Locating Temporary Shelter Areas after an Earthquake: A Case for Istanbul

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In this study, we first analyze the specific dynamics of the shelter site location problem for an application in Turkey and develop a mixed integer linear programming based methodology which incorporates with their requirements of the Turkish Red Cresent and improve their current system. 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 on Kartal, Istanbul, Turkey. Also, we perform a sensitivity analysis on the parameters of the mathematical model using the same and discuss our findings. Lastly, to test the performance of the mathematical model, we use a larger dataset based on the Asian side of Istanbul.

Keywords: Humanitarian Logistics, Disaster Relief, Application in Turkey, Shelter Site Location

1. Introduction

The International Federation of Red Cross and Red Crescent Societies (IFRC) defines 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 the history, many disasters occurred in the geography where Turkey is located. According to Ozmen et al. (2005), 650,654 households have been destroyed from disasters since 1900. Total destruction in Turkey from these disasters is broken down in the table below.

Type of Disaster	# of households destroyed	Percentage (%)
Earthquake	495,000	79
Landslide	63,000	10
Flood	61,000	9
Rockfall	26,500	4
Avalanche	5,154	1
	650,654	100

Table 1: Types of disasters and their respective damages since 1900.

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 no or small death tolls. 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 Northeastern of 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 would 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 first being the most dangerous and the fifth, the least dangerous. According to Ozmen et. al. (1997), 44% of Turkey's population lives in the first degree zones.

Earthquake Zones	Surface Area ($km^{2)}$	%	Population (1990)	%	Forecasted Population (1997)	%
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

Table 2: Distribution of Turkey's surface area and population with respect to its five earthquake 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 1,000. 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 Richter and left 33,000 people dead and hundreds of thousands homeless. 1999 Marmara earthquake had a magnitude of 7.6 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 1,000 people, while leaving thousands of homes damaged and thousands of people homeless. The recorded financial damage of the Marmara earthquake was about 3 to 6.5 billion US dollars.

City	Number of People	Utilization
Kocaeli	18500	100%
Sakarya	906	20%
Yalova	2547	74%
Bolu	16648	100%
Düzce	53000	90%

Table 3a: Utilization and population of shelter areas in five cities in March 2000

As mentioned before, earthquakes are the most destructive type of disaster that occurs in Turkey. During a recovery, shelter areas are established and widely used. For example, on 16 March 2000, seven months after the 1999 Kocaeli Earthquake, Turkish daily *Radikal* published an article with data on the number of residents in temporary shelter areas. According to the article, in Kocaeli, Sakarya, Yalova, Bolu and Düzce, around 91,000 people were still living in some 20,000 tents. The number of people living in the shelter areas established in each city and their utilization are given in Table 3a.

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 article, but the *Milliyet* article reported that although pre-fabricated houses had been constructed offering better living conditions than the tents, people continued to live 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.

City	# in tents	# 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

Table 3b: The number of people living in temporary shelters in 5 cities in August 2000

The aim of this study is to increase 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 formulation to address the problem. In Section 5, we discuss the computational studies that we perform using the mathematical model and in Section 4 and in Section 6, we conclude this article by briefly summarizing the study and pinpointing on some 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 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 International Red Crescent and Red Cross Movement initiated a project to improve the quality of post–disaster humanitarian operations. 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”.

Given the two principles, a set of minimum standards were identified in four essential areas: i) water supply, sanitation and hygiene promotion; ii) food security and nutrition; iii) shelter, settlement and non-food items; and iv) health action. These standards are based on the organizations’ past experiences and included in “*The Sphere Handbook*” (2011), which is updated periodically. 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.

As described in *The Sphere Handbook*, establishing shelter areas is a crucial stage in disaster recovery. Shelter areas play an important role in sustaining security, ensuring personal safety and protecting people from inclement weather and epidemic diseases. As people are 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 in such inhumane conditions.

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 some 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. Experts state that an earthquake is anticipated in Istanbul in 10 years. Because of this, 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 ten criteria, to rank potential shelter areas that can be used in any part of Turkey:

- Transportation of relief items: This criterion measures the accessibility of the shelter area. As the main roads are closer to the shelter areas, transportation of the 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 items.
- Healthcare institutions: it is favorable if a shelter area is close to a functioning hospital and/or medical clinic(s) so that care can be provided to those who need it.

