DISASTER RESPONSE AND RELIEF FACILITY LOCATION FOR İSTANBUL

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ABSTRACT

DISASTER RESPONSE AND RELIEF FACILITY LOCATION FOR İSTANBUL

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A destructive earthquake is anticipated to occur in İstanbul in the near future. The effects of this earthquake on human, infrastructure and economy are anticipated to be enormous. The Metropolitan Municipality of İstanbul has initiated a disaster plan to mitigate the effects of the disaster. Locating disaster response facilities to execute post-disaster activities and relief operations is a part of this plan.

In this study, we address the disaster response and relief facility location problem for İstanbul. Our aim is to study the situation and provide insights on the effects of the number of facilities and their locations. We propose a two-stage distribution system that utilizes existing public facilities as well as the new facilities to be established. We develop a mathematical model that tries to minimize the average distance to the population who need relief services while opening a small number of facilities. We analyze the trade-offs between these two objectives under various circumstances and present the results.

Keywords: disaster, humanitarian relief logistics, facility location

ÖZ

İSTANBUL İÇİN AFET MÜDAHALE VE YARDIM MERKEZİ YER SEÇİMİ

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Yakın bir gelecekte İstanbul'da yıkıcı bir deprem beklenmektedir. Bu depremin insanlar, altyapı ve ekonomi üzerindeki etkilerinin çok büyük olacağı öngörülmektedir. İstanbul Büyükşehir Belediyesi afetin etkilerini hafifletmek için bir afet planı çalışması başlatmıştır. Bu planın bir parçası olarak da İstanbul'a afet müdahale ve yardım merkezleri yerleştirilecektir.

Bu çalışmada, İstanbul için afet müdahale ve yardım merkezi yer seçimi problemini ele alıyoruz. Amacımız, durumu değerlendirerek açılacak merkezlerin sayıları ve yerlerinin etkilerini ortaya çıkarmaktır. Yeni açılacak merkezlerin yanısıra mevcut kamu binalarını da kullanan iki aşamalı bir dağıtım sistemi öngörüyoruz. Depremden etkilenen insanlara olan ulaşım mesafesini ve yeni açılan merkez sayısını en aza indirmeyi amaçlayan bir matematiksel model geliştiriyoruz. Farklı durumlar için bu iki amaç arasındaki ilişkiyi ve sonuçları inceliyoruz.

Anahtar Kelimeler: afet, insani yardım lojistiği, yer seçimi

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Nihan

To my family and İbrahim

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CHAPTER 1

INTRODUCTION

Recent disasters, both in the world and in Turkey, revealed the importance of disaster management in mitigating the negative effects of the disaster. Logistics activities in response to a disaster are commonly known as *humanitarian logistics*. Thomas and Mizushima (2005) define humanitarian logistics as ”the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from point of origin to point of consumption for the purpose of meeting the end beneficiary's requirements”. Similar to the classical logistics operations, the aim is to deliver the right goods, at the right time, to the right place and to the right people as Wassenhove (2006) suggests. However, in case of a disaster the timing and the amount of demand is unknown since it is hard to estimate the exact time and the effect of a disaster. In addition, the frequency of a major disaster is low while its effect may be extremely severe. These factors increase the complexity of decision making and operations in humanitarian logistics.

Turkey is vulnerable to earthquakes as the North Anatolian Fault (NAF) traverses from east to west along the north of Turkey. In the past, many strong earthquakes occurred on different segments of this fault line. Recently, Turkey suffered two destructive earthquakes in 1999, both of which occurred on NAF: The İzmit Earthquake on August 17, 1999 and the Düzce Earthquake on November 12, 1999. The İzmit earthquake had a magnitude of 7.4 on the Richter Scale and caused immense damage to human, buildings and infrastructure. Official sources (Özmen, 2000a) reported that approximately 20,000 people died and 45,000 were injured. However, the actual number of deaths is estimated to be approximately 40,000 (Marza, 2004) . On the other hand, the Düzce Earthquake had a magnitude of 7.2 on the Richter Scale and caused the death of 763 people and the injury of 4948 people. (Özmen, 2000b)

İstanbul was one of the cities affected from the İzmit Earthquake since İzmit and İstanbul are neighboring cities. Another destructive earthquake is anticipated in İstanbul. Parsons et al. (2000) estimated the probability of a destructive earthquake to occur in İstanbul within 10 years from 2000 as 32 ± 12% while the estimate for the probability to occur within 30 years is 62 ± 15%. This is a serious threat to İstanbul since it is the most populated city in Turkey with a population of approximately 12 million people (TÜİK, 2008). In addition, it is the commercial and industrial center of Turkey along with being one of the most popular tourist destinations of Turkey and of the world. Hence, the damages of a big earthquake to both the human life and the economy are estimated to be enormous. In order to alleviate the damages of a potential disaster, The İstanbul Metropolitan Municipality (İMM) has requested Japan International Cooperation Agency (JICA, 2002) to conduct a study on a disaster prevention and mitigation plan. In the scope of this study, they also analyzed the İzmit Earthquake. They suggested that besides the magnitude of the earthquake, there are some other factors that exacerbated the effects of the İzmit earthquake. Some of these factors are listed as follows:

- The public buildings and infrastructures were not resistant against the earthquake
- The governmental offices were also damaged and responsible staff were also victims
- Initial few days were chaotic; the rescue activity was done by the local residents
- Search and rescue operations were not organized or effective
- Relief activities were not organized

In brief, the main factor was the lack of preparedness for the earthquake. Hence, İMM has initiated various activities to improve both pre-disaster and post-disaster operations. Accordingly, the İstanbul Metropolitan Municipality Disaster Coordination Center (abbreviated as AKOM in Turkish) was established in 2000. In addition, İMM is planning to establish disaster response and relief facilities at various locations in İstanbul. Studying the number and locations of these facilities is in the scope of our study.

In Chapter 2, we present the related literature. We first mention the related studies in disaster management and emergency response and then we focus on some of the studies in facility location literature that are pertinent to our problem. In Chapter 3, we describe the problem in detail and present the mathematical formulations that we have developed and the results of the application. Chapter 4 is devoted to our analysis of the different variations of the problem. In Chapter 5, we conclude with our major findings and possible future research directions.

CHAPTER 2

LITERATURE REVIEW

Literature on disaster management is limited when compared to other classical problems of Operations Research. However, it has proliferated in recent years. According to a survey conducted by Altay and Green (2006), there are 109 Operations Research and Management Science related articles on disaster management with 77 of them published in OR/MS related journals. It is reported that 40% of these 109 articles were published between 1990 and 2000, and the rest were published after 2000. In this chapter, we review the literature related to disaster response and relief facility location. We analyze the related literature in two sections. Firstly, in Section 2.1 we mention some studies on the logistics problems faced in disaster management and emergency response operations. Secondly, in Section 2.2 we describe some studies in the facility location literature that have similarities to our problem.

2.1 Disaster Management and Emergency Response

Wright et al. (2006) conducted a survey on Operations Research models and applications in homeland security. They divide their analysis to four main streams, namely border and port security, cyber security, critical infrastructure protection, and emergency preparedness and response. Although the first three categories are related to man-made disasters and attacks, the last is relevant to natural disasters. For this category, they present some studies on location and resource allocation, evacuation models, and disaster planning and response. They claim that there are few studies on disaster response and recovery, and that there is a need for more research on these topics. In this section, we first present some studies directly related to disaster management and emergency response operations.

Studies in disaster management literature are usually applications to some specific regions that suffer from disasters, as it is the case in our study. Similarly, Dekle et al. (2005) conducted a study on locating disaster recovery centers in Florida. They employ a two-stage approach. In the first stage, the covering problem is solved by disregarding many of the evaluation criteria and the optimal locations for the facilities are determined. Then, in the second stage, the existing buildings that are close to these optimal locations are identified and graded based on the combined evaluation criteria.

Jia et al. (2007) provide a modeling framework for facility location of medical services for large scale emergencies such as earthquakes, terrorist attacks, etc. In that study, they review facility location models for emergency services under three categories, namely Covering models, P-median models and p-center models. Then, they propose a general formulation for emergency response facilities that can be cast as a generalization of these three models. Unlike classical formulations, they introduce scenarios and a ”service level” requirement. The service level of a demand point is determined by the number of facilities that serve the demand point and the conditions of these facilities under given scenarios. In other words, the higher the number of facilities serving a demand point and the better their conditions are, the higher the service level is. These two concepts are also commonly employed in disaster management literature.

In another scenario-based study with service levels, Balcik and Beamon (2008) propose a model to determine the number and the location of distribution centers in a relief network. In addition to the locations of the facilities, they also determine the amount of each relief commodity stored at each facility. In their formulation, they consider a single demand point and a set of capacitated supplier locations where the suppliers need neither have the same capacity, nor to supply the same commodities. They differentiate between commodities by assigning a criticality weight to each commodity. Then, the objective is to maximize the total expected demand covered by the located facilities. Here, the weights are determined by the criticality of the commodity and the quality of the service. Scenarios are incorporated such that the model satisfies a set of constraints for each scenario and the expected value over all scenarios is considered in the objective function.

Günneç et al. (2007) propose a facility location model for locating emergency response and distribution centers in İstanbul. We work on the same study area and the potential locations considered in their study are the same with the ones that we use. Similar to the study by Balcik and Beamon (2008) the authors use a set of scenarios and a set of commodities with specified weights indicating their importance. In addition, they employ a service level concept by enforcing an upper bound on the service distance. As it is the case in many scenario-based approaches, the objective is the minimization of the expected total weighted distance over all scenarios and there is a set of constraints in each scenario. In this study, they work with multiple demand points and the facilities are uncapacitated. Günneç and Salman (2006) propose another model for the same problem. In this case they provide a two-stage multi-criteria stochastic programming model where they have five objectives to minimize. These are, the total weighted response time, maximum service time for each commodity, average risk of each facility, expected unsatisfied demand, and finally the cost of opening new facilities. They express each objective function as the expected value over all scenarios and propose a goal-programming approach to solve the problem.

Cheng and Tzeng (2007) proposes a multi-objective model for designing a relief delivery system. The model works with three objectives: minimizing the total cost, minimizing the total travel time and maximizing the minimal satisfaction. Different from the previous studies, they propose temporary storage points rather than establishing new facilities. The supply points and the temporary storage points have capacities. They divide the operation period into time slots and determine inventory and schedule shipments for each slot. Hence, the decisions derived from this model are more operational when compared to the other studies presented in this section. They employ a fuzzy multi-objective linear programming formulation to solve the problem.

Studies on the daily emergency activities have similarities to studies on disasters. Serra and Marianov (1998) formulate a p-median problem in a changing network to locate the fire stations in Barcelona. In this study, the demand and the travel times are uncertain and they are scenario dependent. The authors propose two different objectives. The first one is a min-max type objective where they minimize the maximum travel time per population among the scenarios. The second objective is the minimization of maximum regret over the scenarios. Here they define the regret as the difference between the optimal travel time that would be obtained if the facilities had been optimally located for the scenario that actually occurred, and the value of average travel time that was realized.

Apart from the studies on the facility location problem in disaster response, there is a study in transportation planning that is related to our problem. Barbarosoglu and Arda (2004) provide a two-stage stochastic programming framework for transportation planning for disaster response in İstanbul. In this study, they consider a stochastic demand. Moreover, the capacities of the arcs in the road network and the supply amounts are considered to be random. First stage decisions are made before the scenarios are realized, while the second stage decisions are made based on the realized scenario. Hence, the number of two-stage models to be solved is equal to the number of scenarios. This approach resembles our case, since the facilities are planned to be established before the earthquake and the allocation decisions are made after the earthquake.

2.2 Facility Location

In this section, we present some studies on the facility location problem that are not necessarily related to disaster response, but have some common characteristics to our problem. Some of these characteristics are the uncertainty in demand, existence of possible future states, uncertainty in the number of facilities to be established and multi-period planning. First three of these characteristics are related to the uncertainty in the time and the effect of a disaster. On the other hand, multi-period planning is considered, since it is not practical to establish a large number of facilities at one time due to high investment costs.

Owen and Daskin (1998) provide a detailed review on the strategic facility location problem. They suggest that the high costs associated with facility location make this process a long-term investment and requires careful consideration. In addition, they suggest that these factors together with stochastic and dynamic problem characteristics make facility location a strategic decision. Accordingly, they analyze the literature in three categories. Static and deterministic location problems, dynamic location problems, and stochastic location problems.

Drezner (1993) proposes a formulation for the progressive p-median problem. The aim is to locate p facilities over a time period where the number of facilities to be located in each period is specified before. The aim is to minimize the distance over the planning horizon. A special algorithm is developed for the two-facility case. In this algorithm, the demand points are partitioned into two and a 1-median problem is solved for each partition in every possible partitioning. Then, the least cost partitioning is proposed as the solution.

Scenario-based approaches also exist in the facility location literature. Current et al. (1998) consider a problem where the number of facilities to be established is uncertain. The problem is analyzed with two decision criteria: minimizing the expected opportunity loss and minimizing the maximum regret. They consider a set of potential facility locations and possible future states. Each future state is associated with a probability indicating that it is the final state and the aim is to find the initial set of facility locations that minimizes the sum of expected decision criteria over all future states.

Daskin and Hesse (1997) provide a α-reliable p-minimax regret model for the strategic facility location problem. The motivation for this study comes from the fact that a single extreme scenario can dictate the solution in scenario-based formulations. This is especially valid for the min-max regret type objectives. In order to prevent this situation, they suggest a model that endogenously selects a set of scenarios among all possible scenarios and optimizes the worst case performance over the selected scenarios. They employ an α reliability concept which ensures that the sum of the occurrence probabilities of the selected scenarios is not less than the specified α value. Here, $\alpha = 1$ corresponds to the classical minimax regret problem. With the same concerns, Mulvey et al. (1995) propose an approach called *robust optimization* for the large-scale systems. They suggest that a solution be called "*solution-robust* if it remains close to the optimal for all scenarios of the input data, and *model-robust* if it remains almost feasible for all data scenarios". They add a penalty term to the objective function penalize the violations under different scenarios. By adjusting the weight of this penalty they obtain a set of solutions that reflect the trade-off between the two robustness measures.

CHAPTER 3

MATHEMATICAL MODELS AND APPLICATION

In this chapter, we provide the mathematical models that we have developed for the problem and the results of the application. In Section 3.1, we provide the details of our problem. First, we present a detailed discussions on the functions of the facilities and the proposed distribution system for the relief commodities. Then, we describe the study area and the sources of the data. We also discuss some of the assumptions used in constructing the models. In Section 3.2, we introduce the mathematical models. In section 3.3 we present the solution approach that we propose to solve these models. Finally, in Section 3.4 we present the results of the application.

3.1 Detailed Information on the Problem

In this section we provide detailed information on the facilities to be established and the study area. In Section 3.1.1, we describe the function of the facilities and the characteristics of the proposed distribution system. Then, in Section 3.1.2, we describe the study area and the data we use in models.

3.1.1 Distribution System

As mentioned in Chapter 1, İMM will establish disaster response and relief facilities in İstanbul. These facilities are planned to serve as:

- Coordination centers for the units of İMM and other organizations participating in post-disaster activities
- Warehouses for pre-disaster storage

- Distribution centers after the earthquake

It is also suggested that these facilities will serve people who participate in rescue operations and disaster response activities. However, there is still some ambiguity regarding the type of coordination activities that will be carried out by the facilities and the functions of these facilities in non-disaster times. According to İMM, in non-disaster times, the facilities will house units of İMM, such as fire brigades. In addition, the facilities are planned to serve as warehouses for the social organizations of İMM such as the restaurants operated by the municipality. The items planned to be kept in stocks for disaster response are as follows:

- Tents
- Food and Water
- Sleeping bags
- Blankets
- Medical equipment

A disaster response facility was already established in Halkalı in 2006 as a part of rehabilitation project of the previous garbage disposal area. İMM has identified 40 potential locations for establishing additional facilities. Some of the criteria used in determining these locations are as follows:

- Accessibility by at least two alternative roads
- Proximity to major roads
- Being available to be used by the municipality

In January 2008, a meeting was held at AKOM to discuss the findings of the study conducted by Günneç et al. (2007). There were participants from various organizations that are involved in disasters response activities. Some of these organizations are as follows:

- Metropolitan Municipality Government
- Turkish Red Crescent (Kızılay)
- Provincial Civil Defense Directorate
- AKUT (Search and Rescue Association)

There were disagreements on a number of issues but participants somewhat agreed on three issues. Firstly, it was agreed that it is not practical to establish a large number of facilities that only serve earthquake response activities. They suggested that alternative ways of utilization should be considered before establishing large scale facilities. Secondly, it was suggested that the existing facilities could be utilized for this purpose, rather than constructing new facilities. To do that, they recommended finding the optimal places on the map and then searching the currently available public facilities that could be re-assigned to disaster response operations. In light of these discussions, we decided to develop a model that considers both the existing public facilities and the potential locations for disaster response operations.

We suggest that new facilities to be established store relief commodities. We call these facilities *permanent facilities*. In addition, we suggest dedicating some of the existing public facilities for relief operations. These facilities are planned to serve as local distribution and coordination centers and we call these *temporary facilities*. They may also be considered as temporary shelters for the refugees. Hence, the material flow will be from permanent facilities to temporary facilities and refugees will satisfy their needs from the temporary facilities. Figure 3.1 illustrates the material flow.

