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MAXIMAL COVERING METHOD IN DETERMINING DISTRIBUTION CENTERS IN DISASTER LOGISTICS

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Keywords

Disaster Management, Maximal Covering Location Problem, Geographic Information System

Abstract

Facility location decisions of disaster response centres have an important place in the strategic planning of the activities of public institutions. This study aims to determine the places where the necessary materials will be stored in order to meet the needs of disaster victims such as food, shelter, clothing and first aid in case of a disaster that may occur in our country. For this purpose, the study was carried out by considering the disaster warehouses of Turkish Red Crescent, Turkey disaster map and the disasters experienced in recent years. In Izmir Regional Disaster Management Centre (RDMC), which was selected as an example, by using Geographical Information System (GIS), firstly the coverage distances of each Red Crescent RDMC according to the criteria of response to disaster events, then the demand points for disaster events requiring intervention, and then the candidate points for potential RDMC points with different degrees of importance according to regional characteristics were determined. While determining the most suitable locations for the warehouses to be established, the Maximum Coverage Problem (MCLP) was selected

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from the facility location selection problem types. Six scenarios were created for different time-dependent distance measurements, three of which were based on road distances to reach the disaster points and three of which were based on geodetic distances. The optimal solutions obtained using ArcGIS Route Solver software. Scenario analysis was then performed using several BAYM centers and service distances, and the results were interpreted. The results indicate that the proposed approach can support efficient and effective disaster management.

AFET LOJİSTİĞİNDE DAĞITIM MERKEZLERİNİN BELİRLENMESİNDE EN BÜYÜK KAPSAMA YÖNTEMİ

Anahtar Kelimeler

Afet Yönetimi,
En Büyük Kapsama Problemi,
Coğrafi Bilgi Sistemi

Öz

Afet müdahale merkezlerinin tesis yeri kararları, kamu kurumlarının faaliyetlerinin stratejik planlamasında önemli bir yere sahiptir. Bu çalışma, ülkemizde meydana gelebilecek bir afet durumunda afetzedelerin gıda, barınma, giyim ve ilk yardım gibi ihtiyaçlarının karşılanması için gerekli malzemelerin depolanacağı yerlerin belirlenmesini amaçlamaktadır. Bu amaçla Türk Kızılayı'nın afet depoları, Türkiye afet haritası ve son yıllarda yaşanan afetler göz önünde bulundurularak çalışma gerçekleştirilmiştir. Örnek olarak seçilen İzmir Bölge Afet Yönetim Merkezi'nde (BAYM) Coğrafi Bilgi Sistemi (CBS) kullanılarak öncelikle her bir Kızılay BAYM'sinin afet olaylarına müdahale kriterlerine göre kapsama mesafeleri, daha sonra müdahale gerektiren afet olayları için talep noktaları ve ardından bölgesel özelliklere göre farklı önem derecelerine sahip potansiyel BAYM noktaları için aday noktalar belirlenmiştir. Tesis edilecek depolar için en uygun yerler belirlenirken tesis yeri seçimi problem türlerinden En Büyük Kapsama Problemi (MCLP) seçilmiştir. Zamana bağlı farklı mesafe ölçümleri için altı senaryo oluşturulmuştur; bunlardan üçü afet noktalarına ulaşmak için karayolu mesafelerine, üçü ise jeodezik mesafelere dayanmaktadır. Optimal çözümler ArcGIS Route Solver yazılımı kullanılarak elde edilmiştir. Daha sonra çeşitli BAYM merkezleri ve hizmet mesafeleri *kullanılarak senaryo analizi yapılmış ve sonuçlar yorumlanmıştır. Sonuçlar, önerilen yaklaşımın verimli ve etkili afet yönetimini destekleyebileceğini göstermektedir.*

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1. Introduction

The facility location problem is one of the most widely studied combinatorial optimization problems. Given the large number of alternative locations in which a facility may be located and the group of customers whose needs the facility is intended to meet, the question of facility location becomes deciding where to place it.