- Topography of the terrain: This criterion measures the suitability of the candidate location for building and daily life. Building and living on a plain is easier than in a hilly area.
- Type of terrain: This criterion measures the hardness of the soil. Hard soil is less affected by rain and thus is easier to build and live on.
- Slope of the terrain: This criterion measures the slope of the terrain that the shelter area is established on. Flat terrains are more favorable since it is easier to construct and live on flat terrains.
- Electrical infrastructure: Electricity is important for residents to pursue their daily lives. Many devices used in daily life, including heat sources, run on electricity. Shelter areas should have electrical infrastructure where possible.
- Sewage infrastructure: Water is one of the most important human needs. In addition to sustaining life, it is used for cooking, cleaning, and personal hygiene. To ensure health, water must be properly treated and disposed of. Because of this, sewage infrastructure is important for a shelter area.
- Flora of the terrain: Trees provide oxygen and shade, which is useful during hot weather. Because of this, a dense flora incorporating trees is preferable for shelter areas.
- Ownership: It is easier to get construction permission if the shelter area is publicly owned and harder if the area is privately owned.

These criteria are not equally weighed. They all have respective weights and each candidate shelter location receives a point between 0 and 1 for each criterion. The grade point of a potential shelter area is the convex combination of the points obtained from these ten criteria. The Turkish Red Crescent sorts the potential shelter areas with respect to their grade points and in a disaster, starts construction in the ones with the highest grade point until enough shelter areas are functioning to house all the affected people.

Careful observation of the methodology of the Turkish Red Crescent in choosing shelter sites reveals that the methodology could be improved. The organization does not consider the distance between people's actual homes and the shelter areas. This may result in a situation where a certain district is very far from all open shelters. This will make it hard to reach from that certain district to any open shelter areas, which is not favorable.

Utilization of shelter areas is also important. As evident from Tables 3a and 3b, the shelter area utilizations differ significantly. If there is no balance between shelter areas, one shelter area may be full while others are half utilized. This situation is not desirable as it is more convenient to live in less utilized shelter areas. To overcome this issue, the utilization of each area and the pair-wise utilization difference of the areas should be considered while selecting the shelter area locations and assigning population to them.

In this study, a mixed integer linear programming formulation, which chooses the location of shelter areas, controls their utilization and assigns population to operating shelter areas, is formulated.

3. Literature Review

Many studies in the literature discuss facility location in disaster relief. These studies can be categorized into three problems, which are the emergency medical center location, the relief material warehouse location and the shelter site location problem. Although these three types of facilities have different usages, these problems have similar objectives such as maximizing the total number of people covered, minimizing the distance between facilities and the affected population and selecting the most reliable set of facilities. Thus, in this section, we discuss notable studies regarding these problems.

3.1 Emergency Medical Center Location Problem

This problem addresses the location of emergency medical centers that are established in order to provide medical attention after an emergency due to a disaster.

Dekle et al. (2005) and Ablanedo-Rosas et al. (2009) address the emergency medical center location problem using set-covering models. Jia et al. (2005) consider the same problem by introducing randomness using a scenario analysis, however they face computational limitations. These limitations are resolved by Lu et al. (2009)'s heuristic based on ant colony algorithm. Apart from these deterministic models, Verma and Gaukler (2011) define a two-stage stochastic programming model to determine the location of the facilities while taking transportation of the items into account. While selecting the locations of emergency medical centers, Gül (2008) combines existing facilities with temporary ones and perform a case study based on Istanbul, Turkey. Huang et al. (2010) design a variation of the p-median model with the assumption that a center at a node may fail to respond. Wang and Zang (2006) take emergency occurrence probability for a specific region into account. Paul and Batta (2008) and Chang et al. (2007) optimize locations of the facilities and crew allocation simultaneously.

3.2 Relief Material Warehouse Location Problem

The relief material warehouse location problem addresses the decision process of locating storage facilities for relief items such as canned foods, tents, blankets and water.