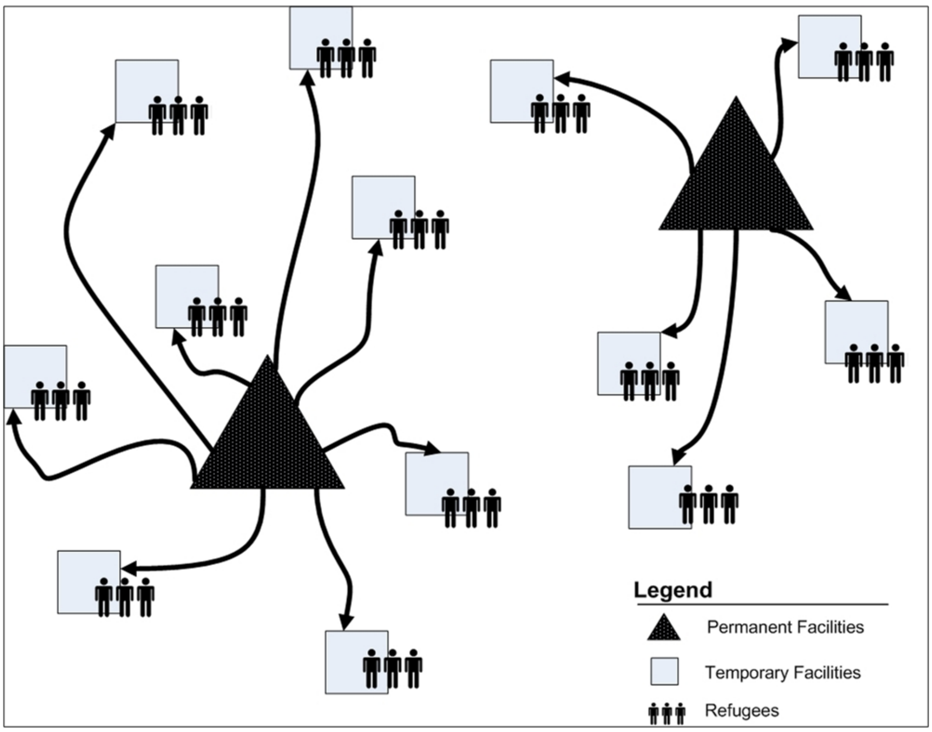


Figure 3.1: Material Flow in the Distribution System

Here, the refugees are the people who are affected from the earthquake and who need shelters and relief commodities. Schools are the most suitable locations for the coordination of local rescue and relief operations as they are usually central to many neighborhoods. Additionally, they are suitable for temporary accommodation after earthquakes. From now on we refer to temporary facilities as "schools" and permanent facilities as "facilities".

In our analysis, we assume that every facility can supply the required amount, i.e. they are uncapacitated. This is a reasonable assumption because İMM is capable of establishing the facilities with the required capacities determined by the analysis. In addition, the results of this study show that there is not large discrepancy in the amount of demand satisfied from each facility. However, we also consider the case where the facilities are capacitated. Additionally, we assume that the facilities give the same service. That is, they are identical in terms of the activities carried out and the commodities supplied. Finally, we assume that the facilities are not affected from the earthquake since it is possible to establish earthquake-resistant buildings.

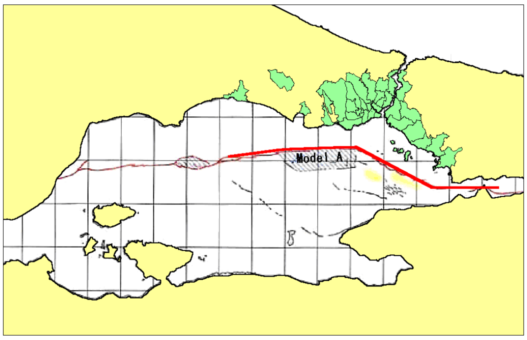
3.1.2 Characteristics of the Study Area

The facility location problem for the İstanbul earthquake is previously studied by Günneç et al. (2007). We use the same data set they obtained from İMM. Moreover, a significant portion of the data used in our studies is taken from the JICA report (JICA, 2002). The area studied in JICA is provided in Figure 3.3. In order the estimate the damage, JICA team identified four scenarios for the İstanbul earthquake. These scenarios are as follows:

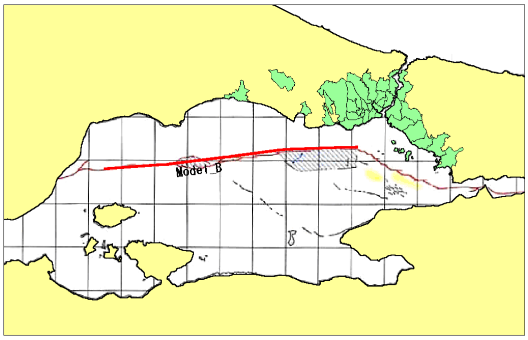
- Scenario A: This scenario is suggested to be the most probable scenario. Its magnitude is estimated to be 7.5 on the Richter Scale.
- Scenario B: The magnitude of this scenario is estimated to be 7.4 on the Richter Scale.
- Scenario C: This is the worst case scenario. Its magnitude is estimated to be 7.7 on the Richter Scale.
- Scenario D: The magnitude of this scenario is estimated to be 6.9 on the Richter Scale.

These scenarios are represented in Figure 3.2. Each figure shows the entire fault line and the portion of the fault line anticipated to be broken for the corresponding scenario. The broken portions are indicated with a bold line. As it is shown in Figure 3.2c, the portion expected to be broken is the longest in Scenario C, the worst case scenario. On the other hand, the portion to be broken is the shortest in Figure 3.2d which corresponds to Scenario

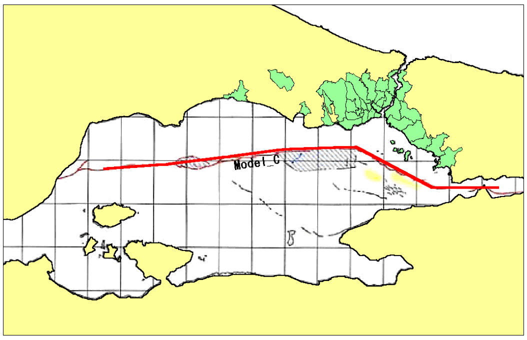
D. In the JICA report, the effects of the earthquake in terms of the damaged buildings and the affected people are estimated for scenarios A and C only. They claim that the effects of Scenario D is similar to Scenario A and the effects of Scenario B is similar to those of Scenario C. In our analysis, we use the data for scenario C. However, in Section 4.7 we provide representative results using the data for Scenario A.



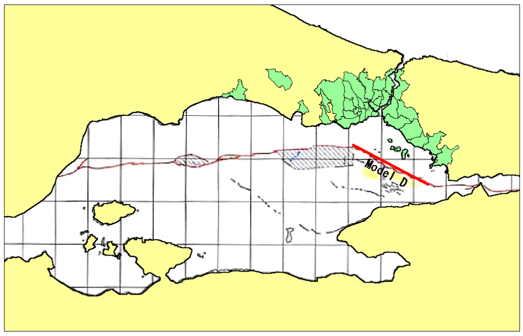
(a) Scenario A



(b) Scenario B



(c) Scenario C



(d) Scenario D

Figure 3.2: Earthquake Scenarios (Taken from JICA (2002))

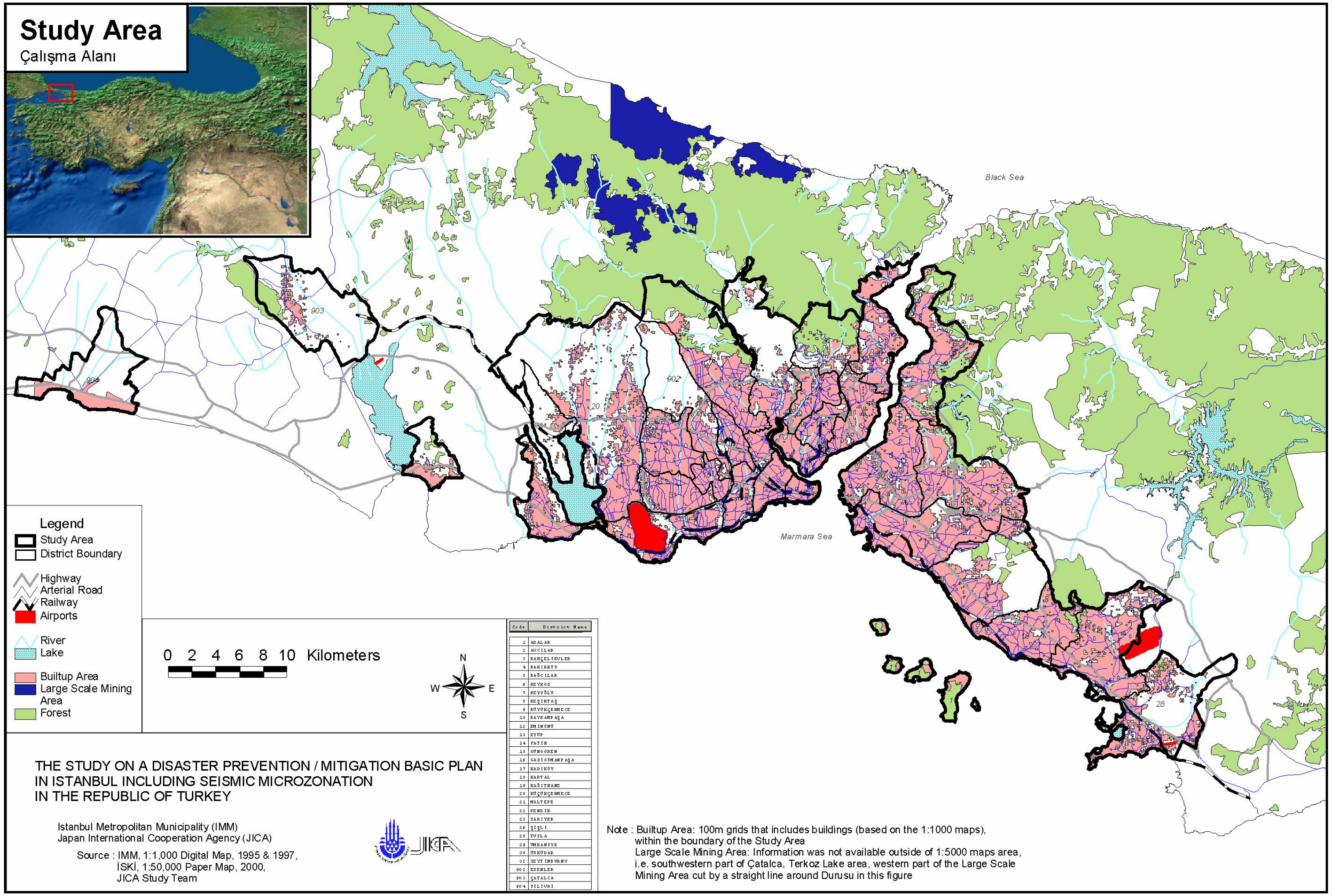


Figure 3.3: JICA Study Area (Taken from JICA (2002))

Potential Facility Locations

As mentioned in Section 3.1 there are 40 potential facility locations that are specified by the İMM and there is an existing facility in Halkalı. Coordinates of these facilities are obtained from the Geographic Information System (GIS) used by the İMM. Figure 3.4 shows the Halkalı facility and other potential facility locations on the İstanbul map. In addition, the coordinates of the facilities are provided in Appendix A.

Figure 3.4: Potential Facility Locations

Demand Points:

In the JICA report, damage estimation and refugee population are provided based on districts. In Sections 3.4.1, 4.1, and 4.2 we use districts as demand points while in the remaining analysis we use neighborhoods as demand points. *District* corresponds to *ilçe* in Turkish while *neighborhood* corresponds to *mahalle*. In our study area, there are 27 districts of the İMM and 2 additional districts, Çatalca and Silivri that are located to the west. In the original study area of JICA, there is an additional district Büyükçekmece which is also outside the boundaries of the İMM. However, we do not consider this district, as the damage estimation is not provided. Figure 3.5 shows the districts except Çatalca and Silivri. The

Figure 3.5: Districts

coordinates of the districts are provided in Appendix A. In the study area, there are 718 neighborhoods. We represent each district with a single (x, y) coordinate calculated as the weighted average of the coordinates of its neighborhoods. In order to find the coordinates of a district, the coordinates and the populations of its neighborhoods are obtained from GIS used by the İMM. Then, the coordinates of a district is calculated by taking the weighted average of the coordinates of its neighborhoods, where the weights are the populations. The neighborhoods are given in Figure 3.6. In addition, the calculated district centers are shown in Figure 3.7 along with the boundaries of the districts.

Figure 3.6: Neighborhoods

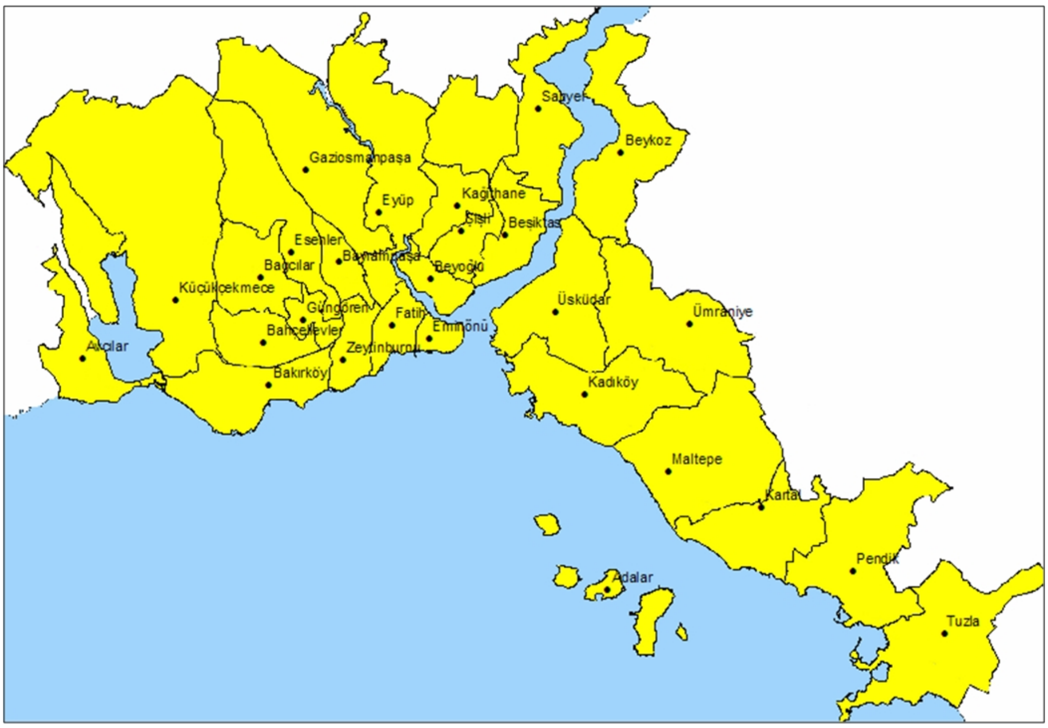


Figure 3.7: District Centers and Boundaries

Demand:

Demand at each district is taken the estimated refugee population in that district, since the commodities to be sent every refugee is identical. In the JICA report, refugee population is estimated by taking the 100% of the surviving population in heavily damaged buildings, 50% of the surviving population in moderately damaged buildings and 10% the of surviving population in partially damaged buildings. Based on these, the refugee population in each district is provided in Appendix A. In addition, Figure 3.8 shows the refugee population in districts.

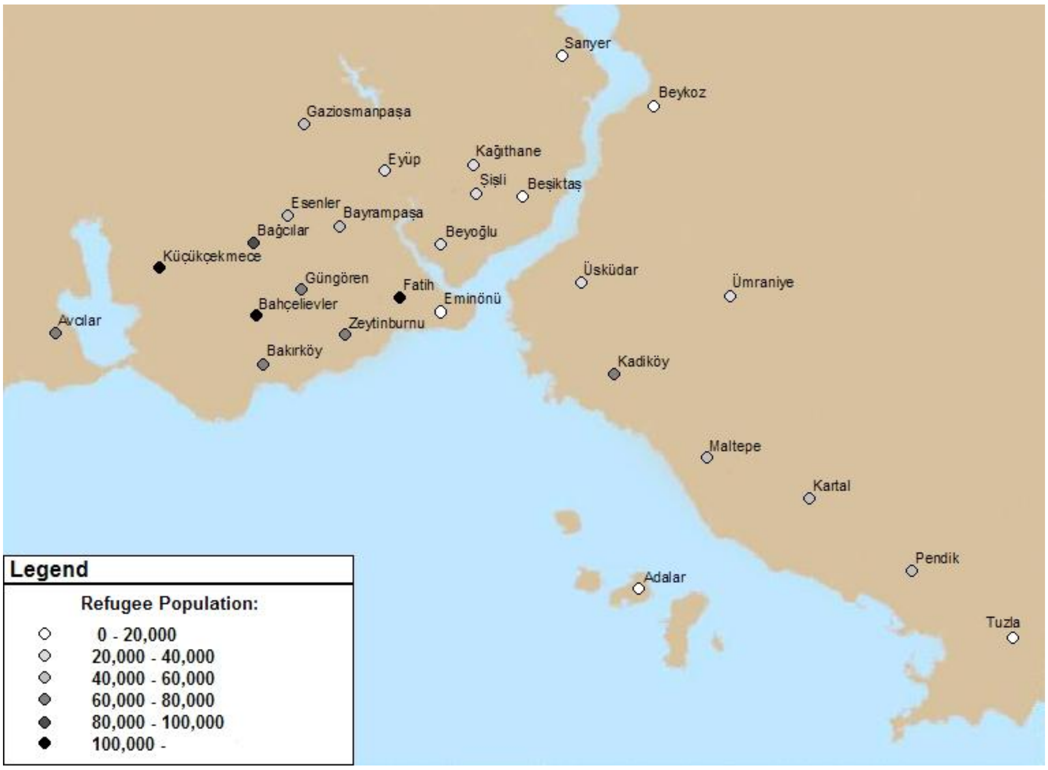


Figure 3.8: Refugee Population by Districts

For the models where we use the neighborhoods as demand points we disaggregate the refugee population estimated for a district to its neighborhoods. We distribute the refugee population to neighborhoods based on the distribution of the actual population.

School Capacity and Maximum Number of Schools:

In the JICA report, the recommended average capacity of a school is approximately 2000 people. Hence, we take the capacity of a school, CS, as 2000 in our studies. Besides, information on the number of public schools in each district, S^k_{max}, is also provided in the

JICA report. S^k_{max} values for the districts are given in Appendix A.

Distances:

In this study, the exact distances between the points are approximated by the Euclidean distances that are calculated by using the coordinates of the points. 1000 units in the coordinate space correspond to approximately 1 km. Distances are rounded to the nearest integers when used in the models.

3.2 Mathematical Models

In this section, we introduce the mathematical models that are developed for the Relief Facility Location Problem. These models are classified according to two properties. The restriction on the number of schools and the strategy in meeting the demand of the refugees. In terms of the restriction on the number of schools, our models are classified as:

- Models with unrestricted number of schools at each demand point
- Models with restricted number of schools at each demand point

We classify the models based on the strategy in meeting the demand as:

- Models that satisfy all demand
- Models that satisfy demand partially
  - Models that satisfy the total demand partially
  - Models that satisfy the demand partially at each demand point

In the following sections, the main attribute of classification is taken as the strategy used in meeting the demand. Accordingly, in Section 3.2.1, we describe the models that satisfy all demand and in Section 3.2.2 we describe the models with partial demand satisfaction.