Efforts to determine the location of a physical object, known as the location problem, are not new. For centuries, people have solved location problems and found various methods by formulating problems or somehow trying to optimally place objects and service centers in relation to other objects and service centers.

Location decisions are of particular importance in strategic planning of operations of public and private organizations. Location problems of production centers, warehouses, distribution centers, schools and hospitals, and emergency service centers such as fire stations, fire brigade, disaster response points are sample problems where location decisions are made. Location problems deal with decisions on the optimal placement of service center(s), taking into consideration demand intensities (Hakimi, 1964).

Disasters such as floods and fires, which have occurred frequently in our country in recent years, leave material and moral damage and create permanent psychological scars for those who experience the disaster. Disaster and Emergency Management Presidency (aka AFAD), the Red Crescent, public institutions, municipalities, and other organizations have a major role in healing these deep wounds. Disaster preparedness is an important criterion to reduce the chaos that will occur in case of a disaster.

The main purpose of disaster management is to minimize the loss of life and property caused by disasters and to save people affected by disasters. This is why pre-disaster studies are just as important as post-disaster studies. The management approach, which includes the pre-disaster and post-disaster phases, is an integrated disaster management approach. Integrated disaster management is a process that includes mitigation, preparation, response, and recovery phases to minimize or prevent damage caused by disasters.

In recent years, studies on location theory have increased greatly. The main objective of these studies is to minimize the inventory and logistics costs of companies or operating structures in many sectors. For this purpose, the first study was made by Alfred Weber in 1909 on the selection of the most suitable warehouse location to serve more than one customer. To minimize the sum of weighted distances between plants and demand points, Weber defined a single plant serving a limited number of demand points.

Four factors play a role in differentiating location problems. It is a measure of the customer's needs, the facilities are located, the area in which the customer and the facility are located, and finally the distance or time between the customer and the facility (ReVelle and Eiselt, 2005).

This study addresses the problem of locating RDMC for the purpose of promptly responding to disasters in a certain area and returning affected people to normal life as soon as possible. The most distinctive feature of these types of problems is that the effectiveness of the response is highly dependent on the distance between the RDMC and the place where the disaster occurred. The main consideration of the decision makers is to place the RDMCs in such a way that they can respond to the maximum number of disasters likely to occur in the region in a timely manner. Considering the regional characteristics of each RDMC to be established, the maximum distance that can effectively respond to the disaster has been determined. Because of these properties, modeling the problem to allow for partial coverage will yield better results than the traditional coating problem approach.

This study is organized as follows: In the second section, information about the types of facility location problems is given and the solution techniques of such problems are mentioned. In the third section, the definition of the problem, the inputs of the mathematical model, the assumptions about the problem and the mathematical model formulation are introduced. In the fourth section, the solution phase of the model created according to different scenarios is explained. The fifth section is a computational analysis, and the last section presents the conclusion.

2. Literature Review

The theory of facility location started in 1909 when Alfred Weber studied how to place distribution centers to minimize the sum of distance between the customers and the distribution centers. After this research, many applications have been carried out by researchers in many fields. This theory gained great momentum with the publication of Hakimi in 1964. Hakimi carried out this study on the relocation of communication networks and police stations within the road grid, to minimize the total distance between crime scene and nearest service centers. It solves more general problems related to the network of one or more service centers.

Facility location analysis was applied to GIS by Densham and Rushton (1992). Drezner and Wesolowsky (1995) studied the location of service centers in urban areas on a unified road or one-way network, using the two basic location problem techniques "Weber" and "Minimax". ReVelle, Williams and Boland (2002) considered 5 types of (0/1) integer programming models for discrete location problems and compared them with each other in the region they studied. Exact and heuristic solution techniques for such problems were discussed. Multi-objective and economic factors were been considered.

For facility location problems, various mathematical models such as minimum cost network structures (p-median), minimax (p-center) models, coverage (set coverage, maximal coverage) model structures have been developed. Despite many different applications, the basic structure of such problems is the same. The simplest formulation of this problem type can be described as both static and deterministic (Owen and Daskin, 1998).