Balcik and Beamon (2008) deal with the prepositioning of relief supplies by formulating a variant of the maximum coverage location problem (MCLP) and Gunneç (2007) consider a similar problem using a variant of the uncapacitated facility location problem (UCFL). Hale and Moberg (2005) formulate a deterministic set-covering problem and propose a four-step site decision process. Similarly, Murali et al. (2011) deal with this problem using a variation of the maximum covering location problem (MCLP). Duran et al. (2011) consider the prepositioning problem for CARE International. For the same problem, Görmez et al. (2011) provide a two-stage multi-objective model that maximizes the total number of refugees covered and decides on the location of facilities. Yushimoto et al. (2010) and Li et al. (2011) provide a heuristic algorithm for selecting prepositioning areas that tries to find a pre-specified number of facilities to cover all the demand points and minimize urgency. Han et al. (2008) perform a location-allocation study and their model optimally locates facilities and allocates disaster areas to opened facilities while minimizing total travel time. Campbell and Jones (2010) and Jia et al. (2007) consider a stochastic prepositioning approach with a single demand point, where the demand depends on a probability distribution. Rawls and Turnquist (2006) and Mete and Zabinsky (2010) provide a stochastic optimization problem to determine the location and quantity of emergency supplies. Apart from the mathematical studies, Kapucu et al. (2007) provide insight on determining potential sites before selecting final sites.

3.3 Shelter Site Location Problem

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 locations of such areas.

Pan (2010) consider the shelter site location problem after a disaster by formulating two deterministic mathematical models that are variations of the maximum set-covering problem. Li and Jin (2010) consider the stochastic nature of hurricanes and introduced this randomness by generating different scenarios and respective occurrence probabilities. Dalal et al. (2007) consider the same problem, using a heuristic based clustering approach and Liu et al. (2010) define the criteria for the shelter location problem and their ideas may be used while identifying potential locations.

Pan (2010) and Jin et al. (2010)'s studies are based on cover models. Dalal et al. (2007) present 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 shelter area locations from a set of candidates and assigns populations to those areas while trying to keep all shelter areas as utilized as possible and minimizing their pairwise utilization difference. Our study considers these factors, thus offering an important contribution to the literature.

4. Problem Definition and Proposed Model

As noted, the Turkish Red Crescent ranks potential shelter areas with respect to a weight function composed of ten criteria, and opens areas until there is enough space to house all the affected population. However, the current methodology does not consider distances between districts and shelter areas, nor does it consider shelter area utilizations.

The aim of this study is to improve the current methodology of locating shelter areas by considering their ten criteria, determining district–shelter area assignments, and controlling the utilization of open shelter areas. To do so, we formulated a mixed integer linear programming model.

A weight function is devised for candidate shelter areas. Seven of the ten criteria, namely, structure, slope, type and flora of the terrain, existence of electrical and sewage infrastructure and ownership are included in the weight function because they are not directly measurable. A weight function similar to the Turkish Red Crescent's function, where the weight of a shelter area is the convex combination of the points that the shelter area obtains from those seven criteria, is constructed. To measure the ability to procure and transport relief items, considering the transfer distance from shelter areas to the nearest main road is sufficient. We apply a similar measurement for the health institution criterion.

For a settlement to be spacious, at least 3.5m^2 covered living space should be assigned to each person in the shelter area. Also, there should be at least 45m^2 space assigned for the utilities such as road, sanitation, health, education and nutrition if these services are to be provided within the shelter area. Thus, we include these measures while calculating the used capacity for each candidate location.

The sets, parameters, and the model formulation are presented 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

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

cap_i : Capacity of candidate location i

$distSorted_{ij}$: ith 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

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

Decision Variables

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

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

u_i : Utilization of candidate location i

In their current methodology, the Turkish Red chooses to operate the shelter areas with the highest weights. Thus, the objective of the mathematical model is to maximize the minimum weight of operating shelter areas (i.e. choose the best possible shelter area combination).

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

Since the shelter areas are capacitated, we do not want the total assigned population to a shelter area plus the utility space to exceed its capacity. Thus, the following constraint is defined.

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

Secondly, we do not let any district to be unassigned. Because of this, the following constraint is added to the mathematical model.

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

Since we want to control the utilization, it needs to be calculated. We define the utilization of a shelter area as the total assigned demand plus the utility space divided by the capacity of the shelter area. The constraint that is used in calculating the utilization can be found below.

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

As mentioned earlier in this section, to measure the procurement and transportation criteria, we define a threshold distance between shelter areas and their nearest main road (*distRoad*). We also define a similar threshold value for the distances between shelter area and their nearest health institution (*distHealth*). We do not allow a shelter area to operate if a main road and a health institution does not exist within the respective threshold distance of the shelter area. To implement this condition, we formulate the following two constraints.

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

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

Also, for the ease of logistical operations, it is preferred that the utilization of the shelter areas to exceed a certain value. For this requirement, we define a lower bound for the utilization of operating shelter areas (β) and include the following constraint to the mathematical model.

