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Evaluation of the Warehouse Location Alternatives for Possible Istanbul Earthquake

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Abstract: The "Istanbul Earthquake" is expected to occur within the next ten years. Preparations have long been made for the Istanbul earthquake, which is expected to cause heavy loss of life and property. One of the important parts of earthquake preparedness is the disaster logistics warehouses, where emergency supplies and shelter equipment are stored to be dispatched to earthquake vi,ctims. The aim of this study is to determine the locations of the warehouses to deliver the aid materials to the points of need as soon as possible and to meet the needs in the event of a large earthquake in Istanbul. The model was set up in two steps to determine the number of warehouses to be opened with the set covering problem in the first step and to minimize the weighted distance with p-median in the second step. The established model was solved using The General Algebraic Modeling System (GAMS), and the optimum scenario was decided according to the results, and the scenarios were mapped.

Keywords: Disaster logistics warehouse, earthquake, location selection, p-median, set covering problem.

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1. INTRODUCTION

An earthquake is the event of sudden vibrations that occur due to fractures in the earth's crust, spreading in waves and shaking the environments they pass through (AFAD, 2019). An earthquake is a natural event that cannot be prevented. It is known that since the beginning of the world, millions of people have been deaded and shelters have been destroyed by earthquakes. Turkey is located in the Alpine-Himalayan belt, which is one of the most critical earthquake zones in the world. In this context, it contains tectonic zones with high earthquake potential (Silahtar, 2022). Ms:8.0 1939 Erzincan, Ms:7.1 1957 Bolu, Mw:7.4 1999 Kocaeli and Mw:7.1 2011 Van earthquakes in the last century are the most important indicators of this activity (Tan et al. 2008; Utkucu et al. 2014).

One of the earthquakes expected to occur is the possible major earthquake in the Marmara Region that will also affect Istanbul. If we examine the major earthquakes that have occurred for the last one century along the North Anatolian fault line, starting with the Erzincan earthquake with a magnitude of 7.9 in 1939, the next significant earthquakes have always occurred further west on this line. This is because the released energy is transferred to the west when an earthquake occurs on this fault line (Yamamotoa et al. 2020). The 1999 Kocaeli earthquake, which was the last devastating earthquake on this fault zone, caused severe loss of life and property. Many studies by experts reveal that it is inevitable that a devastating earthquake will occur in Istanbul shortly (Yamamotoa et al. 2020). Such an earthquake in Istanbul, Turkey's largest metropolis and economic center, will cause significant losses. This issue should be greatly important to reduce these losses and precautions should be taken to prepared for earthquakes.

According to the results obtained from the Istanbul Province Earthquake Loss Estimates Update Project analysis, a total of 120,115 low-rise residential buildings, 47,230 medium-rise residential buildings, and 1060 multi-story residential buildings will be moderately, heavily or very heavily damaged. Therefore, it is estimated that after the Mw:7.5 scenario earthquake, an emergency shelter need of about 640,000 households will occur. (İstanbul Büyükşehir Belediyesi, Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü, 2020) Given the population of 3 people per household, approximately 2,000,000 people are expected to be in urgent need of shelter (İstanbul Büyükşehir Belediyesi, 2019). Various disaster logistics warehouse location selection studies have already been carried out. However, in this study, current damage estimation data from Istanbul metropolitan municipality (I.M.M.) and Kandilli Observatory will be used, and the large Istanbul earthquake will be highlighted.

Various preparations are being made against the expected earthquake in Istanbul. One of them is disaster logistics warehouses. The centers where emergency aid materials are stored to be sent to the damaged areas in disasters and emergencies are defined as disaster logistics warehouses (AFAD, 2014). Disaster logistics warehouses contain materials such as medical supplies, tents, beds, blankets, heaters, and kitchen sets.

In this study, using mathematical programming methods, the focus will be on determining the optimum logistics warehouse locations to deliver the emergency aid materials to the points of need as soon as possible and to meet the requirements in case of a potential major Istanbul earthquake. Here, based on Aydın et al. (2017)'s research in the Maltepe district, the whole of Istanbul was emphasized instead of Maltepe. Facility location optimization model established by Boonmee et al. (2017) in their study was also employed while creating the model. According to the outputs obtained from this study, it can be decided where the warehouses should be established, the suitability of the existing warehouse and facility locations can be discussed, and arrangements can be made to ensure that the citizens suffer as minor damage as possible in a possible Istanbul earthquake.