MCLP method is widely used in distribution logistics literature. The main reason for this is that natural disasters such as earthquakes, fires, floods, avalanches, and storms etc. are unpredictable in nature and therefore the most appropriate solution method for these disasters is to approach such problems with the MCLP method, which has a flexible structure and allows partial coverage.

MCLP, presented in the literature on location theory, refers to the coverage of the maximum number of demands in each service distance or time by several service centers on the network (Church and ReVelle, 1974). These authors first introduced MCLP and defined such kind of problems as partial coverage. In their mathematical model, they expressed the number of service centers to be placed with limited resources in constraints. Daskin and Stern (1981) studied the provision of certain services by ambulance vehicles with emergency service centers. The fact that service centers are busy or in periods of non-operation has given rise to emergence of a new type of model that attempts to cover multiple demand points even if a service center is busy. The model derived by these two forms a hierarchical objective function that minimizes the number of vehicles that meet the service needs and then maximizes the coverage area. Batta and Mannur (1990) also studied multiple deployments of emergency service vehicles in an environment where high demand rates increase the busyness period of each unit. The authors predicted that demands that need to be serviced by more teams are more critical and therefore a more stringent level of coverage, and formulated generalized deterministic set coverage and maximum coverage models that combine multiple response units and coverage-related demand requirements. Serra and ReVelle (1995) studied the location of competing factory outlets in a region independently from each other and introduced an extension of the maximal coverage problem, namely "Maximum Capture Problem".

It can be seen that there are many studies on disaster logistics using MCLP in the literature. A summary of the literature on the determining distribution locations in disaster logistics using MCLP method is listed in Table 1.

Table 1

Summary Of Studies on Determining Distribution Locations in Disaster Logistics

Author(s)	Problem	Method(s)	Findings
Santoso and Heryanto (2023)	Determining the location and type of distribution center.	Capacitated Maximal Covering Location Problem (CMCLP)	The model determines the optimal location for a company to build a distribution center, the number of products that the distribution center will allocate to each demand point, and the maximum number of requirements that can be met.
Hashtarkhani et al. (2023)	Location-allocation model for emergency medical services (EMS).	Integrated GIS and mathematical optimization techniques	The authors showed that the integration of GIS techniques with optimization modeling can enable effective management of scarce health resources, especially when time is limited.
Alizadeh et al. (2021)	Multi-period maximum coverage problems for different types of system configurations.	Multi-period MCLP	Two upper bounds (LR1) and (LR2) and the Lagrange decomposition (LD) were developed in solving the problem. The results show that the LD method combined with the lower bound obtained from the developed heuristic (LD-HLB) performs better when solving both large and small problems, especially with respect to bound tightness and efficiency.
Alizadeh and Nishi (2020)	Emergency Humanitarian Logistics Problem	Hybrid covering location problem (HCLP)	The proposed model was used to locate first aid centers in a humanitarian logistics service in Japan. After validating the developed model, they compared it with other problems and solved several randomly generated examples. The results confirmed that the developed hybrid model can provide better coverage compared to traditional models and other hybrid variants.
Sarıkaya et al. (2020)	Determining the location of gendarmerie posts	MCLP	Timely intervention in most incidents occurred in area of responsibility.
Cordeaua et al. (2019)	Bender's decomposition for very large-scale partial set covering and MCLP.	PSCLP and MCLP	Optimal solutions were found quickly for a real-life situation where the number of customers was much larger than the number of potential plant locations.