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

Moreover, similar life standards should be preserved in each operating shelter area. For this, the difference between utilization of the shelter area should be kept as low as possible. To include this condition to the mathematical model, we define a threshold value for the pairwise utilization difference of open shelter areas (α) and formulate the following constraint.

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

In a state of emergency, every person will want to go to the nearest possible shelter area. Thus, in our model, every district is assigned to the nearest open shelter area. To implement this condition, we make use of the "nearest neighbor" constraints.

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

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

A shelter area is either open or close. Thus, the decision variables that control the state of each candidate location are binary (10a). Similarly, we assume that a district cannot be assigned to more than one shelter area. Hence, the decision variables related to the assignments are binary (10b). The utilization of each shelter area can take any value between 0 and 1. Because of this, we define them as continuous variables (10c). It is not necessary to define an additional constraint for the upper bound of these variables since they are implied in constraints (2) and (4)

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

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

$$u_i \ \geq 0 \ \forall \ i \in I \tag{10c}$$

To turn this formulation into a mixed integer linear programming model, objective function (1) and constraint (8) need to be linearized. To linearize the objective function, we define the following variable.

w_{min}: minimum weight of operating candidate shelter areas

Then, the objective function becomes:

Maximize w_{min} (1')

In addition to this objective, we include the following constraint.

$$w_{min} \leq x_i * w_i + (1-x_i) \ \ \forall \ i \in I \tag{11}$$

To linearize constraint (8), we include the following inequalities.

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

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

For any pair of shelter areas, if at least one of them is closed, then the constraints become redundant. Otherwise, the constraints set the pairwise utilization difference to be within the threshold value.

After defining all the sets, parameters, equations, and inequalities, the linear mathematical model that addresses the defined problem can be formulated as follows:

Maximize (1')

Subject to,

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

5. Computational Studies

5.1 The Case of Kartal, Istanbul, Turkey

For computational studies, we use sample data based on Kartal district of Istanbul, Turkey. The locations of candidate shelter areas are obtained from Unal (2010), the district data are obtained from Google Maps and the population data are obtained from Turkish Statistical Institute.

Kartal is one of the 39 districts of Istanbul. Its surface area is 38.54 km^2 and it is the thirteenth most populous district of Istanbul, with approximately 425,000 inhabitants. In Kartal, there are 20 sub-districts (blue squares in Figure 1) and 25 potential shelter area locations (red points in Figure 1). As in Unal (2010), we assumed that approximately 12.5% of the population would need to stay in shelter areas after an earthquake.

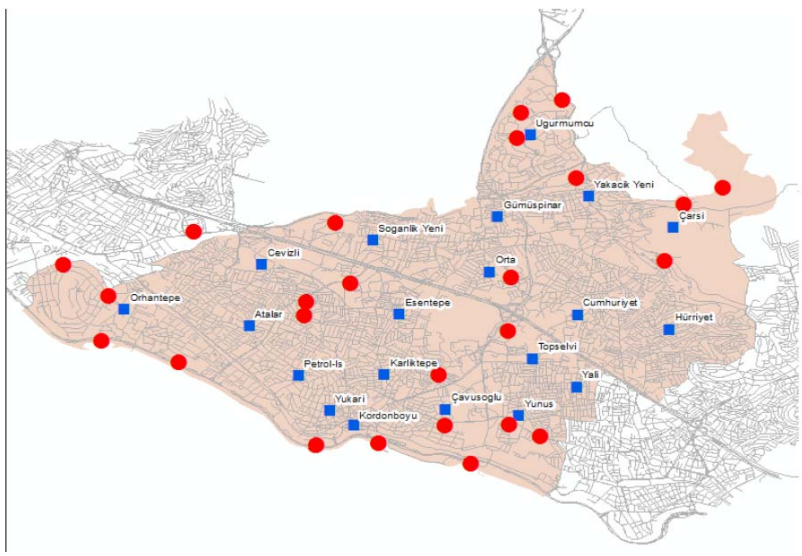

Figure 1: The points that represent sub-districts and the location of candidate locations in Kartal

The Turkish Red Crescent assigns 3.5m^2 of living space to each resident and 45m^2 for group sanitary and dining facilities. In our computations, we use these measures.

