risks and vulnerability to danger is minimal in the neighborhood. After identifying the potential shelter areas, the property ownership of each such area should be inspected. Owners and usage rights of each shelter area should be determined beforehand and necessary permissions should be obtained. Also, safe and clear routes should exist from affected area to shelter area and from shelter areas to essential service facilities.

In order to make people live comfortably in shelter areas, every resident should have adequate space to live. This includes both personal and shared areas. Also, for convenience, necessary separation between different sexes, age groups and families should be provided. Since family is an important constitution in society, organizations should make sure that each family can pursue their everyday activities in their provided covered living space.

For a regular camp type settlement, if private housing is available, there should be at least 45 square meters usable area per settlement. This area includes personal areas as well as infrastructural facilities such as kitchen, sanitation, roads and education. If these facilities are provided outside the settlement area, then there should be at least 30 square meters allocated to each person. If this cannot be provided, high – density occupation should be implemented and effects should be reduced as much as possible.

Since weather conditions may not allow people to reside in open air, usage of tents, tent materials should be encouraged. If conditions are suitable for construction of prefabricated buildings, their usage is preferable. In addition, necessary utilities for one to achieve best thermal conditions should be provided for each season separately.

Construction of shelter sites should be done in a fashion that minimizes the undesirable impact on environment. For example, flora structure, especially trees, should be protected since they also provide prevention from erosion, increase water retention and yield natural shades in very hot weather conditions.

3.2 The Methodology of Turkish Red Crescent

As mentioned earlier in this chapter, disaster response and relief services are among the responsibilities of Turkish Red Crescent. In fact, TRC is the only organization that establishes temporary shelter areas and provides relief supplies such as water, food and blankets for the affected people.

Especially in disaster prone areas, like Istanbul, Turkish Red Crescent identifies the eligible sites for shelter areas before the disaster. For example, experts state that there is an expected earthquake in Istanbul within 10 years. For the preparedness phase for this earthquake, Turkish Red Crescent and Istanbul Greater Municipality conducted a study in order to define the potential temporary shelter areas. To rank potential sites, Turkish Red Crescent uses ten criteria [18]. These are;

- Transportation of relief items: This attribute measures the reachability of the shelter area. As the main roads are closer to the shelter areas, transportations of the relief items become easier.
- Procurement of relief items: Relief items are purchased from a market, supermarket or a warehouse. Because of this, it will be less costly if the shelter area is closer to a market or a warehouse

- Healthcare institutions: If a situation that calls for medical intervention, the patients will be taken to a healthcare institution such as a hospital or a clinic. Because of this, it is favorable if a shelter area is close to such institutions.
- Terrain: This criterion can be divided into four subcategories; i) structure of the terrain; ii) type of the terrain; iii) slope of the terrain; iv) flora of the terrain.

  Structure of the terrain is the attribute that states whether candidate location is located on a savannah, on a vold, on a valley or on a piedmont. Since savannah represents a wide flat area of land, construction and living on such areas are easier. Construction and living becomes more difficult if the structure of the terrain is vold, valley or piedmont.

  Type of terrain measures the hardness of the soil. As the soil becomes harder, it is less affected by rain and construction is easier on hard terrains.

  Also, the slope of the terrain that the shelter area is established on is important. As it is easier to live on flat surfaces, terrains with smaller slopes are always favorable.

  The flora of the terrain is also important since trees provide people oxygen and natural shades, which are useful during hot summer weather. Because of this, a dense flora which consists of trees is plausible.
- Electrical and sewage infrastructure: Electricity is important for residents to pursue their daily lives. Most of the devices run on electricity and also electricity can be used for heating. Because of this, it is a plus if the shelter area has electrical infrastructure.
- Water is one of the most imminent needs of humankind. Water is used for the continuity of biological activities, cooking, cleaning, etc. When the water is used, it needs to be disposed in a hygienic way. Because of this, sewage infrastructure is important for a shelter area.
- Usage permission of the land: It is easier to get construction permission if the shelter area is publicly owned and more difficult if shelter area is owned by

treasury, municipality or a person. Also, if the area is privately owned, purchasing or leasing costs may be applicable.

The weight function is a convex combination of those ten criteria. Each criterion has respective weights $(wt_1, wt_2, \dots, wt_{10})$ in the function, whose sum of equal to 1. Also, each shelter area *i* has respective points between 0 and 1 for each criterion depending on its attributes $(pt_{1i}, pt_{2i}, \dots, pt_{10i})$. These attributes for each criteria are obtained from Aksoy et al. and can be found in Appendix 2. The value of the function for each shelter area is calculated by using the equation below. In Table 3-1 an example calculation can be found.

$$weight_i = \sum_{k=1}^{7} wt_k * pt_{ki}$$

Criteria	Weight (w)	Attribute	Attribute Value (pt)	Weighted pt
Relief - Procurement	0.05	Easy	1	0.05
Relief - Transportation	0.1	40	0.5	0.05
Distance to Health	0.15	20	0.5	0.075
Terrain - Type	0.05	Savannah	1	0.05
Terrain- Structure	0.1	Sandy	0	0
Terrain - Flora	0.1	Rare	0.5	0.05
Terrain - Slope	0.05	3%	1	0.05
Electricity	0.1	Available	1	0.1
Sewage	0.1	Available	1	0.1
Permission	0.2	Treasury	0.8	0.16
			Value	**0.685**

Table 3-1 Example calculation of the weight function

After identifying grade points for each candidate shelter area, Turkish Red Crescent sorts all potential shelter areas with respect to their weighted sum points and in case of a disaster, TRC establishes the ones starting with the highest point until enough shelter areas are opened to reside all the affected people.

3.3 Possible Improvements and Problem Definition

Although the methodology of Turkish Red Crescent seems reasonable, it has some drawbacks. Firstly, it does not consider the distance between the population and established shelter areas. As a result, all of the opened shelter areas may be very far from a certain district. In this case, it will be very hard for the people living in this district to reach an open shelter area in case of a disaster.

Secondly, there is no district – shelter area assignment in their methodology. After a disaster, if a person needs a temporary shelter, he/she will want to reside in the nearest shelter area, which may be full. This may bring out a conflict. To prevent this possible conflict, a district – shelter area assignment may be included in the methodology of Turkish Red Crescent.

Thirdly, utilization of shelter areas is important. After making district – shelter area assignments, it is possible to estimate the utilization of each shelter area. If a shelter area is nearly full and another one is halfway utilized, a conflict may arise since the life conditions in the less utilized shelter area may be better and people may want to choose the emptier one even if they are not assigned to it. To overcome this issue, pairwise difference in utilization all shelter areas cannot exceed a certain threshold value. Also, because of the logistical reasons, it is more efficient to open as few shelter areas as possible. In order to do that, a minimum utilization requirement is included to the problem.

With the addition of above mentioned possible improvements, the problem that is considered in this thesis can be stated as providing a decision support system for Turkish Red Crescent in order to help the decision process of locating shelter areas which assigns each district to the closest open shelter area while controlling the minimum utilization of each shelter area and pair wise utilization of each shelter areas.

Chapter 4

Literature Review

The above defined problem is related with a facility location problem in the literature. Because of this, this section focuses on the literature review about the fundamentals of facility location problems on disaster relief.

Throughout the literature, many studies can be found about facility location in disaster relief. These studies mainly consider three problems which are shelter site location, emergency medical center location and relief material warehouse location problem. In this section, notable studies about shelter site location, emergency medical center location and relief material warehouse location problem are discussed.

4.1. Emergency Medical Center Location Problem

Emergency medical centers are established in order to provide medical care services after an emergency. As disasters do result in emergency situations, such facilities can also be related to disasters. As these facilities are to be used for the whole population, it needs to be within a certain distance from each population point or district. Because of this, locating emergency medical centers within a cover distance from each district or maximizing the number of people covered are the objectives used in this problem.

Federal Emergency Management Agency (FEMA) aims to construct a systematic and a sustainable solution for locating disaster recovery centers (DRC) problem which frequently arises in Florida due to seasonal hurricanes in 2001 [19]. For this reason, FEMA initiated a research team composed of experts in the field and this team came up with a very simplistic but relatively efficient solution. At the end of the research the team publishes their findings. They simply try to find a feasible solution for the problem of locating three DRC's such that every residence remains within 20 miles distance from at least one DRC. Then they relax 20 mile constraint and calculate the values of different evaluation measures for different covering ranges. The three evaluation measures were: maximum travel distance, average travel distance and percentage of parcels within travel limit radius of a DRC. Finally, they present the solutions which performed well in terms of these measures to the decision makers.

Another application of this problem is considered in Ablanedo-Rosas et al. [20] for Hidalgo, Mexico. They consider the existing hospitals and try to figure out which of these hospitals should serve as emergency centers after a large-scale disaster. They solve a standard set covering model where the coverage radius is 55 kilometers and fixed costs of the facilities are the same. Then, they update the model according to concerns of municipality of Hidalgo. Equal fixed cost assumption is relaxed and the requirement for availability of physicians in hospitals which are suggested as emergency centers have also taken into account. Both of these issues are handled in the objective function of the set covering model.

These two papers are actually based on government decision making issues and are solved with set covering models. The results are instance-specific and the outcomes are not suitable to adapt to any other problems. Jia et al. [21] is one of the studies which focuses on more general problems and designs a modeling framework for medical service location. Their methodology can be summarized in 4 steps:

1. A survey of existing generic facility location models in the literature.
2. An analysis of the characteristics of large scale emergencies.
3. Development of models with respect to these characteristics. (Such as low frequency vs. high impact, very intense but short term demands etc.)
4. Test and validation of the models with actual data of Los Angeles area.

Their study contains a covering model, a p-median model and a p-center model for emergency medical center location problem. These models do not deviate from the original model drastically, but still they impose emergency related constraints fairly well.

Jia et al.'s [21] models differs from the original set covering models since their models have multiple coverage approach, but this problem is NP-Hard as well as the original set covering problem. Because of this, they faced computational limitations. Hence, Lu et al. [22] develop a solution strategy based on ant colony algorithm to overcome these computational limitations, which decreased the computation time without deviating from the optimal solution.

Even if it is efficiently solved, a fully deterministic model may have its own shortages due to stochastic nature of disasters and their outcomes. Thus, Verma and Gaukler [23] defines a 2-stage stochastic programming model where first stage considers identifying the locations of emergency centers and the second one considers identifying the routes of the medical supplies and physicians between the affected areas and the facilities. They also update their cost function to reflect the risk associated with the facilities that are close to the epicenter of the disaster. They mainly believe that if an emergency center comes closer to the epicenter the functionality of the center decreases. Hence, using this assumption, they test their model on the data set of previous California earthquakes.

For the post-disaster emergency center location problem, researchers generally have two different options: utilization of existing facilities or opening new ones. In her MSc. Thesis, Gül [24] approaches this problem systematically and solve it for Istanbul. First she develops a dynamic transportation model of medical care units and physicians from the existing facilities to possible demand points for some certain scenarios. Even with this optimized system the existing facilities fail to cover a high percentage of demands for most of the scenarios. Hence, additional temporary emergency units need to be considered. In order to determine the locations of these units, she proposed a joint transportation and location model with objective that minimizes total travel and waiting times. Finally, the model is solved under various scenarios such as road blockage, different treatment needs, and variable number of people who demand emergency services.

In her thesis, Gül [24] assumes that all existing facilities will be still usable after a disaster. However, this may not always be the case depending on the scale of the disaster. Many existing facilities may become functionless after a disaster due to physical damage or overload. Huang et al. [25] build their model keeping this in mind. They state that during a disaster a customer may not rely on the closest facility as it is suggested by classical p-median models. Consequently, a variation of p-median model is defined with the additional assumption that a center at a node may fail to respond to that node. They use dynamic programming approach for path network models and a problem specific meta-heuristic for general networks.

Wang and Zhang [26] take emergency occurrence probability for a specific region into account with a catastrophe diffusion function from the epicenter and a rescue function. These kinds of functions are needed when the disaster has a spread tendency (nuclear disasters, pandemics, fire, flood etc.). Both the diffusion function and the rescue function are time dependent and non-linear. Thus, the authors generate a heuristic embedded (approximation of function values for certain points) genetic algorithm to solve the problem.

All the studies described previously consider the emergency center location problem under some assumptions and simplify the problem to come up with recommendations to decision makers in a way that a posteriori evaluation of the decision maker is not permitted. However, after a disaster many other problems may arise and they are not taken into account in the suggested models. Generally, the impacts of disasters are quite large and operations need to be performed in a chaos environment. Hence, a more flexible (relaxed) set of recommendations instead of suggesting specific solutions may be more useful for many cases. This idea actually summarizes the motivation of the study of Lu and Hou [27]. They do not directly solve the problem, but instead, they compute the "optimal" ranges of decision variables using grey degree modeling technique. So, the combinations of these intervals for variables yield many "good" solution alternatives, and the final decision is left to the decision makers.

Determining the locations of emergency centers in isolation may yield some problems in operations which are related with these centers such as allocation of the crew, and the distribution of the medical supplies. Paul and Batta [28] try to optimize center location and crew allocation simultaneously. They developed two models: one minimizes the mean travel distance over a variety of scenarios and another reallocates crews to maximize center effectiveness. Finally, they conduct experiments based on earthquake data of Northridge, California and hurricane data of New Orleans.

Similarly, Chang et al. [29] study on a location-allocation type of problem for locating rescue teams in case of urban floods. They level their teams and equipments so the allocation is performed on teams with different weights. The objective of the problem is minimizing the total expected cost over different rainfall scenarios subject to cover of expected demand.

Zeng et al. [30] consider a location-routing problem where the crew or the equipment need to visit some survivors who cannot come to the centers. They divide their problem into two sub-problems as locating and routing emergency resources. In order to solve this problem, authors develop a 2-stage heuristic. The first stage clusters the potential demand points to determine the location and the second stage utilizes an ant colony heuristic for the routing based on the findings of the first stage. The objective for both cases is the minimization of the cost.

Although the response center location for disasters problem has very specific considerations on its own and relatively new topic it has very remarkable similarities with common emergency center (hospitals, fire stations, ambulance stations etc.) location problems which is a relatively well-studied area of research. For more detailed information, readers may want to examine the study of Li et al. [31], which is very recent and a comprehensive review on emergency response center facility location problem.

4.2. Relief Material Warehouse Location Problem

After a disaster, affected population needs relief materials such as tents, emergency kits, shelter kits and canned foods. These items need to be dispatched soon after the disaster and usually obtaining them from suppliers is not efficient in terms of time. Because of this, organizations tend to procure these items beforehand and store them in a warehouse in case of an emergency situation. The "relief material warehouse location problem" addresses the decision process of locating such facilities. Common objectives in this problem are maximizing the number of people covered within a certain radius and minimizing the distance between warehouses and affected population.

In their article, Balcik and Beamon [32] deal with the prepositioning of relief supplies which are to be sent to those who are affected after a disaster. They formulate a model which is a variant of maximum coverage location problem (MCLP). They improve the MCLP formulation to handle different scenarios. Their model maximizes the expected demand covered by the opened distribution centers over all scenarios, while it decides the number and the distribution centers and amount of each relief good to be stocked in each distribution center. To test the formulation, they solve it with GAMS optimization package using 286 independent scenarios and 45 candidate distribution center locations. For the generation of the scenarios, they use 639 events, which have a death toll greater than 10 and occurred between 1990 and 2006.

A similar scenario based approach is considered by Gunneç [33] in her thesis. She used a variant of uncapacitated facility location problem (UCFL) in order to find the optimal locations of emergency response and distribution centers (ERDC) in Istanbul. Since time is imminent in disaster response, she minimized the total travel distance during distribution. In the model, scenarios are introduced with respective probabilities and also commodity distinction is also considered. According to her model, every commodity has different weights and this distinction is implemented in the objective function. The model is solved using real data of Istanbul. Furthermore, study was expanded in order to consider link reliability.

Hale and Moberg [34] combines FEMA's recommendations with a deterministic simple set covering problem. They propose a four step site decision process. Their methodology starts with identifying the types of emergency resources. Later, they define all the critical facilities within the supply chain. Then, the determine maximum time goals and minimum secure site distances. Lastly, they decide on the number and the locations of the distribution centers by using a basic set covering model. At the end of their study, they tested the model for the data generated in northeast of the USA.

Murali et al. [35] deal with the facility location problem of medicine distribution in a big city. The provide model is a variation of maximum covering location problem (MCLP) with a loss function and distance sensible demand. Model provides decision about the number and the location of the facilities and the demand assignment to each location. They solve they model with a location–allocation heuristic.

Horner and Downs [36] consider the problem of prepositioning inventory as a three echelon supply chain where distribution centers receive goods from logistical service areas and distribute the neighborhoods. They define Q different relief material, so there are Q types of distribution centers. Their model is a deterministic linear model which decides on the location of the distribution centers, the type of it, their neighborhood assignment and the number of relief goods received at distribution centers from logistical staging areas while minimizing the overall three echelon supply chain costs. At the end of their study, they provide a GIS-based spatial analysis of Florida's comprehensive emergency plan, where hurricanes are seen very often.

Duran et al. [37] consider the prepositioning problem for CARE. Their problem is to locate warehouses over the world and preposition items such that disaster areas are served from these warehouses, or directly from suppliers. They assumed that the demand points are the 22 sub-regions that are defined by United Nations and if a disaster occurs in some part of a region, demand is assumed to be at the center of the region. CARE has

12 candidate prepositioning warehouses. Food, water, sanitation kits, tents, household kits and hygiene kits are stored in these locations. They consider to hold some inventory in those warehouses and replenishing them after the disaster occurs. To solve the problem, authors generate several disaster scenarios and gave them a probability. They formulate a MIP such that it minimizes the expected average response time over all scenarios. MIP decides which warehouses to be opened and whether the demand is satisfied directly from the supplier or from the warehouse.