3.2.1 Models that Satisfy All Demand

In this section, we first present the model with "Unrestricted Number of Schools" (*UNS*) in each demand point. In this case, we assume that there is no restriction on the number of schools at individual demand points, while the total number of schools to be allocated for relief operations is limited by *MaxSc*. In all formulations, we consider a set of potential facility locations J and a set of demand points K. The rest of the notation is as follows: *Parameters*

$df_{j,k}$: Distance between facility location j and demand point k

$dd_{k,k'}$: Distance between demand point k and demand point k'

RP_k: Refugee population of demand point k

CS: Capacity of each school

$MaxSc$: Maximum number of schools that can be allocated for relief operations

M: A Sufficiently large positive number

Decision Variables

$$o_j: \begin{cases} 1, & \text{if facility } j \text{ is open} \\ 0, & \text{otherwise} \end{cases}$$

$x_{j,k}$: Number of people whose demand is satisfied from facility j through the schools at demand point k

$y_{k,k'}$: Number of people in demand point k' whose demand is satisfied from the schools at demand point k

n_k: Number of schools that are allocated for relief operations at demand point k

$$\text{Objective 1:} \quad \text{Min} \quad \frac{\sum_j \sum_k df_{j,k}.x_{j,k} + \sum_k \sum_{k'} dd_{k,k'}.y_{k,k'}}{\sum_k RP_k} \tag{3.1}$$

$$\text{Objective 2:} \quad \text{Min} \quad \sum_j o_j \tag{3.2}$$

subject to

Model (*UNS*)

$$\sum_k n_k \leq MaxSc \tag{3.3}$$

$$\sum_k x_{j,k} \leq M.o_j \quad \forall j \tag{3.4}$$

$$\sum_j x_{j,k} \leq CS.n_k \quad \forall k \tag{3.5}$$

$$\sum_k y_{k,k'} = RP_{k'} \quad \forall k' \tag{3.6}$$

$$\sum_j x_{j,k} = \sum_{k'} y_{k,k'} \quad \forall k \tag{3.7}$$

$$o_j \in \{0, 1\} \tag{3.8}$$

$$n_k \geq 0, integer \tag{3.9}$$

$$x_{j,k}, y_{k,k'} \geq 0 \tag{3.10}$$

Here, we have two objectives to minimize: The average distance traveled to serve a refugee and the number of new facilities to establish. We assume that the schools are located at the centers of the demand points. Hence, the distance between the schools and the facilities are taken as the distance between the facilities and the demand points where the schools are located. Constraint (3.3) limits the number of schools that can be allocated for relief operations. We take *MaxSc* as the minimum integer value which leads to a feasible solution. This value is determined by dividing the total population by the capacity of a school and rounding it up to the nearest integer, $\lceil \sum_k RP_k / CS \rceil$. Constraint (3.4) ensures that a facility cannot serve unless it is open. Constraint (3.5) enforces the number of schools at a demand point to be sufficient to meet the demand that is served from that point. Constraint (3.6) ensures that the demand at each point is met. Finally, constraint (3.7) balances the incoming and outgoing flows of demand points k.

If we assume that there is no limit to the total number of schools, and if it is allowed that the required number of schools can be allocated at each demand point, then the number of schools to be opened at demand point k simply becomes $\lceil RP_k/CS \rceil$. This is the number of schools required to meet the demand at that point without any shipment from schools at other demand points. In this case the model (*UNS*) reduces to:

Model (*UNS_simple*)

$$\text{Objective 1:} \quad \text{Min} \quad \frac{\sum_j \sum_k df_{j,k}.x_{j,k}.RP_k}{\sum_k RP_k} \tag{3.11}$$

$$\text{Objective 2:} \quad \text{Min} \quad \sum_j o_j \tag{3.12}$$

subject to

$$\sum_k x_{j,k} \leq M.o_j \quad \forall j \tag{3.13}$$

$$\sum_j x_{j,k} = 1 \quad \forall k \tag{3.14}$$

$$o_j, x_{j,k} \in \{0, 1\} \tag{3.15}$$

where, the new decision variable is

$$x_{j,k} : \begin{cases} 1, & \text{if demand point } k \text{ is served by facility } j \\ 0, & \text{otherwise.} \end{cases}$$

The variable o_j and the parameters used in this model are same with those used in model (*UNS*). Although $x_{j,k}$ is specified as binary, LP relaxation also leads to values $\in \{0, 1\}$. Since the facilities are uncapaciteted, each demand point is assigned to closest facility.

In the previous two models, we assume an unrestricted number of schools at each demand point. However, the number of temporary facilities at a demand point can be limited based on the actual number of facilities that are available. In that case, the following constraint is added to the model (*UNS*).

$$n_k \leq S^k_{max} \quad \forall k \tag{3.16}$$

Here, we denote the maximum possible number of temporary facilities at a demand point k by S^k_{max}. Constraint (3.16) ensures that the total number of schools that are assigned to relief operations should be less than or equal to the actual number of schools at that point. We call the resulting model as (*RNS*).

3.2.2 Models that Satisfy Demand Partially

In Section 3.2.1 we assume that all demand is satisfied. However, this may not be possible due to the restrictions on the stock and processing capacity. In this section, we consider the case where the İMM satisfies a proportion of demand. As mentioned, we consider two cases when the demand is satisfied partially. İMM may satisfy the same proportion of demand at each point, or they may decide to select some of the demand points and meet their demand.

If the İMM meets the demand of selected demand points, Constraint (3.6) of models (*UNS*) and (*RNS*) are replaced with the following constraint.

$$\sum_k \sum_{k'} y_{k,k'} \geq PS. \sum_k RP_k \tag{3.17}$$

In addition, Objective 1 becomes:

$$\text{Objective 1:} \quad \text{Min} \quad \frac{\sum_j \sum_k df_{j,k}.x_{j,k} + \sum_k \sum_{k'} dd_{k,k'}.y_{k,k'}}{\sum_k RP_k.PS} \tag{3.18}$$

Here, we have an additional parameter PS, that specifies the percentage of total demand that can be satisfied. Constraint 3.17 ensures that PS percent of the whole demand will be satisfied. This may result in complete demand satisfaction at some of the demand points while the demand of others may only be met partially or may not be met at all. Hereafter, we call the models that satisfies the "Total Demand Partially" as (*TDP*). According to models (*TDP_UNS*) and (*TDP_RNS*), İMM concentrates its relief operations at some of the demand points. This kind of strategy is meaningful when other parties that are involved in relief operations concentrate on the remaining points. In this case, the remaining relief areas will be allocated to different relief organizations.

On the other hand, İMM may also prefer the case where all demand points are served with an equal service level. That is, the same proportion of demand at each point is met by the İMM. This can be interpreted as meeting the demand of each refugee partially. If PS percent of demand at each point is met, Constraint (3.6) of models (*UNS*) and (*RNS*) are modified as follows:

$$\sum_k y_{k,k'} \geq PS.RP_{k'} \quad \forall k \tag{3.19}$$

Constraint (3.19) ensures that PS percent of the demand of each point will be satisfied. In the following sections, we refer the models that satisfies "District's Demand Partially" as

(*DDP*). According to models (*DDP_UNS*) and (*DDP_RNS*), İMM allocates its relief efforts to each demand point evenly. Since the magnitude of demand changes with the same proportion at all demand points, the solution is identical to the case where all demand is satisfied.

3.3 Solution Approach

In Section 3.2 we provide models with two objectives to minimize. In this section, we introduce the approach that we use to solve these models. Let f_1 and f_2 be the first and the second objectives to minimize, respectively. In Multi Criteria Decision Making (MCDM) terminology, a solution x is said to be efficient if and only if there is no other solution y such that

$$f_1(y) \geq f_1(x) \quad \text{and} \quad f_2(y) \geq f_2(x)$$

with a strict equality for one of the objectives. We employ the ε-constraint method with an augmented objective function to obtain the efficient solutions to the models provided in the previous section. Accordingly, the model (*UNS*) becomes:

$$\text{Min} \quad \frac{\sum_j \sum_k df_{j,k}.x_{j,k} + \sum_k \sum_{k'} dd_{k,k'}.y_{k,k'}}{\sum_k RP_k} + \varepsilon . \sum_j o_j \tag{3.20}$$

subject to

$$\sum_j o_j \leq MaxFac \tag{3.21}$$

$$+$$

Other Constraints ((3.3) - (3.10))

Similarly, the reduced model (*UNS_simple*) becomes:

$$\text{Min} \quad \frac{\sum_j \sum_k df_{j,k}.x_{j,k}.RP_k}{\sum_k RP_k} + \varepsilon . \sum_j o_j \tag{3.22}$$

subject to

$$\sum_j o_j \leq MaxFac \tag{3.23}$$

$$+$$

Other Constraints ((3.13) - (3.15))

Here, ε is a sufficiently small positive constant and *MaxFac* is the maximum number of facilities that can be opened. In order to obtain the efficient solutions, we solve the model repeatedly by varying the parameter *MaxFac* from 1 to 41, the maximum possible number of facilities. In addition, we augment the objective function by $(\varepsilon . \sum_j o_j)$ to avoid inefficient solutions. However, solving the model without the augmented objective until two consecutive objective values are the same also leads to the same solutions. Let UNS_n be the model (*UNS*) with $MaxFac = n$. Then, once the objective value of UNS_{n+1} is equal to that of UNS_n, we conclude that the results of the models UNS_n to UNS_{41} are identical.

3.4 Application

3.4.1 Models with Districts

As mentioned, there is an existing facility in Halkalı. Hence, the locations of the new facilities should be determined by taking this facility into account. In this section, we present the results for the models (*UNS*) and (*RNS*) where we fix the Halkalı facility and take districts as the demand points. We provide the results for all variations in meeting the demand. That is, we consider the cases: satisfy all demand, satisfy the total demand partially, and satisfy the demand partially in each district.

First, we solved the models (*UNS*) and (*RNS*) that satisfy all demand and find the efficient solutions. Efficient solutions corresponding to models (*UNS*) and (*RNS*) are provided in Figure 3.9. In addition, the comparison of these two models in terms of average distance per refugee resulting is provided in Table 3.1.

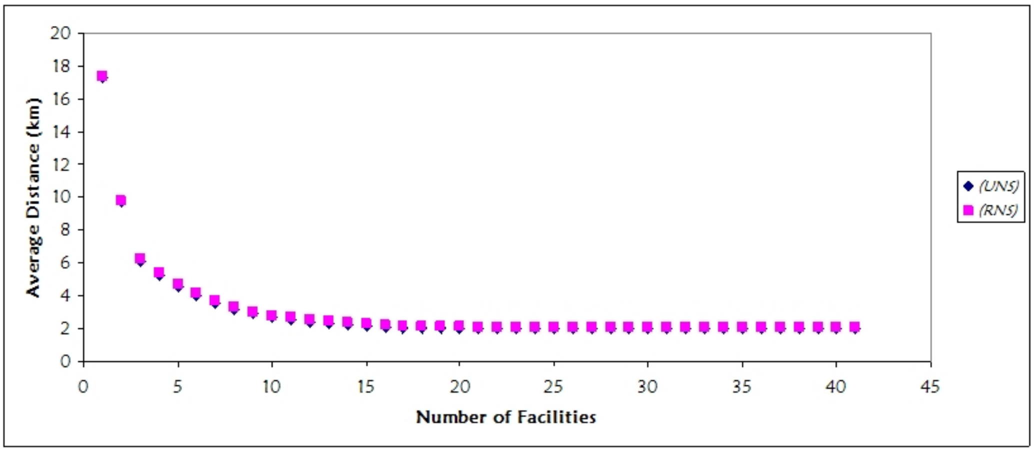


Figure 3.9: Efficient Solutions for (*UNS*) and (*RNS*)

Table 3.1: Average distance per refugee comparisons of (*UNS*) and (*RNS*) models

Number of Facilities	**Average Distance (km)** *UNS*	*RNS*	**Absolute Difference**	**% Difference**
1	17.33	17.36	0.02	0.14
2	9.67	9.78	0.11	1.08
3	6.09	6.24	0.15	2.41
4	5.20	5.35	0.15	2.89
5	4.56	4.72	0.15	3.27
6	3.99	4.14	0.15	3.56
7	3.54	3.65	0.11	3.05
8	3.16	3.27	0.11	3.45
9	2.90	3.01	0.11	3.75
10	2.69	2.81	0.11	4.02
11	2.55	2.67	0.11	4.23
12	2.42	2.54	0.12	4.88
13	2.31	2.43	0.12	5.10
14	2.21	2.35	0.14	5.94
15	2.13	2.27	0.14	6.18
16	2.07	2.21	0.14	6.36
17	2.03	2.17	0.14	6.45
18	2.00	2.14	0.14	6.54
19	1.99	2.13	0.14	6.58
20	1.98	2.12	0.14	6.62
21	**1.97**	**2.11**	**0.14**	**6.62**
22	1.97	2.11	0.14	6.62
23	1.97	2.11	0.14	6.62
24	1.97	2.11	0.14	6.62
25	1.97	2.11	0.14	6.62
26	1.97	2.11	0.14	6.62
27	1.97	2.11	0.14	6.62
28	1.97	2.11	0.14	6.62
29	1.97	2.11	0.14	6.62
30	1.97	2.11	0.14	6.62
31	1.97	2.11	0.14	6.62
32	1.97	2.11	0.14	6.62
33	1.97	2.11	0.14	6.62
34	1.97	2.11	0.14	6.62
35	1.97	2.11	0.14	6.62
36	1.97	2.11	0.14	6.62
37	1.97	2.11	0.14	6.62
38	1.97	2.11	0.14	6.62
39	1.97	2.11	0.14	6.62
40	1.97	2.11	0.14	6.62
41	1.97	2.11	0.14	6.62

Note that the solutions are the same for the cases where 21 or more facilities are opened. As it is observed, the difference in the average distances obtained in (*UNS*) and (*RNS*) is small. The solutions are very close because in only a few districts, the number of public schools are insufficient to meet the demand of that district. In the majority of the districts, the number of schools is sufficient to meet the demand. In addition, the deficiency in the required number of schools is small in districts that fail to meet their own demand. Since the solutions are almost the same, hereafter we assume that for every district, the number of temporary facilities is enough to meet the demand of that district. This is also plausible since there are some other public facilities that can be allocated for relief operations. Accordingly, we use the model (*UNS_simple*) in the following sections.

Besides the analysis for the models that satisfy all demand, we also present the results for the case where the demand is satisfied partially. We solve both (*TDP_UNS*) and (*DDP_UNS*). Efficient solutions for the partial satisfaction of total demand are given in Figure 3.10.

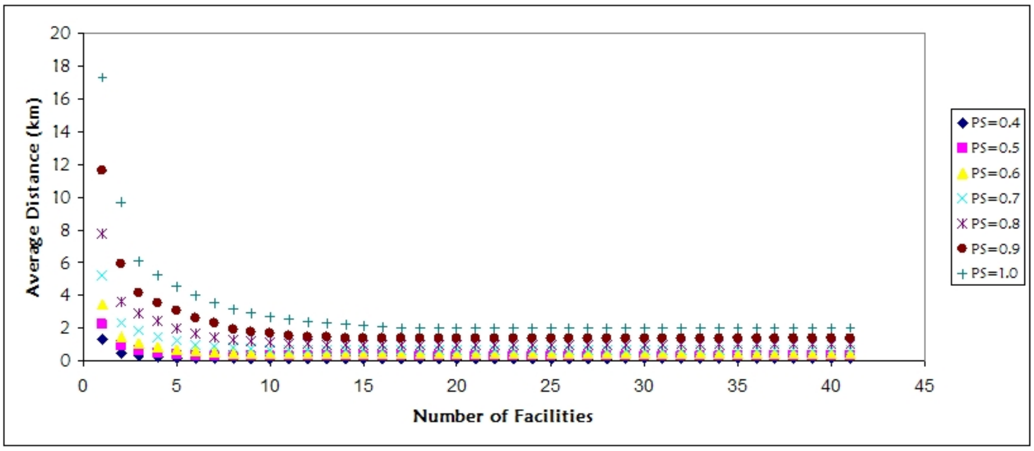


Figure 3.10: Efficient Solutions for (*TDP_UNS*)

Here, *PS* is the percentage of the demand satisfied. As it is expected, the average distance to serve a refugee decreases as the number of people to be served decreases. This is because, the model prefers to serve the most populated districts by locating the facilities close to these districts. The results are provided in Table 3.2. Here, we should note that the Halkalı facility is utilized by the model only for the single-facility and two-facility cases when $PS = 0.4$. As the number of facilities increases to three, the Halkalı facility does not satisfy any demand, because the other facilities are uncapacitated. It indicates that the location of the Halkalı facility is not promising in terms of its proximity to the demand points. In addition, the Halkalı facility is abandoned because we do not explicitly consider the cost of establishing a facility. We only limit the number of facilities that can be established.