We obtain distance data from ArcGIS, a commercial geographical information system. Using Kartal's road network, candidate shelter area locations, health institutions, and main road junctions are pinned on the map. The centroid of each sub-district is chosen as the representation point. By using the Network Analyst extension of ArcGIS, we calculate the distances from shelter areas to sub-district centroids, health institutions, and main road junctions for the mathematical model.

We first generate a basic scenario where each shelter area is at least 60% utilized, their pairwise utilization difference is less than 20%, and there should be a hospital within five kilometers at most of each shelter area. Further, for ease of procurement, main roads should be within five kilometers of all shelter areas. We solved the mathematical model using these parameters in less than one second. The results are schematized in Figure 2.

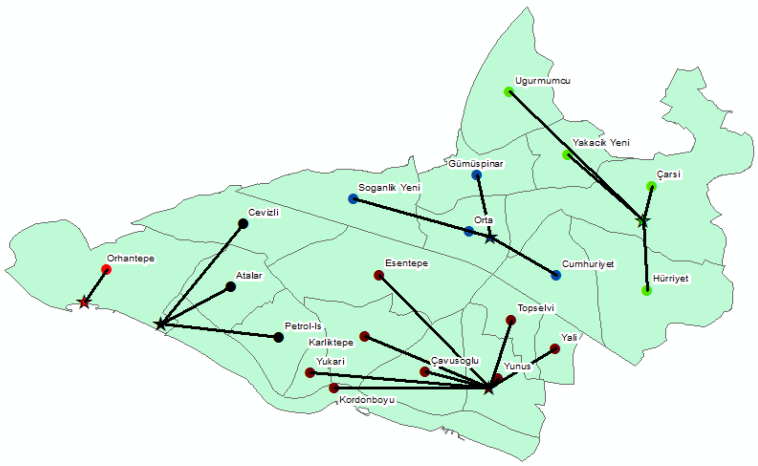

Figure 2: Solution of the basic scenario

In this map, stars represent the open shelter areas, solid circles represent district centroids and lines represent the 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 3.8 kilometers, which is traversed by the residents of Ugurmumcu, the northmost sub-district.

To observe the behavior of the mathematical model with respect to problem parameters, we generate 3000 different scenarios by varying β (threshold value for minimum utilization), α (threshold value for maximum pairwise utilization difference), and DistHealth and DistRoad (threshold distances from shelter areas to the nearest health institution and to the nearest main road). In our instances, β varies from 0 to 0.9 with increments of 0.1, and α varies from 1 to 0.1 with decrements of 0.1. For DistHealth we use 5, 4, 3, 2.5, 2, and 1.5 kilometers and for DistRoad we use 5, 4, 3, 2.5, and 2 kilometers. We use a PC with an Intel Core2Duo T6400 (2.0 GHz) processor, 4GB RAM and Gurobi 4.5.2 to compute the optimal solutions. Given the dataset, all instances are solved in less than a second.

We observe that as we decrease DistHealth and DistRoad values, the maximum of the minimum weight of open shelter areas decreases, and eventually the problem becomes infeasible. As DistHealth and DistRoad became smaller, the number of eligible shelter areas decreases. Because of this, the model is forced to select shelter areas with smaller weights, and eventually the objective value decreases. The tables below (Tables 4a, 4b, and 4c) show the objective values with different β and α values, with DistHealth and DistRoad 5; DistRoad 5 and DistHealth 1.5; and DistRoad 2 and DistHealth 5 respectively.

From Table 4a, we observe that the value of objective function is 0.85 for β smaller than 0.7 and for α greater than 0.3 and after inspecting each solution individually; we observe that the solution of the mathematical model is different for each instance. However, the solution that is obtained when β is equal to 0.6 and α is equal to 0.3 is feasible for all other instances with an objective value 0.85. Thus, we can say that there are plenty of alternative optimal solutions. Similarly, for the cases where the value of the objective function is 0.827, a similar case occurs with two different solutions.

However, when β is 0.9, the utilization difference of the shelter areas can be at most 0.1. Thus, for all choices of α, the mathematical model has the same feasible set and therefore reports the same solution. This situation implies that if the β is chosen beforehand, α can be at most 1 – β. Similarly, if α is chosen first, then β needs to be at most 1- α.

Also, when we increase β and decrease α while keeping DistHealth and DistRoad constant, the average utilization of open shelter areas increases. This increase is expected because as β (the minimum utilization threshold) increases the minimum utilization of open shelter areas increases. Table 5 shows the average of the average utilization over 30 different DistHealth and DistRoad combinations with different β and α values.