2. MATERIAL AND METHOD

This study will establish a mathematical model to determine the optimum disaster logistics warehouse locations for a possible major Istanbul earthquake. The problem under consideration is modeled in two steps. In the first step, different scenarios with different coverage distances will be established, and the minimum number of warehouses designed with the set covering problem will be determined. In the second step, the results of the first step will be given as input to the p-median problem, and demand-weighted distance minimization and assignments will be made.

Indices
i: Index of the demand points (Districts)
j: Index of the facilities (Candidate logistics warehouses)
Parameters
n : Number of potential facilities
S : Coverage distance of the facilities planned to be opened (km)
a_{ij} : 1 if the distance between demand point i and facility j is less than or equal to S, 0 otherwise
w_i : Demand of the demand point i
d_{ij} : Minimum distance between demand point i and facility j
p : Number of facilities to serve
Decision variables
x_j : 1 if a facility is established at point j, 0 otherwise
y_j : 1 if a facility is opened at point j, 0 otherwise
g_{ij} : 1 if demand point i is assigned to facility j, 0 otherwise

Step 1:
Objective function
$$\min z = \sum_{j=1}^{n} x_j \tag{1}$$
Constraints
$$\sum_{j\in J} a_{ij} . x_j \geq 1 \qquad \forall i \ (i = 1, \dots, n) \tag{2}$$
$$x_j \in \{0,1\} \qquad \forall j \ (j = 1, \dots, n) \tag{3}$$

Step 2:
Objective function
$$\min z = \sum_{i=1}^{n} \sum_{j=1}^{n} w_i . d_{ij} . g_{ij} \tag{4}$$

Constraints
$$\sum_{j=1} g_{ij} = 1 \qquad \forall i \ (i = 1, \dots, n) \tag{5}$$
$$g_{ij} \leq y_j \qquad \forall i, j \tag{6}$$
$$\sum_{j=1}^{n} y_j = p \tag{7}$$
$$g_{ij}, y_j \in \{0,1\} \tag{8}$$

In Step 1, Eq. 1 indicates that we want to minimize the number of facilities placed. Eq. 2 means that each demand point must be serviced by at least one facility. In this model, more than one facility can serve a demand point because not only one is assigned to a facility. Eq. 3 is the constraint of the decision variable being a 0-1 integer.

In Step 2, Eq. 4 minimizes the distance between demand points and candidate facilities. Eq. 5 ensures that each demand point receives service from only one facility. Eq. 6 provides that no demand point is assigned to the facility that is not open. Eq. 7 allows p units to be opened. Eq. 8 is the constraint for decision variables to be 0-1 integers.

3. CASE STUDY

For determining the locations of disaster logistics warehouses, the booklet of possible earthquake loss estimates in Istanbul by districts, prepared in 2020 by Istanbul Metropolitan Municipality and Kandilli Observatory, is used. In the booklet, the number of households in very heavy, heavy, and moderately damaged residential buildings is used to estimate the number of families that will need emergency shelter after a possible Istanbul earthquake. In accordance with this, number of households that will need temporary shelter were calculated for the Mw=:7.5 earthquake scenario for each district. These values in the booklet are used as demands in the model. Districts are demand points. The district centers' coordinates were used to determine the demand points.

I.M.M. established a disaster response facility in Halkalı in 2006. Then, 40 potential locations were identified to set up additional facilities and warehouses. In this study, these candidate logistics warehouse locations compiled by Görmez (2008) were used (Figure 1).

Figure 1. Map of the candidate logistics warehouses (modified from Görmez, (2008))

In the study, the distances of each demand point (districts) to each facility (logistics warehouses) were calculated using the Euclidean distance formula (Eq. 9)

$$d(A,B) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \qquad (9)$$

These data were entered while running our model. ~~In~~ The first step considered seven scenarios with 40, 45, 50, 55, 60, 65, and 70 km coverage distances. Seven experiments were conducted by entering S as 40, 45, 50, 55, 60, 65, and 70. According to the test results, the number of warehouses to be opened for each scenario and which warehouses to be opened will be found. By using the results obtained at this step in the second step, it will be seen which warehouse will serve which districts and a decision will be made according to the results of the objective function that minimizes the total distance between the districts and the candidate warehouses. The GAMS program will be used to run the model.

4. RESULTS AND DISCUSSIONS

The problem is coded in GAMS, the results in Table 1 for Step 1 and Table 2 for Step 2 are obtained. The name of the districts are provided in Table 3.