Table 3.2: Average distance per refugee for Model (*TDP_UNS*)

Number of	**Average Distance (km)**						
Facilities	**PS=0.4**	**PS=0.5**	**PS=0.6**	**PS=0.7**	**PS=0.8**	**PS=0.9**	**PS=1.0 (UNS)**
1	1.30	2.21	3.49	5.23	7.79	11.59	17.33
2	0.48	0.92	1.45	2.28	3.64	5.91	9.67
3	0.33	0.63	1.09	1.87	2.90	4.18	6.09
4	0.23	0.47	0.85	1.49	2.45	3.57	5.20
5	0.19	0.38	0.70	1.21	2.02	3.08	4.56
6	0.17	0.33	0.59	1.01	1.69	2.65	3.99
7	**0.16**	0.30	0.53	0.90	1.43	2.28	3.54
8	0.16	0.29	0.49	0.83	1.30	1.96	3.16
9	0.16	**0.28**	0.47	0.77	1.21	1.78	2.90
10	0.16	0.28	**0.45**	0.73	1.13	1.67	2.69
11	0.16	0.28	0.45	0.71	1.07	1.58	2.55
12	0.16	0.28	0.45	**0.69**	1.05	1.49	2.42
13	0.16	0.28	0.45	0.69	1.02	1.45	2.31
14	0.16	0.28	0.45	0.68	1.01	1.42	2.21
15	0.16	0.28	0.45	0.68	**0.99**	1.40	2.13
16	0.16	0.28	0.45	0.67	0.99	1.38	2.07
17	0.16	0.28	0.45	0.67	0.99	**1.37**	2.03
18	0.16	0.28	0.45	0.67	0.98	1.37	2.00
19	0.16	0.28	0.45	0.67	0.98	1.37	1.99
20	0.16	0.28	0.45	0.67	0.98	1.37	1.98
21	0.16	0.28	0.45	0.67	0.98	1.37	**1.97**
22	0.16	0.28	0.45	0.67	0.98	1.37	1.97
23	0.16	0.28	0.45	0.67	0.98	1.37	1.97
24	0.16	0.28	0.45	0.67	0.98	1.37	1.97
25	0.16	0.28	0.45	0.67	0.98	1.37	1.97
26	0.16	0.28	0.45	0.67	0.98	1.37	1.97
27	0.16	0.28	0.45	0.67	0.98	1.37	1.97
28	0.16	0.28	0.45	0.67	0.98	1.37	1.97
29	0.16	0.28	0.45	0.67	0.98	1.37	1.97
30	0.16	0.28	0.45	0.67	0.98	1.37	1.97
31	0.16	0.28	0.45	0.67	0.98	1.37	1.97
32	0.16	0.28	0.45	0.67	0.98	1.37	1.97
33	0.16	0.28	0.45	0.67	0.98	1.37	1.97
34	0.16	0.28	0.45	0.67	0.98	1.37	1.97
35	0.16	0.28	0.45	0.67	0.98	1.37	1.97
36	0.16	0.28	0.45	0.67	0.98	1.37	1.97
37	0.16	0.28	0.45	0.67	0.98	1.37	1.97
38	0.16	0.28	0.45	0.67	0.98	1.37	1.97
39	0.16	0.28	0.45	0.67	0.98	1.37	1.97
40	0.16	0.28	0.45	0.67	0.98	1.37	1.97
41	0.16	0.28	0.45	0.67	0.98	1.37	1.97

Although the solutions change due to the partial satisfaction of the total demand, they remain the same when the demand is met with the same proportion in all districts as mentioned in Section 3.2.2. This can be interpreted as traveling the same distance to serve every refugee but with less commodity than actually needed. Since, the open facilities and the facility-district assignments remain the same and only the amount of commodity sent changes, we do not provide the results for this case.

When we examine the efficient frontiers provided in Figure 3.9 and Figure 3.10, we observe in all cases that the marginal improvement in average distance is diminishing as the number of facilities to be established increases. The improvement is relatively larger for the first few facilities and it is very small after 5-7 facilities. Note that, no improvement can be attained in average distance to be traveled after certain number of facilities. This state is achieved when all the districts can be assigned to their closest potential facilities among 41 locations. Since the facilities are uncapacitated, there is no restriction on the assignment of districts to their closest facilities. Let *CF* be the set of facilities that are closest to at least one district. When all the facilities in set *CF* are open, then each neighborhood is served by its closest facility. Thus, once all the facilities in this set are open, establishing an additional facility that is not included in *CF* cannot improve the service distance.

We arbitrarily select "5" as the maximum value for the parameter *MaxFac* and provide the results up to 5 facilities in the following analyses. This is also meaningful since it is not possible to establish a large number of facilities due to the cost. Figure 3.11 to Figure 3.15 show the location of open facilities and the districts assigned to these facilities for 1- to 5-facility cases.

Figure 3.11: Open Facilities and District Assignments for Single-Facility Case

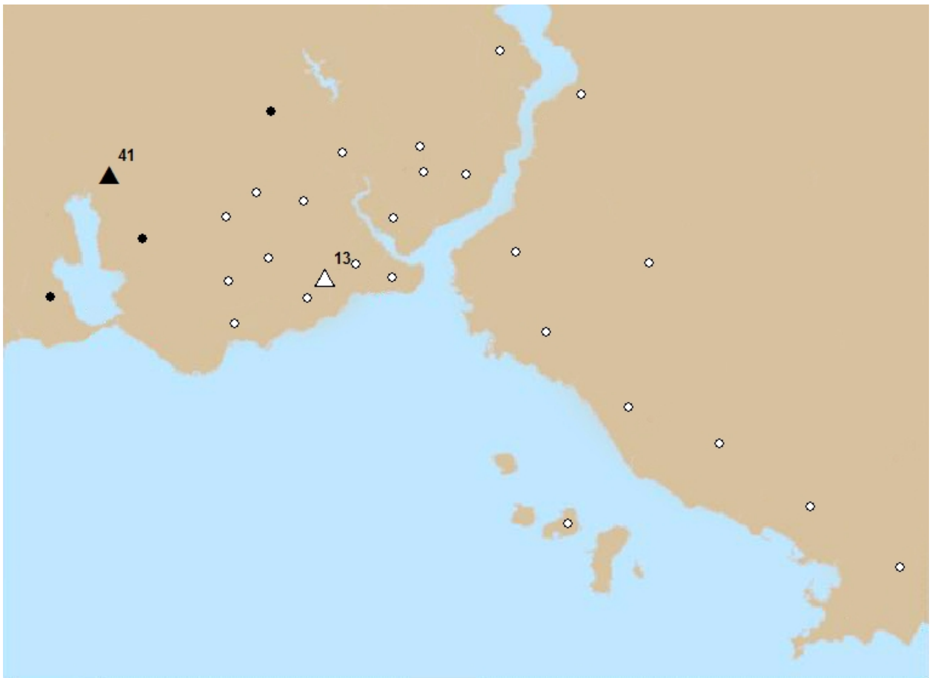


Figure 3.12: Open Facilities and District Assignments for Two-Facility Case

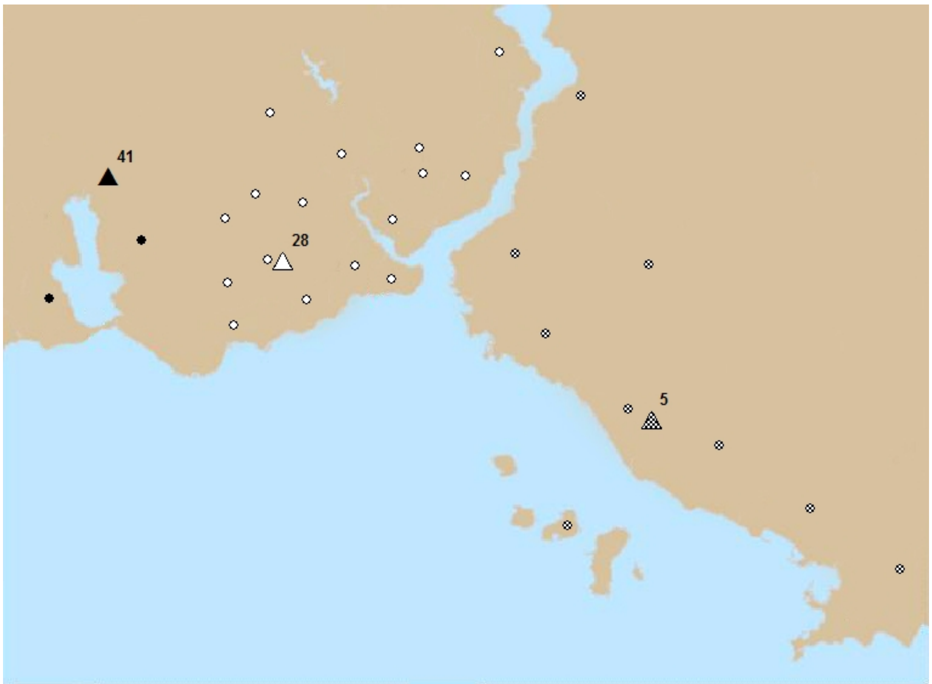


Figure 3.13: Open Facilities and District Assignments for Three-Facility Case

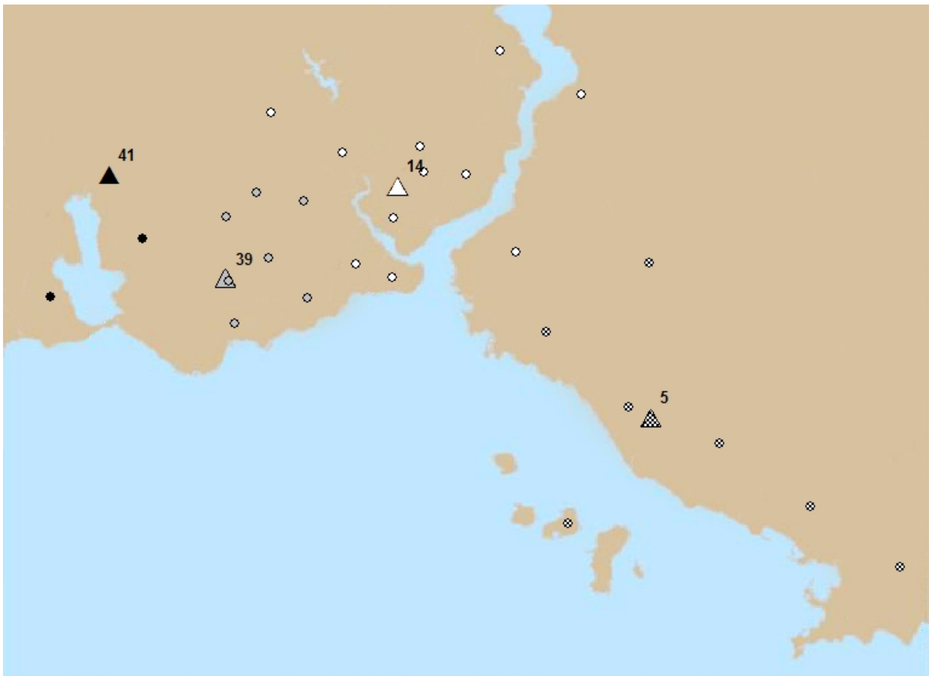


Figure 3.14: Open Facilities and District Assignments for Four-Facility Case

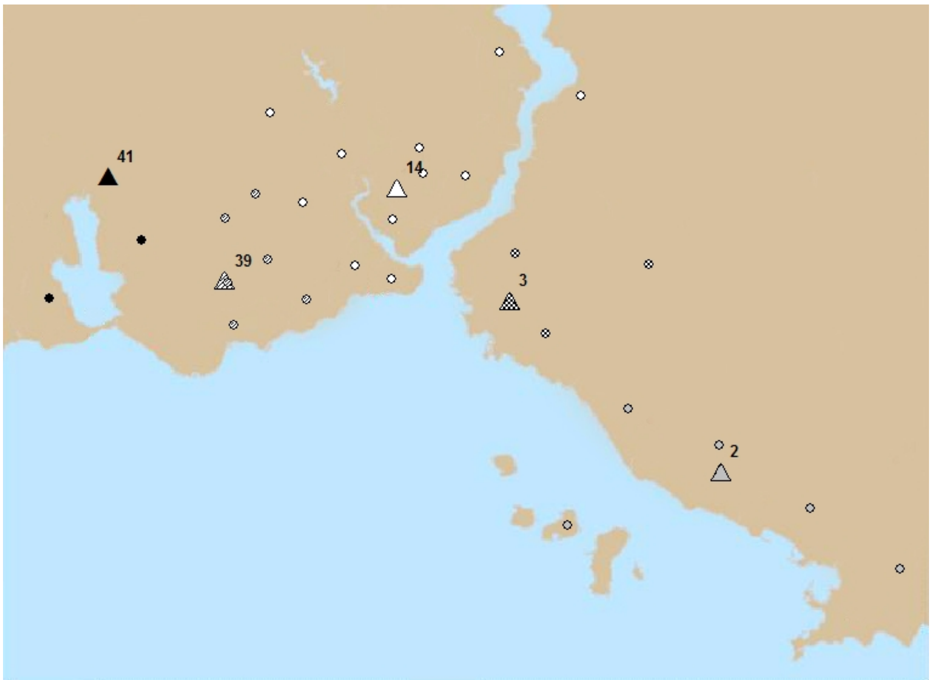


Figure 3.15: Open Facilities and District Assignments for Five-Facility Case

In these figures, facility 41 corresponds to the Halkalı facility. Note that, Çatalca and Silivri are not shown in these figures. In all solutions, these two districts are assigned to the leftmost facility on the map, which is the Halkalı facility except for the cases where Halkalı is not open.

3.4.2 A Two-Stage Approach

As mentioned in section 3.4.1, there is little difference in the solutions to the models (*UNS*) and (*RNS*), because only few districts do not have enough public schools to allocate for relief operations. In addition, we mentioned that the shortages in these districts are negligible so that they do not affect the locations of the facilities. Thus, we assumed that each district is capable of meeting its own demand from the schools in that district. In that case the model (*UNS*) reduces to (*UNS_simple*). Remember, for simplicity we do not determine the locations of the schools and assume that they are all located in district centers in these formulations. However, if we assume that the number of schools in each district is sufficient to meet the demand of that district, each district can be treated separately. In other words, a separate model can be solved to find the locations of schools in a district.

We propose a two-stage approach in which we also find the locations of the schools. In the first stage, we solve a model to locate the required number of schools to the neighborhoods within each district and we find the number of people served from each school. Then, in the second stage, we take the neighborhoods that have schools as the demand points and locate the facilities so that they can provide the best service. In the first stage, we solve the following model for each district to find the neighborhoods where schools will be located. Let N be the set of all neighborhoods of the district.

Parameters:

$d_{n,n'}$: Distance between neighborhood n and neighborhood n'

RP_n: Refugee population in neighborhood n

NSc: Number of schools to locate

CS: Capacity of a school

Decision Variables:

s_n: Number of schools in neighborhood n

$u_{n,n'}$: Number of people in neighborhood n that are served by the schools in neighborhood n'

Model(STN)

$$\text{Min} \quad \frac{\sum_n \sum n' d_{n,n'}.u_{n,n'}}{\sum_n RP_n} \tag{3.24}$$

subject to

$$\sum_n s_n = NSc \tag{3.25}$$

$$\sum_n u_{n,n'} = RP'_n \quad \forall n' \tag{3.26}$$

$$\sum_{n'} u_{n,n'} \leq CS.s_n \quad \forall n \tag{3.27}$$

$$u_{n,n'} \geq 0 \tag{3.28}$$

$$s_n \geq 0 \quad integer \tag{3.29}$$

In this model, demand points are taken as the neighborhoods. The objective is again to minimize the average distance to reach a refugee. Constraint 3.25 ensures that NSc schools are allocated for relief operations in total. Here, NSc is taken as $\lceil \sum_k RP_k/CS \rceil$ for every district k, i.e. it is the minimum number of schools required in district k to meet the demand of that district. Constraint 3.26 ensures that the demand is met. Finally, Constraint 3.27

Figure 3.16: Neighborhoods with at least One School Allocated for Relief Operations

ensures that the number schools located in neighborhood n is sufficient to meet the demand met by the schools in that neighborhood.

By solving the model (*STN*), we decide on the number of schools to be located in each neighborhood and the neighborhoods that are served from these schools. Figure 3.16 shows the neighborhoods in which at least one school is located. The number of such neighborhoods is 407 while total number of neighborhoods in 718.

In the second stage, we solve the model (*UNS_simple*). However, this time the demand points are taken as the neighborhoods that are given in Figure 3.16. Their demands are determined by the total number of people served from the school in those neighborhoods. This two-stage approach is more realistic when compared to the approach where we solve (*UNS_simple*) with districts as the demand points. First of all, the location of the demand is better represented in the two-stage approach. Remember that we find the coordinates of the districts by taking the weighted averages of its neighborhoods. However, now we do not aggregate the demand points. Secondly, in the original model (*UNS_simple*) we assume that schools are located at district centers. However, in the two-stage approach we better approximate the exact locations of the schools by locating them at the neighborhoods. In Figure 3.17 to Figure 3.21 we provide the facility locations and the assignments found when the neighborhoods are taken as the demand points.