As evident from Table 5, when β is 0.7, the average of the 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 cases, regardless of DistHealth and DistRoad, the mathematical model yields the same optimal solution.

Similarly, as we increase β and decrease α while keeping DistHealth and DistRoad constant, the number of open shelter areas decreases. This is expected because as the minimum utilization threshold increases the model tries to utilize the open shelter areas more and more and therefore it opens fewer shelter areas. Table 6 shows the maximum number of open shelter areas over 30 different DistHealth and DistRoad combinations with different β and α values.

In Table 6, we observe that when β is 0.9, at most two shelter areas are opened in the solution. When the same data for the minimum number of shelter areas are inspected, we observe that the minimum is 2 for all cases when β is 0.9. This implies that when β is 0.9, regardless of DistHealth, DistRoad, and α, the optimal solution is the same.

We also measure the number of infeasibilities in each α, β pair among 30 different combinations of DistHealth and DistRoad. As we increase β and decrease α, the number of infeasible cases increases. Table 7 shows the number of infeasible cases for each α, β pair.

When DistHealth is 2 or 1.5 and DistRoad is 2, all instances return infeasible because there is not enough eligible shelter areas to house all the population. As evident from Table 7, when β is less than or equal to 0.6 and α is greater than or equal to 0.4, the only infeasible cases are the ones noted above. However, as we narrow the feasible set by increasing β and decreasing α, depending on the values of DistHealth and DistRoad, more infeasible cases occur.

In all those 3000 instances, we assume that 12.5% of the population will be in need of temporary shelters. In addition to those instances, we generate additional 21 instances to observe the effect of the percentage of affected population on the value of the objective function. In those 21 instances, the values of β, α, DistHealth and DistRoad are equal to the ones that we use in the base case scenario and the percentage of affected population changes from 10 to 20, with increments of 0.5. From Table 8, it can be observed that as the percentage of affected population increases, the value of the objective function decreases. The solution of each instance is different, even for the ones with the same objective value. However, in each solution that returned the same objective value, the shelter area with the minimum weight is the same. The objective value of each solution and the name of the shelter area with the minimum weight can be found in Table 8.

5.2 Greater Istanbul, Turkey

A major earthquake is expected to occur in Istanbul, Turkey within 10 years. Because of this prediction, we choose to test our model on the entire geography of Istanbul. Also, solving the model for the entire city rather than just a single district, namely Kartal, allows us to test our model on a larger dataset.

Istanbul is Turkey's most populous city with 15 million inhabitants. The city houses 775 sub-districts, with 270 on the Anatolian side and 505 on the European side. Transportation between the European and Asian sides of the city is provided by two bridges and scheduled ferries. After an earthquake, these means of transport may not be usable due to bottleneck congestion or infrastructural damage, thus someone who lives on the Asian side could not be designated to stay in a shelter area on the European side, and vice versa. For this reason, we divide Istanbul into two parts.

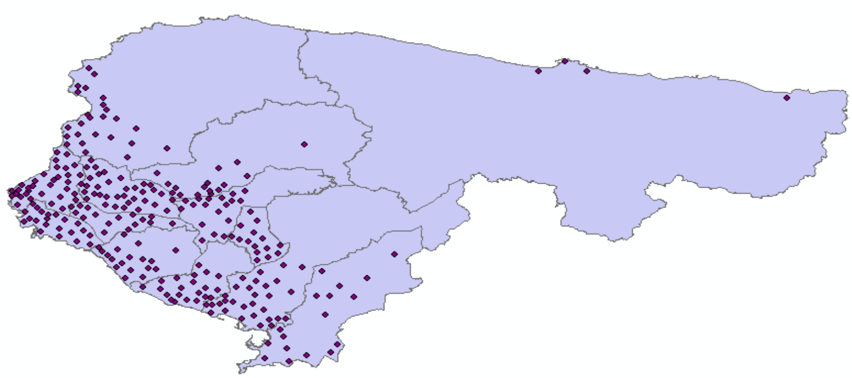

Figure 3: The points that represent the districts in Asian side of Istanbul

First, we determine points that represent sub-districts and their population as we do for the Kartal case. We obtain the points from Google Maps and their population from Turkish Statistical Institute. The location of the points that represent the can be seen in Figure 3. We select potential shelter area locations from a set of public points of interest (POIs), such as outdoor parking lots, football stadiums and parks. Locations of such facilities are obtained from the website of Istanbul Greater Municipality and can be found in Figure 4. We generate the capacities and weight attributes from uniformly distributed random variables (based on the generation schema explained in Kilci, 2012). As in Kartal, we calculate the distance matrices with ArcGIS Network Analyst extension.