Zhu et al. [38] approach the prepositioning problem with a deterministic model which identifies the locations of the warehouses and their capacity, while minimizing cost and satisfying the demand occurred after a possible disaster. They solve their integer program with LP-rounding technique.

In his dissertation, Jia [39] considers large-scale emergency medical supply location problem. He approaches the problem with four different formulations, which are based on covering, p-median and p-center models. These models are formulated for each scenario separately and identify the location of the facilities to be opened and their service level. Also, models decide on which neighborhood receives service from which facility and at which service level. For the global optimization over all scenarios, he provides a regret model. To solve the models, he uses a heuristic based methodology.

Görmez et al. [40] provide a two stage multi objective model for the prepositioning problem. Given the refugees in each neighborhood, first model decides on the location and the number of temporary facilities while maximizing the number of refugees covered. In the second stage, they consider permanent facilities, which send supplies to temporary supplies. The second stage model minimizes the total number of operating permanent facilities and average response time while deciding the number and the location of permanent facilities and the permanent facility – temporary facility assignment.

Another multi objective approach on humanitarian prepositioning problem is provided by Roth and Gutjahr [41]. Their model is a variation of location routing problem (LRP), which decides on the number and the location of the depots, depot – manufacturing plant assignment and the routing from depots to manufacturing plant, while minimizing fixed facility costs, operational and transportation costs and maximizing the demand covered. They conclude their study by providing decomposition based exact solution method.

Yushimoto el al. [42] provide a heuristic algorithm for selecting prepositioning areas after a disaster. The heuristic tries to find a pre-specified number of facilities that covers all the demand points and minimizes urgency. The quality of the heuristic solution is highly dependent on initial solution. Because of this, they also provide a guide on selecting the initial solution.

Quite similar to previous articles, in his master thesis, Akkihal [43] asks the question of prepositioning humanitarian aid materials while minimizing the delivery lead-time to those in need. He addresses the problem with a simple model which maximizes the total number of homeless people covered while opening n facilities. In case of an addition, such as adding $(n+1)^{th}$ facility, he uses the solutions in n facility case and makes iteration from that solution. Also, he proposes a sensitivity analysis method instead of solving the generic model.

Li et al. [44] also consider the same location problem of prepositioning facilities with routing. While routing, they consider different mode of transportations. In their model, they minimize the total travel time and total loss while locating facilities and routing from facilities to affected areas optimally. To solve the multi modal, multi objective location routing problem, they propose a genetic algorithm.

In addition to previously mentioned articles, Widener and Horner [45] consider the hierarchy among the candidate facilities. In their model, they considered several stages of service facilities. Their model minimizes the total distance travelled to those in need while satisfying all the demand. In their case, demand is deterministic and known before the hurricane occurs. They study the model with the estimated data obtained from Leon County, Florida and provide a comparison with the non-hierarchy case. Also, Widener and Horner [46] consider the non-hierarchical but capacitated version of the same problem. Their model is a capacitated median problem which locates facilities optimally and with respect to capacity constraint while it minimizes the total costs of providing relief goods to those in need. They study the model with the estimated data obtained from Leon County, Florida.

Han et al. [47] conduct a location – allocation study on prepositioning humanitarian supply goods. Their model optimally locates facilities and allocates disaster areas to opened facilities while minimizing the total travel time. There are also deadlines for each disaster area and for each commodity. So, the authors introduce time windows in the model. They conclude their study with a lagrangian based computation algorithm and test it on a small instance.

Campbell and Jones [48] consider a stochastic prepositioning approach with single demand point, where demand depends on a probability distribution. With a given failure probability of a facility, they consider the total inventory cost of each facility separately and then decide whether to open or not each facility and the amount to be stored in each facility. They conclude their study by conducting an analysis of the effects of parameter changes on costs and stock amounts.

Jia et al. [49] consider the facility location problem for prepositioning medical supplies. They also took demand uncertainty into account. They formulated the problem as a maximum coverage which determines the quantity and the location of the facilities and their service level. Furthermore, they proposed three heuristic based solution algorithms, namely: a genetic algorithm heuristic, a locate–allocate heuristic and a lagrangian relaxation heuristic. They conclude their study by testing the performance of three heuristics.

Rawls and Turnquist [50] provide a two stage stochastic optimization problem in order to determine the location and the quantity of the emergency supplies. The stochastic nature of the problem arises from the uncertainty of the demands, demand locations, capacity of the roads and the possibility of the destruction of the supplies during a disaster. They perform a scenario based analysis which minimizes cost. They test their model with a data set generated on southeast of the US. In Rawls and Turnquist [51], they extend the model with service quality constraints, which states that every demand point should receive a service that is above a certain measure of quality.

Mete and Zabinsky [52] also conduct a study on facility location of warehouses and transportation of relief goods in a stochastic environment. They propose a two stage stochastic program, where in the first stage determines the warehouse locations and inventory levels, and the second stage determines the transportation of the relief goods to disaster areas. Their study is scenario based and considers several types and magnitudes of disaster. They conclude their study with two earthquake scenarios in Seattle area based on real data.

Wang et al. [53] consider a three echelon supply chain where there are suppliers, distribution centers and affected people. Authors use a bi-level modeling in order to determine the optimal locations of distribution centers while minimizing the total supply chain cost. They use a particle swarm optimization based method for the solution of their model.

Kapucu et al. [54] provide insight about determining the potential sites for staging areas and distribution points before selecting exact sites. Their study is based on the key principles in selecting the potential sites. The authors pinpoint on attributes such as location, access, safety & security, hardstand, equipment, storage and utilities.

4.3. Shelter Area Location Problem

As mentioned, shelter areas are established for the affected people who lost their homes after a disaster. The "shelter site location problem" is used for determining the location of shelter areas. There are many different criteria in determining the ideal location of shelter areas, however locating shelter areas as close to the population as possible and opening enough shelter areas to reside all the homeless people are the main objectives of this problem.

In his article, Pan [55] considers shelter site location problem after a disaster by formulating two mathematical models. In the first model, Pan simply maximizes number of people covered by utilizing Maximal Covering Set Problem which is a variation of Set Covering Problem with an additional binary variable for the decision of cover a set of population or not. In his second model, he adds shelter capacity constraint to make the model more realistic. Finally, he tests his model with random data which imitates a typhoon condition in China.

Similarly, Li and Jin [56] focus on shelter location problem for hurricane survivors. However, they consider the stochastic nature of hurricanes. They introduce this randomness by generating different scenarios and respective occurrence probabilities. Each scenario is defined by two different parameters: the landfall and the hurricane category. As the scenarios change, the cost functions, number of shelter residents also change. They broke down the problem into two stages: preparedness and response. For the preparedness stage they choose permanent shelter sides and define capacities by minimizing the total expected cost over all scenarios. For the second stage, they minimize the transportation costs of residents and resources in order to come up with an allocation plan of shelters including transportation of survivors.

However, the second stage (allocation-network flow) problem challenges the solvers, so that the authors used the L-shape method, which is widely referenced in the literature, in order to evaluate the model for each scenario separately. Finally, they test their solution methodology with the real data obtained after Hurricane Katrina in Gulf Coast Region of United States.

Dalal et al. [57] consider hurricane shelter locations, uses a heuristic approach based on Elzinga-Hearn method instead of solving the mathematical model. They aim to cluster the villages and construct a shelter area for each cluster. Heuristic starts with the closest village pair, and continues by adding new villages to that cluster. For each step, the algorithm computes the shelter location by using Elzinga-Hearn method. If the radius of this circle exceeds a pre-determined distance the last point that is added is removed, and a new cluster is started.

In their study Liu et al. [58] define the criteria for the shelter location problem after earthquakes. The ideas in this paper may be utilized by the preprocessing phase of mathematical models such as identifying potential locations, distances etc. The paper emphasizes the importance of the physical conditions of the disaster area in terms of distance between active faults, consideration of mountainous areas.

Pan's study [55] is based on a cover model that maximizes the total number of people covered. However, since they are maximizing the total number of people covered, they do not guarantee a shelter for all of the affected population.

Li and Jin's study [56] locates the shelter areas and assigns population to them. However, they do not consider the attributes of the shelter areas and all the locations are identical according to their study. This approach may not be suitable for Turkey as the terrain is erratic even in small geographies.

Dalal et al. [57] presented a clustering based approach that assumes there will be enough space to build a shelter area in each cluster. However, this assumption may not always hold. Because of this, making a decision from a pre-determined set of potential shelter areas and their capacities is a more solid approach.

To the best of our knowledge, there is no study that determines the best possible shelter area locations from a set of candidates and assigns all of the affected population to those areas while trying to keep all shelter areas as utilized as possible and minimizing their pairwise utilization difference. This study considers these factors, thus offering an important contribution to the literature.

Chapter 5

Model Development

The problem proposed is to develop a methodology on locating shelter areas that takes the Turkish Red Crescent's ten criteria into consideration, decides on district – shelter area assignments and controls the utilization of open shelter areas. In order to address the problem, a mixed integer linear programming model is formulated.

In order to implement the Turkish Red Crescent's criteria on shelter areas, a weight function is constructed. Seven of the criteria, namely; structure, slope, type and flora of the terrain, existence of electrical and sewage infrastructure and ownership are included in this weight function. Since they are not directly measurable, the measures determined by the Turkish Red Crescent are used for those criteria.

The remaining three criteria, namely; procurement of relief items, transportation of relief items and health institutions, can be measured via the help of the distance between a shelter area and the nearest main road (for procurement and transportation of relief items criteria) or the distance between a shelter area and the nearest health center (for health institutions criterion) and thus, they are not included in the weight function. Instead, these three criteria are implemented in the mathematical model.

The sets, parameters and the formulation of the model can be found below.

Sets

I: set of candidate locations

J: set of districts

Parameters

w_i : Weight of candidate location *i*, between 0 and 1

d_i^{health} : Distance between candidate location *i* and nearest health center

d_i^{road} : Distance between candidate location *i* and nearest main road

$population_j$: Total number of people in district *j*

cap_i : Capacity of candidate location *i*

$livingSpace$: The allocated living space per person in shelter areas.

$utilitySpace$: The allocated space for dining and sanitary utilities per shelter area

$percentAffected$: The percent of the population that is expected to be in need of a shelter after a disaster.

$distSorted_{ij}$: i^{th} closest candidate location index to demand point *j*

$distHealth$: Threshold value for shelter area – health center distance

$distRoad$: Threshold value for shelter area – main road distance

α : Threshold value for pair wise utilization difference of candidate shelter areas

β : Threshold value for minimum utilization of open shelter areas

Decision Variables

$x_i : \begin{cases} 1 \text{ if candidate location i is chosen as a shelter area} \\ 0 \text{ otherwise} \end{cases}$

$y_{ij} : \begin{cases} 1 \text{ if district j is assigned to location i} \\ 0 \text{ otherwise} \end{cases}$

u_i : Utilization of the candidate location i.

The population parameter is in terms of the number of people in district. On the other hand, the capacities of the shelter areas are in terms squared meters. Thus, the population parameter needs to be converted into the required shelter area per district. For this conversion, the following parameter is defined.

$demand_j$: Total demand of district j in terms of m^2

For the conversion, the following equation can be used.

$$demand_j = \lceil population_j * percentAffected \rceil * livingSpace \qquad \forall j \in J$$

To convert the population of a district to the required shelter area, first, the population of the district ($population_j$) is multiplied by the percent of the population that is expected to be in need of a shelter after a disaster ($percentAffected$) and the resulting value is rounded up in case it is a non-integer value. With these operations, the expected number of people who will be in need of a shelter is obtained. By multiplying this value with the living space assigned per person ($livingSpace$), the total area needed to house all the people who will be in need of a shelter is found.

Since it is the current objective of Turkish Red Crescent, the objective function of the mathematical model is to select the best possible combination of shelter areas, or in other words, maximize the minimum weight of the operating shelter areas.

$$\max(\min(w_i * x_i + (1 - x_i) \mid i \in I)) \quad (1)$$

As the problem is capacitated, the total demand assigned to a shelter area cannot exceed its capacity. Because of this, the following constraint, which implies that the total used capacity of a shelter area, which is the sum of demands of the districts that are assigned to that shelter area plus the space for utilities, should not exceed its capacity, is included in the formulation.

$$\sum_{j \in J} y_{ij} * demand_j + utilitySpace * x_i \leq cap_i * x_i \quad \forall\, i \in I \qquad (2)$$

All districts must be assigned to a shelter area. To implement this, the following constraint is added.

$$\sum_{i \in I} y_{ij} = 1 \quad \forall\, j \in J \qquad (3)$$

Since the utility of each shelter area is important, the below constraint that calculates the utilization of each shelter area is included in the formulation. In this constraint, the utilization of each shelter area is defined by the total used space in the shelter area divided by its capacity.

$$u_i = \frac{\sum_{j \in J} y_{ij} * demand_j + utility * x_i}{Cap_i} \qquad \forall\, i \in I \qquad (4)$$

As stated earlier in this chapter, the three criteria (procurement and transportation of relief items and the distance to the health institutions) are not included in the weight function as they are directly measurable. In the model, these criteria are implemented with threshold distances. For the procurement and transportation of relief items, a threshold distance (*distRoad*) is defined. A similar threshold distance for health facilities (*distHealth*) is defined and these two thresholds are implemented with the two constraints below.

$$d_i^{health} * x_i \leq \ DistHealth \quad \forall\ i \in I \qquad (5)$$

$$d_i^{road} * x_i \leq DistRoad \quad \forall\ i \in I \qquad (6)$$

Constraints (5) and (6) state that a candidate shelter area i can be opened if there is a main road and a health institution within the radius defined by the respective threshold distance. Alternatively, the candidate locations that do not satisfy constraint (5) can be identified and excluded from the candidate location set. A similar analysis can be performed for the ones that do not satisfy constraint (6) and the violators can be removed. After these operations, all remaining members of the set will surely satisfy constraints (5) and (6). Thus, these two constraints can be removed after preprocessing.

Also, it is desired that if a, its utilization must be greater than a threshold value (β). To implement this requirement, the following constraint is included in the formulation.

$$u_i \ \geq \beta * \ x_i \quad i \in I \qquad (7)$$

In order to avoid possible conflicts, the utilizations of operating shelter areas need to be balanced. To balance the utilization of open shelter areas, a threshold value (α) is defined and a constraint is formulated. The constraint, which can be found below, forces the utilization difference of any pair of operating shelter areas to be less than the threshold value.

$$|u_i - u_j| * x_i * x_j \leq \ \alpha \quad \forall\ i \in I, j \in I \qquad (8)$$

Both β and α affect the utilization of the shelter areas. Since utilization is between 0 and 1, β can have values between 0 and 0.9 and α can have values between 1 and 0.1. However, for the constraint (8) to be effective, α should be less than or equal to min(β, 1- β). For example, if β is chosen as 0.7, choosing α as 0.4 will not any effect as the utilization of every operating shelter area will be between 0.7 and 1, and the length of this interval is 0.3. Thus, when β is chosen as 0.7, α must be less than or equal to 0.3. Otherwise, constraint (8) will be redundant.

After a disaster, a person will strongly prefer to be housed in the nearest shelter area. Because of this, "nearest allocation" constraints that force the mathematical model to assign each district to its closest operating shelter area are included in the formulation.

$$y_{distSorted(1,j),j} = x_{distSorted(1,j)} \ \forall j \in J \tag{9a}$$

$$y_{distSorted(i,j),j} \geq x_{distSorted(i,j)} - \sum_{k=1}^{i-1} x_{distSorted(k,j)} \ \forall j \in J, i = 2..|I| \tag{9b}$$

For each district, if the closest shelter area is open, then constraint (9a) performs the assignment of the district to the nearest shelter area. Otherwise, constraint (9b) initiates a search from the second closest shelter area to the furthest one and performs the assignment to the first available shelter area. The domain of x_i is the candidate shelter area set (*I*) and the domain of y_{ij} is the candidate shelter area set (*I*) and district set (*J*), however, in constraints (9a) and (9b), the index that represents (*I*) is replaced by *distSorted*. As each value of *distSorted* represents an element candidate shelter area set and it is a one-to-one function, it can replace the candidate shelter area set (*I*).

As a shelter area is either open or close, the decision variables that symbolize the state of the shelter areas are binary. Moreover, a district cannot be partially assigned to more than one shelter areas. Because of this, the decision variables that control the assignment of the districts are binary. The utilizations can be any value between 0 and 1. Because of this, they are defined are continuous variables. The constraints that define the domain of the variables can be found below.

$$x_i \in \{0,1\} \ \forall i \in I \tag{10a}$$

$$y_{ij} \in \{0,1\} \ \forall i \in I, \ j \in J \tag{10b}$$

$u_i \geq 0 \; \forall \, i \in I$ (10c)

All of the definitions of the model are now complete, however the objective (1) and constraint (8) are not linear. In order to obtain a linear model, these equations need to be linearized. To linearize objective (1), following variable is defined.

MinWeight: minimum weight of chosen candidate locations

With this addition, the objective function becomes:

Maximize *MinWeight* (1')

As this variable is not bounded above, regardless of the solution, the value of this variable will diverge to infinity. Because of this, the upper bound to this variable should be defined such that its value will be as less as the minimum weight of open shelter areas. To do so, following constraint is defined.

$MinWeight \leq x_i * w_i + (1\text{-}x_i) \;\; \forall \, i \in I$ (11)

For any candidate location, if it is closed, then the variable *MinWeight* is bounded above by 1. Otherwise, it is bounded above by the weight of the candidate location. After combining the inequality for all candidate locations, the upper bound of the variable will exactly be the minimum weight of open shelter areas. Since the objective is to maximize the variable, its final value will be the minimum weight of open shelter areas.