Figure 3.17: Open Facilities and Neighborhood Assignments for Single-Facility Case

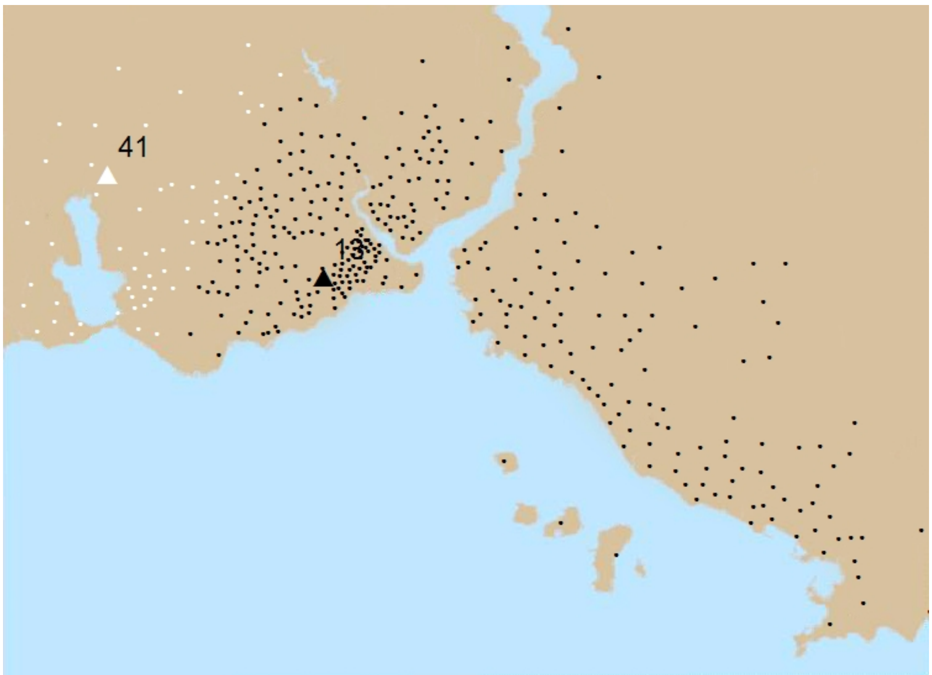


Figure 3.18: Open Facilities and Neighborhood Assignments for Two-Facility Case

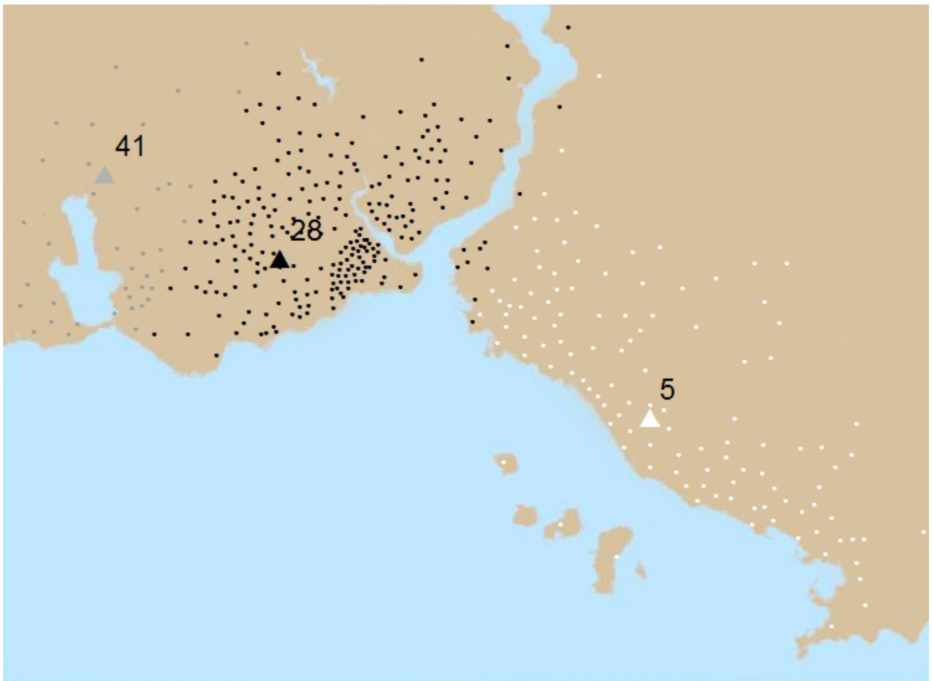


Figure 3.19: Open Facilities and Neighborhood Assignments for Three-Facility Case

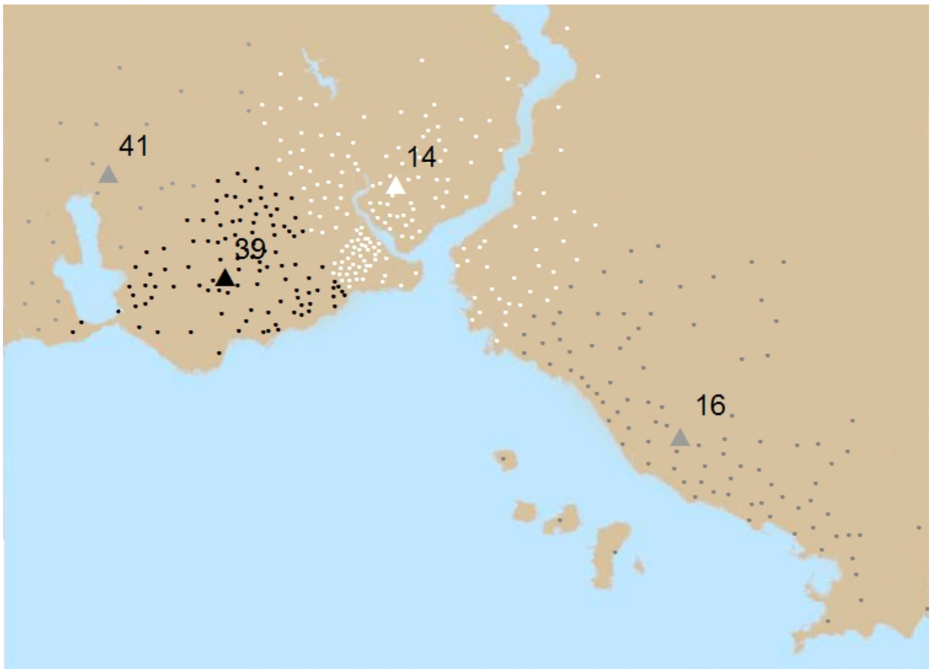


Figure 3.20: Open Facilities and Neighborhood Assignments for Four-Facility Case

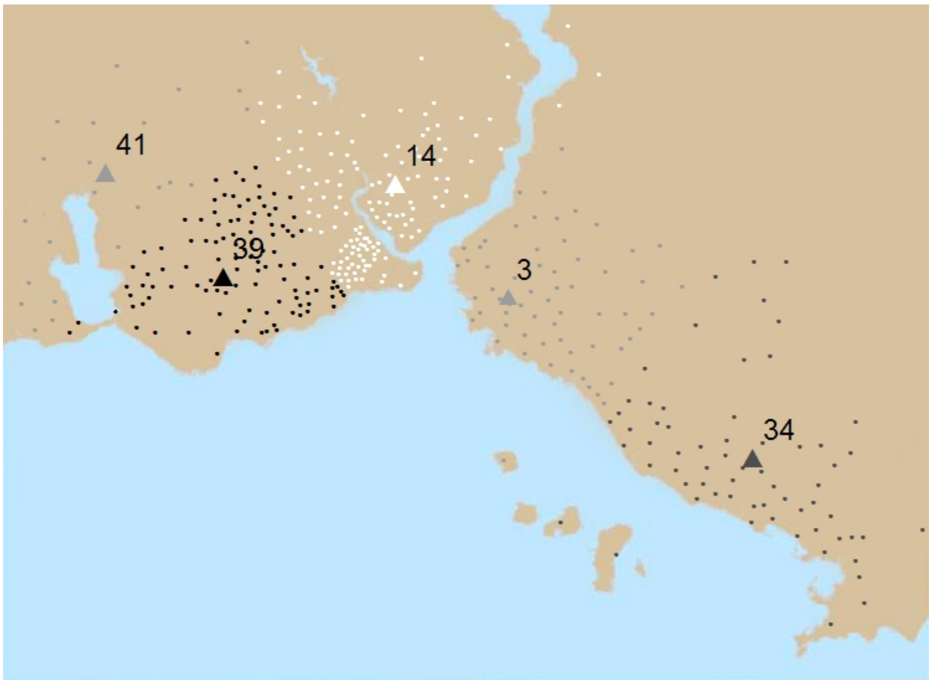


Figure 3.21: Open Facilities and Neighborhood Assignments for Five-Facility Case

In Table 3.3 we provide the average distances obtained for (*UNS_simple_WN*) and (*UNS_simple*). Difference in the average distances obtained by these two approaches is very small. Although the absolute difference in the average distance remains almost the same, the percent difference increases because the denominator decreases. Figure 3.22 shows the efficient frontiers for both models.

Table 3.3: Average distance per refugee comparisons of (*UNS_simple_WN*) and (*UNS_simple*) models

Number of Facilities	Average Distance (km) (*UNS_simple*)	(*UNS_simple_WN*)	Absolute Difference	% Difference
1	17.33	17.57	0.24	1.34
2	9.67	9.70	0.03	0.35
3	6.09	6.32	0.24	3.72
4	5.20	5.43	0.23	4.24
5	4.56	4.84	0.27	5.67

In the comparison provided in Table 3.3 and the other comparisons presented in the remaining sections, we calculate the percent difference by dividing the absolute difference by the higher of the values to be compared.

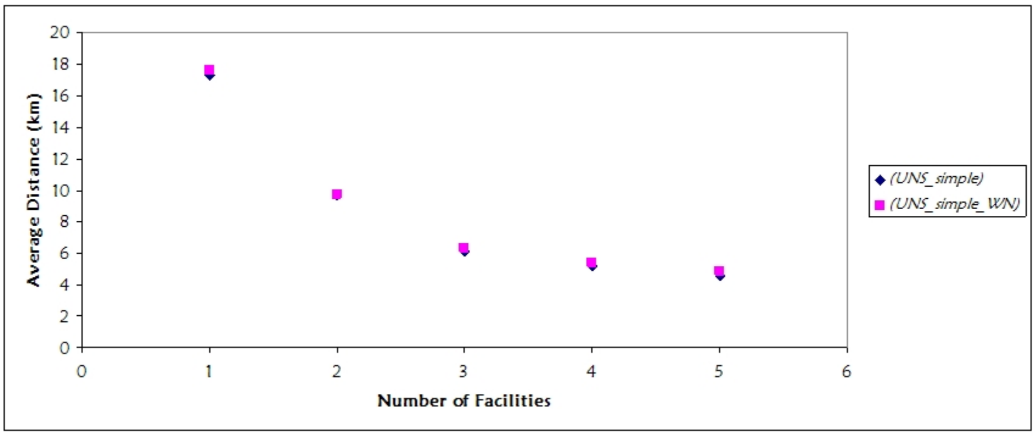
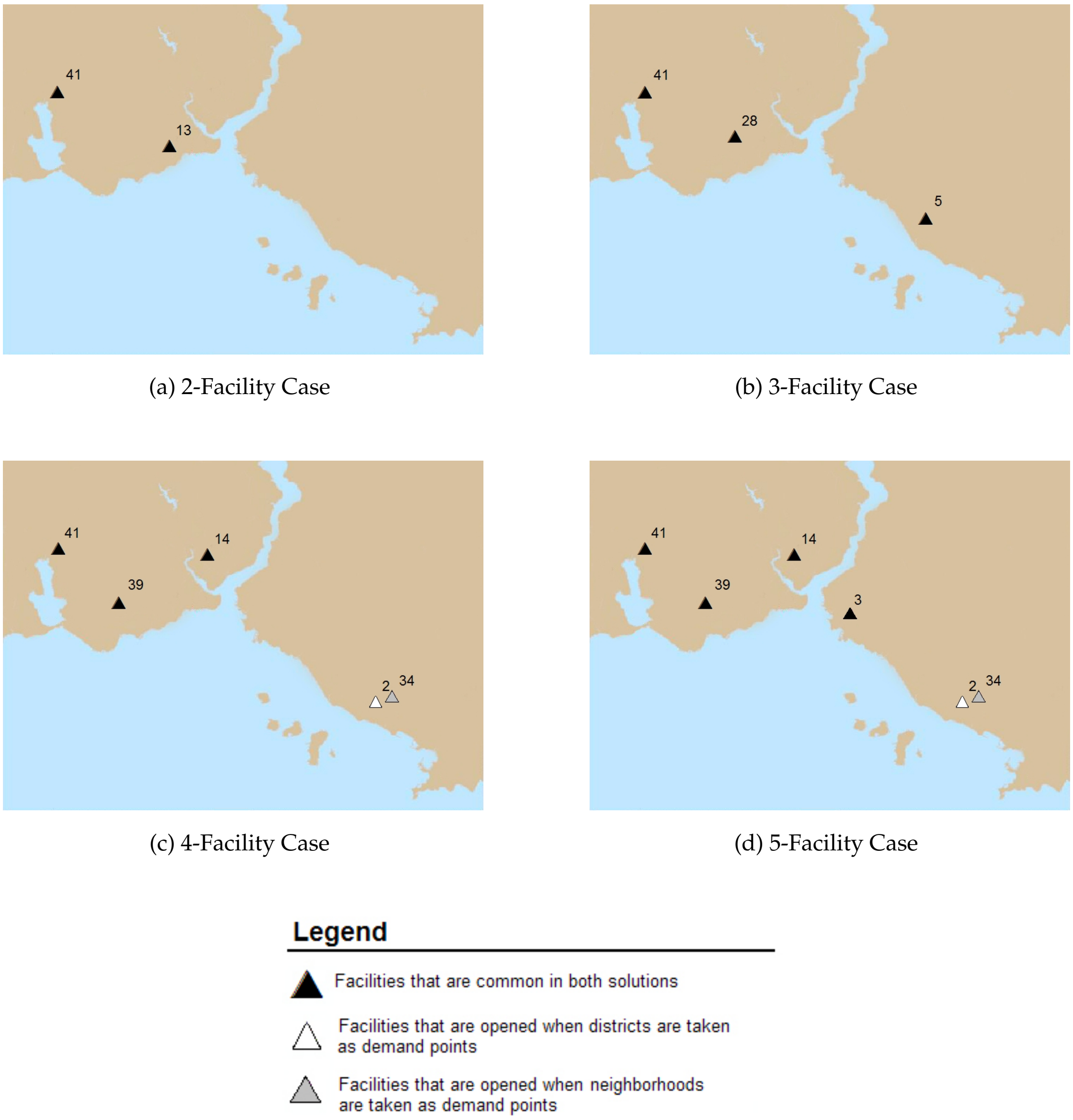


Figure 3.22: Efficient Solutions for (*UNS_simple*) and (*UNS_simple_WN*)

In Figure 3.23 we present the comparison of the facility locations for (*UNS_simple*) and (*UNS_simple_WN*). We observe that the location of the facilities that are open remains the same except for a slight change in the location of a facility for the five-facility case. Although we have a better approximation to reality in the two-stage approach, facility locations are not affected. However, although the facility locations are the same, the average distances are different. This is because the neighborhoods are taken as the demand points in the two-stage approach, rather than taking the aggregate demand at district centers.



(a) 2-Facility Case

(b) 3-Facility Case

(c) 4-Facility Case

(d) 5-Facility Case

Figure 3.23: Comparison of Facility Locations: (*UNS_simple*) and (*UNS_simple_WN*)

3.4.3 Discussions on the Results

In this section we mention the major findings of the analyses that we performed in Sections 3.4.1 and 3.4.2. In addition, we provide information about the computer environment that we use in this study and the solution time for the models.

In our main classification that we make in Section 3.2, we consider

- Unrestricted number of schools at each demand point and restricted number of schools at each demand point

- Satisfying all demand, satisfying the total demand partially and satisfying the demand partially at each demand point

Additionally, we solved the models with districts as demand points and with neighborhoods as demand points.

In Section 3.4.1, we take the districts as demand points and solve models (*UNS*) and (*RNS*) for every demand satisfaction strategy. It turned out that restricting the number of schools at each district has little effect on the solution for the study area of İstanbul. Almost all districts have a sufficient number of schools to meet their own demands with little scarcity in the ones that fail to do so. On the other hand, when the strategy in meeting the demand is considered, we see that the solution to the case where the demand of each person is partially met, model (*DDP_UNS*), is the same with the original case as expected. However, the facilities are located in the crowded regions if the demand of some districts will be met while the other districts are to be served by other organizations, which is the case that we refer to as (*TDP_UNS*).

In all the models that we consider, we observe the same pattern in the distribution of efficient solutions. For the first few facilities, the average distance to be traveled to serve a refugee decreases sharply as the number of facilities increases. However, the decrease diminishes as we further increase the number of facilities to be opened. Together with the fact that it is costly to establish and operate these facilities, this pattern in the efficient solutions indicates that establishing five or six facilities is reasonable.

Our two-stage approach that takes the neighborhoods as the demand points is better in representing reality. However, facility locations are not affected when the demand is disaggregated to neighborhoods. Taking 29 districts as demand points and taking 407 neighborhoods as demand points lead to same facility locations.

Lastly, we summarize the specifications of the computer environment that we use in solving the models in Table 3.4.

Table 3.4: Computer Environment

Computer Environment		
CPU	:	Intel Pentium IV 2.8 GHz
Memory	:	1024 MB
Operating System	:	Microsoft Windows XP Professional Service Pack 2
Optimization Suite	:	ILOG Cplex 8.1, GAMS 22.5 with Cplex 10.2

We use GAMS and the associated CPLEX solver for all models that we solve, except for the ones that we use the continuous space and its approximation as facility locations. In these two specific cases we directly use the CPLEX solver to solve the models because we could not solve the models with GAMS in reasonable time. Solution times for the models are very small. Many of the modes are solved within seconds for the models with neighborhoods as the demand points while the solution time is usually less than a second when we use districts as the demand points. To illustrate, in Table 3.5 we provide the CPU times (in seconds) for the models (*UNS*) and (*UNS_simple*) with districts as demand points; and (*UNS_simple*) with neighborhoods as demand points. Recall that the solution times for the (*UNS_simple*) models are the LP relaxation solution times.

Table 3.5: Solution Time for Models

	CPU Time (in seconds)		
	UNS_simple with districts	**UNS with districts**	**UNS_simple with neighborhoods**
Average:	0.14	4.17	18.23
Maximum:	0.64	35.56	306.22
Minimum:	0.02	0.06	0.16

The rest of the models have also similar solution times with a small increase in the variations that we consider in Chapter 4.

CHAPTER 4

VARIATIONS OF THE PROBLEM

In this chapter, we present the results for the different variations of the problem and discuss these results. In Section 4.1, we consider the case where the Halkalı facility is not open. Section 4.2 continues with the analysis of the facility locations in continuous space rather than the given potential locations. In sections 4.3 and 4.4 we consider the case where the facilities are sequentially opened one by one. We introduce the suppliers in Section 4.5 and provide results for that case. In Section 4.6 we introduce the capacitated models. In Section we provide the analysis for Scenario A. Finally, in Section 4.8 we present the discussions on the results.

4.1 Halkalı Facility is not Open

The results in section 3.4.1 give a clue about the disadvantaged location of the Halkalı facility in terms of the average distance to serve the affected people. Thus, we solve the models without considering the facility in Halkalı to observe what if the facilities were located to optimal places starting from the first facility. We compare the results for ”Halkalı is Open” (*HO*) and ”Halkalı is Not Open” (*HNO*) for the cases that all demand is satisfied and (*TDP*) with a 40% of demand satisfaction. Corresponding efficient frontiers are provided in Figure 4.1. A summary of results is also provided in Table 4.1.