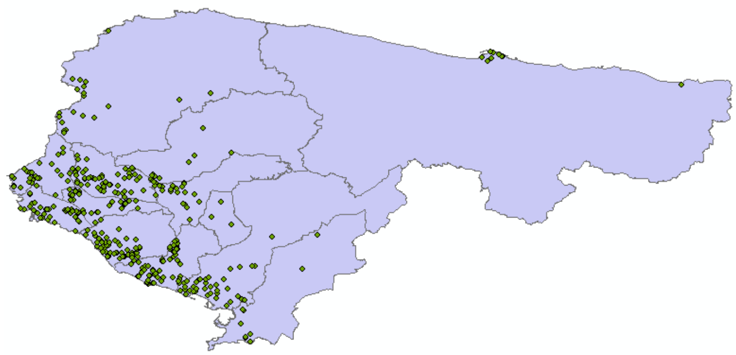

Figure 4: The location of candidate shelter areas in Asian side of Istanbul

In the Asian part of Istanbul, we identify 361 candidate shelter area locations. While solving the problem, the above-noted PC proved insufficient due to computer memory. Because of this, we use a PC with an Intel® Xeon® Processor E3-1220 (8M Cache, 3.10 GHz), 16 GB RAM, running Gurobi 4.5.2. The model solves a particular instance that relaxes the utilization constraints (by taking $\beta = 0$ and $\alpha = 1$) in 40,074 seconds (approximately 11 hours). For the Asian side of Istanbul, the model opens 75 shelter areas. Their utilization values vary between 0.01 and 0.978, with an average of 0.419 and the value of the objective function is 0.549.

6. Conclusion and Future Work

In this study, we address the problem of locating temporary shelter areas after a disaster. We review the relevant literature and develop a mathematical model to select the best shelter area locations from a set of criteria. The model determines shelter area locations and matches population areas (districts) with the nearest open shelter while taking shelter area utilizations into account. We test the model using the data for Kartal, a district of Istanbul, as well as for the entire city of Istanbul, dividing the city into the Asian side and the European side.

By varying the problem parameters, we test our model on 3000 different instances using the Kartal data. After inspecting the outputs, we observe that when the threshold distances to health institutions and main roads decrease, the objective value also decreases. Also, as the value of $\boldsymbol{\beta}$ increases and the value of $\boldsymbol{\alpha}$ decreases, the average utilization of open shelter areas increases and the number of open shelter areas decreases. Lastly, increasing the value of $\boldsymbol{\beta}$ and decreasing the value of $\boldsymbol{\alpha}$ result in an increase in the number of infeasibility cases over different DistHealth and DistRoad values. The model returns a solution for the Kartal case in less than one second. For the Anatolian side of Istanbul, the solution time is 40,074 seconds.

Our model considers a deterministic case where the number of affected people is known. However, in the aftermath of a disaster, such data is usually not immediately available to decision makers. To compensate for this drawback, the mathematical model can be extended in a robust optimization model to consider different scenarios.

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 4a: The objective value when DistHealth = DistRoad = 5

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 4b: The objective value when DistHealth =1.5 and DistRoad = 5

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 4c: The objective value when DistHealth = 5 and DistRoad = 2

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	0.777	0.777	0.783	0.783	0.808	0.808	0.872	0.885
0.6	0.804	0.815	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 5: The average of the average utilization

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: The maximum number of shelter areas opened

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 7: Number of infeasibility cases for each α, β pair

% Affected	Objective	Location
10	0.85	B14
10.5	0.85	B14
11	0.847	L2
11.5	0.847	L2
12	0.847	L2
12.5	0.827	B7
13	0.827	B7
13.5	0.809	B8
14	0.809	B8
14.5	0.803	O27
15	0.803	O27

% Affected	Objective	Location
15.5	0.803	O27
16	0.801	BO2
16.5	0.801	BO2
17	0.801	BO2
17.5	0.801	BO2
18	0.801	BO2
18.5	0.801	BO2
19	0.801	BO2
19.5	0.795	B1
20	0.739	T4

Table 8: The value of the objective function with different values of percentAffected

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