Also, constraint (8) is non-linear because of the absolute value function. To linearize this constraint, following inequalities are included.

$u_i - u_j \leq \alpha + (1 - x_i) + (1 - x_j) \; \forall \, i \in I, j \in I$ (8a)

$u_i - u_j \geq -\alpha - (1 - x_i) - (1 - x_j) \; \forall \, i \in I, j \in I$ (8b)

For any pair of candidate locations, if at least one of them is closed, then the constraints will be redundant. Otherwise, it will yield $|u_i - u_j| \leq \alpha$.

Finally, the linear formulation of the model can be presented as follows;

Maximize (1')

Subject to,

(2), (3), (4), (5), (6), (7), (8a), (8b), (9a), (9b), (10a), (10b), (10c), (11).

For a dataset with *m* candidate shelter areas and *n* districts, there are *m* + *m*n* binary variables and *m* continuous variables in the mathematical model. Also, the order of each constraint set is shown in Table 5-1.

Constraint	**2**	**3**	**4**	**5**	**6**	**7**	**8a**	**8b**	**9a**	**9b**	**10a**	**10b**	**10c**	**11**
Order	m	n	m	m	m	m	m*n	m*n	n	n*(m-1)	m	m*n	m	m

Table 5-1 The order of each constraint.

According to the Table 5-1, it can be said that the mathematical model is of O(m*n) constraints.

Chapter 6

Computational Results

To test the behaviour of the mathematical model, computational studies were performed. In these studies, data based on Kartal, Istanbul, Turkey, which is relatively small, and the Asian side of Istanbul, Turkey, which is larger, was used. In order to use the mathematical model, the required data are listed in Table 6-1. This chapter discusses the generation of the data that are mentioned in Table 6-1 and the results obtained from computational experiments.

Shelter Area	**District**	**Distance (From - To)**
Weight	Population	Midpoint of Districts - Shelter Areas
Capacity		Shelter Areas - Closest Health Institution
		Shelter Areas - Closest Main Road

Table 6-1 The required data for the model.

6.1. Data Based on Kartal

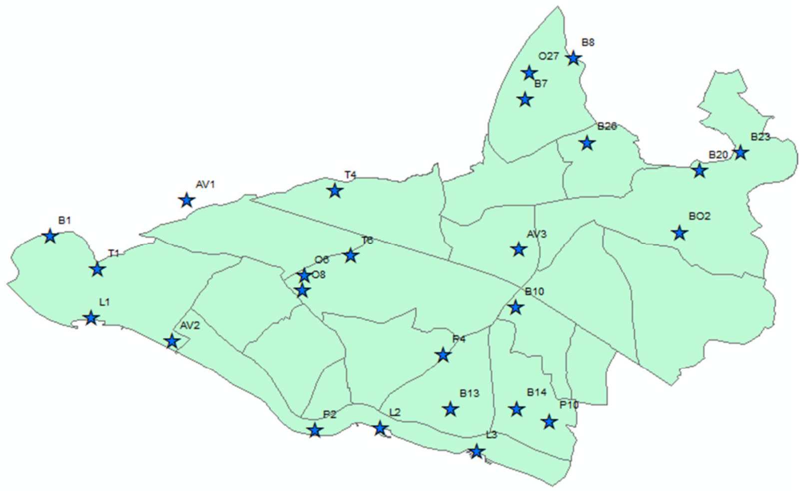

Figure 6-1 The location of shelter areas in Kartal.

In Kartal, there are 25 potential shelter areas and 20 districts [59]. The capacities in terms of m^2 and weight values of each potential shelter area are obtained from Unal (2010). The location of each potential shelter area is obtained with the help of Google Maps and pinned on ArcGIS. The locations of the candidate shelter areas can be seen in Figure 6-1 and their weights and the capacities can be found in Appendix 3. Moreover, as the districts are assumed to be single points, the centroid of the each district polygon is chosen to represent them. The location of districts can be seen in Figure 6-2. The populations of the districts are obtained from Turkish Statistical Institute (TÜİK) and can be found in Appendix 4. 12.5% of the population is assumed to be in need of a shelter area in case of an earthquake [59]. Also, the capacities of the shelter areas are in terms of square meters whereas the demand data is in terms of number of people. Turkish Red Crescent assigns 3.5 m^2 living space to each resident and 45 m^2 for utilities for sanitary and dining and in our computations, shelter areas are utilized by using those measures.

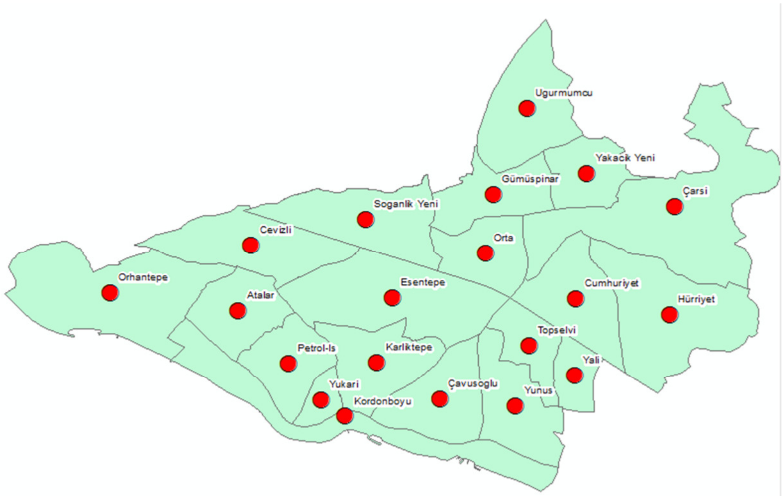

Figure 6-2 The points representing the districts in Kartal.

To generate the distance data, ArcGIS is used. Given a road network of Kartal, in order to obtain the distance between the points representing districts and candidate shelter locations, an Origin – Destination Cost Matrix problem was defined by using the Network Analyst extension where the impedance was defined as road distance. To obtain the distance from each shelter area to its closest health institution, health institutions are pinned on ArcGIS as points and a distance matrix from all potential shelter areas to all eight health institutions is generated using Network Analyst. Later on, the obtained matrix is sorted in order to get the closest distances. Similarly, in order to calculate the distance between all potential shelter areas and its closest main road, the main road junctions are pinned on ArcGIS and the closest distances are calculated in a similar way.

First, a base case scenario is generated. In this case, it is desired that each shelter area to be at least 60% utilized and their pairwise utilization difference to be less than 20%. Also, in case of medical emergencies, there needs to be a hospital within the 5 kilometer radius of each shelter area. Similarly, for procurement issues, main roads have to be reachable from all shelter areas within 5 kilometers. A solution is obtained by solving the mathematical model given in Chapter 5 by using a Pith Intel Core2Duo T6400 (2.0 GHz) processor, 4GB ram and Gurobi 4.5.2. The list of assignments for this solution can be found in Table 6-2 and the map of the solution for this scenario, which is generated by using ArcGIS, can be found in Figure 6-3.

District	Assigned To	Distance	District	Assigned To	Distance
ATALAR	AV2	2412.67	TOPSELVI	B14	1643.75
PETROLIS	AV2	3019.61	KARLIKTEPE	B14	2216.96
CEVIZLI	AV2	3658.04	KORDONBOYU	B14	2389.43
ORTA	AV3	855.83	YUKARI	B14	2692.12
GUMUSPINAR	AV3	1589.36	ESENTEPE	B14	2943.08
CUMHURIYET	AV3	1589.42	YAKACIKYENI	BO2	1676.42
SOGANLIKYENI	AV3	2304.08	HURRIYET	BO2	1724.07
YUNUS	B14	262.65	CARSI	BO2	1982.70
CAVUSOGLU	B14	1130.69	UGURMUMCU	BO2	3827.76
YALI	B14	1444.27	ORHANTEPE	L1	1436.41

Table 6-2 The assignment list of the solution of the base case scenario.

In Figure 6-3, open shelter areas are represented by stars, centroids of districts are represented by points and lines represent the shelter area - district assignments. There are five open shelter areas. The minimum of their weights is 0.827 and their average utilization is 0.863. Also, the longest travel distance from a district to a shelter area is 3.827 kilometers, which means there is reachable shelter within 3.827 kilometer radius of each district.

The computation time and the solution of the model is highly dependent on the number of population points. From a geographical point of view, the number of demand points depends on the level of aggregation. In this thesis, the population is aggregated in districts. It can be observed from Figure 6-3 that Carsi is assigned to the shelter area that is represented by the green star, however, some parts of the district is actually closer to the shelter area that is represented by the blue star. This is a result of the shape of Carsi.

To overcome this situation, such odd-shaped districts needs to be disaggregated to two or more subdistricts. This disaggregation will yield a solution with a better implementation of “nearest neighbor” constraints. On the other hand, further disaggregation will increase the number of population points, thus increase the problem size and computation time. Therefore, it can be said that there is a tradeoff between aggregation of districts and computation time.

To observe the impacts of the proposed methodology, the solution of the base case scenario is compared with the Turkish Red Crescent’s current methodology. To implement the Turkish Red Crescent’s methodology, the potential shelter areas are sorted with respect to their weights. Then, the areas are opened one by one until there is enough space to house all the affected population and finally, all the districts are assigned to the nearest open shelter area.

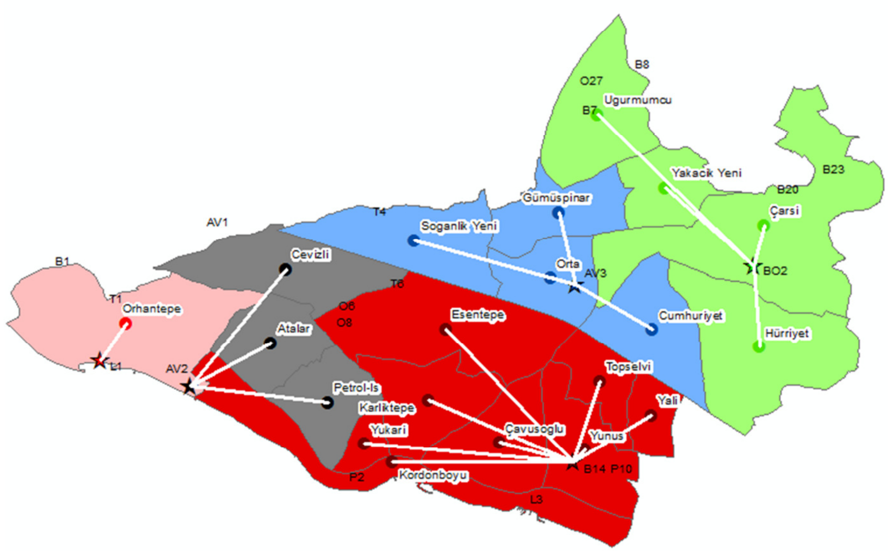

Figure 6-3 The map of the solution of the base case scenario.

For comparison, the maximum of the distances between a district and its assigned shelter area, the minimum utilization, the maximum utilization, the average utilization and the number of operating shelter areas are used. Objective value (minimum of the weights of the operating shelter areas) is not taken into consideration while doing this comparison since the calculations of the weight function in the proposed methodology and in the Turkish Red Crescent's methodology are different. The comparison can be found in Table 6-3.

	Base Case	TRC
The Maximum Distance	3827.768	4116.069
The Minimum Utilization	0.772	0
The Maximum Utilization	0.953	1.353
The Average Utilization	0.863	0.663
Number of Open Shelter Areas	5	5

Table 6-3 The comparison of base case scenario and TRC's methodology.

While determining assignments, it is assumed that a resident of a district tends to go to the nearest operating shelter area with respect to the point that represents that district. The assignment list can be found in Table 6-4.

The benefit of the utilization constraints can be seen by observing values of minimum, maximum and average utilization. In the base case scenario, the range of the utilizations of the shelter areas is 0.181 whereas the same value in the TRC's case is 1.353. By observing these values, it can be concluded that the utilizations are more balanced in the base case scenario.

Moreover, in the TRC's case, the minimum utilization is 0, which means that a shelter area (AV1) is empty, and the maximum utilization is 1.353, which means that a shelter area (AV3) is overcrowded. AV1 is empty because with respect to the level of aggregation that is used in this study, it is not the closest operating shelter area to any of the points that represent the districts. For greater level of aggregations, this shelter area may not be empty; however, it will be lowly utilized. On the other hand, AV3 is overcrowded since it is the closest operating shelter area 8 districts and all the affected people living in those 8 districts will tend to move to AV3. However, the capacity of AV3 is not enough to house all of those people, thus, it is overcrowded.

District	Assigned To	Distance	District	Assigned To	Distance
ATALAR	AV2	2,412.67	CAVUSOGLU	P4	825.58
ORHANTEPE	AV2	1,800.80	KARLIKTEPE	P4	1,026.51
CARSI	AV3	3,484.57	KORDONBOYU	P4	1,764.88
CUMHURIYET	AV3	1,589.42	PETROLIS	P4	2,565.11
GUMUSPINAR	AV3	1,589.36	TOPSELVI	P4	1,635.85
HURRIYET	AV3	2,760.20	YALI	P4	2,122.84
ORTA	AV3	855.83	YUKARI	P4	1,883.36
SOGANLIKYENI	AV3	2,304.08	YUNUS	P4	1,341.17
UGURMUMCU	AV3	4,116.07	CEVIZLI	T6	2,342.99
YAKACIKYENI	AV3	2,642.41	ESENTEPE	T6	1,346.65

Table 6-4 The assignment list of the solution w.r.t. TRC's methodology

To further analyze the behavior of the mathematical model, 3000 instances are generated by varying β (threshold value for minimum utilization) from 0 to 0.9, α (threshold value for maximum pairwise utilization difference) from 1 to 0.1, and giving *DistHealth* (threshold distance from shelter area to its closest health institution) values 5, 4, 3, 2.5, 2 and 1 kilometers and giving *DistRoad* (threshold distance from shelter area to its main road) values 5, 4, 3, 2.5 and 2 kilometers. To obtain the optimal solution for the above mentioned instances, the above mentioned mathematical model is solved using a PC with Intel Core2Duo T6400 (2.0 GHz) processor, 4GB ram and Gurobi 4.5.2 is used. Given this dataset, all instances are solvable in less than a second.

We observed that as we decrease *DistHealth* and *DistRoad* values, maximum of minimum weight of open shelter areas decreased and eventually, problem became infeasible. Main reason of this is as the threshold values decrease, the number of shelter areas that have health institution and main road within the threshold distance decrease. As a result of this, the model tends to open shelter areas with smaller weights and therefore, the objective function value decreases. In the three tables below, one can find the value of the objective function with different values of β and α when both *DistHealth* and *DistHealth* are at their maximum (Table 6-5) and one of them is at its maximum while the other one is at its minimum (Tables 6-6 and 6-8). Note that the case when both parameters are at their minimum is omitted as the problem is infeasible for those cases.

β \α	**1**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**
0	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.827	0.827
0.1	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.827	0.827
0.2	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.827	0.827
0.3	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.827	0.827
0.4	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.827	0.827
0.5	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.827	0.827
0.6	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.827	0.827
0.7	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.827
0.8	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.827
0.9	0.739	0.739	0.739	0.739	0.739	0.739	0.739	0.739	0.739	0.739

Table 6-5 The objective value when DistHealth = DistRoad = 5.

From Table 6-5, it can be observed that when β is less than or equal to 0.6 and α is greater than or equal to 0.3, all solutions have the same objective value. Although it may be thought that they are the same solutions at first sight, further inspection showed that the number of open shelter areas change between 4 and 5 in each solution. After the solutions for each instance are inspected individually, it is seen that they are different from each other. However, the feasible set narrows down as β increases and α decreases. So, the solution obtained for $\beta = 0.6$ and $\alpha = 0.3$ is feasible for all other cases where the objective value is 0.85. Thus, it can be concluded that there exists alternative optimal solutions when β is less than or equal to 0.6 and α is greater than or equal to 0.3. After inspecting the cases where the objective value is 0.827, a similar case is observed. On the other hand, in all 10 cases where the objective value is 0.739, the model returned the same solution.

β\α	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
0	0.739	0.739	0.739	0.739	0.739	0.739	0.739	INF	INF	INF
0.1	0.739	0.739	0.739	0.739	0.739	0.739	0.739	INF	INF	INF
0.2	0.739	0.739	0.739	0.739	0.739	0.739	0.739	INF	INF	INF
0.3	0.739	0.739	0.739	0.739	0.739	0.739	0.739	INF	INF	INF
0.4	0.739	0.739	0.739	0.739	0.739	0.739	0.739	INF	INF	INF
0.5	0.739	0.739	0.739	0.739	0.739	0.739	0.739	INF	INF	INF
0.6	0.739	0.739	0.739	0.739	0.739	0.739	0.739	INF	INF	INF
0.7	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF
0.8	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF
0.9	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF

Table 6-6 The objective value when DistHealth =1.5 and DistRoad = 5.

From Table 6-6 it can be observed that all of the cases are either infeasible, or has an objective value of 0.739. Upon observing the solutions, it is seen that there are either 2 or 3 open shelter areas. The utilization of the open shelter areas in these solutions are shown in Table 6-7. Table 6-7 implies that the solution with 3 open shelter area becomes infeasible when β is 0.6. For any other combinations of β and α, given that β is not greater than 0.6 and α is not smaller than 0.4, there are two alternative optimal solutions.

2 Shelter Areas			**3 Shelter Areas**		
Area Name	Utilization	Weight	Area Name	Utilization	Weight
B14	0.964	0.85	B14	0.504	0.85
T4	0.644	0.739	L2	0.993	0.847
			T4	0.553	0.739

Table 6-7 The utilization values of two solutions when DistHealth =1.5 and DistRoad = 5.