Çavdur and Sebatlı (2019)	Allocation of disaster response facilities to disaster areas.	Two-stage stochastic programming	The adaptable decision support system enables users to create various scenarios to consider alternative cases in potential disasters.
Özkan et al. (2019)	Assignments of victims to the shelters in times of disasters	GIS-Based MCLP	The ArcGIS capacitated coverage maximization tool was used and tested using the city of Tunceli as an example.
Coco et al. (2018)	Formulation and algorithms for the robust counterpart of MCLP.	Min-max regret MCLP	A robust counterpart of MCLP, in which the utility of each column was modeled as an uncertain and intermittent data, as mixed integer linear programming (MILP) and tested it with classical examples in the literature.
Doungpan et al. (2018)	Emergency rescue	MCLP P-median, and P-center	They compared facility location models to determine the optimal location of emergency management facilities and applied them to a case study of Chiang Rai province, Thailand.
Blanquero et al. (2016)	MCLP on networks with regional demand	MCLP as a mixed integer nonlinear programming (MINLP) model	A Branch and Bound algorithm was proposed for the solution. Computational results showed the suitability of the procedure for solving overlay problems for small values of p.
Drakulic' et al. (2016)	New model of MCLP with fuzzy conditions	MCLP and Particle Swarm Optimization (PSO) Heuristic	Two types of fuzzy numbers were used for describing two main parameters of MCLP- coverage radius and distances between locations. The model was defined, then PSO method was introduced and tested.
Kurban and Can (2016)	Emergency intelligence, surveillance, and operation of processes for the selection of ground control stations of mini unmanned aerial vehicles	MCLP and Maximum Expected Pavement Problem	Different scenarios were generated, and optimal solutions were tested for each scenario. Then, the variations of the optimal solution were studied by changing the problem parameters.
Ergin (2016)	Warehouse selection in disaster logistics	P-median and clustering mathematical modeling techniques	The author divided the country into regions by clustering it with certain provinces, and then determined which regions and cities within the allocated regions can serve the most suitable warehouse locations.
Durak and Yıldız (2015)	Determining the optimum warehouse location for a food company in Düzce province	P-median	Two scenarios were created as to whether the current warehouse location was included in the model or not. In both scenarios, the number of warehouses was tried up to five, and as a result of the comparison of the scenarios, it was revealed that the

			current location of the warehouse was chosen incorrectly and this was the most important factor affecting the company's costs.
Ağdaş et al. (2014)	The disaster logistics distribution center location problem.	Multi-criteria decision making (MCDM)	Since the criteria used to solve disaster distribution center location problems contain uncertainty and are expressed by probability distributions, they used the Stochastic Multi-Criteria Acceptability Analysis-2 (SMAA-2) method and applied to a sample problem.
Rath and Gutjahr (2014)	Warehouse location–routing problem in disaster relief	Mathematical heuristic method based on MILP formulation	The authors designed a supply system consisting of temporary camps to provide basic supplies to people affected by natural disasters. To solve the problem of optimising a constrained objective, they proposed a "mathematical heuristic" method based on the MILP formulation with a set of constraints and an exact solution method embedded inside the heuristic.
Karabay et al. (2014)	Facility location problem of a public institution.	Stochastic Multi-Criteria Admissibility Analysis-TRI (SMAA-TRI)	Firstly, with the mathematical programming model, where new facilities should be placed and which district centers will receive service from which facilities, apart from the facilities in the city centers, were determined, then the SMAA-TRI method was used to determine the most appropriate criteria among those public institutions have been identified. As a result, it was seen that the facilities located by both models are the same.
Rawls and Turnquist (2011)	Pre-positioning planning for emergency response with service quality constraints.	Stochastic MILP	A stochastic model was developed to determine the locations and capacities of emergency supply depots and minimize costs in response to a hurricane disaster in the southeastern United States.
Davari et al. (2011)	MCLP with fuzzy travel times.	Fuzzy MCLP	A fuzzy simulation and annealing simulation hybrid algorithm were used to solve Fuzzy MCLP. Numerical results showed that the simulated annealing algorithm was effective in finding near-optimal solutions.
Curtin et al. (2010)	Determining optimal police patrol areas using maximum coverage and backup coverage	MCLP and backup coverage using GIS	They tested the model with the police geography of Dallas, Texas. They proved that the optimal solutions improved the total distance travelled and incidents covered compared to the existing police geography.