Table 1. Results of Step 1

Scenario	Coverage distance S (km)	Number of storages to open	Storage no
Scenario 1	40	2	7, 21
Scenario 2	45	2	32, 36
Scenario 3	50	2	25, 35
Scenario 4	55	2	12, 25
Scenario 5	60	1	11
Scenario 6	65	1	10
Scenario 7	70	1	3

When we consider the objective functions, we see that the optimal scenario is Scenario 3, with a coverage distance of 50. According to this scenario, logistics warehouses should be established at location 25 in Kartaltepe, Küçükçekmece, and location 35 in Ümraniye, Fatih Sultan Mehmet. This scenario mapped in Figure 2.

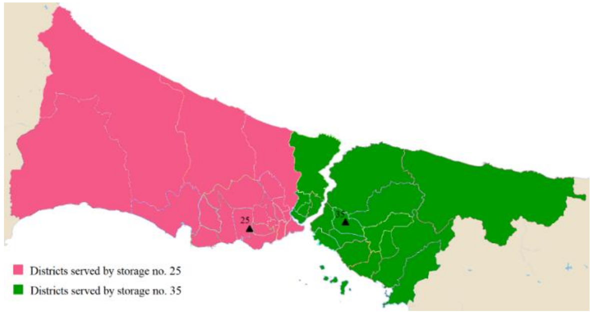

Figure 2. Map of Scenario 3

In real life, it can be decided that warehouses cannot be established in these locations for some reason. Therefore the areas of the other six scenarios can be evaluated. For example, since congestion and damage may occur on the Bosphorus bridges after the earthquake, it may be decided to serve the districts on the side where each warehouse is located, so that Scenario 2 can be implemented. The maps of the other six scenarios are in Figures 3-8.