From Table 6-8, it can be observed that the objective value is 0.827 when β is less than or equal to 0.6 and α is greater than or equal to 0.3. In each of these instances, there are four open shelter areas. The solutions of those instances are inspected, and concluded that they are identical. Similarly, solutions of other cases, where the objective value is 0.739 and there are two open shelter areas, are also inspected and concluded that they are identical.

β\α	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
0	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.739	0.739
0.1	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.739	0.739
0.2	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.739	0.739
0.3	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.739	0.739
0.4	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.739	0.739
0.5	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.739	0.739
0.6	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.827	0.739	0.739
0.7	0.739	0.739	0.739	0.739	0.739	0.739	0.739	0.739	0.739	0.739
0.8	0.739	0.739	0.739	0.739	0.739	0.739	0.739	0.739	0.739	0.739
0.9	0.739	0.739	0.739	0.739	0.739	0.739	0.739	0.739	0.739	0.739

Table 6-8 The objective value when DistHealth = 5 and DistRoad = 2.

Additionally, in Table 6-9, all objective values that are observed in 3000 instances, the interval of parameters that yielded each objective value and the name of the shelter areas that forced each objective value can be found. According to Table 6-9, the highest objective value is 0.850 and it is the weight of B14. Thus, this objective occurs only in cases where B14 is in the feasible set with respect to health and main road cover distances (i.e. *distHealth* is greater than 2.5 and *distRoad* is equal to 5). The lowest objective that is observed in those instances is 0.674 and either B23 or B20 is chosen to operate in those solutions.

Objective	DistHealth	DistRoad	β	α	Shelter Area(s)
0.85	[2.5, 5]	5	[0, 0.6]	[0.3, 1]	B14
0.847	[2.5, 5]	[4,5)	[0, 0.6]	[0.3, 1]	P10, B10, L2
	[2.5, 5]	[2.5 ,3]	[0, 0.3]	[0.7, 1]	
0.829	[2.5, 5]	[3,4)	[0.4, 0.5)	[0.7 , 1]	L3
			[0, 0.4]	[0.5, 0.6]	
0.827	[2.5, 5]	5	[0.7, 0.8]	[0.3, 1]	B7
			[0, 0.8]	[0.1, 0.2]	
	[2.5, 5]	[4,5)	[0.7, 0.8]	[0.3, 1]	
			[0, 0.8]	[0.2, 0.3)	
	[2.5, 5]	[3,4)	[0.5, 0.7]	[0.5, 1]	

			[0, 0.7]	[0.2, 0.4]	
	[2.5, 5]	[2.5,3)	[0.4, 0.6]	[0.7, 1]	
			[0, 0.6]	[0.3, 0.6]	
	[2.5, 5]	[2, 2.5)	[0, 0.6]	[0.3, 1]	
0.803	[3, 5]	[4, 5)	[0, 0.7]	[0.1, 0.2)	O27
	[3, 5]	[3, 4)	[0.8, 0.9)	[0.2, 1]	
	[3, 5]	[2.5, 3)	[0.7, 0.8]	[0.3, 1]	
			[0, 0.8]	[0.2, 0.3)	
0.801	[2, 2.5)	5	[0, 0.5]	[0.2, 1]	BO2
	[3, 5]	[4, 5)	[0.8, 0.9)	[0.1, 0.2)	
	[2.5, 3)	[4, 5)	[0, 0.8]	[0.1, 0.2)	
	[2, 2.5)	[4, 5)	[0, 0.5]	[0.3, 1]	
0.795	[2, 2.5)	5	[0, 0.5]	[0.1, 0.2)	B1
	[2, 2.5)	[4, 5)	[0, 0.5]	[0.1, 0.2]	
0.739	[3, 5]	[2.5 ,5]	0.9	ALL	T4
	[2, 2.5]	[4, 5]	[0.6, 0.7)	[0.4, 1]	
	[1.5, 2)	[3, 5]	[0, 0.6]	[0.4, 1]	
			[0, 0.8]	[0.1, 0.2)	
	[2.5, 3)	[3, 4)	[0.8, 0.9)	[0.2, 1]	
			[0.1, 0.2)	[0, 0.4]	
	[2 ,2.5)	[3, 4)	[0, 0.4]	[0.3, 1]	
			[0.5, 0.6]	[0.4, 1]	
	[2.5, 3)	[2.5, 3)	[0.7, 0.8]	[0.3, 1]	
			[0, 0.8]	[0.2, 0.3)	
	[2, 2.5)	[2.5 ,3)	[0, 0.6]	[0.4, 1]	
	[1.5, 2)	[2.5, 3)	[0, 0.6]	[0.4, 1]	
	[3, 5]	[2, 2.5)	[0.7, 0.9]	[0.3, 1]	
			ALL	[0.1, 0.2]	
	[2.5, 3)	[2, 2.5)	[0.7, 0.8]	[0.3, 1]	
			[0, 0.8]	[0.2, 0.3)	
0.674	[2, 2.5)	[4, 5]	[0.6, 0.7)	[0.2, 0.3]	B23, B20
			[0.7, 0.8)	[0.2, 1]	

Table 6-9 The interval of parameters for each objective value

Also, as β is increased and α is decreased, the average utilization of open shelter areas increases. This is expected as β increases, the minimum utilization of open shelter areas increases, hence the average utilization increases. In table 6-10, the average of average utilization over 30 different *DistHealth* and *DistRoad* combinations with different β and α pairs can be found.

One can see from Table 6-10 that, when β is 0.7, the average of average utilization does not change until α is decreased to 0.2. A similar case occurs when β is 0.8 and α is between 1.0 and 0.2 and when β is 0.9. This means that, in those combinations of β and α, for all 30 pairs of *DistHealth* and *DistRoad*, the mathematical model reported the same optimal solution.

β\α	**1.0**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**
0.0	0.671	0.687	0.692	0.720	0.779	0.779	0.787	0.797	0.875	0.875
0.1	0.688	0.691	0.716	0.724	0.755	0.769	0.792	0.798	0.875	0.875
0.2	0.711	0.711	0.717	0.725	0.764	0.771	0.785	0.785	0.877	0.877
0.3	0.717	0.713	0.697	0.713	0.756	0.763	0.793	0.797	0.877	0.877
0.4	0.761	0.758	0.762	0.762	0.762	0.764	0.797	0.798	0.875	0.875
0.5	0.782	0.783	0.783	0.783	0.783	0.783	0.808	0.808	0.872	0.885
0.6	0.804	0.814	0.814	0.814	0.814	0.814	0.814	0.823	0.899	0.918
0.7	0.880	0.880	0.880	0.880	0.880	0.880	0.880	0.880	0.881	0.918
0.8	0.904	0.904	0.904	0.904	0.904	0.904	0.904	0.904	0.904	0.933
0.9	0.971	0.971	0.971	0.971	0.971	0.971	0.971	0.971	0.971	0.971

Table 6-10 The average of average utilizations.

In addition, as β increases and α decreases, the number of open shelter areas decrease for constant *DistHealth* and *DistRoad* values. This occurs because as the minimum utilization threshold increases, the model tends to fill up the open shelter areas more. As a result, in order to satisfy this constraint, the model chooses to open less shelter areas for the same number of people. In table 6-11, the maximum of number of open shelter areas over 30 different *DistHealth* and *DistRoad* combinations with different β and α values can be found.

Moreover, the number of infeasibilities for each α, β pair over 30 different *DistHealth* and *DistRoad* combinations. It is observed that as β increases and α decreases, the number of infeasible cases increases. The number of infeasible cases out of 30 different *DistHealth* and *DistRoad* combinations for each α, β pair can be found in Table 6-12.

β\α	**1**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**
0	8	8	6	6	6	6	6	6	5	5
0.1	7	7	7	6	6	6	6	6	5	5
0.2	6	6	6	6	6	6	6	6	5	5
0.3	5	5	5	5	5	5	5	4	4	4
0.4	5	5	5	5	5	5	5	4	4	4
0.5	5	5	5	5	5	5	5	4	4	4
0.6	5	5	4	4	4	4	4	4	4	4
0.7	5	5	4	4	4	4	4	4	4	4
0.8	5	5	4	4	4	4	4	4	4	4
0.9	2	2	2	2	2	2	2	2	2	2

Table 6-11 The maximum number of operating shelter areas.

β\α	**1**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**
0	2	2	2	2	2	2	2	7	8	10
0.1	2	2	2	2	2	2	2	7	8	10
0.2	2	2	2	2	2	2	2	7	8	10
0.3	2	2	2	2	2	2	2	7	8	10
0.4	2	2	2	2	2	2	2	7	8	10
0.5	2	2	2	2	2	2	2	8	8	11
0.6	2	2	2	2	2	2	2	8	8	13
0.7	8	8	8	8	8	8	8	8	8	13
0.8	10	10	10	10	10	10	10	10	10	13
0.9	15	15	15	15	15	15	15	15	15	15

Table 6-12 The number of infeasible cases.

It is observed that when *DistHealth* is 2 or 1.5 and *DistRoad* is 2, all instances returned infeasible. This implies that for any α, β pair, there has to be at least 2 infeasible cases.

When β is less than 0.6 and α is greater than 0.4, all cases returned a solution except when *DistHealth* is 2 or 1.5 and *DistRoad* is 2. As β increases and α decreases, the feasible set gets narrower. Because of those reasons, the increase in the number of infeasible cases is expected.

% Affected	Objective
10	0.85
10.5	0.85
11	0.847
11.5	0.847
12	0.847
12.5	0.827
13	0.827
13.5	0.809
14	0.809
14.5	0.803
15	0.803

% Affected	Objective
15.5	0.803
16	0.801
16.5	0.801
17	0.801
17.5	0.801
18	0.801
18.5	0.801
19	0.801
19.5	0.795
20	0.739

Table 6-13 The objective with different values of percentAffected

In addition, 21 instances is generated to observe the response of the mathematical model to the different values of the percent of affected people (*percentAffected*). In those instances, *percentAffected* varies from 10 to 20 with increments of 0.5 and the values of *β, α, DistHealth and DistRoad* are constant and equal to their values in the base case scenario. From table 6-13, it can be observed that as *percentAffected* increases, the objective value decreases. When *percentAffected* is increased, the total required size of shelter areas increase, thus, the mathematical model tends to utilize shelter areas with larger capacities and smaller weights.

Chapter 7

GIS Framework and DSS Implementation

To provide a powerful tool that selects the location of shelter areas and decides on the population assignment using the mathematical model that is given in Chapter5, a decision support system is developed with the help of a geographical information system. The tool is an ArcGIS extension which retrieves the distance data from the software, receives parameters from the user, solves the model using Gurobi and displays the solution on the map upon user's request. The tool is developed and the user interface is designed using C#.

To use the decision support tool, user needs to open a map document that contains six data layers. The content of these six layers can be listed as;

i) district polygons,

ii) midpoint of district polygons,

iii) locations of candidate shelter sites as points,

iv) location of hospitals as points,

v) junction points of main roads,

vi) the road network.

Also, for the mathematical model, in the data table of (ii) there should be a column that contains the population of each district and in the data table of (iii) there should be two columns that contain the capacity and weight of each candidate shelter site. Furthermore, for the visualization of the solution, there should be columns that contain the X and Y coordinate of each district and shelter site and an empty column in the data table of (ii) and (iii) to be filled later by some values that will be used in visualizing the obtained solution.

The intended user of this decision support system is the Turkish Red Crescent since they are responsible for the decision of the locations of the temporary shelter areas. The decision support can be used in both pre-disaster and post-disaster.

- Pre-disaster: The mathematical model and the decision support system provides decisions about post-disaster. However, they can be used for pre-disaster sensitivity analysis similar to the one provided in Table 6-10. To perform this analysis, the decision maker can generate different scnearios by varying *β, α, DistHealth, DistRoad* and *percentAffected*. Inspecting the solutions of those different scenarios can provide insight about critical shelter areas (i.e. the shelter areas that are chosen to operate in most or all of the instances) or critical assignments (i.e. common district-shelter area assignments that appear in most or all of the instances) and a disaster plan can be determined.

  Also, pre-disaster sensitivity analysis can help the decision maker to determine the desired values of β*, α, DistHealth* and *DistRoad*. The value of *percentAffected* is not known before the disaster. Because of this, the decision maker should run the mathematical model with different values of β, *α, DistHealth* and *DistRoad* and determine the values of these parameters for different values of *percentAffected* by observing the behavior of the objective function.

- Post-disaster: After the disaster occurs, the value of *percentAffected* can be estimated and with the use of the mentioned analysis, the best combination of parameters for the estimated value of *percentAffected* is available to the decision maker. Thus, the decision maker can run the mathematical model with the pre-determined values of *β, α, DistHealth* and *DistRoad* and apply the solution immediately and save time which is even more valuable than usual in such situations.

For the fast and efficient use of the decision support system, a user interface is developed. The user interface is divided into four tabs and a welcome screen. The first tab is for inputing the above mentioned layers and computing the distance matrices. In the second one, the user can input the problem parameters and solve the problem. The third tab is for viewing, visualizing and editing the solution and the last tab is for comparing different scenarios. These tabs are further explained in the latter sections.

7.1 The Initialization Tab

In this tab, there are 16 drop down menus, an initialization button and a listbox (Figure 7-1). 11 of the menus and the button is initially inactive. The functions of these menus and the button is explained below.

Given a map with the above mentioned layers, the user selects the layers that represent road network, midpoints of each district, shelter site locations, hospitals and main road junction points from a drop down menu. The user do not need to select the layer that contains districts as polygons as it is assumed that there will be only one polygon shaped layer contained in the map.

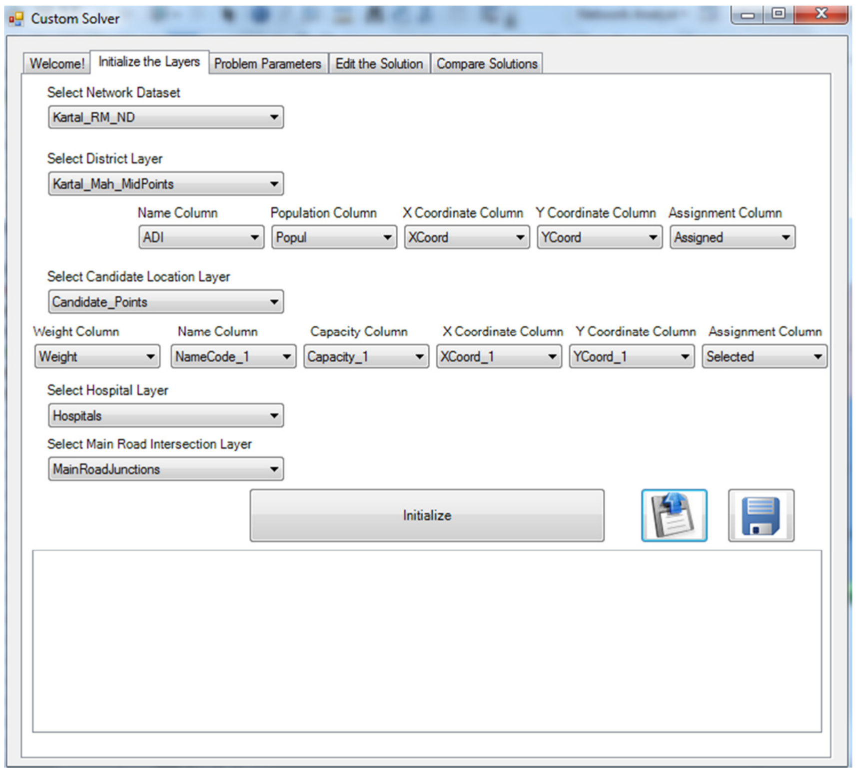

Figure 7-1 The "Initialization" Tab

After selecting the layer that features midpoints of districts, five drop down menus become active and all the available columns in the selected layer is listed in those menus. The user needs to identify the columns that contains the population, names, X and Y coodrinates of the districts. Also, as mentioned, an empty column needs to be selected for the visualization process. Similarly, after selecting the layer that features the shelter site locations, six drop down menus become active. These menus are for selecting the columns that contains weights, capacities, names and X and Y coordinates of the sites and an empty column respectively. The function of these two empty columns will be clarified while explaining the visualization process. Alternatively, with the help of the save/load buttons, the user can save the current selection of layer and column names to a text file or load those names from a text file.

7.2 Model Tab

In this tab, there are eight text boxes, a solver button and a list box (Figure 7-2). The eight textboxes are for inputing the values for the minimum utilization threshold (β), the maximum pair-wise utilization difference (α), the threshold distance from candidate shelter sites to the nearest health institution (*distHealth*), the threshold distance from candidate shelter sites to the nearest main road (*distRoad*), the living space per person in square meters (*livingSpace*), the area for sanitary utilities per shelter area in square meters (*utilitySpace*), the percent of affected population (*perfectAffected*), and the number of people per household (*perHH*) respectively. Each parameter is represented with a variable and each textbox is related to its respective variable. Alternatively, as in the initialization tab, those parameters can be saved to a text file and loaded from a text file.

In addition, the user may choose to exclude the utilization constraints from the model. To do so, the user can use the two checkboxes that are located at the left of the textboxes that are related to β and α. The upper checkbox controls the minimum utilization constraint and the lower one controls the maximum pairwise utilization difference constraint.

More importantly, the number of districts that are not assigned to the closest shelter area tends to decrease as p increases. When p is 20, the regarding value is 18, which is 6.66% of all the districts. Then it decreases to 0 when p is 30. And when p is incremented to 40, the number of districts that are not assigned to the closest shelter area does not exceed 4 (1.4% of all districts).