Balcik and Beamon (2008)	Determining location of distribution centers in relief networks for rapid response to disasters.	Variant of MCLP	The model is a multi-product, budget- and capacity-constrained MCLP, which determines the number and location of distribution centers as well as the stocks required to meet the needs of people affected by natural disasters. Computational experiments were conducted to demonstrate the functionality of the model in a real-world problem.
Yi and Özdamar (2007)	Distribution and location routing model for disaster emergencies	Min-max Regret MCLP	The authors generated two scenarios for expected earthquakes in Istanbul. The model was solved using a heuristic algorithm.
Gencer and Açıkgöz (2006)	The problem of determining the locations of Turkish Armed Forces Search and Rescue (SAR) stations within given zone.	MCLP	For the solution of the problem, four main scenarios and two special cases were created, the optimal results were compared with the current situation and parametric analysis was performed.

After reviewing the literature, this study focuses on the problem of logistics warehouse location selection during disasters, which falls into the category of disaster preparedness. This study is important as it sets an example for reducing the devastating effects of floods, fires and earthquake disasters in recent years. Many studies such as this study have been conducted. The importance of this study is that it does not take all disaster management regions of Turkey as a basis, but only allows the determination of a disaster management center. It is shown that the data obtained by determining only one disaster management center becomes more meaningful and can be based on regional differences. In addition, the competencies of GIS were also applied in this study to ensure that the location to be selected in disaster logistics is not just a point or coordinates on the map, but a place suitable for disaster logistics. This study has managed to differentiate itself from other similar studies in terms of both the types of disasters resulting from regional differences and the applicability of the geographic information system in this study.

3. Material and Method

Researh and publication ethics were complied with in this study. There is no need for ethical approval.

3.1. Overview of MCLP

In many real-world applications, decision makers when finding a service center find that resources are insufficient to achieve the required service level. If a facility serves a demand node, the facility is closer to the demand node than the defined threshold. This predefined threshold is often referred to as coverage distance (S) and directly affects the solution. This occurs when there is not enough money or resources to meet the needs of all nodes. A node is considered covered if at least one facility is within a predefined distance from the node. The coverage objective at distance S may not be solvable given the resources for plant construction. In such cases, site selection goals must be modified to provide the customer with the level of coverage possible with the available resources. Problems related to this goal are called MCLP.

MCLP aims to maximize the number of claims covered by locating a specified number of service centers within a specified service distance. In formulating this problem mathematically, the notation used to formulate the problem mathematically is shown below.

Indices:

i : Demand points; $i = 1,\ldots,I$

j : Potential service center points; $j = 1,\ldots,J$

Parameters:

h : number of demands at node i

d_{ij} : Distance between nodes i and j

p : Number of service centers to be deployed.

Variables:

$$Z_i = \begin{cases} 1, & \text{if demand point } i \text{ is covered} \\ 0, & \text{otherwise} \end{cases}$$

Accordingly, the MCLP is formulated as follows:

Objective function:

$$\text{Max } f = \sum_{i\in I} h_i Z_i \tag{1}$$

Subject to:

$$z_i \leq \sum_{j \in N_i} X_j, \forall_i \in I \tag{2}$$

$$\sum_{j \in J} X_j \leq p \tag{3}$$

$$X_j \in \{0,1\} \quad \forall_j \in J \tag{4}$$

$$Z_i \in \{0,1\} \quad \forall_i \in I \tag{5}$$

The objective function (1) maximizes the number of demands covered. Constraint (2) specifies which demand nodes are covered within the acceptable service distance. A node i is said to be covered if the service center is placed at any point j within the coverage distance (S) of node i. Constraint (3) limits the number of service centers to be placed. Constraints (4) and (5) are defining constraints for the decision variables.

