European Journal of Operational Research 243 (2015) 323–332

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

# Locating temporary shelter areas after an earthquake: A case for Turkey

Fırat Kılcı [a], Bahar Yetiş Kara [a,*], Burçin Bozkaya [b]

[a] Department of Industrial Engineering, Bilkent University, 06800, Ankara, Turkey
[b] School of Management, Sabanci University, 34956, Istanbul, Turkey

ARTICLE INFO

*Article history:*
Received 26 October 2013
Accepted 24 November 2014
Available online 9 December 2014

*Keywords:*
Location
Shelter site selection
Humanitarian logistics
Practice of OR
Disaster planning

ABSTRACT

In this study, we propose a mixed integer linear programming based methodology for selecting the location of temporary shelter sites. The mathematical model maximizes the minimum weight of open shelter areas while deciding on the location of shelter areas, the assigned population points to each open shelter area and controls the utilization of open shelter areas. We validate the mathematical model by generating a base case scenario using real data for Kartal, Istanbul, Turkey. Also, we perform a sensitivity analysis on the parameters of the mentioned mathematical model and discuss our findings. Lastly, we perform a case study using the data from the 2011 Van earthquake.



## 1. Introduction

The International Federation of Red Cross and Red Crescent Societies (IFRC) defines a 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" (IFRC, "What is a disaster?").

Turkey is among the countries that are especially vulnerable to natural disasters. Throughout history, many disasters have occurred in the geography where Turkey is located. According to Özmen, Nurlu, Kuterdem, and Temiz (2005), 650,654 households have been destroyed by disasters since 1900. Total destruction in Turkey from these disasters is broken down in Table 1 below.

Turkey is not subject to tornados or hurricanes, but earthquakes, landslides, floods, rock falls and avalanches frequently occur. The latter four disaster types are usually small-scaled, with relatively little or no death toll. Earthquakes, however, are the most feared type of disaster in Turkey, as many lives are often lost. Several fault lines run through Turkey, but the North Anatolian Fault, from Thrace to Northeast Turkey, is the most active one. The danger posed by this fault line is evident when one compares the percentages of surface area and population to be affected in a high-magnitude earthquake.

There are five different earthquake zones in Turkey, with Table 2 showing them ordered according to degrees, with the first being the most dangerous and the fifth the least dangerous. According to Özmen, Nurlu, and Güler (1997), 44 percent of Turkey's population lives in the first degree zones.

Since the beginning of the twentieth century, approximately 110 destructive earthquakes have occurred in Turkey. About 15 of those had death tolls greater than 1000. The most important ones in terms of causalities are the 1939 Erzincan earthquake and the 1999 Marmara earthquake.

The Erzincan earthquake was the most devastating earthquake in Turkey's history. It had a magnitude of 7.8 on the Richter scale and left 33,000 people dead and hundreds of thousands homeless. The 1999 Marmara earthquake had a magnitude of 7.6 on the Richter scale and killed about 17,000 people, injured nearly 50,000 people and left about 500,000 homeless. The aftershocks of this earthquake lasted several months with the greatest aftershock in Düzce, with a magnitude of 7.2. That event killed about 1000 people, while leaving thousands of homes damaged and thousands of people homeless (Al Jazeera Turk, 2013). The recorded financial damage of the Marmara earthquake was about 3–6.5 billion US dollars (Aslanzadeh, Rostami, & Kardar, 2009).

On 16 March 2000, seven months after the 1999 Kocaeli Earthquake, the Turkish daily *Radikal* published an article with data on the number of residents in temporary shelter areas. According to this article, in Kocaeli, Sakarya, Yalova, Bolu and Düzce, around 91,000 people were still living in tents. The number of people living in the shelter areas established in each city and their utilization are given in Table 3a.

The Turkish daily *Milliyet* published a series of articles between 11 and 16 August 2000 reporting the numbers of people that were still homeless and living in shelters exactly a year after the disaster. The number of people living in the tents had decreased since *Radikal*'s

* Corresponding author. Tel.: +90 312 2901262; fax: +90 312 2664054.
*E-mail address:* bkara@bilkent.edu.tr (B.Y. Kara).

http://dx.doi.org/10.1016/j.ejor.2014.11.035
0377-2217/

**Table 1**
Types of disasters and their respective damages since 1900 (Özmen et al., 2005).

| Type of disaster | Number of households destroyed | Percentage |
|---|---|---|
| Earthquake | 495,000 | 79 |
| Landslide | 63,000 | 10 |
| Flood | 61,000 | 9 |
| Rockfall | 26,500 | 4 |
| Avalanche | 5,154 | 1 |
| Total | 650,654 | 100 |

article, but the *Milliyet* article reported that although pre-fabricated houses had been constructed offering better living conditions than the tents, people continued living in the tents because the new housing areas were located very far away from city centers. The number of people living in tents and pre-fabricated houses can be found in Table 3b.