With these results, it can be said that the modified model is not an exact representation of the model that is explained in Chapter 5. However, for the large datasets, such as the one represents the Asian side of Istanbul, the modified model can be advantageous in terms of computation times. However, as the solution of the modified model may not be feasible for the original model, it may need some additional time for manual iterations.

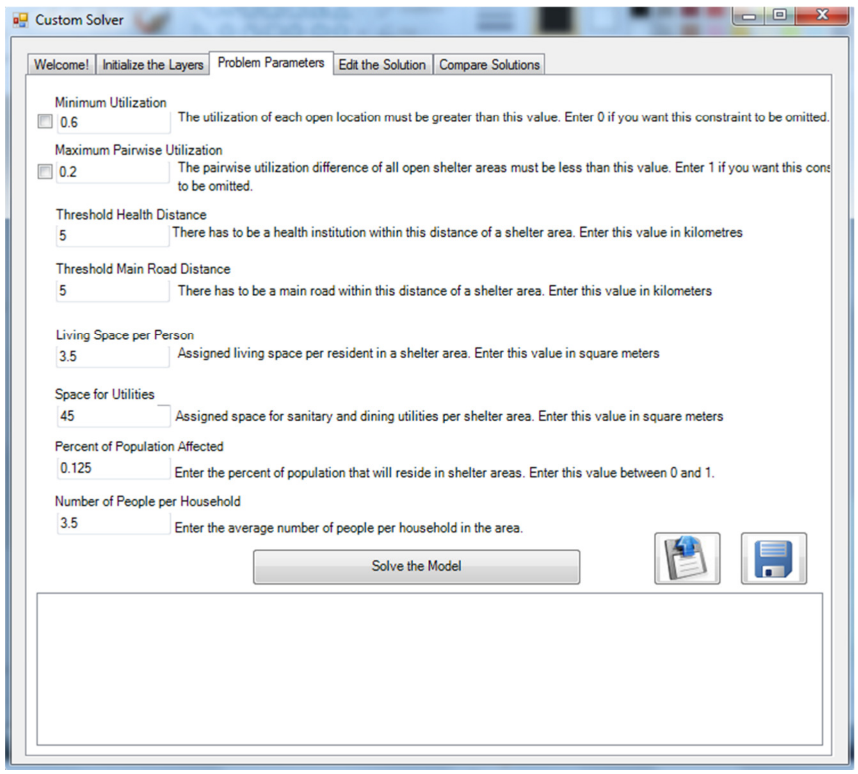

Figure 7-2 The "Model" Tab

After the values of all eight parameters are entered into textboxes, solver button becomes active. After clicking the button, the code snippet converts the number of affected people into the demand value using the equation mentioned in Chapter 5. Then, it generates a Gurobi environment and implements the formulation using Gurobi .NET library and solves the generated model. Lastly, the solution is written to the list box.

7.3 The Solution Tab

After the user has completed the solution procedure, he/she has the opportunity to view and edit the solution. This tab consists of a tabbed control for editing the solution and three other sub-controls for visualizing the solution, listing the district assignments and graphing the utilization of selected shelter sites (Figure 7-3).

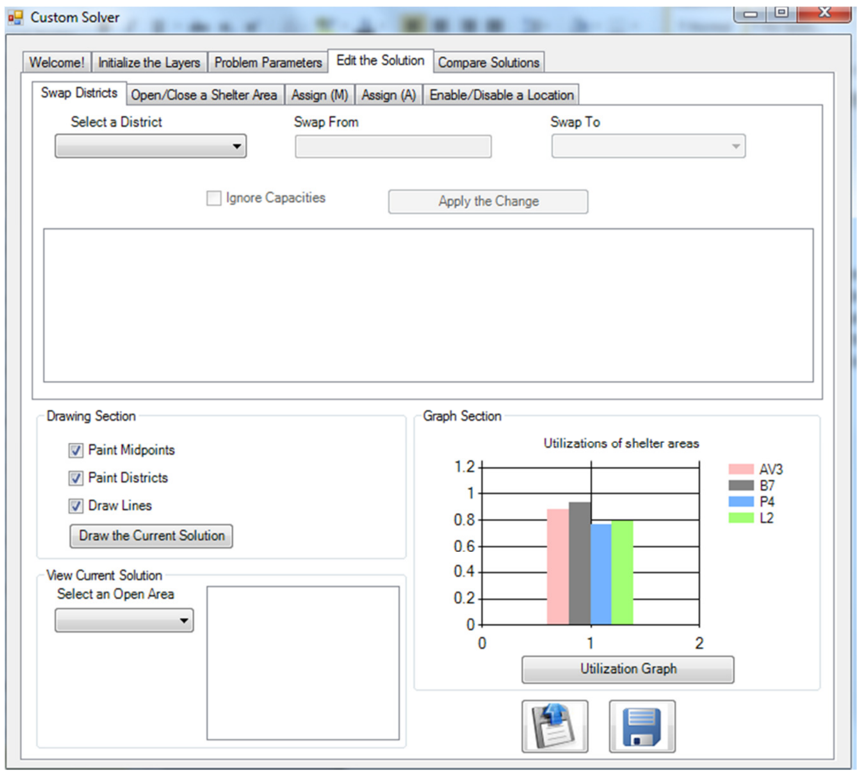

Figure 7-3 The "Solution" Tab

In the tabbed control, the user has seven editing options distributed in five different tabs. These options are (i) changing a district's assignment, (ii) opening an empty shelter area, (iii) closing an open shelter area, (iv) assigning unassigned districts to open shelter areas manually, (v) assigning unassigned districts automatically, (vi) disabling a shelter area, and (vii) enabling a shelter area. Below, these options and their application are explained in detail.

i. Swap District: Using this option, the user can swap a district's assignment. To do so, the user should first go to "Swap District" tab (Figure 7-4) and select a district. After a district is chosen, the name of the shelter area which the district is assigned to is shown in the textbox. Next, the user should select a shelter area in order to change the assignment. After the selection is completed, the resulting utilizations of the shelter areas that will be affected from the change are displayed in the listbox. If the shelter areas are not overcapacitated (i.e. their utilizations are less than 1), the user can perform the operation by clicking the "Apply the Change" button. To override the capacity constraint, the user should check the box labeled "Ignore Capacities" and then click the button. After the button is clicked, a message will confirm the change.

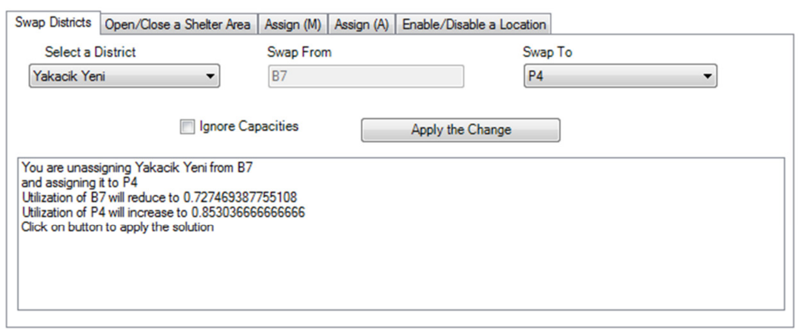

Figure 7-4 "Swap Districts" Tab

ii. Open a Shelter Area: This option allows user to open an empty shelter area. To do so, user should first go to "Open/Close a Shelter Area" tab (Figure 7-5). From the drop down menu at the left side, the user should select a shelter area and to open the selected shelter area, the user should click the button labeled "Open the Selected Location". After clicking, a message will appear in the listbox stating that the operation was successful. To avoid complications, selecting shelter areas from both drop down menus is not allowed. Because of this, if the user wants to abandon the change, he/she has to click the cancel button.

iii. Close a Shelter Area: With this option, the user is able to close an open shelter area. Similar to the option (ii), the user should select an open shelter area and click the button labeled "Close the Selected Location" to finalize the operation and to abandon the change, he/she has to click the cancel button. As there are districts assigned to each shelter area, some of them will be unassigned after this operation. To reassign them, the user should use option (iv) or option (v).

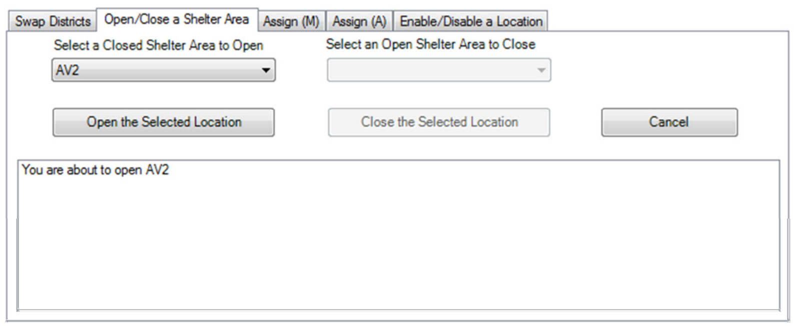

Figure 7-5 The "Open/Close Shelter Area" Tab

iv. Assign (Manual): This option will help the user to reassign an unassigned district to an open shelter area. To make use of this option, the user should go to the tab that is labeled "Assign (M)" (Figure 7-6). First, the user should select an unassigned district from the drop down menu at the left of the tab. Then, he/she selects an open shelter area from the drop down menu at the left. After the selections are complete, the anticipated utilization of the selected shelter area is displayed in the listbox. By clicking the button, the user approves the change. Similar to the option (i), if the selected shelter area is overcapacitated, the user needs to check the capacity override box before clicking the button.

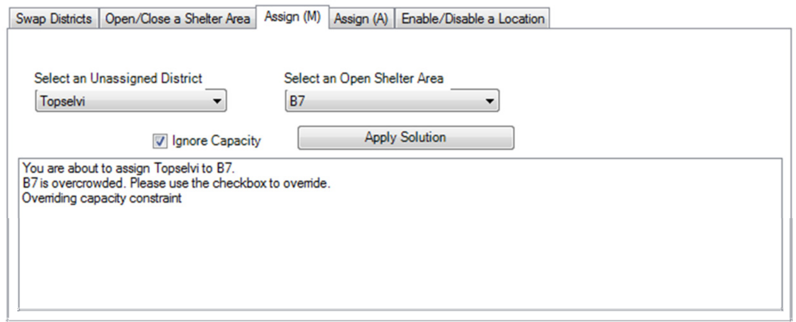

Figure 7-6 The "Manual Assignment" Tab

v. Assign (Automatic): With this option, the user has given the opportunity to assign all unassigned districts automatically. The tool offers two ways to do this, and hence, there are two buttons in the "Assign (A)" tab (Figure 7-7) related to this option. First one assigns the unassigned districts without opening new areas. After clicking, the tool searches for the closest open shelter area of each district, lists the suggested changes and asks the user whether he/she wants to apply the suggested changes via a dialog box. The solution is updated upon the approval of the user.

Second button generates a sub-model of the model that is mentioned in Chapter 5. In this problem, all unassigned districts are taken as the set of districts and the enabled shelter areas are taken as the set of candidate locations. As in the model tab, the model is solved using Gurobi .NET library. After a solution is generated, the user is asked whether he/she wants to apply the suggested changes via a dialog box and the solution is updated if the user approves the changes.

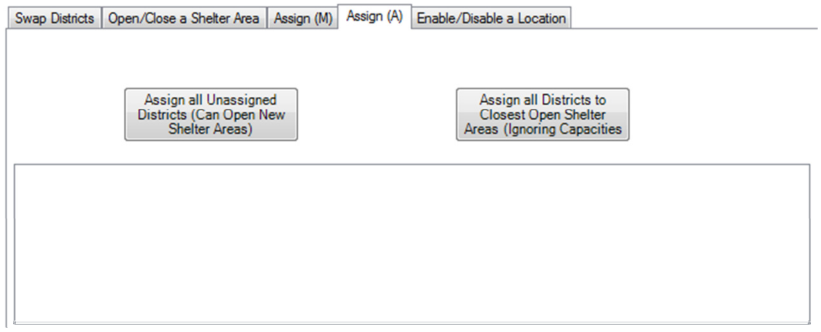

Figure 7-7 The "Automatic Assignment" Tab

vi. Disable a Shelter Area: The user may not want to consider a shelter area in next solutions. Consequently, an option to "disable" the shelter areas in included to the decision support tool. To disable the shelter area, the user needs to go to "Enable/Disable a Location" tab (Figure 7-8). In this tab, the left hand drop down menu and button is related to this option. To disable a location, the user should select a closed shelter area from the drop down menu and click the "disable" button. As in option (ii) and (iii), enabling and disabling a shelter area at the same time is not permitted. Because of this, the user should click on "cancel" in order to abandon the change.

vii. Enable a Shelter Area: Similar to option (vi), the user may want to reconsider a shelter area in further solutions, or in other words, "enable" a shelter area. The right hand drop down menu and button in the "Enable/Disable a Location" tab is related to this option (Figure 7-8). The procedure of enabling a location is similar to the previous option. The user should select a disabled shelter area from the drop down menu and click on the "enable" button to apply or click on "cancel" in to abandon the change.

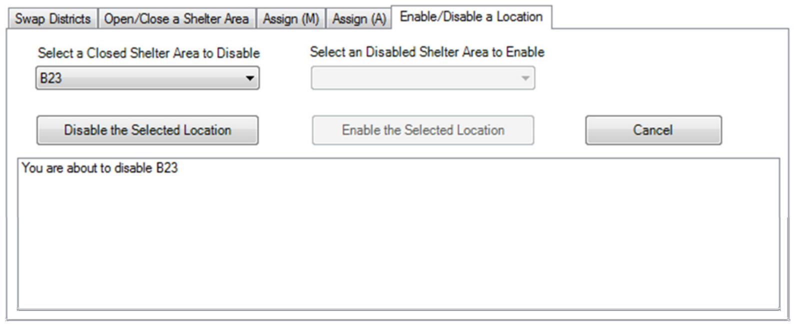

Figure 7-8 The "Enable/Disable a Location" Tab

As mentioned, the user can visualize the current solution with a map. The "Drawing Section" (Figure 7-9) is related to this property. For creating the map of the solution, the user has three options. These options are i) marking the midpoints of districts and the location of open shelter areas, ii) painting the district polygons and marking the location of open shelter areas, and iii) drawing lines between each open shelter area and midpoints of its assigned districts and the user can view the solution by choosing any three combination of these options.

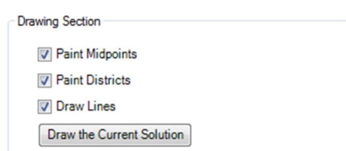

Figure 7-9 The "Drawing Section"

Lines between the shelter areas and midpoints of districts are drawn bu using the X coordinate and Y coordinate data of the points. For the other two drawing options, the blank columns that are mentioned earlier are made use of. To make use of this column, using the symbology property of ArcGIS, the user must assign different colored markers for the candidate location points and district's midpoints and different fill colors for district polygons for the different values of this column. In the most general case, the value of this column can vary between one and number of candidate locations and they are initially set to 0. Then, the algorithm performs a search in the candidate location set and when it discovers an open location, it assigns the value of a counter variable to the location, where the counter variable starts from one and is incremented by one after it is assigned to a location and these values are stored in the blank column. Also, each district is given the same value with their assigned shelter area (i.e. if a district is assigned to a shelter area that has a blank column value of two, then its blank column value is also two). For the best use of this property, the symbology of candidate locations, district midpoints and district polygons should contain similar colors for the same values of respective columns.

To graph the utilization of open shelter areas, a chart object is included in the form (Figure 7-10). For each open shelter area, a data series with a single point, which is the utilization of the shelter area, is added to the chart. To overcome possible confusions, the color of the bar that represents a shelter area is chosen to be similar to the color of the point that represents it on the map.

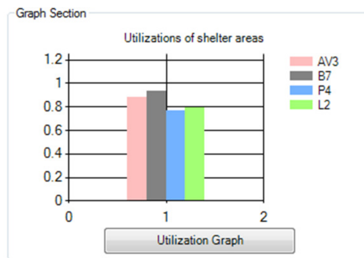

Figure 7-10 The "Graph Section"

Additionally, for viewing the status of each open shelter area, a drop down box and a listbox is added to the form (see Figure 7-11). To view the status of an open shelter area, the user should select it from the drop down box. After the selection, the name, utilization and names of the districts that are assigned to the chosen shelter area will be displayed.

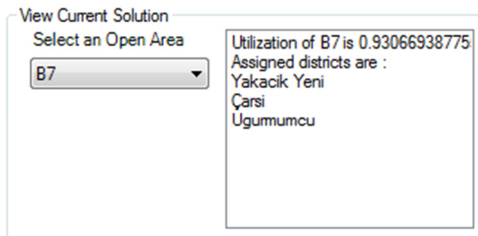

Figure 7-11 The "View Current Solution Section"

7.4 The Comparison Tab

With this tab, the user is allowed to compare up to four different scenarios. For comparison, six different statistics, namely i) the objective value, ii) the maximum distance travelled by a person, iii) the minimum utilization of open shelter areas, iv) the maximum utilization of open shelter areas, v) the average utilization of open shelter areas and vi) the number of open shelter areas, are used.

To allow comparison, a table is attached to the form (Figure 7-12). To add scenarios to the table, the user should click on the "Add Scenario" button and select a solution file. After the solution is loaded, the statistics of it will be included in the table. To exclude a scenario from the table, the user should select the name of the scenario from the drop down menu which is located below the table and click on the "Delete Scenario" button. Also, the user can clear the data table by clicking on the "Clear Table" button.