In the MCLP, the following "coverage parameter" is defined as to whether the distance between points i and j $\left(d_{ij}\right)$ is within the coverage distance:

$$d'_{ij} = \begin{cases} 1, & \text{if } d_{ij} \leq \text{S} \\ 0, & \text{if } d_{ij} > \text{S} \end{cases}$$

3.2. Problem Definition

The aim of this study is to locate minimum number of facilities within the borders of Izmir AFAD and to maximize the area covered by AFADs (area of responsibility), thus ensuring that the Turkish Red Crescent Disaster Management Association can meet the nutritional needs of disaster victims as quickly as possible in case of possible disasters. In this context, it is aimed to determine the disaster management centers that can be opened by applying the MCLP method in possible disaster scenarios, based on the existing disaster management centers and their capacities.

There are some assumptions in the model that may affect the solution. These are the number of disaster response centers (candidate points), coverage distances and regional characteristics. The number of disaster response centers in the responsibility center is limited considering the cost.

In the model, the size and capacities of disaster response centers do not differ according to regions. The effectiveness of the Red Crescent's disaster response units is measured by their ability to reach an event occurring in their area of responsibility within a maximum of two hours. Upon receiving a notification of an incident, an RDCM is expected to reach the scene within two hours at the latest and provide the necessary support. This time includes the time spent in preparation and distribution.

This research has been conducted based on data provided by TRC and expert opinions and assessments that formed the criteria of the mathematical model. While identifying the demand points, the events that have occurred in the regions for which Izmir RDMC is responsible in the last two decades have been taken into consideration. In the last two decades, 230 incidents have occurred in Izmir RDMC regions. The disaster types and percentage of the disasters experienced are given in Figure 1.

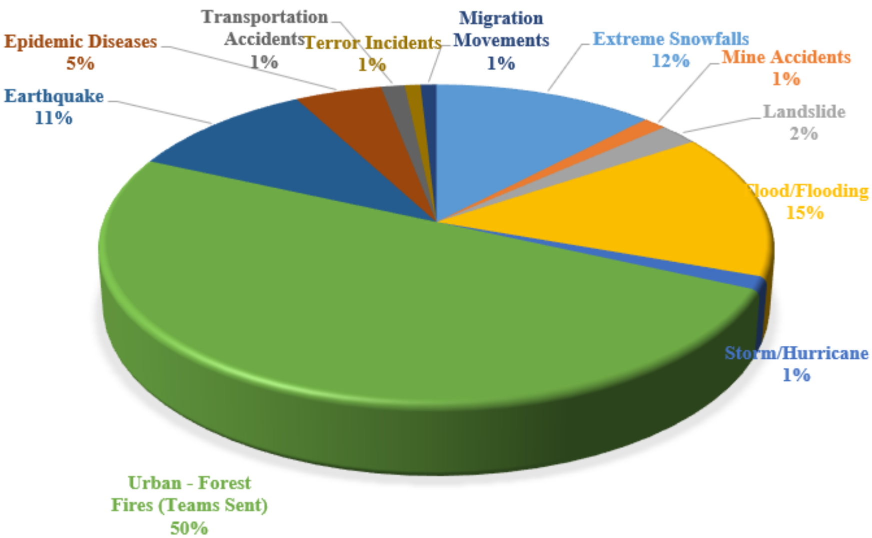


Figure 1. Types and Percentages of Disasters That Have Occurred in Izmir RDMC İn The Last Two Decades

3.3. Identification of Demand Points

The criteria such as the number of disasters that occurred in the last two decades, the road and transportation status of the candidate point, and population density of the provinces within the provincial borders of Izmir RDMC were taken into consideration. Table 2 refers to the the number of disasters that have occurred in the RDMC governorates of Izmir over the past two decades.

Table 2

Number of Disaster Events by Province in Izmir RDMC

Izmir RDMC	Number of Events
Izmir	47
Manisa	63
Kütahya	14
Uşak	4
Afyonkarahisar	15
Aydın	13
Denizli	12
Isparta	8
Muğla	33
Burdur	6
Antalya	15
Total	230

Figure 2 shows the disasters that occurred in the last two decades within the responsibility area of Izmir RDMC in the form of dots. A total of 230 disasters occurred within this area.