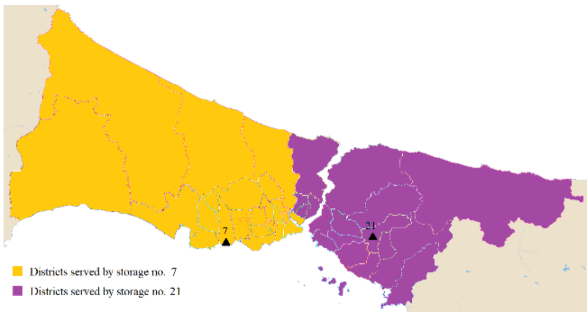

Figure 3. Map of Scenario

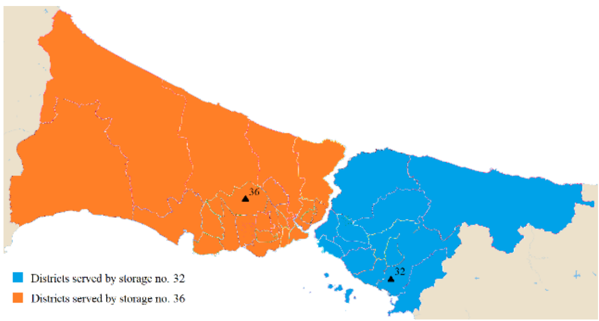

Figure 4. Map of Scenario 2

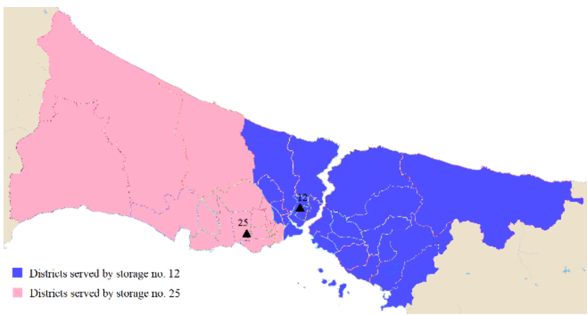

Figure 5. Map of Scenario 4

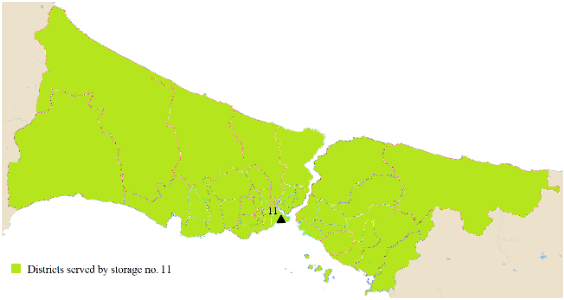

Figure 6. Map of Scenario 5

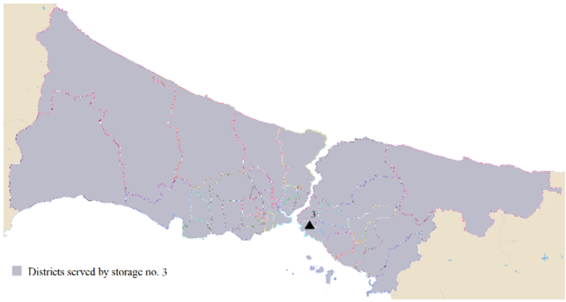

Figure 8. Map of Scenario 7

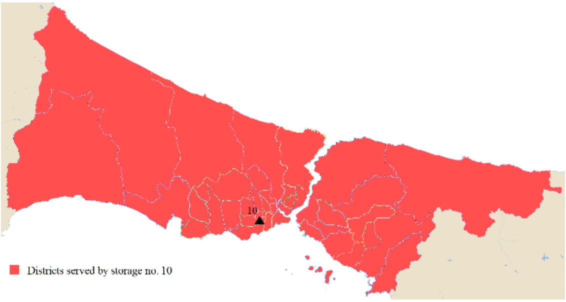

Figure 7. Map of Scenario 6

Table 2. Results of Step 2

Scenario	S (km)	Objective function	Storage No.	Districts to be served
Scenario 1	40	10.862.805,98	7	2:6, 9:13, 17, 25:30, 34:37
			21	1, 7, 8, 14:16, 18:24, 31:33, 38, 39
Scenario 2	45	10.513.175,91	32	1, 8, 14, 16, 18, 19, 22:24, 31:33, 38, 39
			36	2:7, 9:13, 15, 17, 20, 21, 25:30, 34:37
Scenario 3	50	8.468.443,53	25	2:6, 10:13, 17, 25:30, 34:37
			35	1, 7:9, 14:16,18:24, 31:33, 38, 39
Scenario 4	55	9.615.695,88	12	1, 6:12, 14:16, 18:24, 30:33, 38, 39
			25	2:5, 13, 17, 25:29, 34:37
Scenario 5	60	13.290.759,13	11	All
Scenario 6	65	11.946.363,12	10	All
Scenario 7	70	16.690.656,53	3	All

Table 3. District no

1.	Adalar	11.	Fatih	21.	Şişli	31.	Sancaktepe
2.	Avcılar	12.	Gaziosmanpaşa	22.	Tuzla	32.	Ataşehir
3.	Bakırköy	13.	Güngören	23.	Ümraniye	33.	Çekmeköy
4.	Bağcılar	14.	Kadıköy	24.	Üsküdar	34.	Arnavutköy
5.	Bahçelievler	15.	Kağıthane	25.	Zeytinburnu	35.	Beylikdüzü
6.	Bayrampaşa	16.	Kartal	26.	Esenler	36.	Büyükçekmece
7.	Beşiktaş	17.	Küçükçekmece	27.	Silivri	37.	Esenyurt
8.	Beykoz	18.	Maltepe	28.	Çatalca	38.	Sultanbeyli
9.	Beyoğlu	19.	Pendik	29.	Başakşehir	39.	Şile
10.	Eyüp	20.	Sarıyer	30.	Sultangazi		

5. CONCLUSIONS

To prevent the chaos that may occur after the earthquake, it is vital to determine the locations of the warehouses where the aid materials will be stored with accurate analysis, to avoid that unnecessary traffic and lost time. Having access to help as soon as possible after the earthquake is important for the health of the citizens affected by the earthquake and their psychology. The sooner these earthquake victims get help, the sooner they can go on with their lives with less harm. The return of the earthquake victims to their daily lives also has a social significance. This is how the country's service and education systems can survive. We believe that the results of this study will contribute to these issues.

In this study, factors such as cost, highways, and traffic conditions in Istanbul were not considered. In addition, estimates of the number of households needing emergency shelter are considered deterministic, and it is assumed that there are no capacity limits. The study can be developed to be more realistic in the future, taking into account costs, highways, capacity, and traffic. Scenarios can be developed for the number of households that will need shelter, and different possibilities can be evaluated. Scenarios can be improved regarding the magnitude of the earthquake as well. The earthquake's location and the fault's rupture direction will also be considered.

Ethics Committee Approval
N/A

Peer-review
Externally peer-reviewed.

Author Contributions
Conceptualization: M.D.; Investigation: N.G.; Material and Methodology: A.G.Y., M.D.; Supervision: M.D.; Visualization: A.G.Y; Writing-Original Draft: A.G.Y, N.G.; All authors have read and agreed to the published version of manuscript.

Conflict of Interest
The authors have no conflicts of interest to declare.

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