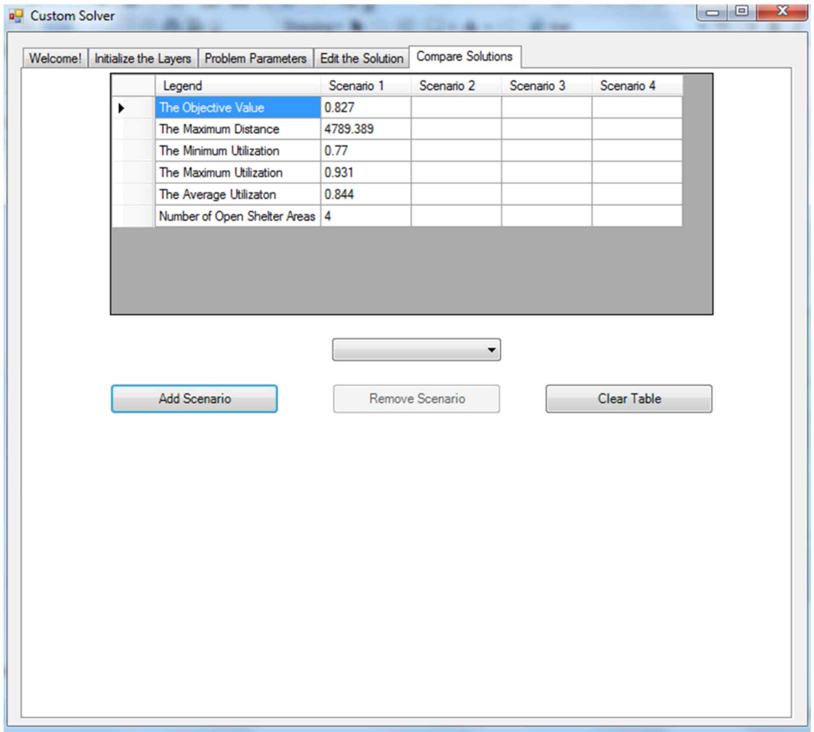

Figure 7-12 The "Comparison" Tab

Chapter 8

Performance Analysis

In Chapter 6, computational studies are performed using a small dataset based on Kartal, Istanbul, Turkey. Although, the mathematical model and the decision support system is not expected to be used in a much larger dataset, the performance of the mathematical model is a matter of curiosity. Thus, the effects of the size of the dataset on the mathematical model are discussed in this chapter.

To test the performance of the model in a large dataset, a sample data based on the Asian side of Istanbul is used. Istanbul is the most populous city of Turkey with 15 million inhabitants in 775 districts. 270 of them are in Asian side of the city and 505 of them are in the European part of the city. Two parts of the city is separated by the Bosphorus, which is a water channel that connects the Marmara Sea and the Black Sea. There are two bridges and scheduled boat rides that connects two parts of the city. As these means of transportation may not be usable after a disaster, it is assumed that a person who lives in Asian side cannot reside in a shelter area in European part, or vice versa. As solving the model for the whole Istanbul is not very logical, only Asian side of the city is selected for computational studies.

As mentioned, there are 270 districts in the Asian side of Istanbul. Similar to the Kartal case, the centroid of each district polygon is selected to be the point that represents that district. The polygon data are obtained from the website of Istanbul Greater Municipality and the population data of districts are obtained from Turkish Statistical Institute (TÜİK). The locations of the points that represent the districts can be seen in Figure 8-1 and their populations can be found in Appendix 5. For the Istanbul case the location of candidate shelter areas are not available. So, we considered a set of points of interests (POIs) such as open air parking lots, football stadium and parks as alternative shelter locations. The list of points of interest is obtained from the website of Istanbul Greater Municipality. After filtering those facilities, 361 candidate shelter area locations are identified. The coordinates of these locations are obtained from Google Maps and then pinned on ArcGIS.

The capacity and weights of candidate shelter area locations are generated randomly. Weights of all candidate locations are uniformly distributed between 0.2 and 0.9. Capacities depend on the type of facility. Capacities of parking lots assumed to be between 25,000 m^2 and 100,000 m^2, capacities of football fields are assumed to be 15,000 m^2, capacities of stadiums are assumed to be 25,000 m^2 and capacities of parks are assumed to be between 10,000 m^2 and 125,000 m^2. The locations of the candidate shelter areas can be seen in Figure 8-2 and their capacities and weights can be found in Appendix 6.

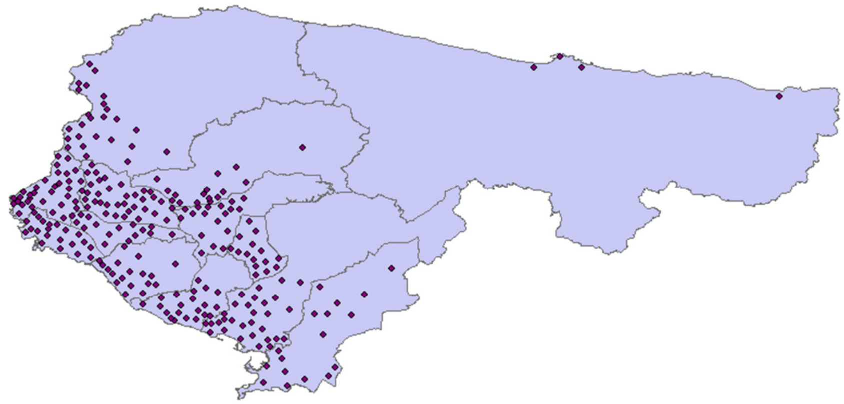

Figure 8-1 Location of districts in Asian side of Istanbul

The matrices that contain the distance from all districts to all shelter areas, distances from each shelter area to its closest health institution and its closest main road are calculated in the same way that is done in Kartal case. There are 30 main road junctions and 448 health institutions in Asian side of Istanbul. Given a road network of Istanbul, locations of candidate shelter areas, centroid of districts, hospitals and main road junctions are pinned on ArcGIS and the matrices were calculated by using the Network Analyst extension.

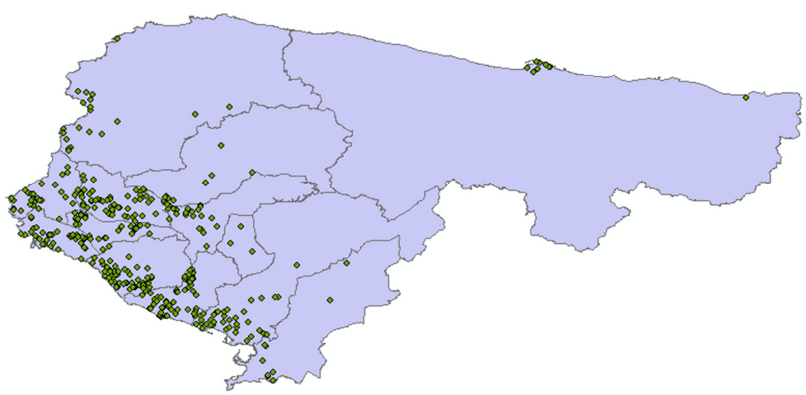

Figure 8-2 Location of candidate shelter locations in Asian side of Istanbul

While solving the problem for Asian side of Istanbul, using the above mentioned PC proved insufficient due to computer memory. Because of this, in all computations regarding to the Asian side of Istanbul, a PC with Intel® Xeon® Processor E3-1220 (8M Cache, 3.10 GHz), 16 GB RAM and Gurobi 5.0.0 was used. A particular instance which relaxes the utilization constraints (by taking $\beta = 0$ and $\alpha = 1$) is solved in 40074 seconds (approximately 11 hours). The model opened 75 shelter areas. Their utilization differs from 0.01 to 0.978 with an average of 0.419 and the objective function value is 0.549.

Although 75 seems like a large number, there are 10 municipalities with 270 districts in Asian side of Istanbul and our model located five shelter sites in Kartal in the base case. Also, it is observed that the whole affected population of Kartal can be accommodated in two shelter areas by tightening the utilization constraints (see Table 6-8). Because of this, finding the minimum number of shelter areas to house the Asian side of Istanbul is chosen to be the next objective.

However, even for $\beta = 0.1$ and $\alpha = 1$, the mathematical model is unable to return a feasible integer solution. Because of this, the objective function is modified to minimize the number of open shelter sites. In a computation that lasted 24 hours, a lower bound of 15 and an upper bound of 20 are obtained. Thus, it is accepted that 20 shelter areas for the Asian part of the Istanbul is enough to house all the affected population. To implement this facility limit, the following constraint, which implies that the number of open shelter areas is exactly "p", was added to the mathematical model given in Chapter 5.

$\sum_{i \in I} x_i = p$ (12)

Also, since the nearest allocation constraints are challenging the model computationally, we decided to relax those constraints. As a result of this relaxation, there is no condition that controls the distance between districts and their assigned shelter area left in the mathematical model. Thus, the objective function is modified in order to minimize the sum of the distance between districts and their assigned shelter areas and to implement this objective an additional parameter $dist_{ij}$ that represents the distance between candidate shelter area *i* and district *j*. However, since the problem is capacitated, this modification will not guarantee the nearest assignment, but it is anticipated that this change will make it easier to obtain a solution. Also, since the model is forced to open a certain number of shelters with constraint (11), there is no need to control the shelter area utilizations with β and α. Because of this, constraints (3), (4c), (7), (8a) and (8b) are omitted and utilizations of the shelter areas are calculated manually after an optimal solution is obtained. After these modifications, the mathematical model used in this instance is as follows:

Minimize $\sum_{i \in I} \sum_{j \in J} x_{ij} * dist_{ij}$

subject to; (2), (3), (5), (6), (10a), (10b), (12).

The optimal solution was obtained in approximately 10 minutes for the p = 20 case. However, as mentioned some districts are not assigned to the closest shelter area. To observe the behavior of the modified mathematical model, 21 instances are generated by varying *p* from 20 to 40 and the objective value, minimum, maximum and average utilization of shelter areas, number of district that are not assigned to the closest shelter area and the runtime for each instance is listed in Table 8-1.

As observed from Table 8-1, the objective value, which is the sum of the distance between districts and their assigned shelter areas, decreased as the number of open shelter areas increased. This is expected since as *p* increases, the number of facilities increases and thus, some districts are assigned to a closer shelter area.

For all instances, the maximum distance traversed by a district is the same and is the distance between Agva Merkez and its assigned shelter area. Agva Merkez is a small, non-urban town located in the northeast of the region and it can be said that the model always chose to assign Agva Merkez to a shelter area in the urban zone rather than opening one just for that town.

As p increases, the minimum and maximum utilizations of open shelter areas do not change drastically. On the other hand, although there is not a constant trend, it can be concluded that, in general, the average utilization decreases as the number of open shelter areas increase and this is plausible as the model this to accommodate same number of people in greater quantity of facilities when p increases. Similarly, running time is also inversely proportional to the number of open facilities.

p	Objective Value (m)	Maximum Distance Traversed (m)	Average Utilization	Minimum Utilization	Maximum Utilization	Number of "Not Closest"	Run Time in Seconds
20	774,220.37	30,299.39	0.85	0.06	1.00	18	533.35
21	747,637.37	30,299.39	0.72	0.06	1.00	10	427.55
22	721,078.41	30,299.39	0.57	0.06	0.98	7	224.02
23	701,811.30	30,299.39	0.78	0.06	1.00	7	69.74
24	683,671.27	30,299.39	0.75	0.06	1.00	7	23.25
25	670,723.61	30,299.39	0.70	0.06	0.99	7	177.82
26	659,227.80	30,299.39	0.73	0.06	0.99	5	66.57
27	647,762.09	30,299.39	0.71	0.06	0.99	3	143.90
28	636,480.71	30,299.39	0.70	0.06	0.99	3	45.22
29	626,536.55	30,299.39	0.62	0.06	0.99	3	104.85
30	616,887.68	30,299.39	0.57	0.06	0.98	0	170.00
31	607,284.90	30,299.39	0.71	0.06	0.99	4	96.51
32	598,835.85	30,299.39	0.69	0.06	0.96	3	71.68
33	590,530.60	30,299.39	0.67	0.06	0.97	2	20.48
34	582,586.08	30,299.39	0.66	0.06	0.97	2	22.71
35	575,174.49	30,299.39	0.67	0.06	0.97	4	30.23
36	568,140.45	30,299.39	0.65	0.06	0.97	4	25.99
37	561,178.02	30,299.39	0.63	0.06	0.97	4	20.68
38	554,573.36	30,299.39	0.63	0.06	0.97	4	11.92
39	549,791.66	30,299.39	0.61	0.06	0.97	4	10.53
40	545,250.86	30,299.39	0.60	0.06	0.97	4	13.82

Table 8-1 Statistics of the modified mode

More importantly, the number of districts that are not assigned to the closest shelter area tends to decrease as p increases. When p is 20, the regarding value is 18, which is 6.66% of all the districts. Then it decreases to 0 when p is 30. And when p is incremented to 40, the number of districts that are not assigned to the closest shelter area does not exceed 4 (1.4% of all districts).

With these results, it can be said that the modified model is not an exact representation of the model that is explained in Chapter 5. However, for the large datasets, such as the one represents the Asian side of Istanbul, the modified model can be advantageous in terms of computation times. However, as the solution of the modified model may not be feasible for the original model, it may need some additional time for manual iteration

Chapter 9

Conclusion

In this study, the shelter area location problem was addresses. This problem can be considered as important since shelter areas play an important role in disaster recovery, the location of them should be planned and areas should be established right after the disaster.

In Chapter 2, we define disaster, give information about the disasters in Turkey and explain the responsibilities of Turkish Red Crescent. In Chapter 3, we briefly summarize the Sphere Project and explain the standards of shelter areas. Later, we narrate the Turkish Red Crescent's methodology on selecting shelter area locations and define our problem. In Chapter 4, we conduct a research on related studies in the literature and give a brief summary about those studies. In Chapter 5, we formulate a mathemetical model that addresses the problem that is defined in Chapter 3. In Chapter 6, we share the results of the experiments that are performed using the mathematical model in Chapter 5 and in

Chapter 7, we explain the development and usage of the decision support system that helps the decision maker to select the location of the shelter area.

Currently, the Turkish Red Crescent sorts all potential shelter areas with respect to their weighted sum points and opens the ones with the highest point until enough shelter areas are opened to reside all the affected people. However, they do not consider the utilization of the shelter areas and the distance from them to the affected population.

In this study, a different methodology is proposed. To implement this methodology, we formulated a mathematical model that selects the best possible shelter areas, controls the utilization and assigns each district to its closest shelter area. The mathematical model is of O(m*n) given a dataset with m candidate shelter area locations and n districts.

To test the model, a real data based on Kartal, Istanbul is used and a base case is generated. In this base case, five shelter areas are selected to house 20 districts. In this scenario, the objective value is 0.827, the average utilization of open shelter areas is 0.863 and in this solution, there is a shelter area within 3.827km of each district. Then, to observe the behavior of the model, a series of experiments is conducted by varying α, β, *DistHealth* and *DistRoad.* Moreover, a solution for the Asian side of Istanbul is generated using the mathematical model.

The experiments show that as we increase β (the minimum threshold utilization) and decrease α (the maximum pairwise utilization difference), the objective value and the number of open shelter areas decrease and the average utilization increases. Also, with decreasing *DistHealth* (threshold distance to health institutions) and *DistRoad* (threshold distance to main roads), the objective value decreases.

Also, a decision support system is developed in order to implement the mathematical model. The decision support system that is developed has two functionalities. The user may obtain a new solution or load a previously obtained one. In both cases, the user has the opportunity to edit the solution, view the solution on the map, the list of districts that are assigned to each shelter area and the utilization graph of the open shelter areas. Moreover, using the comparison tab, the user is able to load more than one solution to the tool and compare them using a set of statistics.

In addition, performance of the mathematical model is tested using a dataset based on the Asian side of Istanbul. It is observed that the model returned a solution in approximately 11 hours when the utilization constraints are relaxed. Because of this a variation of the mathematical model, where the objective is to minimize total distances between districts and their assigned shelter areas, is proposed for large datasets.

BIBLIOGRAPHY

1) Aslanzadeh ,M., Rostami ,E. A., Kardar, L., “Logistics Management and SCM in Disasters” in Farahani, R. Z., Asgari, N., Davarzani, H., “Supply Chain and Logistics in National, International and Governmental Environment: Concepts and Models”, Springer, 2009.

2) Tomasini, R., van Wassenhove, L., “Humanitarian Logistics”, INSEAD Business Press Series, PALGRAVE MACMILLAN, 2009.

3) IFRC. “What is a Disaster?”. Accessed 06 June 2012. <http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/what-is-a-disaster/>

4) van Wassenhove, L., “Humanitarian aid logistics: supply chain management in high gear”, Journal of the Operational Research Society, 57, p475-489, 2006.

5) Özmen, B., Nurlu, M., Kuterdem, K., Temiz, H., Afet Yönetimi ve Afet İşleri Genel Müdürlüğü, Deprem Sempozyumu Kocaeli 2005, 23-25 Mart 2005, Grand Yükseliş Hotel, Kocaeli, 2005.

6) Hürriyet, “Rize’de yağmur operasyonu”, 25 September 2011, accessed 14 January 2012, < http://hurarsiv.hurriyet.com.tr/goster/ShowNew.aspx?id=18826411>

7) Hürriyet, “Tekirdağ’da Hayat Durdu”), 22 September 2011, accessed 14 January 2012, <http://hurarsiv.hurriyet.com.tr/goster/ShowNew.aspx?id=18799211>

8) Hürriyet, “Yaz yağmuru Giresun'u yıktı; 1 ölü”, 22 July 2011, accessed 14 January 2012, <http://hurarsiv.hurriyet.com.tr/goster/ShowNew.aspx?id=18317397>

9) Hürriyet, “Van’da acı seli”), 17 July 2011, accessed 14 January 2012, <http://hurarsiv.hurriyet.com.tr/goster/ShowNew.aspx?id=18276927>

10) Pampal, S., and Özmen, B., “Development of Earthquake Zoning Maps of Turkey”, Sixth National Conference on Earthquake Engineering, 16-20 October 2007, Istanbul, Turkey.