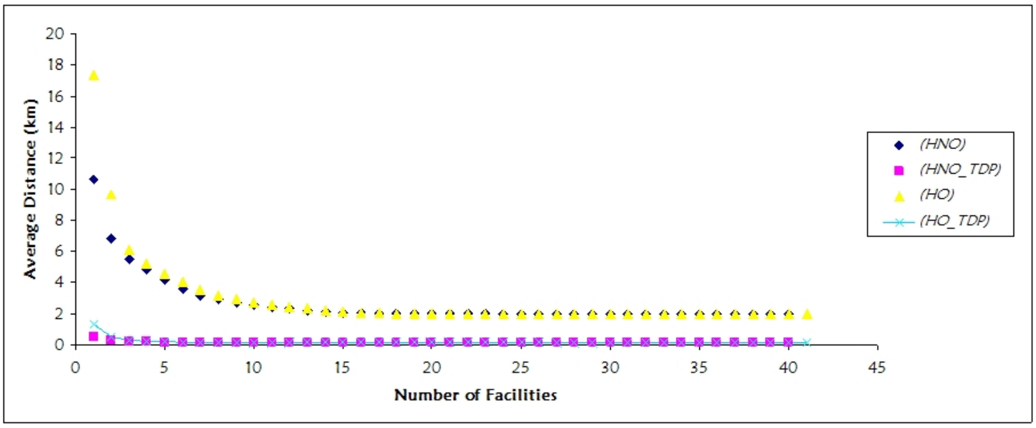


Figure 4.1: Efficient Solutions for (*HO*) and (*HNO*)

Here, the disadvantage due to Halkalı is very high in both cases for the single facility case. The average distance would be approximately 40% lower when all demand is satisfied and it is 60% lower for TDP with $PS = 0.4$, if the first facility was located at the optimal place rather than at Halkalı. As the number of facilities increases, the average distance to be traveled to serve a refugee converges to the original case where Halkalı is open. This is because the nuisance due to Halkalı is compensated with the new facilities. Remember that the Halkalı facility is not used in TDP with PS=0.4 after three facilities. Hence, the solutions to both cases are the same for three or more facilities. Figure 4.2 shows the comparison of facility locations when all demand is satisfied.

Table 4.1: Average distance per refugee comparisons of Comparisons of (*HO*) and (*HNO*) models

Number of Facilities	**Average Distance (km)** (*HNO*) (*UNS*)	**PS=0.4**	(*HO*) (*UNS*)	**PS=0.4**	**% Difference** (*UNS*)	**PS=0.4**
1	10.59	0.52	17.33	1.30	38.89	60.25
2	6.80	0.33	9.67	0.48	29.67	31.43
3	5.46	0.23	6.09	0.33	10.27	29.83
4	4.82	0.19	5.20	0.23	7.22	16.29
5	4.19	0.17	4.56	0.19	8.22	10.27
6	3.62	0.16	3.99	0.17	9.40	6.68
7	3.17	0.16	3.54	0.16	10.59	0.89
8	2.91	0.16	3.16	0.16	7.86	0.00
9	2.70	0.16	2.90	0.16	6.83	0.00
10	2.56	0.16	2.69	0.16	4.96	0.00
11	2.42	0.16	2.55	0.16	5.23	0.00
12	2.31	0.16	2.42	0.16	4.37	0.00
13	2.22	0.16	2.31	0.16	4.09	0.00
14	2.13	0.16	2.21	0.16	3.57	0.00
15	2.07	0.16	2.13	0.16	2.88	0.00
16	2.04	0.16	2.07	0.16	1.49	0.00
17	2.00	0.16	2.03	0.16	1.40	0.00
18	1.99	0.16	2.00	0.16	0.58	0.00
19	1.98	0.16	1.99	0.16	0.58	0.00
20	1.97	0.16	1.98	0.16	0.07	0.00
21	1.97	0.16	1.97	0.16	0.00	0.00
22	1.97	0.16	1.97	0.16	0.00	0.00
23	1.97	0.16	1.97	0.16	0.00	0.00
24	1.97	0.16	1.97	0.16	0.00	0.00
25	1.97	0.16	1.97	0.16	0.00	0.00
26	1.97	0.16	1.97	0.16	0.00	0.00
27	1.97	0.16	1.97	0.16	0.00	0.00
28	1.97	0.16	1.97	0.16	0.00	0.00
29	1.97	0.16	1.97	0.16	0.00	0.00
30	1.97	0.16	1.97	0.16	0.00	0.00
31	1.97	0.16	1.97	0.16	0.00	0.00
32	1.97	0.16	1.97	0.16	0.00	0.00
33	1.97	0.16	1.97	0.16	0.00	0.00
34	1.97	0.16	1.97	0.16	0.00	0.00
35	1.97	0.16	1.97	0.16	0.00	0.00
36	1.97	0.16	1.97	0.16	0.00	0.00
37	1.97	0.16	1.97	0.16	0.00	0.00
38	1.97	0.16	1.97	0.16	0.00	0.00
39	1.97	0.16	1.97	0.16	0.00	0.00
40	1.97	0.16	1.97	0.16	0.00	0.00
			1.97	0.16		

(a) Single-Facility Case

(b) 2-Facility Case

(c) 3-Facility Case

(d) 4-Facility Case

(e) 5-Facility Case

Figure 4.2: Comparison of Facility Locations: (*HO*) and (*HNO*)

We also analyze how much İMM is better off by the already established Halkalı facility. If the municipality will establish n new facilities, the total number of facilities will be $n + 1$. In this analysis we compare the n-facilities case of HNO with the $(n + 1)$-facilities case of HO. Table 4.2 gives the average distance for HO and HNO with respect to the number of new facilities.

Table 4.2: Average distance per refugee comparisons of (*HO*) and (*HNO*) models with respect to number of new facilities

	Average Distance (km)					
Number of	**HNO**		**HO**		**% Difference**	
New Facilities	**UNS**	**PS=0.4**	**UNS**	**PS=0.4**	**UNS**	**PS=0.4**
1	10.59	0.52	9.67	0.48	8.71	7.81
2	6.80	0.33	6.09	0.33	10.48	0.00
3	5.46	0.23	5.20	0.23	4.81	0.00
4	4.82	0.19	4.56	0.19	5.41	0.00

4.2 Continuous Space Approximation

We made further analysis to observe what happens if the facilities can be located anywhere in İstanbul rather than the locations provided by İMM. We first tried to solve the facility location problem on the continuous space and determine the coordinates of optimal facility locations on the x-y plane. In this analysis we consider both the (*HO*) and (*HNO*) cases. We propose the following p-median-like model to find the optimal places on the coordinate space. Again, we consider a set of potential permanent-facility locations J and a set of demand points (districts) K. The rest of the notation is as follows:

Parameters

xc_k: x-coordinate of district k

yc_k: y-coordinate of district k

RP_k: Refugee population in district k

M: A Sufficiently large positive number

Decision Variables

$u_{j,k}$: $\begin{cases} 1, & \text{if district } k \text{ is assigned to facility } j \\ 0, & \text{otherwise} \end{cases}$

x_j: x-coordinate of facility j

y_j: y-coordinate of facility j

$dx_{j,k}$: Distance between facility j and district k in the x-coordinate

$dy_{j,k}$: Distance between facility j and district k in the y-coordinate

$drec_{j,k}$: Rectilinear distance between facility j and district k

dk: Distance traveled to serve district k

Model (CS)

$$\text{Min} \quad \frac{\sum_k d_k.RP_k}{\sum_k RP_k} \tag{4.1}$$

subject to

$$drec_{j,k} = dx_{j,k} + dy_{j,k} \quad \forall j,k \tag{4.2}$$

$$dx_{j,k} \geq xc_k - x_j \quad \forall j,k \tag{4.3}$$

$$dx_{j,k} \geq x_j - xc_k \quad \forall j,k \tag{4.4}$$

$$dy_{j,k} \geq yc_k - y_j \quad \forall j,k \tag{4.5}$$

$$dy_{j,k} \geq y_j - yc_k \quad \forall j,k \tag{4.6}$$

$$d_k \geq drec_{j,k} - M.(1 - u_{j,k}) \quad \forall j,k \tag{4.7}$$

$$\sum_j u_{j,k} = 1 \quad \forall k \tag{4.8}$$

$$u_{j,k} \in \{0,1\} \tag{4.9}$$

$$dx_{j,k}, dy_{j,k}, drec_{j,k}, x_j, y_j, d_k \geq 0 \tag{4.10}$$

This time, we use rectilinear distances between the points to formulate a linear model. Hence, it is not coherent to compare the average distance found in that model with those in the original case. In Figure 4.3 we compare the locations of the facilities found on the continuous space with the solutions of the cases *HNO* and *HO*. We provide the solutions only for the single-facility and two-facility cases for (*HNO_CS*), and for the two-facility case for (*HO_CS*). The optimal solution to these models could only be found for the single-facility and two-facility cases on the continuous coordinate space, due to complexity of the models. The results are provided in Table 4.3.

Table 4.3: Average distance per refugee for Model (*CS*)

	Number of Facilities	Average Distance (km)
HNO	1	13.20
	2	8.31
HO	2	12.20

(a) Single-Facility Case- Halkalı is not open

(b) 2-Facility Case - Halkalı is not open

(c) 3-Facility Case - Halkalı is open

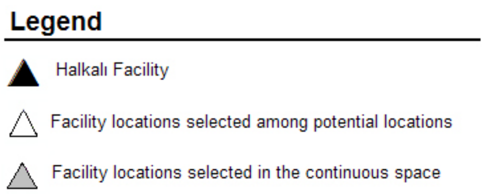


Figure 4.3: Comparison of Facility Locations: (*UNS*) and (*CS*)

Since the optimal solution to model (*CS*) cannot be found for more than two facilities, we use an approximation to continuous space. In this approach, we use the model (*UNS_simple*). However, we take the neighborhoods as the potential facility locations and the districts as the demand points. This means that we use neighborhoods to have an approximation of the continuous space. The reason why we choose the neighborhoods to approximate the continuous space is that they are spread over the study area. We solve the model by fixing the Halkalı facility. Results of the comparisons with the original case are provided in Table 4.4.

Table 4.4: Average distance per refugee comparisons of (*UNS*) and (*CSA_UNS*) models

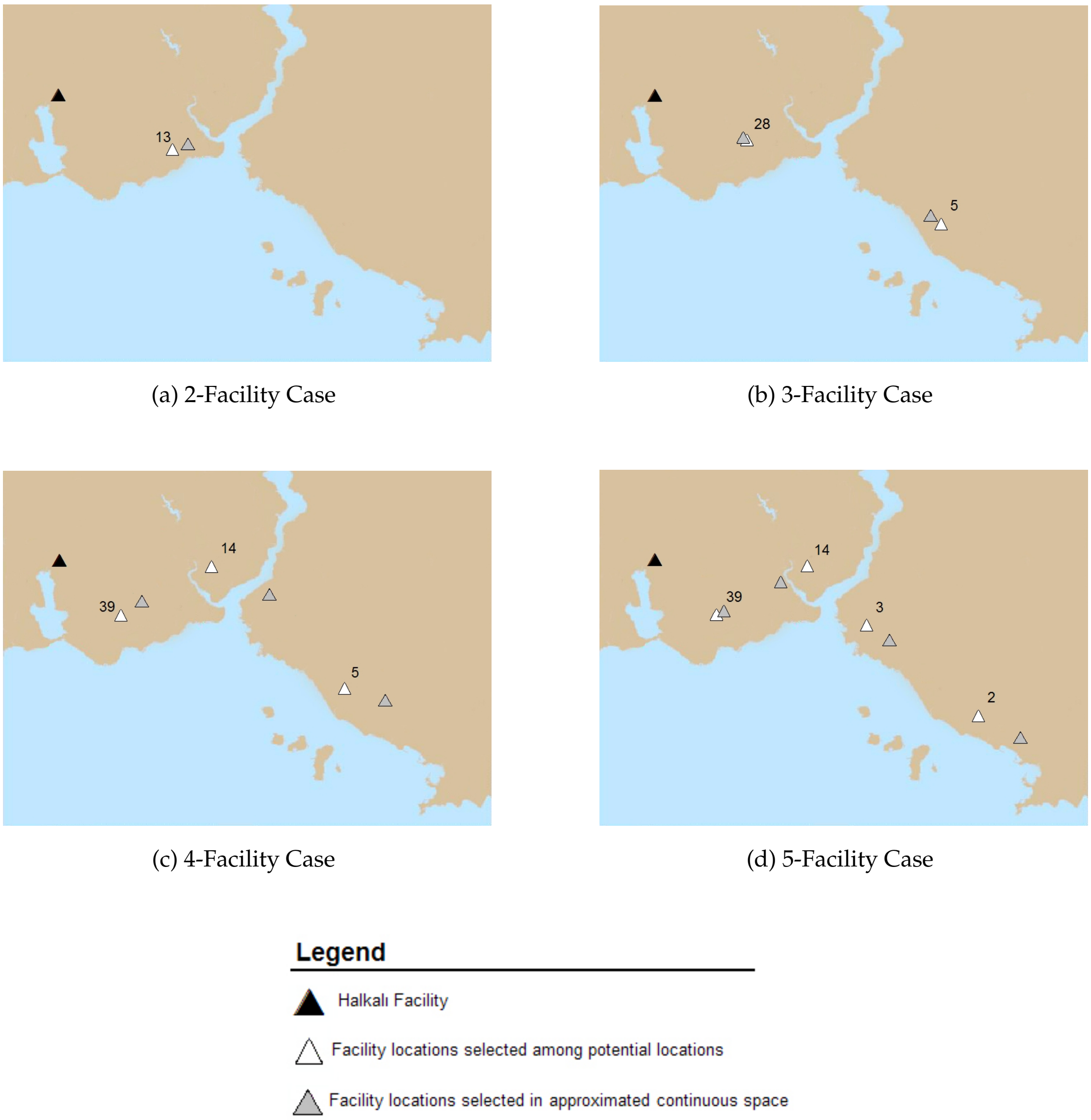
Number of Facilities	**Average Distance (km)** (***UNS***)	(***CSA_UNS***)	**Absolute Difference**	**% Difference**
1	17.36	17.36	0.00	0.00
2	9.69	9.53	0.16	1.68
3	6.09	6.01	0.08	1.27
4	5.20	5.04	0.16	3.04
5	4.56	4.21	0.35	7.76

Note that, the difference in the average distance is very low. It indicates the potential locations that are identified by the İMM are well chosen as oppose to the location of Halkalı facility. As it is shown in Figure 4.4, the optimal locations on the approximated coordinate space are quite close to the optimal locations selected among the potential facility locations. Hence, we may conclude that the potential facility locations are reasonably well-chosen in terms of proximity to demand areas.

In the subsequent we will represent the results for the variations of the two-stage approach, since it better represents reality. However, we also solved for the case where the districts are taken as the demand points, and we observed that the solutions are almost the same.

4.3 Previous Facilities Fixed

In Chapter 2, we mention that multi-period planning is a commonly applied procedure in strategic facility location problems. Facility establishment is a costly procedure that also takes some time. In addition, the facilities are long lasting so that their locations affect the future states. These concerns are also valid for the facilities to be established by İMM. Multi-period planning fits our problem because it is difficult to locate many facilities at once. Hence, the number and the timing of these establishments should be considered carefully so that a desirable solution is found for the planning period. However, the solutions turned out to be robust with our data set and it was not necessary to explicitly consider multi-period planning in the models presented in Section 3.2. The reason to abandon multi-period



(a) 2-Facility Case

(b) 3-Facility Case

(c) 4-Facility Case

(d) 5-Facility Case

Figure 4.4: Comparison of Facility Locations: (*UNS*) and (*CSA_UNS*) , Halkalı is open

planning is the fact that the effect on the solution is negligible when each period is optimized individually. In this section we provide the details for that analysis.

In Section 3.4.2 we present the optimal solutions corresponding to a given number of facilities. These are the best locations in terms of average service distance when we know the number of facilities to locate. If the timing of the earthquake were known, İMM would determine the exact number of facilities and they would establish these facilities at optimal locations before the earthquake happens. However, this is not possible. We do not know how many facilities will exist when the earthquake happens. Assuming that the facilities will be established one by one, we may consider a multi-period problem where a single facility will be established in each period. For such a case, we examine the effect of optimizing each period individually without considering the future periods. In this approach, we solve the model (*UNS_WN*) to find the optimal locations given that the facilities established in the previous periods are fixed. We call this version of the model (*WN_PFF*). It determines the optimal facility locations in a way that optimizes the current state, given that the facilities open in the previous period remain open. Comparison of the average distance with the original case is provided in Table 4.5 and Figure 4.5.

Table 4.5: Average distance per refugee comparisons of (*WN*) and (*WN_PFF*) models

Number of Facilities	Average Distance (km) (*WN*)	(*WN_PFF*)	Absolute Difference	% Difference
1	17.57	17.57	0.00	0.00
2	9.70	9.70	0.00	0.00
3	6.32	6.56	0.23	3.58
4	5.43	5.63	0.20	3.62
5	4.84	4.94	0.10	2.00

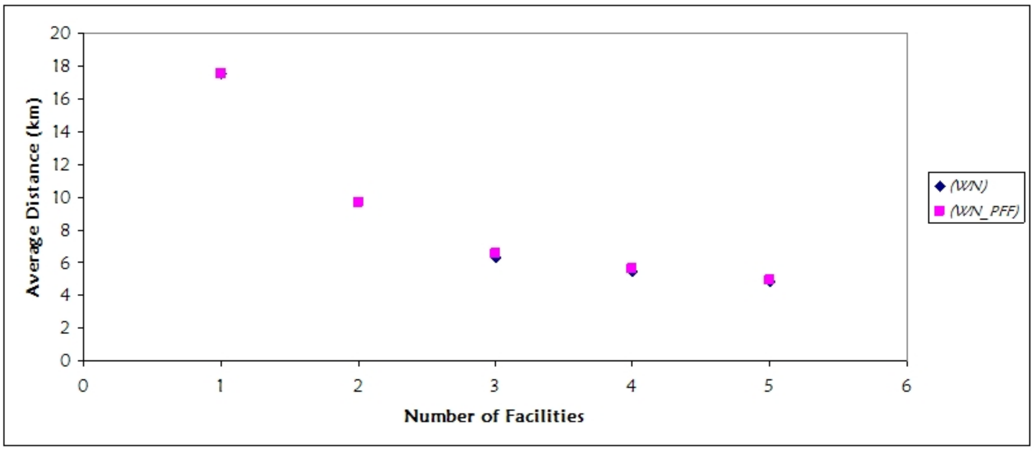
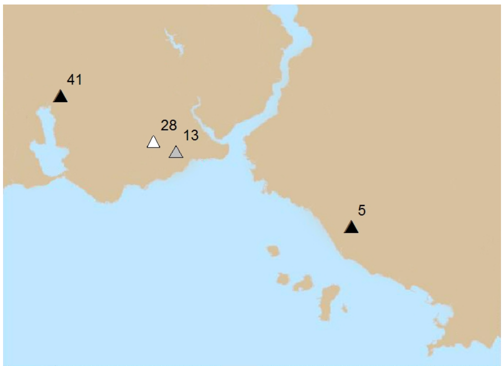


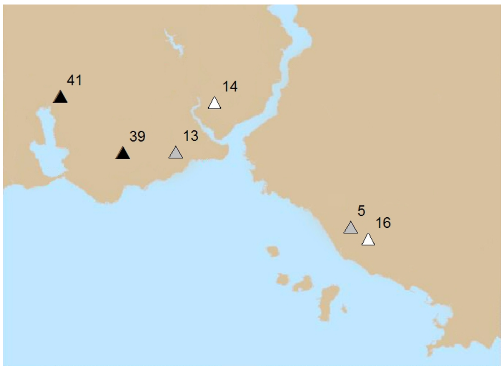
Figure 4.5: Efficient Solutions for (*WN*) and (*WN_PFF*)

As it is given in Table 4.5, there is not much difference in the average distances found for the optimal case and the case where we open facilities in a greedy manner, each time optimizing the current state. Thus, for the given study area of İstanbul, a multi-period planning that considers the future periods turned out to be not that essential. Comparison of facility locations are provided in Figure 4.6.