The aim of this study is to improve the disaster preparedness of Turkey by developing a methodology for selecting shelter site locations. In this section, we provide brief information about disasters and past data related to shelter areas in Turkey. In Section 2, we present the principles and standards used while constructing the shelter areas and discuss the Turkish Red Crescent's methodology on shelter site selection. In Section 3, we briefly summarize the related literature. In Section 4, we define the problem and propose a mathematical model to address the problem. In Section 5, we discuss the computational studies that we performed using the mathematical model, and in Section 6, we conclude this article by briefly summarizing the study and pinpointing possible future research areas.

## 2. Current methodology on shelter site selection in Turkey

After a large-scale disaster, houses become damaged or destroyed, and a notable number of residents become homeless. Because people need to continue their everyday life, they must reside in a temporary place until the disaster recovery process is completed. Because of this, to address the needs of the affected population, shelter areas are established. Ideally, these areas should be designed with respect to quality measurements.

In 1997, several humanitarian organizations and the International Red Crescent and Red Cross Movement initiated a project to improve the quality of post-disaster humanitarian operations (Sphere Project 2011). The philosophy is based on two principles: i) the affected population has the right to live with dignity and receive necessary assistance, and ii) whenever human suffering is caused by disaster or such conflict, any necessary action should be taken in order to suppress it. The respective project that defines these quality measurements is called "The Sphere Project". This publication is an important source of information in the humanitarian sector as it is the most comprehensive document that defines the standards of humanitarian relief operations, compiled by the most experienced organizations in the sector.

**Table 3a**
Utilization and population of shelter areas in five cities in March 2000 (Radikal, 2000).

| City | Number of people | Utilization (percent) |
|---|---|---|
| Kocaeli | 18500 | 100 |
| Sakarya | 906 | 20 |
| Yalova | 2547 | 74 |
| Bolu | 16648 | 100 |
| Düzce | 53000 | 90 |

**Table 3b**
The number of people living in temporary shelters in five cities in August 2000 (Milliyet, 2000).

| City | Number in tents | Number in pre-fabricated houses |
|---|---|---|
| Kocaeli | 9,865 | 55,399 |
| Sakarya | 229 | 38,131 |
| Yalova | 0 | 15,946 |
| Bolu | 10,591 | 14,296 |
| Düzce | 8,232 | 22,822 |

Because of shelter areas' importance, they must be strategically planned. Ensuring sufficient relief materials such as tents, shelter kits, and construction kits is of course necessary. The responsible organization should also ensure that established shelter areas are located within a distance from threat zones, while considering the need for and distance of safe routes between the shelter area and the homes of affected people and from the shelter area to essential service facilities. Also, ownership and usage rights of each shelter area should be pre-determined and any necessary permission should be obtained.

In Turkey, the Red Crescent is the main body responsible for establishing temporary shelter areas. After a disaster, it determines the shelter locations and supplies the necessary amount of tents in order to provide residence to the homeless. It is also responsible for supplying enough food and non-food items for those living in the shelter areas and for ensuring the security of the shelters.

Especially in disaster prone areas like Istanbul, the Turkish Red Crescent defines the eligible sites for shelter areas before the disaster. In mid 2000s, experts stated that an earthquake is anticipated in Istanbul within 10 years. Because of this, the Turkish Red Crescent and Istanbul Greater Municipality conducted a study in order to define the potential location of temporary shelter areas. The Turkish Red Crescent has defined 10 criteria to rank potential shelter areas that can be used in any part of Turkey, which are listed below.

- Transportation of relief items: this criterion measures the accessibility of the shelter area. If main roads are closer to the shelter areas, transportation of relief items becomes easier.
- Procurement of relief items: relief items are purchased from a market, supermarket, or warehouse. The closer such an establishment is to the shelter area, the less costly it will be to procure the items.

**Table 2**
Surface area and population with respect to five earthquake zones in Turkey (Özmen et al., 1997).

| Earthquake zones | Surface area square kilometers | Percentage | Population (1990) | Percentage | Forecasted population (1997) | Percentage |
|---|---|---|---|---|---|---|
| First degree | 328,995 | 42 | 25,052,683 | 44 | 28,498,740 | 45 |
| Second degree | 186,411 | 24 | 14,642,950 | 26 | 16,674,656 | 26 |
| Third degree | 139,594 | 18 | 8,257,582 | 15 | 9,334,138 | 15 |
| Fourth degree | 97,894 | 12 | 7,534,083 | 13 | 8,129,711 | 13 |
| Fifth degree | 32,051 | 4 | 985,737 | 2 | 1,107,757 | 2 |
| Total | 784,945 | 100 | 56,473,035 | 100 | 63,745,002 | 100 |