11) Özmen, B., Nurlu, M., Güler, H.,Coğrafi Bilgi Sistemi ile Deprem Bölgelerinin İncelenmesi, Bayındırlık ve İskan Bakanlığı, Afet İşleri Genel Müdürlüğü, Ankara, 1997.

12) USGS Earthquake Hazards Program, accessed 14 January 2012. < http://earthquake.usgs.gov/>

13) Radikal., “Mevsimler Çadırlarda Geçiyor”, 16 March 2000, accessed 6 June 2012. <http://www.radikal.com.tr/2000/03/16/t/turkiye/01mev.shtml>

14) Milliyet. “175 bin kişi hala evsiz”, 11-16 August 2000, accessed 6 June 2012. <http://www.milliyet.com.tr/ozel/depremdosyasi/index.html>

15) Akşam, “Van'da 232, Erciş'te 220 çadır kent kuruldu”, 23 October 2011. Accessed 6 June 2012. < http://www.aksam.com.tr/vanda-232,-erciste-220-cadir-kent-kuruldu--75175h.html>

16) Turkish Red Crescent, “About Us”, accessed 14 January 2012, <http://www.kizilay.org.tr/english/sayfa.php?t=-Turkish.Red.Crescent>

17) Sphere Project, Sphere Project Humanitarian Charter and Minimum Standards in Disaster Response, 2011.

18) Aksoy, F.A., Aktan, D., Aktaş, Ö. D., Dönmez, E., Erman, N., Yenidünya, B., Şavur, E., Yaman, H., “Toplu Barınma Alanları Belirleme ve Planlama Sistem Tasarımı Projesi”, Endüstri Projeleri 2011, Bilkent Üniversitesi Endüstri Mühendisliği Bölümü, 2011.

19) Dekle, J., Lavieri, M. S., Martin, E., Emir-Farinas, H., Francis, R. L.,“A Florida county locates disaster recovery centers”, Interfaces, Vol:35, No:2, p133-139, 2005.

20) Ablanedo-Rosas, J. H., Gao, H., Alidaee, B., Teng, W., "Allocation of emergency and recovery centres in Hidalgo, Mexico", Int. Journal of Services Sciences, Vol. 2, No. 2, 2009.

21) Jia, H., Ordonez, F., Dessouky, M., "A modeling framework for facility location of medical services for large-scale emergencies", University of Southern California, 2005.

22) Lu, X., Hou, Y.,"Ant Colony Optimization for Facility Location for Large-Scale Emergencies." Management and Service Science, 2009. MASS '09. International Conference on pg. 1-4. 20-22 September 2009.

23) Verma, A., Gaukler, G. M., "A stochastic optimization model for positioning disaster response facilities for large scale emergencies", International Network Optimization Conference, 2011.

24) Gül, S., "Post-Disaster Casualty Logistics Planning for Istanbul". MS thesis. Koç University, 2008.

25) Huang, R., Kim, S., Menezes, M. B. C.,"Facility location for large-scale emergencies", Annals of Operations Research, Vol:181, p271-286, 2010.

26) Wang, D., Zhang, G.,"Model and algorithm for optimization of rescue center location of emergent catastrophe", Frontiers of Electrical and Electronic Engineering in China, Vol:3, p265-268, 2006.

27) Lu, X., Hou, Y., "A Grey Degree Model for Facility Location in Large-Scale Emergencies", Proceedings of 2009 IEEE International Conference on Grey Systems and Intelligent Services, November 10-12, Nanjing, China, 2009.

28) Paul, J. A., Batta, R., "Models for hospital location and capacity allocation for an area prone to natural disasters." International Journal Operational Research, Vol. 3, No. 5, 2008. pg 473-496.

29) Chang, M., Tseng, Y., Chen, J., "A scenario planning approach for the flood emergency logistics preparation problem under uncertainty", Transportation Research Part E, No:43, p737-754, 2007.

30) Zeng, M., Cui, Z., Wu, X., "Research on Location-Routing Problem of Relief System Based on Emergency Logistics", IEEE, 2009.

31) Li, L., Jin, M., Zhang, L., "Sheltering network planning and management with a case in Gulf Coast region", Internatioal Journal of Production Economics, Vol: 131, p231-240, 2011.

32) Balcik, B., Beamon, B. M., "Facility location in humanitarian relief", International Journal of Logistics: Research and Applications, Vol. 11, No. 2, p101–121,2008.

33) Günneç, D., "Network Optimization Problems for Disaster Mitigation: Network Reliability, Investment for Infrastructure Strengthening and Emergency Facility Location", MS thesis, Koç University, 2007.

34) Hale, T., Moberg, C. R., "Improving Supply Chain Disaster Preparedness", International Journal of Physical Distribution & Logistics Management, Vol:35, No:3, p195-207, 2005.

35) Murali, P., Ordonez, F., Dessouky, M. D., "Facility location under demand uncertainty: Response to a large-scale bio-terror attack." Socio-Economic Planning Sciences. September 2011.

36) Horner, M. W., Downs, J. A., "Optimizing hurricane disaster relief goods distribution: model development and application with respect to planning strategies", Disasters, 2010, 34(3): 821–844. 2010.

37) Duran, S., Gutierrez, M. A., Keskinocak, P., "Pre-positioning of emergency items worldwide for CARE international", Interfaces, Vol. 41 No. 3 223-237, 2011.

38) Zhu, J., Liu, D., Huang, J., Han, J., "Determining Storage Locations and Capacities for Emergency Response", The Ninth International Symposium on Operations Research and Its Applications (ISORA'10) Chengdu-Jiuzhaigou, China, August 19–23, 2010.

39) Jia, H., "Models and Solution Approaches for Facility Loction of Medical Supplies for Large-Scale Emergencies", Ph.D. Dissertation, University of Southern California, 2006.

40) Görmez, N., Köksalan, M., Salman, F. S., "Locating disaster response facilities in Istanbul", Journal of Operational Research Society, Vol: 62, p1239-1252, 2011.

41) Rath, S., Gutjahr, W. J., "A Math-heuristic for the Warehouse Location–Routing Problem in Disaster Relief", Computers and Operations Research(2011).

42) Yushimoto W. F., Jaller, M., Ukkusuri, S., "A Voronoi based heuristic algorithm for locating distribution centers in disasters", Network and Spatial Economics, 2010.

43) Akkihal, A. R., "Inventory Pre-Positioning for Humanitarian Operations", M.Sc Thesis, Massachusetts Institute of Technology, 2006.

44) Li, S., Ma, Z., Zheng, B., Dai, Y., "Multiobjective Location-Transportation Problem in Post-Earthquake Delivery of Relief Materials, IEEE, 2011.

45) Widener, M. J., Horner, M. W., "A hierarchical approach to modeling hurricane disaster relief goods distribution", Journal of Transport Geography Vol: 19 p. 821–828, 2011.

46) Widener, M. J., Horner, M. W., "The effects of transportation network failure on people's accessibility to hurricane disaster relief goods: a modeling approach and application to a Florida case study." Journal of Natural Hazards, 2011.

47) Han, Y., Guan, X., Shi, L., "Optimization based method for supply location selection and routing in large scale emergency material delivery", IEEE, 2008.

48) Campbell, A. M., Jones, P. C., “Prepositioning supplies in preparation for disasters”, European Journal of Operational Research, No: 209, p156-165, 2011.

49) Jia, H., Ordonez, F., Dessouky, M., “Solution approaches for facility location of medical supplies for large-scale emergencies”, Computers and Industrial Engineering, Vol:52, p257-276, 2007.

50) Rawls, C. G., Turnquist, M. A., “Pre-positioning of Emergency Supplies for Disaster Response”. Technology and Society, 2006. ISTAS 2006. IEEE International Symposium , 8-10 June 2006.

51) Rawls, C. G., Turnquist, M. A., “Pre-positioning planning for emergency response with service quality constraints”, OR Spectrum 33:481–498, 2011.

52) Mete, H. O., Zabinsky, Z. B., “Preparing for Disasters: Medical Supply Location and Distribution.” Interfaces. 2009

53) Wang, J., Zhu, J., Huang, J., Zhang, M., “Multi-level emergency resources location and allocation”, IEEE, 2010.

54) Kapucu, N., Lawther, W. C., Pattison, S., “Logistics and Staging Areas in Managing Disasters and Emergencies”, Journal of Homeland Security and Emergency Management, Volume: 4, Issue:2, 2007.

55) Pan A., “The Applications of Maximal Covering Model in Typhoon Emergency Shelter Location Problem.” Industrial Engineering and Engineering Management (IEEM), 2010 IEEE International Conference on . pg. 1727-1731. 7-10 December 2010.

56) Li, L., Jin, M., “Sheltering Planning and Management for Natural Disasters”. THC-IT-2010 Conference & Exhibition, 2010.

57) Dalal, J., Mohapatra, P. K. J., Mitra, G. C.,“Locating cyclone shelters: A case”, Disaster Prevention and Management, Vol. 16, No: 2, p235-244, 2007.

58) Liu, Q., Ruan, X., Shi, P., “Selection of emergency shelter sites for seismic disasters in mountainous regions: Lessons from the 2008 Wenchuan Ms 8.0 Earthquake, China”. Journal of Asian Earth Sciences (March 2011), 40 (4), pg. 926-934

59) Unal, “Acil Lojistik Yardım Operasyonlarında (Deprem Lojistiği) Kullanılacak Bir “Model Tabanlı Lojistik Karar Destek Sistemi” Geliştirilmesi.”, Ph.D. Dissertation, Turkish Military Acedemy Defense Sciences Institutes, 2010.

APPENDIX

Appendix 1: The earthquakes in Turkey with death tolls between 1900 – NOW (Source: Boğaziçi University Kandilli Observatory and Earthquake Research Institute)

Location	Date	Magnitude	Death Toll
Çankırı	09.03.1902	5.6	4
Malazgirt	24.04.1903	6.7	2626
Mürefte	09.08.1912	7.3	216
Afyon Bolvadin	04.10.1914	5.1	400
Çaykara	13.05.1924	5.3	50
Pasinler	13.09.1924	6.9	310
Afyon Dinar	07.08.1925	5.9	3
Milas	08.02.1926	4.7	2
Finike	18.03.1926	6.9	27
Kars	22.10.1926	5.7	355
İzmir Torbalı	31.03.1928	7	50
Sivas Suşehri	18.05.1929	6.1	64
Hakkari	06.05.1930	7.2	2514
Denizli Çivril	19.07.1933	5.7	20
Bingöl	15.12.1934	4.9	12
Erdek	04.01.1935	6.7	5
Digor	01.05.1935	6.2	200
Kırşehir	19.04.1938	6.6	149
İzmir Dikili	22.09.1939	7.1	60
Tercan	21.11.1939	5.9	43
Erzincan	26.12.1939	7.9	32962
Niğde	10.01.1940	5	58
Kayseri Develi	20.02.1940	6.7	37
Yozgat	13.04.1940	5.6	20
Muğla	23.05.1941	6	2
Van Erciş	10.09.1941	5.9	194
Erzincan	12.11.1941	5.9	15
Bigadiç Sındırgı	15.11.1942	6.1	7
Osmancık	21.11.1942	5.5	7
Çorum	11.12.1942	5.9	25
Niksar - Erbaa	20.12.1942	7	3000
Adapazarı Hendek	20.06.1943	6.6	336
Tosya - Ladik	26.11.1943	7.2	2824

Bolu Gerede	01.02.1944	7.2	3959
Mudurnu	05.04.1944	5.6	30
Gediz - Uşak	25.06.1944	6.2	21
Ayvalık - Edremit	06.10.1944	7	27
Adana Ceyhan	20.03.1945	6	10
Kadınhan - Ilgın	21.02.1946	5.6	2
Varto - Hınıs	31.05.1946	5.7	839
İzmir Karaburun	23.07.1949	7	1
Karlıova	17.08.1949	7	450
Kığı	04.02.1950	4.6	20
İskenderun	08.04.1951	5.7	6
Kurşunlu	13.08.1951	6.9	52
Hasankale	03.01.1952	5.8	133
Yenice - Gönen	18.03.1953	7.4	265
Kurşunlu	07.09.1953	6.4	2
Aydın - Söke	16.07.1955	7	23
Eskişehir	20.02.1956	6.4	2
Fethiye	25.04.1957	7.1	67
Bolu - Abant	26.05.1957	7.1	52
Hınıs	25.10.1959	5	18
Iğdır	04.09.1962	5.3	1
Çınarcık - Yalova	18.09.1963	6.3	1
Malatya	14.06.1964	6	8
Manyas	06.10.1964	7	23
Denizli - Honas	13.06.1965	5.7	14
Varto	07.03.1966	5.6	14
Varto	19.08.1966	6.9	2394
Adapazarı	22.07.1967	7.2	89
Pülümür	26.07.1967	6.2	97
Akyazı	30.07.1967	6	2
Bingöl - Elazığ	24.09.1968	5.1	2
Bartın	03.09.1968	6.5	29
Gönen	03.03.1969	5.7	1
Alaşehir	28.03.1969	6.6	41
Gediz	28.03.1970	7.2	1086
Burdur	12.05.1971	6.2	57
Bingöl	22.05.1971	6.7	878

Van	16.07.1972	5.2	1
İzmir	01.02.1974	5.2	2
Kars - Susuz	25.03.1975	5.1	2
Lice	06.09.1975	6.9	2385
Doğu Beyazıt	02.04.1976	4.8	5
Ardahan	30.04.1976	5	4
Denizli	19.08.1976	4.9	4
Çaldıran - Muradiye	24.11.1976	7.2	3840
Lice	25.03.1977	4.8	8
Palu	26.03.1977	5.2	8
Biga	05.07.1983	4.9	3
Erzurum	30.10.1983	6.8	1155
Erzurum Balkaya	18.09.1984	5.9	3
Malatya Sürgü	06.06.1986	5.6	1
Kars Akyaka	07.12.1988	6.9	4
Erzincan	13.03.1992	6.8	653
Dinar	01.10.1995	6	96
Adana Ceyhan	27.06.1998	6.3	145
Kocaeli	17.08.1999	7.4	17127
Bolu Düzce	12.11.1999	7.2	845
Çankırı - Orta	6.6.2000	6.1	2
Afyon - Sultandağı	15.12.2000	5.8	6
Tunceli Pülümür	27.1.2003	6.2	1
Bingöl	1.5.2003	6.4	176
Erzurum Çat	25.3.2004	5.1	9
Doğu Beyazıt	2.7.2004	5.1	18
Hakkari	25.1.2005	5.5	2
Van	23.10.2011	7.1	550

Appendix 2: List of the attributes and values of each criterion [18].

Criterion	Attribute	Value
Procurement of Relief Items	Easy	1
	Hard	0
Transportation of Relief Items	Max: 100 km	$\frac{1-e^{\frac{-(Max-distance)}{p}}}{1-e^{\frac{-(Max-Min)}{p}}}$
	Min: 0 km	
	Midpoint: 40 km	
	p = 25245	
Distance to the Health Institutions	Max: 45 km	$\frac{1-e^{\frac{-(Max-distance)}{p}}}{1-e^{\frac{-(Max-Min)}{p}}}$
	Min: 0 km	
	Midpoint: 20 km	
	p = 94198	
Type of the Terrain	Piedmont	0.2
	Valley	0.2
	Savannah	1
	Stream Bed	0
Structure of the Terrain	Humic	0.4
	Clayed	1
	Sandy	0
	Chalky	0
Slope of the Terrain	2-4%	1
	1%	0.4
	0%	0.2
	5%	0.5
	6%	0.1
	7+%	0
Flora of the Terrain	Dense	0
	Medium Dense	0.2
	Rare	0.5
	No Flora	1
Electrical Infrastructure	Available	1

	Not Available	0
Sewage Infrastructure	Available	1
	Not Available	0
Usage Permission	Owned by Public	1
	Owned by Treasury	0.8
	Owned by Municipality	0.9
	Private Ownership	0.3

Appendix 3: The capacity and weights of shelter areas in Kartal [59]

Name Code	Name	Capacity	Weight
L1	Dragos Sahil Seridi	24,000	0.865
B1	Bos Alan	45,000	0.795
B26	Bos Alan	25,000	0.781
AV2	Migros	60,000	0.948
AV3	Real	60,000	0.948
B23	Bos Alan	25,000	0.674
B20	Bos Alan	30,000	0.674
BO2	Orman ve Makilik	75,000	0.801
P10	Eczacibasi Fab. Bahce	25,600	0.847
B14	Bos Alan	100,000	0.850
B13	Bos Alan	30,000	0.694
B10	Bos Alan	62,500	0.847
B8	Bos Alan	60,000	0.809
O27	Disk Anadolu Meslek Lisesi	50,000	0.803
B7	Bos Alan	30,625	0.827
T6	Kizilay Marmara Bolge Afet Merkezi	30,000	0.982
P4	Kamyoncular Parki	75,000	0.982
L3	Is Ocaklari ve Sahil	45,000	0.829
L2	Kartal Limani	60,000	0.847
P2	Park	30,000	0.865
O8	Kartal IHL	25,000	0.689
O6	Kartal IMKB Meslek Lisesi	25,000	0.689
T4	Dikimevi	150,000	0.739
T1	Tekel Fab. Dagitim Unitesi	30,000	0.948
AV1	Carrefour	60,000	0.948

Appendix 4: The population of each district in Kartal (Source: TÜİK)