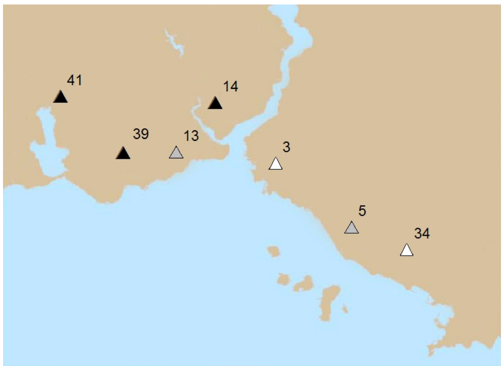
(a) 2-Facility Case



(b) 3-Facility Case



(c) 4-Facility Case



(d) 5-Facility Case

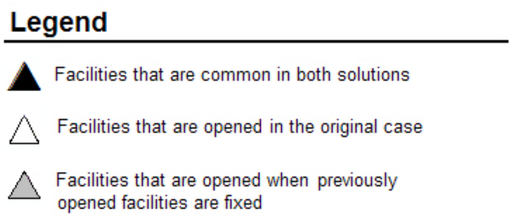


Figure 4.6: Comparison of Facility Locations: (*WN*) and (*WN_PFF*)

4.4 Five Facilities Fixed

In this section we investigate the situation where the number of facilities to be opened is set to five. Given the five facilities to be opened, we determine the order in which these facilities will be established. Similar to Section 4.3 we assume that the facilities are opened one by one. Again, we use the model (*WN*), but this time with the set of potential locations J consisting of the given five locations. In addition, we fix the facilities that are opened in the previous period. The results are provided in Table 4.6 and Figure 4.7.

Table 4.6: Average distance per refugee comparisons of (*WN*) and (*WN_5FF*)

Number of Facilities	Average Distance (km) (*WN*)	(*WN_5FF*)	Absolute Difference	% Difference
1	17.57	17.57	0.00	0.00
2	9.70	10.33	0.63	6.07
3	6.32	7.33	1.01	13.72
4	5.43	5.84	0.41	7.01
5	4.84	4.84	0.00	0.00

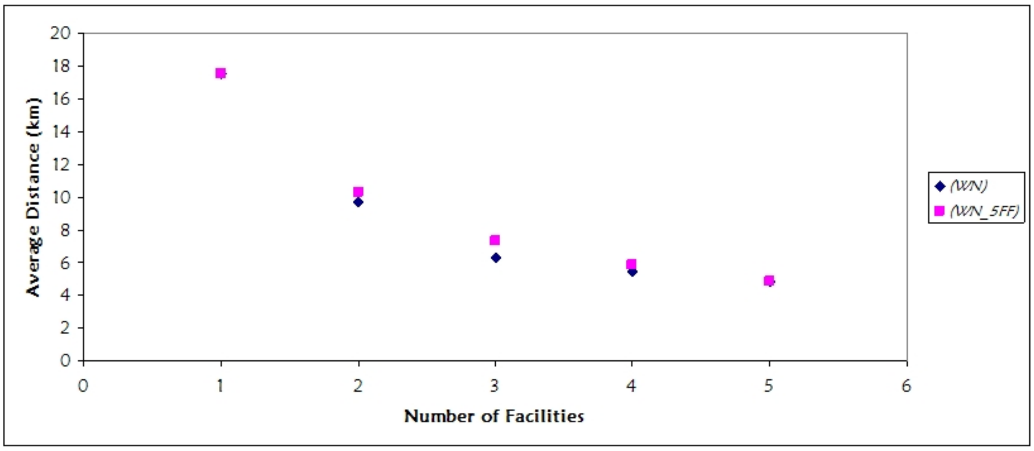
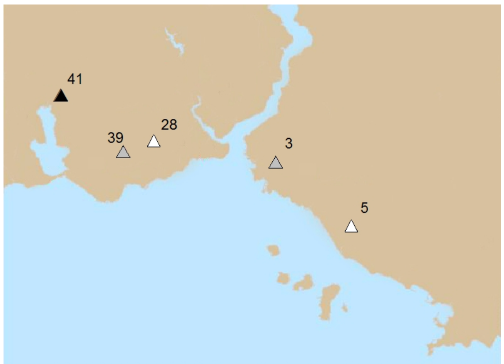


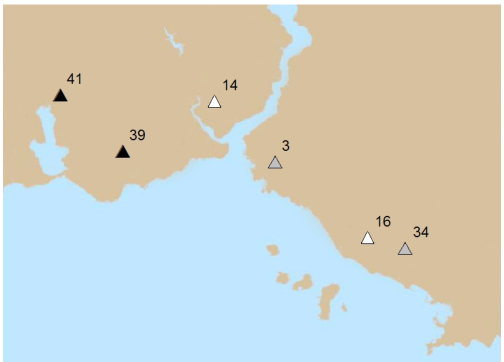
Figure 4.7: Efficient Solutions for (*WN*) and (*WN_5FF*)

Again the deviation from the optimality is low for the two- and four-facility cases. However, the difference is relatively high for the three facility case. This means the distance to serve each refugee would be 1 km (13%) longer if the earthquake happens when there are 3 facilities that are established according to (*WN_5FF*). Thus, a careful planning is required for that case. Establishing the fourth facility just after the third one or establishing them simultaneously may be desirable. Figure 4.8 shows the facility locations in comparison with the original case.

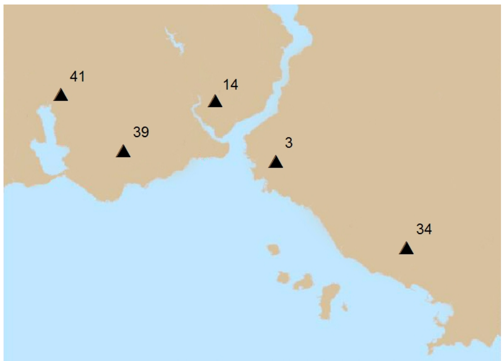
(a) 2-Facility Case



(b) 3-Facility Case



(c) 4-Facility Case



(d) 5-Facility Case

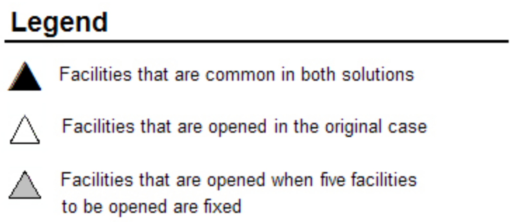


Figure 4.8: Comparison of Facility Locations: (*WN*) and (*WN_5FF*)

4.5 Models with Suppliers

In the previous sections we do not consider the suppliers for the commodities. We assume that all the shipments will be made from the stocks. However, it may not be practical to stock the whole demand until the earthquake happens. Therefore, in this section, we analyze the circumstance in which the suppliers of the commodities are considered. Although the suppliers are considered, it is hard to specify supplier locations for the commodities. Hence, we take the airports and the ports in İstanbul as the suppliers. We assume that majority of the international aid and the aid from the other cites of Turkey would arrive at these locations. Figure 4.9 shows the locations of the ports and the airports in İstanbul.

Figure 4.9: Suppliers

We consider two approaches for incorporating suppliers into our models. Firstly, we consider the case that all the commodities will be received from the suppliers and processed at the facilities before shipment to schools. Secondly, we consider the case that a portion of the demand is kept in stocks and the remaining amount is received from the suppliers. In both cases, we assume that the suppliers are uncapacitated and thus each facility is assigned to its closest supplier. Therefore, the distance traveled to serve a commodity that is received from supplier i through facility j to demand point k becomes:

$$d'_{j,k} = d_{j,k} + \underbrace{\min_{i \in S}\{d_{i,j}\}}_{\text{Distance to Closest Supplier}} \tag{4.11}$$

where S is the set of suppliers, $d_{j,k}$ is the distance between facility j and demand point k and $d_{i,j}$ is the distance between supplier i and facility j.

If we assume all the commodities are received from suppliers through the facilities, the only change in model (*WN*) is in the distances. We simply replace the distance $d_{j,k}$ with the distance $d'_{j,k}$ for all (j,k) pairs. We refer to this version of the model as (*WN_WS*). The resulting average distances are provided in Table 4.7.

Table 4.7: Average distance per refugee comparisons of (*WN*) and (*WN_WS*) models

Number of Facilities	**Average Distance (km) (*WN*)**	**(*WN_WS*)**	**Absolute Difference**	**% Difference**
1	17.57	26.94	9.37	34.79
2	9.70	12.87	3.16	24.58
3	6.32	9.94	3.62	36.41
4	5.43	8.29	2.86	34.49
5	4.84	7.74	2.91	37.52

As expected, the average distance values are higher for (*WN_WS*) because the distance from closest supplier to a facility is also added.

Figure 4.10 shows the facility locations determined by model (*WN_WS*) together with the facility locations found without considering the suppliers. It is obvious that the location of the suppliers strongly effect the facility locations. As expected, the optimal facility locations move toward the suppliers.

(a) 2-Facility Case

(b) 3-Facility Case

(c) 4-Facility Case

(d) 5-Facility Case

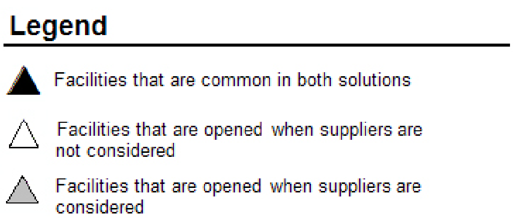


Figure 4.10: Comparison of Facility Locations: (*WN*) and (*WN_WS*)

In the second approach, we assume that a portion of demand is kept in stocks while the remaining amount is received from suppliers. This case is more realistic than the two extreme cases of meeting all demand from the stocks and supplying all demand from the suppliers. In this case we develop a slightly different model. Again we have a set of potential permanent-facility locations J and a set of demand points (neighborhoods with districts) K. The rest of the notation is as follows:

Parameters:

$d_{j,k}$: Distance between potential facility j and the demand point k

$d'_{j,k}$: Total distance traveled if the demand of point k is met from a supplier through facility j

RP_k: Refugee population served by demand point k

PFS: Percentage of demand that is received from suppliers

M: A Sufficiently large positive number

Decision Variables:

$$o_j: \begin{cases} 1, & \text{if facility } j \text{ is open} \\ 0, & \text{otherwise} \end{cases}$$

$x_{j,k}$: Amount of demand at point k that is satisfied from facility j

$y_{j,k}$: Amount of demand at point k that is satisfied from a supplier through facility j

$$\text{Objective 1:} \quad \text{Min} \quad \frac{\sum_j \sum_k d_{j,k}.x_{j,k} + d'_{j,k}.y_{j,k}}{\sum_n RP_k} \tag{4.12}$$

$$\text{Objective 2:} \quad \text{Min} \quad \sum_j o_j \tag{4.13}$$

subject to

Model (*WN_WSP*)

$$\sum_k x_{j,k} + y_{j,k} \leq M.o_j \quad \forall j \tag{4.14}$$

$$\sum_j x_{j,k} + y_{j,k} = RP_k \quad \forall k \tag{4.15}$$

$$\sum_k x_{j,k} \leq (1 - PFS). \sum_k RP_k \quad \forall j \tag{4.16}$$

$$\sum_k y_{j,k} \geq PFS. \sum_k RP_k \quad \forall j \tag{4.17}$$

$$o_j \in \{0, 1\} \tag{4.18}$$

$$x_{j,k}, y_{j,k} \geq 0 \tag{4.19}$$

Here , we define an additional variable, $y_{j,k}$ to represent the amount of demand received from suppliers. In addition, we have a parameter to specify the percentage of demand to be received from suppliers at each facility. It is hard to specify an exact value for the parameter PFS. This requires a separate study. However, in order to illustrate the effect of this model we solved the case where at most 40% of demand is kept in stocks and the remaining 60% is to be provided from the suppliers. The comparison of the results with (*WN*) and (*WN_WS*) is provided in Table 4.8 and Table 4.9, respectively. In addition, the efficient solutions are provided in Figure 4.11.

Table 4.8: Average distance per refugee comparisons of (*WN*) and (*WN_WSP*) models

Number of Facilities	**Average Distance (km) (*WN*)**	**(*WN_WSP*)**	**Absolute Difference**	**% Difference**
1	17.57	23.19	5.62	24.25
2	9.70	11.71	2.00	17.11
3	6.32	8.85	2.53	28.57
4	5.43	7.50	2.07	27.60
5	4.84	6.74	1.91	28.26

Table 4.9: Average distance per refugee comparisons of (*WN_WS*) and (*WN_WSP*) models

Number of Facilities	Average Distance (km) (*WN_WS*)	(*WN_WSP*)	Absolute Difference	% Difference
1	26.94	23.19	3.75	13.92
2	12.87	11.71	1.16	9.01
3	9.94	8.85	1.09	10.97
4	8.29	7.50	0.79	9.51
5	7.74	6.74	1.00	12.90

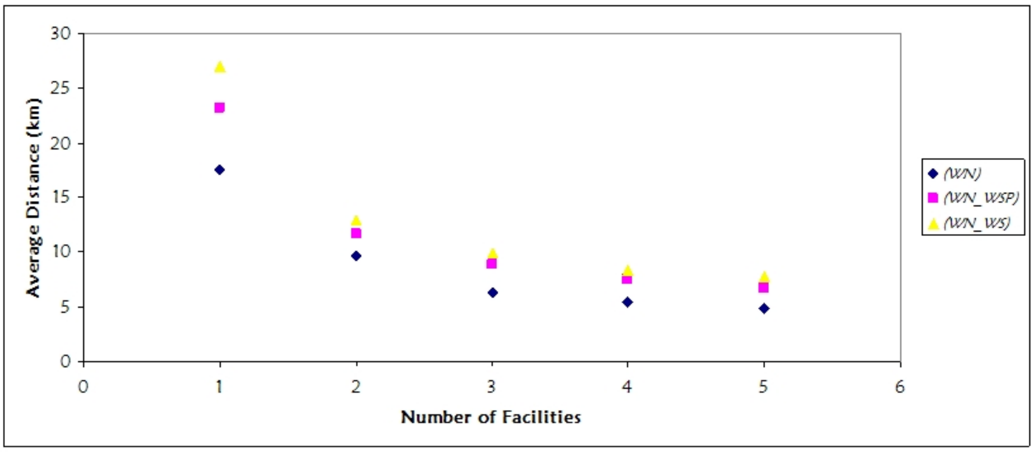


Figure 4.11: Efficient Solutions for (*WN*), (*WN_WSP*) and (*WN_WS*)

Figure 4.12 shows the locations of the facilities in comparison with the facility location obtained in (*WN_WS*). As it is observed, the locations remain the same in all cases except the five-facility case. The location of a facility is changed when the number of facilities to be opened is five. However, even in this case, if we force the solution to be the same with the five facility case of (*WN_WS*), the increase in average distance will probably be very small. For the given set of suppliers, their locations strongly effect the facility locations, even when only a portion of the demand is satisfied from the suppliers. This is because the number of suppliers is small and they are not evenly spread over the region. Especially ports are concentrated in a particular region, although there are 5 of them. Therefore, possible supplier locations should be identified carefully if a considerable portion of demand will be received from few suppliers.

(a) 2-Facility Case

(b) 3-Facility Case

(c) 4-Facility Case

(d) 5-Facility Case

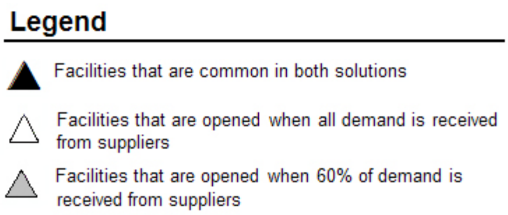


Figure 4.12: Comparison of Facility Locations: (*WN_WS*) and (*WN_WSP*)

Although we analyzed the case where we consider the suppliers, we believe that it is reasonable to disregard the suppliers and assume that the required amount of commodities will be kept in stocks. There are basically three bases for this reasoning. Firstly, although the aid may arrive through the ports and airports that we consider in this study, they are not the actual suppliers of the commodities. We believe that majority of the commodities are likely to be received from local suppliers. Secondly, it is reasonable to store required amount of durable items like tents and blankets in the new facilities. In that case, the items to be received from the suppliers are mainly food and water and it is reasonable to assume that the stocks will be replenished quickly. Therefore, it may be reasonable to assume that the stock of these items will always be available in the facilities, and only their shipment durations to demand points will be critical. Finally, the suppliers for the food and water type items are likely to be local suppliers like the warehouses of large retailers. Usually there are many of such suppliers and they are not concentrated in a particular region but located in different parts of İstanbul. Thus, their locations will not be as influential as the case that we consider in this study.