Name	Population
Yakacık Yeni	14242
Atalar	30003
Yalı	10302
Gümüşpınar	22978
Soğanlık Yeni	22380
Cumhuriyet	17390
Esentepe	25261
Petrol-İş	29124
Orta	14366
Çavuşoğlu	13744
Yunus	14827
Topselvi	11720
Çarşı	13718
Hürriyet	43433
Karlıkepe	27568
Cevizli	28591
Uğurmumcu	37144
Yukarı	8093
Orhantepe	30147
Kordonboyu	11649

Appendix 5: The populations of districts in Asian side of Istanbul

ID	Name	Population
1	Atasehir Atatürk	23589
2	Ferhat Pasa	20018
3	Barbaros	24549
4	Esatpasa	22107
5	Fetih	11204
6	Kayisdagi	32379
7	Kücükbakkalköy	23152
8	Mevlana	19129
9	Mimar Sinan	10194
10	Mustafa Kemal	14508
11	Yeni Sahra	12088
12	Yeni Çamlica	14779
13	Yenisehir	11199
14	Örnek	20168
15	Inönü	18408
16	Icerenköy	72907
17	Acarlar	5766
18	Anadolu Hisari	2769
19	Anadolu Kavagi	1334
20	Baklaci	2909
21	Fatih	4038
22	Göksu	2622
23	Göztepe	7643
24	Gümüssuyu	15427
25	Kanlica	4343
26	Kavacik	21597
27	Merkez	6168
28	Ortacesme	8452
29	Pasabahce	4512
30	Rüzgarli Bahce	8229
31	Soguksu	10531

ID	Name	Population
136	Fatih	12837
137	Hilal	5368
138	Kemal Türkler	12226
139	Meclis	16548
140	Merve	13764
141	Mevlana	11358
142	Osman Gazi	24758
143	Safa	7154
144	Abdurrahman Gazi	15633
145	Sarigazi Merkez	13404
146	Veysel Karani	16481
147	Yenidogan	7668
148	Yunusemre	10989
149	Inönü	14530
150	Abdurrahmangazi	27779
151	Adil	10690
152	Ahmet Yesevi	26008
153	Aksemsettin	11366
154	Battalgazi	26838
155	Fatih	20409
156	Hamidiye	23987
157	Hasanpasa	17179
158	Mecidiye	20911
159	Mehmet Akif	26355
160	Mimar Sinan	13780
161	Necip Fazil	12969
162	Orhangazi	12860
163	Turgut Reis	18327
164	Yavuz Selim	17164
165	Anadolu	873
166	Aydinli	26991

32	Tokatköy	15245
33	Yaliköy	5541
34	Yavuz Selim	4237
35	Yeni Mahalle	19236
36	Çamlibahce	6424
37	Çengeldere	4495
38	Çiftlik	4901
39	Çigdem	12112
40	Çubuklu	22577
41	Incirköy	18900
42	19 Mayis	33795
43	Acibadem	33961
44	Bostanci	37952
45	Caddebostan	20810
46	Caferaga	23595
47	Dumlupinar	25333
48	Erenköy	36591
49	Egitim	16604
50	Fenerbahce	20774
51	Feneryolu	27161
52	Fikirtepe	20024
53	Göztepe	39609
54	Hasanpasa	15585
55	Kozyatagi	37416
56	Kosuyolu	6952
57	Merdivenköy	41793
58	Osmanaga	7502
59	Rasimpasa	13791
60	Sahrayi Cedit	33775
61	Suadiye	27836
62	Zühtüpasa	8332
63	Atalar	30003
64	Cevizli	28591

167	Aydintepe	17037
168	Cami	4760
169	Evliya Çelebi	9456
170	Fatih	688
171	Firat	2465
172	Mescit	3978
173	Mimar Sinan	17097
174	Orhanli Merkez	2083
175	Orta	4458
176	Postane	14979
177	Tepeören	3598
178	Yayla	22584
179	Istasyon	15769
180	Icmeler	11841
181	Sifa	22991
182	Alemdag Eksioglu	6658
183	Alemdag Merkez	4145
184	Alemdag Nisantepe	4623
185	Alemdag Çatalmese	6748
186	Hamidiye	19229
187	Mehmet Akif Ersoy	18071
188	Merkez	11359
189	Mimar Sinan	17411
190	Tasdelen Aydinlar	8011
191	Tasdelen Cumhuriyet	6900
192	Tasdelen Güngören	4596
193	Tasdelen Kirazlidere	5754
194	Tasdelen Sogukpinar	6207
195	Tasdelen Sultanciftligi	7259
196	Çamlik	3080
197	Çamlik	15291
198	Ömerli Merkez	3800
199	Adem Yavuz	15363

65	Cumhuriyet	17390
66	Esentepe	25261
67	Gümüspinar	22978
68	Hürriyet	43433
69	Karliktepe	27568
70	Kordonboyu	11649
71	Orhantepe	30147
72	Orta	14366
73	Petrolis	29124
74	Soganlik Yeni	22380
75	Topselvi	11720
76	Ugurmumcu	37144
77	Yakacik Yeni	14242
78	Yali	10302
79	Yukari	8093
80	Yunus	14827
81	Çarsi	13718
82	Çavusoglu	13744
83	Altaycesme	28011
84	Altintepe	31916
85	Aydinevler	14126
86	Baglarbasi	41435
87	Basibüyük	18384
88	Büyükbakkalköy	5075
89	Cevizli	31833
90	Esenkent	23146
91	Feyzullah	20265
92	Findikli	33133
93	Girne	14400
94	Gülensu	16883
95	Gülsuyu	16816
96	Kücükyali	25843
97	Yali	12885
98	Zümrütevler	51994

200	Altinsehir	25170
201	Armagan Evler	25556
202	Atakent	21307
203	Atatürk	24139
204	Asagi Dudullu	10539
205	Cemil Meric	22182
206	Dumlupinar	14169
207	Elmalikent	20869
208	Esenevler	21017
209	Esensehir	14936
210	Fatih Sultan Mehmet	2508
211	Hekimbasi	8688
212	Huzur	10241
213	Ihlamurkuyu	16384
214	Kazim Karabekir	18277
215	Madenler	8907
216	Mehmet Akif	13000
217	Namik Kemal	26542
218	Necip Fazil	20975
219	Parseller	12454
220	Saray	851
221	Site	19038
222	Tantavi	8327
223	Tatlisu	11057
224	Tepeüstü	12806
225	Topagaci	16698
226	Yaman Evler	11213
227	Yeni Sanayi	11606
228	Yukari Dudullu	17087
229	Çakmak	25469
230	Çamlik	14422
231	Inkilap	25949
232	Istiklal	42411
233	Serifali	3108

99	Çinar	19823	234	Acibadem	22420
100	Idealtepe	21073	235	Ahmediye	9881
101	Ahmet Yesevi	16358	236	Altunizade	14099
102	Bahcelievler	10820	237	Aziz Mahmud Hüdayi	9631
103	Bati	14611	238	Bahcelievler	21176
104	Dogu	15934	239	Barbaros	19531
105	Dumlupinar	22317	240	Beylerbeyi	5952
106	Ertugrul Gazi	16512	241	Bulgurlu	29924
107	Esenler	21232	242	Burhaniye	16478
108	Esenyali	11847	243	Cumhuriyet	31138
109	Fatih	17620	244	Ferah	16713
110	Fevzi Çakmak	34452	245	Güzeltepe	13233
111	Güllü Baglar	12024	246	Kandilli	1574
112	Güzelyali	26441	247	Kirazlitepe	13837
113	Harmandere	4721	248	Kuleli	2255
114	Kavakpinar	55394	249	Kuzguncuk	4873
115	Kaynarca	43230	250	Küplüce	18257
116	Kurtköy	14372	251	Kücük Çamlica	8864
117	Orhangazi	23827	252	Kücüksu	17621
118	Orta	5437	253	Kisikli	18696
119	Ramazanoglu	3376	254	Mehmet Akif Ersoy	21692
120	Sanayi	3700	255	Mimar Sinan	12647
121	Sapan Baglari	9841	256	Murat Reis	14339
122	Sülüntepe	19589	257	Salacak	10479
123	Velibaba	24712	258	Selami Ali	13079
124	Yayalar	8705	259	Selimiye	7595
125	Yeni Mahalle	13951	260	Sultantepe	12564
126	Yenisehir	33056	261	Valide-i Atik	22561
127	Yesilbaglar	5144	262	Yavuztürk	35081
128	Çamlik	7096	263	Zeynep Kamil	13775
129	Çamcesme	32152	264	Çengelköy	14885
130	Çinardere	18915	265	Cúnalan	31915
131	Seyhli	11099	266	Icadiye	17614

132	Akpinar	15509	267	Agva Merkez	2126
133	Atatürk	18044	268	Balibey	2349
134	Emek	13241	269	Haci Kasim	1109
135	Eyüp Sultan	10094	270	Kumbaba	339

Appendix 6: The capacity and weight of candidate shelter areas.

Location ID	Capacity	Weight
1	90101	0.70408
2	86635	0.392633
3	54005	0.635457
4	97336	0.282347
5	61781	0.573696
6	31162	0.258058
7	54775	0.396729
8	70106	0.788021
9	44492	0.6009
10	63062	0.471939
11	240000	0.394369
12	30000	0.512831
13	18000	0.23091
14	18000	0.554847
15	18000	0.404522
16	24000	0.287178
17	18000	0.847595
18	119450	0.844608
19	70789	0.587395
20	80396	0.44716
21	88409	0.63416
22	66136	0.694403
23	43356	0.746029
24	77538	0.33493
25	131570	0.459644
26	77221	0.843545
27	98915	0.417498
28	130607	0.68507
29	112782	0.577434
30	36100	0.7132
31	128514	0.74029

Location ID	Capacity	Weight
181	12193	0.334871
182	137129	0.224548
183	119207	0.546913
184	39617	0.346952
185	143605	0.405868
186	127000	0.28479
187	57092	0.317195
188	62490	0.863612
189	60074	0.387725
190	23893	0.293636
191	123001	0.27454
192	95174	0.519523
193	115286	0.554462
194	39622	0.501614
195	23257	0.30204
196	141462	0.41886
197	73999	0.38488
198	23970	0.602462
199	57662	0.203167
200	142534	0.837197
201	91793	0.543763
202	138568	0.217289
203	35236	0.672932
204	113074	0.401731
205	56440	0.358362
206	59470	0.68529
207	25202	0.524299
208	129866	0.758436
209	70206	0.380882
210	68099	0.771772
211	27908	0.498298

32	70588	0.579393
33	147791	0.467642
34	61716	0.413235
35	130961	0.268146
36	16285	0.542226
37	120620	0.793249
38	31891	0.410241
39	85518	0.251144
40	63023	0.209982
41	80966	0.599873
42	39752	0.688227
43	62903	0.572222
44	77650	0.462376
45	52854	0.219722
46	74300	0.39872
47	56467	0.219115
48	137440	0.630426
49	19709	0.358591
50	20364	0.887214
51	115253	0.850611
52	31627	0.775971
53	60064	0.402083
54	104981	0.693027
55	105282	0.347547
56	84667	0.275141
57	34042	0.440204
58	15997	0.785684
59	147419	0.733194
60	81887	0.498412
61	104218	0.322426
62	83209	0.876523
63	98048	0.885537
64	147940	0.556093
65	27475	0.767436
212	90054	0.370518
213	70360	0.457265
214	142188	0.876425
215	87780	0.224919
216	40685	0.871602
217	90586	0.702316
218	68942	0.238716
219	129406	0.339003
220	14009	0.20337
221	48886	0.556921
222	105737	0.44046
223	66468	0.266206
224	63422	0.268336
225	116453	0.502137
226	41995	0.606903
227	73175	0.88716
228	142666	0.580393
229	82589	0.729141
230	141686	0.685121
231	117749	0.521222
232	84906	0.747721
233	105108	0.241292
234	76710	0.673552
235	129834	0.209692
236	59663	0.406742
237	50473	0.745839
238	96527	0.377874
239	49988	0.473755
240	121691	0.420029
241	87133	0.707786
242	127402	0.589418
243	106969	0.655986
244	27642	0.209521
245	130362	0.649808

66	86227	0.337936	246	16912	0.56108
67	48630	0.63732	247	105139	0.698594
68	116984	0.677054	248	40686	0.569972
69	12539	0.791261	249	19296	0.642215
70	44460	0.752814	250	16871	0.436526
71	34025	0.651641	251	37019	0.241312
72	88225	0.781146	252	14075	0.8508
73	136945	0.267742	253	112334	0.224388
74	81793	0.231084	254	78403	0.659275
75	57109	0.873054	255	69100	0.301764
76	30522	0.271293	256	17276	0.749781
77	34736	0.841827	257	86942	0.215851
78	14076	0.851855	258	118332	0.855716
79	17802	0.586155	259	131886	0.341633
80	114292	0.813283	260	72638	0.796147
81	103127	0.550223	261	19784	0.612714
82	138898	0.406158	262	88034	0.805162
83	124844	0.211374	263	57020	0.778936
84	39769	0.688528	264	34522	0.677557
85	32044	0.342253	265	40495	0.206678
86	64777	0.322147	266	91888	0.893454
87	36504	0.664886	267	24930	0.471498
88	132402	0.417943	268	85118	0.203004
89	71383	0.264064	269	97360	0.205178
90	51652	0.452655	270	61513	0.612795
91	67687	0.335902	271	58012	0.86626
92	62790	0.557601	272	124505	0.595974
93	24186	0.81323	273	104304	0.792973
94	72450	0.493685	274	53998	0.326348
95	90876	0.668144	275	84924	0.37608
96	98687	0.373562	276	116348	0.499711
97	30854	0.697025	277	58462	0.237836
98	145448	0.666293	278	34807	0.330274
99	99420	0.57276	279	92929	0.653351

100	84300	0.869223	280	67348	0.253225
101	106274	0.618329	281	110606	0.670365
102	23929	0.310248	282	83482	0.228036
103	30782	0.321305	283	101584	0.75544
104	58063	0.481999	284	26632	0.860316
105	52894	0.255252	285	128354	0.618098
106	17825	0.77978	286	51494	0.59077
107	24235	0.54445	287	87419	0.33556
108	17466	0.413381	288	51655	0.665614
109	86977	0.404926	289	50443	0.709928
110	72367	0.227318	290	27786	0.784235
111	71119	0.837535	291	34032	0.549351
112	141212	0.548599	292	84779	0.652191
113	43802	0.574081	293	25154	0.738763
114	104464	0.265126	294	44728	0.381316
115	144742	0.819059	295	23768	0.562251
116	84607	0.507915	296	116366	0.205077
117	15115	0.234926	297	26737	0.662938
118	70106	0.43319	298	71033	0.802445
119	47653	0.833693	299	101302	0.30624
120	62171	0.54234	300	71290	0.676241
121	41174	0.306267	301	82638	0.247876
122	69785	0.552217	302	28072	0.522748
123	92612	0.350627	303	98040	0.646462
124	81154	0.324364	304	118178	0.820383
125	105584	0.380253	305	66271	0.822575
126	35518	0.208884	306	36677	0.483685
127	129449	0.379376	307	42392	0.791815
128	104100	0.837859	308	136694	0.444251
129	53580	0.423114	309	144886	0.691889
130	117319	0.603678	310	24294	0.707899
131	83249	0.26464	311	146614	0.340633
132	34741	0.432429	312	129054	0.810284
133	92365	0.699879	313	48923	0.808402

134	16852	0.851823	314	41150	0.482943
135	113842	0.650643	315	26952	0.308417
136	72799	0.635516	316	38000	0.247471
137	38033	0.33451	317	62711	0.581978
138	79885	0.52156	318	58387	0.607958
139	13855	0.382201	319	62518	0.74377
140	122393	0.733447	320	107669	0.791751
141	118156	0.360272	321	118772	0.256848
142	111532	0.588019	322	29190	0.714699
143	145844	0.800685	323	116804	0.434373
144	135092	0.345058	324	96792	0.725173
145	140189	0.720678	325	75601	0.835689
146	52350	0.774264	326	77194	0.649347
147	56177	0.70158	327	87940	0.877855
148	125483	0.891362	328	31908	0.649569
149	35906	0.497796	329	49748	0.569941
150	83299	0.780623	330	104891	0.588874
151	80360	0.510776	331	49153	0.688539
152	82453	0.241883	332	104153	0.25293
153	97584	0.250533	333	79024	0.652326
154	15056	0.736764	334	121861	0.239518
155	54415	0.369463	335	90090	0.589301
156	29608	0.279111	336	20940	0.331867
157	106758	0.780655	337	54317	0.424028
158	15782	0.652724	338	54389	0.456578
159	27845	0.822208	339	12827	0.496592
160	108494	0.685416	340	127620	0.790012
161	20111	0.56094	341	105067	0.329613
162	94615	0.284405	342	96977	0.410607
163	145253	0.441329	343	57674	0.376865
164	44478	0.633967	344	97093	0.800323
165	15367	0.49568	345	51458	0.613916
166	32930	0.545685	346	146750	0.533132
167	36191	0.699757	347	144412	0.504517

168	70661	0.467304	348	17716	0.861639
169	124705	0.221543	349	38836	0.456256
170	16818	0.421071	350	101996	0.545592
171	99298	0.574319	351	121128	0.236415
172	13988	0.455303	352	109229	0.337031
173	17674	0.66974	353	91578	0.634925
174	33289	0.251652	354	28157	0.584539
175	65459	0.637573	355	57655	0.380602
176	110380	0.360731	356	36798	0.666141
177	42647	0.70167	357	126212	0.20788
178	139241	0.49457	358	88232	0.485232
179	96805	0.859889	359	74815	0.459037
180	103990	0.866857	360	55254	0.83901
			361	49424	0.326595