4.6 Capacitated Facilities

In our models provided in Section 3.2 and their variations introduced in this chapter, we assume that the facilities are uncapacitated while the schools have capacities. In this section, we present the results of an analysis where the facilities are also considered as capaciated. In this approach, we assume that the total capacity of the facilities is 110% of the total demand and each facility has the same capacity. Accordingly, the following constraint is added to model (*WN*):

$$\sum_k RP_k.x_{j,k} \leq (110\backslash 100)\frac{\sum_k RP_k}{MaxFac} \tag{4.20}$$

Here we solved for both $x_{j,k} \in \{0, 1\}$ and $x_{j,k} \geq 0$. The former does not allow meeting the demand of a demand point from different facilities while the latter may allow meeting the demand from different facilities. However, they give the same solution in terms of the locations of the facilities to be opened and the difference in the average distance between these two cases turned out to be negligible (less than 0.05%). This is because the number of points whose demands are divided turned out to be 1, 2, 2 and 3 for the number of facilities 2, 3, 4 and 5 respectively. Thus, we select the binary case and assume that the demand of a point cannot be divided and should be met from a single facility. The comparison of the average distances for the capacitated model(*WN_CAP*) and (*WN*) are provided in Table 4.10. In addition, the efficient solutions are provided in Figure 4.13

Table 4.10: Average distance per refugee comparisons of (*WN_CAP*) and (*WN*) models

Number of Facilities	Average Distance (km) (*WN*)	(*WN_CAP*)	Absolute Difference	% Difference
1	17.57	17.57	0.00	0.00
2	9.70	10.19	0.48	4.73
3	6.32	7.39	1.07	14.47
4	5.43	5.77	0.34	5.86
5	4.84	5.04	0.20	4.00

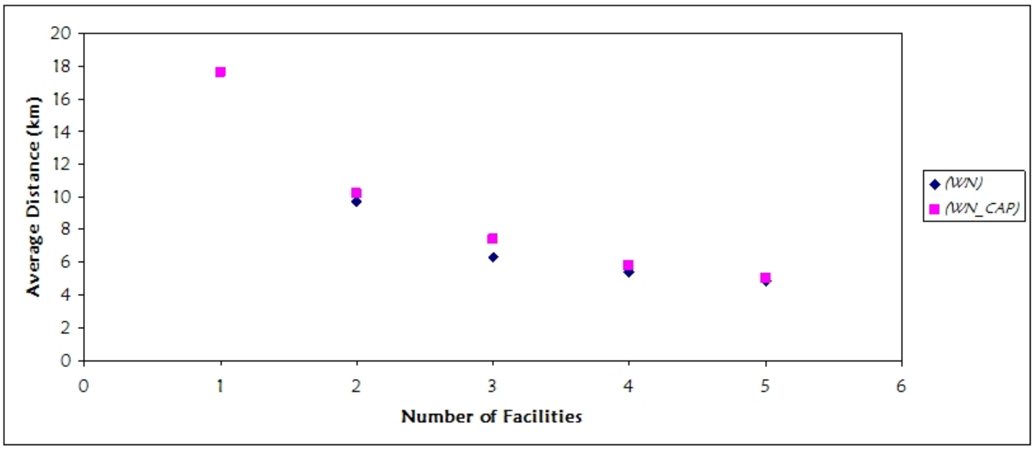
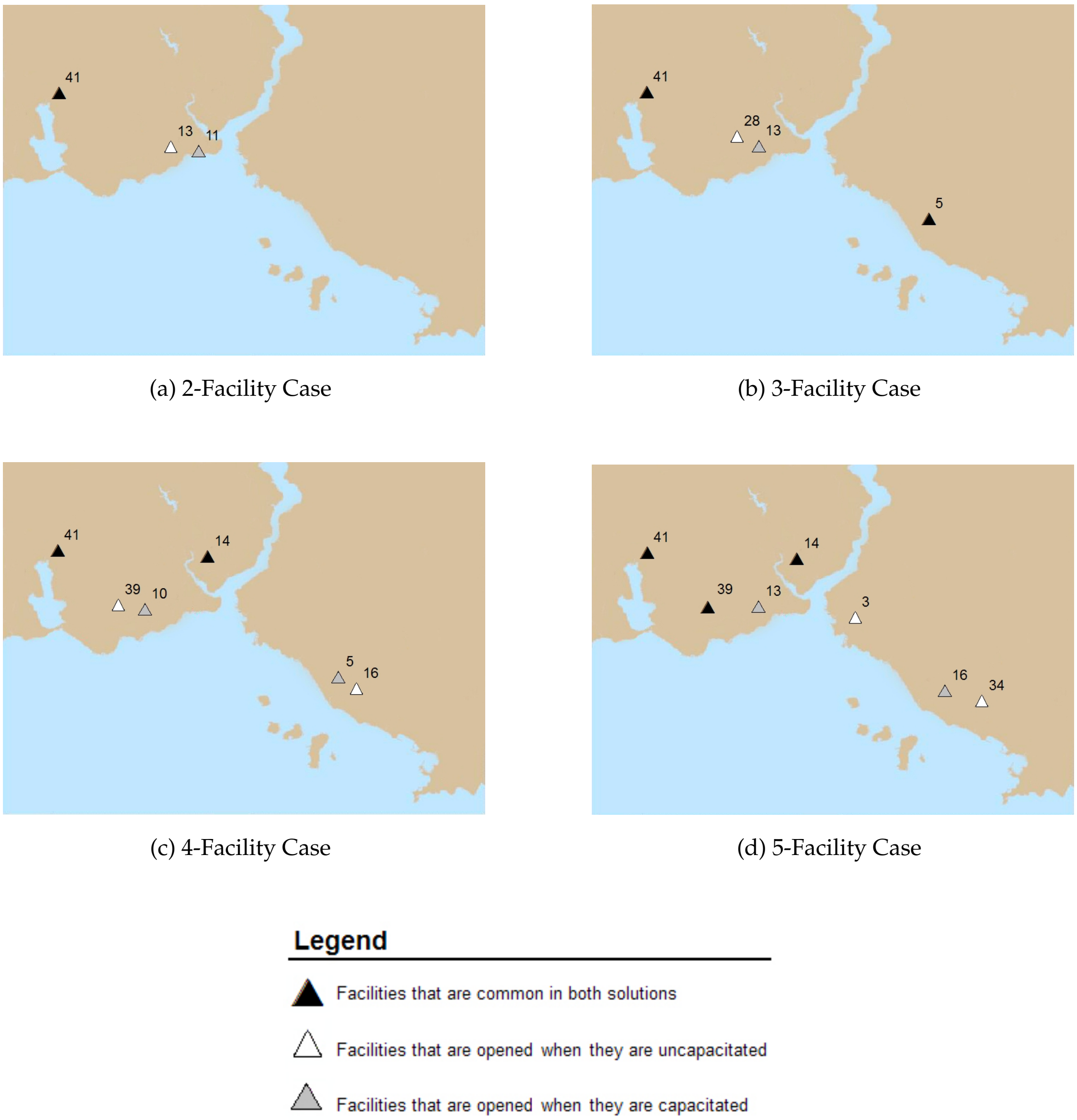


Figure 4.13: Efficient Solutions for (*WN*) and (*WN_CAP*)

Note that the difference is relatively high for the three-facility case while it is low for other cases. The resulting facility locations are provided in Figure 4.14.

It is observed that the location of the second facility moves away from the Halkalı facility when the number of facilities to be opened is two. This is because, the Halkalı facility has to meet a higher portion of demand than usual due to the capacity restriction on the second facility. This approach increases the utilization of the Halkalı facility, which has low utilization levels when compared to other facilities in the uncapacitated case. In Table 4.11 and Table 4.12, we provide the percentages of demand satisfied from each facility for the uncapacitated and capacitated cases, respectively.



(a) 2-Facility Case

(b) 3-Facility Case

(c) 4-Facility Case

(d) 5-Facility Case

Figure 4.14: Comparison of Facility Locations: (*WN*) and (*WN_CAP*)

Table 4.11: Percentage of Demand Satisfied from each Facility when the Facilities are Uncapacitated

2 facilities		**3 facilities**		**4 facilities**		**5 facilities**	
Facility	% Demand Satisfied	Facility	% Demand Satisfied	Facility	% Demand Satisfied	Facility	% Demand Satisfied
13	80.23	5	22.14	14	29.27	3	11.07
41	19.77	28	62.00	16	18.19	14	24.12
		41	15.87	39	43.44	34	12.27
				41	9.10	39	43.44
						41	9.10

Table 4.12: Percentage of Demand Satisfied from each Facility when the Facilities are Capacitated

2 facilities		**3 facilities**		**4 facilities**		**5 facilities**	
Facility	% Demand Satisfied	Facility	% Demand Satisfied	Facility	% Demand Satisfied	Facility	% Demand Satisfied
11	54.99	5	26.71	5	20.34	13	21.99
41	45.01	13	36.65	10	27.49	14	21.95
		41	36.64	14	27.50	16	18.43
				41	24.67	39	21.91
						41	15.72

As expected, the amount of demand satisfied from each facility is more balanced when the facilities are capacitated. In addition some facilities in the crowded regions that never appears in the solutions of the uncapacitaed case are now open.

4.7 Comparison with Scenario A

Similar to multi-period planning we also consider scenario-based planning because the timing and the effect of the earthquake are not known and İMM should be prepared to serve refugees effectively by considering every possible situation. However, we also abandon scenario-based approach because very few scenarios were identified in the JICA report (JICA, 2002). In addition, these scenarios are similar in terms of the magnitude and the affected areas. Hence, the decisions are not very sensitive to different scenarios. In this section we provide the details for that analysis.

We mention in Section 3.1.2 that the JICA team has identified four scenarios for the İstanbul earthquake. The demand data we used in our analysis belongs to Scenario C, which is provided in Figure 3.2c. It is stated in the JICA report that the scenarios are similar in terms of the affected area but the magnitude of the effect changes. We solve our models with the data corresponding to Scenario A to observe the effect of another scenario on the facility locations. Refugee estimation is only made for Scenario C in the JICA report. Recall that this estimation is based on the building damage and the population in these buildings. Although the refugee estimation is not provided for Scenario A, the building damage estimations are provided for both scenarios. Assuming a linear relation between the number of buildings and the population, we derive the refugee estimation for Scenario

A. Replacing the refugee population of scenario C by that of scenario A, we solve Model (*WN*). The optimal facility locations turned out to be the same with the ones obtained in Scenario C. The resulting average distances for Scenario A are provided in Table 4.13.

Table 4.13: Average distance per refugee and the opened facilities for Scenario A

Number of Facilities	**Average Distance (km)**	**Opened Facilities**
1	15.68	41
2	8.67	13, 41
3	5.63	5, 28, 41
4	4.84	14, 16, 39, 41
5	4.31	3, 14, 34, 39, 41

Although the facility locations are the same, average distance values are different from the ones obtained in Scenario A. This is because the change in refugee population is not the same for all districts. Some of the districts are affected more than the others. However, the proportion of change is not so significant to change the facility locations.

4.8 Discussions on the Variations

In Sections 4.1 to 4.7, we consider some variations of the original problem as:

- The Halkalı facility is not open
- Facility locations in continuous space and approximation to continuous space
- Previously opened facilities fixed
- Five facilities to be opened fixed
- Commodities received from suppliers completely and partially
- Capacitated facilities
- Scenario A

When we examine the set of potential locations, they appeared to be appropriate in terms of proximity to the demand points. Selected points among this set and the best locations on the continuous space are quite close. However the location of the Halkalı facility appeared to be disadvantageous, where the disadvantage can be compensated by assigning little demand to the Halkalı facility, as the number of facilities increases.

In variations (*WN_PFF*) and (*WN_5FF*) of the problem, we assume that a single facility is opened at each period and that the previously opened facilities are fixed. Recall that the difference between (*WN_5FF*) and (*WN_PFF*) is that the potential location is selected among five facilities to be opened. Solutions to these models appeared to be similar to the original case, except for some small changes in the facility locations.

Similarly, the average distance remains close to the original case when the capacitated version of the model is solved. However, it resulted in facility locations that are slightly different from the locations found in the uncapacitated case. This resulted from the fact that utilization of the Halkalı facility increases due to the capacity restriction on the other facilities.

Finally, as opposed to other variations, the solutions turned out to be sensitive to the extension where we consider the suppliers. Supplier locations highly effect the location of the facilities leading them to be located closer to the supplier locations. This effect is observed even when only 60% of the total demand is received from suppliers.

In general, we observe that the facility locations are robust. They are only slightly affected from the variations. In fact, it is reasonable because the demand is mostly concentrated in the southern part of the European side while it is low in the northern parts of both the European and the Anatolian sides (see Figure 3.8 on page 18). Concentration of demand in a particular region reduces the sensitivity of the solutions to the variations.

Solution times for the models that we consider in this chapter are similar to the ones presented in Chapter 3 except the models (*CS*) and (*CSA*). Solution times are longer for the models where we use the continuous coordinate space and its approximation as the potential facility locations. In these cases, it takes hours to find the optimal solutions. Moreover, the computers run out of memory for three and more facilities in the continuous space.

CHAPTER 5

CONCLUSIONS

The anticipated earthquake is expected to affect İstanbul seriously. It threatens the human, infrastructure and the economy deeply. İstanbul Metropolitan Municipality takes actions to strengthen the existing infrastructure against the earthquake and they plan post-disaster activities that are aimed at reducing the effects of the earthquake. Establishing disaster response and relief facilities is one of the actions that is planned to reduce the effect by organizing post-disaster activities. These facilities are mainly planned to serve as warehouses and distribution centers for commodities like tents, blankets, food, and water. that are needed after an earthquake. A facility is already established in Halkalı and İMM identified 40 other potential locations for establishing facilities. In this study, we provide information on the number of facilities to locate and the locations of these facilities by analyzing variations for the problem.

Reviewing the related literature and receiving the opinions of people who are directly participating in both pre-disaster planning and post-disaster activities, we propose a storage and distribution system where two kinds of facilities are employed. Permanent facilities that will be established on the possible facility locations to store relief commodities, and temporary facilities that are the existing public facilities to be allocated for relief operations. We propose a mathematical model with two objectives to minimize. The first objective is to minimize the average distance traveled to serve a person affected from the earthquake and the second objective is to minimize the number of permanent facilities to be established. We use an ε-constraint method with augmented objective function to find the efficient solutions to the model.

We solved the model for many cases such as: districts as the demand points vs. neighborhoods as the demand points, capacitated vs. uncapacitated, without suppliers vs. with suppliers, the Halkalı facility is open vs. Halkalı is not open, restricted number of temporary facilities vs. unrestricted number of temporary facilities, satisfaction of all demand vs. partial satisfaction of the demand, Scenario C vs. Scenario A, potential locations vs. anywhere in the continuous space. There are a number of findings that might be useful in establishing the facilities. Firstly, we observe that a small number of new facilities may be sufficient. This is because the facility establishment costs are high and more importantly, the marginal improvement of establishing an additional facility diminishes after the first few facilities. Secondly, we found that facility locations are quite robust. Individual optimization of the location of each facility without considering the possible future facilities and limiting the capacities of the facilities have little effect on the solution. In addition, the facility locations are not affected either from different scenarios we solved for or from taking neighborhoods as the demand points rather than the districts. Thirdly, we observed that the location of the Halkalı facility is not appropriate. İMM would be better off in terms of average distance to serve a refugee if the first facility would be located at the optimal location. However, other potential locations specified by İMM are quite proper that they almost overlap with the optimal facility locations on the coordinate space. We also found that the supplier locations are vastly influential when a portion or all of the commodities will be received from suppliers. Thus, the supplier locations should be determined clearly and taken into consideration when deciding on the locations of the facilities.

Besides our analysis, there are a number of issues that should be studied further. First of all, there is some ambiguity regarding the functions of the facilities both in disaster and non-disaster times and their possible storage and operating capacities. These issues should be clarified before deciding on the locations of the facilities. Secondly, in conjunction with these, the possible suppliers, their locations and the amounts of commodities received from these suppliers should be identified. We found that they are highly effective in determining the locations of the facilities. Thirdly, the duration of provided service is not specified. Some commodities like tents and blankets may be served just once while the others like food and water require multiple shipments. In that case the duration of service may effect the decisions. Finally, we did not use real travel distances between the points since they were not available. It would be useful to conduct the analysis with real distances.

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Appendices

Appendix A

Table A.1: Facility Coordinates

Facility ID	x-coordinate	y-coordinate	Facility ID	x-coordinate	y-coordinate
1	441847.87	4524656.60	22	433953.88	4538861.03
2	433054.28	4530547.48	23	391056.74	4545122.74
3	420166.65	4540965.37	24	391327.59	4548373.26
4	421785.05	4547140.06	25	399923.04	4541785.20
5	428739.91	4533720.67	26	398527.54	4545970.43
6	396918.77	4543135.29	27	401832.39	4547417.07
7	392124.02	4538419.82	28	406348.75	4543387.57
8	399182.91	4538992.80	29	408758.63	4551423.98
9	403658.82	4546245.09	30	408168.91	4549759.51
10	405961.17	4541696.29	31	441095.49	4522083.35
11	412101.72	4541728.26	32	437361.82	4530631.06
12	414352.11	4548881.47	33	433890.68	4533507.59
13	408867.55	4542278.02	34	434979.76	4531189.54
14	413295.67	4547825.48	35	426408.52	4543503.48
15	443676.26	4531319.73	36	398278.53	4552495.89
16	430688.74	4532422.38	37	399026.56	4553232.83
17	422746.94	4551889.53	38	394353.95	4538910.91
18	429428.31	4540370.84	39	402854.92	4542181.77
19	429237.12	4540001.88	40	402672.46	4542113.15
20	430270.94	4544719.22	Halkalı(41)	395724.71	4548516.93
21	435228.99	4540002.61			

Table A.2: Districts

District ID	District Name	x-coordinate	y-coordinate	Refugee Population	Number of Public Schools
1	Adalar	423684	4527244	4900	6
2	Avcılar	392123	4541111	66200	30
3	Bakırköy	403339	4539469	67800	41
4	Bağcılar	402815	4545956	86100	67
5	Bahçelievler	402962	4542010	127200	53
6	Bayrampaşa	407544	4546930	48200	34
7	Beşiktaş	417475	4548522	15000	43
8	Beykoz	424485	4553443	7600	56
9	Beyoğlu	413047	4545881	34000	39
10	Eminönü	412983	4542259	8600	20
11	Eyüp	409936	4549849	28900	53
12	Fatih	410749	4543055	106400	68
13	Gaziosmanpaşa	405571	4552382	53300	96
14	Güngören	405425	4543426	67100	28
15	Kadıköy	422316	4538927	72300	100
16	Kağıthane	414679	4550246	30600	71
17	Kartal	432904	4532162	52900	59
18	Küçükçekmece	397746	4544592	113500	78
19	Maltepe	427318	4534342	47100	55
20	Pendik	438388	4528292	53300	69
21	Sarıyer	419484	4556063	7400	50
22	Şişli	414893	4548716	20800	46
23	Tuzla	443877	4524610	15900	33
24	Ümraniye	428593	4543179	27300	90
25	Üsküdar	420512	4543842	34900	88
26	Zeytinburnu	407777	4540984	72900	35
27	Esenler	404700	4547441	55600	27
28	Silivri	355942	4552007	3900	47
29	Çatalca	375148	4563718	1000	52