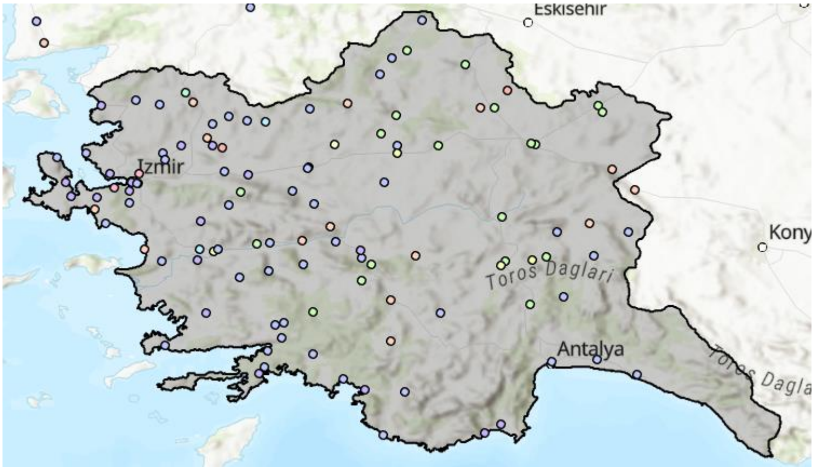


Figure 2. Disasters That Occurred Within the Responsibility Area of Izmir RDMC in The Last Two Decades and Their Locations

The area of responsibility is based on provincial borders. Demand points have been determined by geodetic measurement, a method of measuring geodetic distances or areas using curved (nonplanar) surfaces to model the Earth. In this way, the lost distances due to the curvature of the earth at long distances within the borders of the country are minimized. The number of disasters covered by the identified demand points is specified as the number of events. The number of events occurring in this area also shows the importance (weighted value) of the demand points. The weighted value of the warehouses to be established is determined according to the number of events occurring over the last two decades. Considering the disaster events that occurred in the last two decades, the demand points identified for Izmir RDMC have been prioritized into 14 separate demand point sets and their locations are shown in Figure 3.

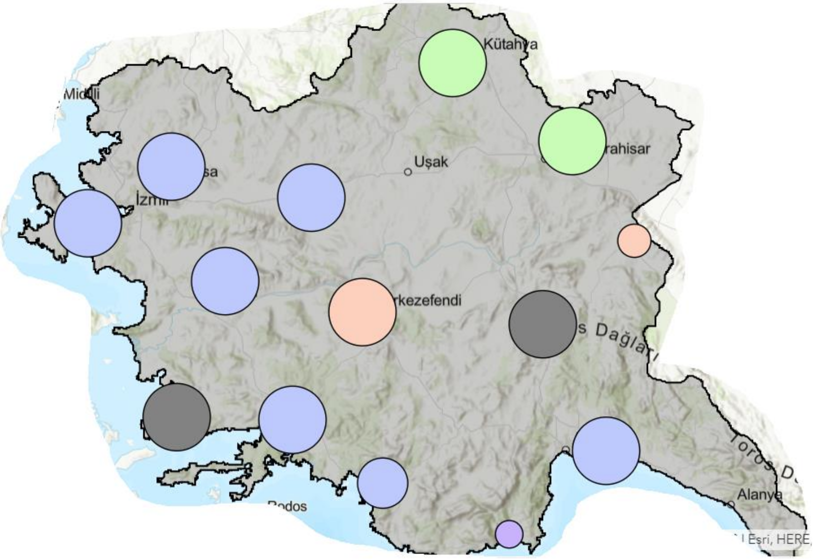


Figure 3. Set of Demand Points

Figure 4 shows the number of disasters occurring within the combined disaster groups. The number of disasters covered by the determined demand points is indicated as a number of events. Severity is also rated according to the number of events covered.

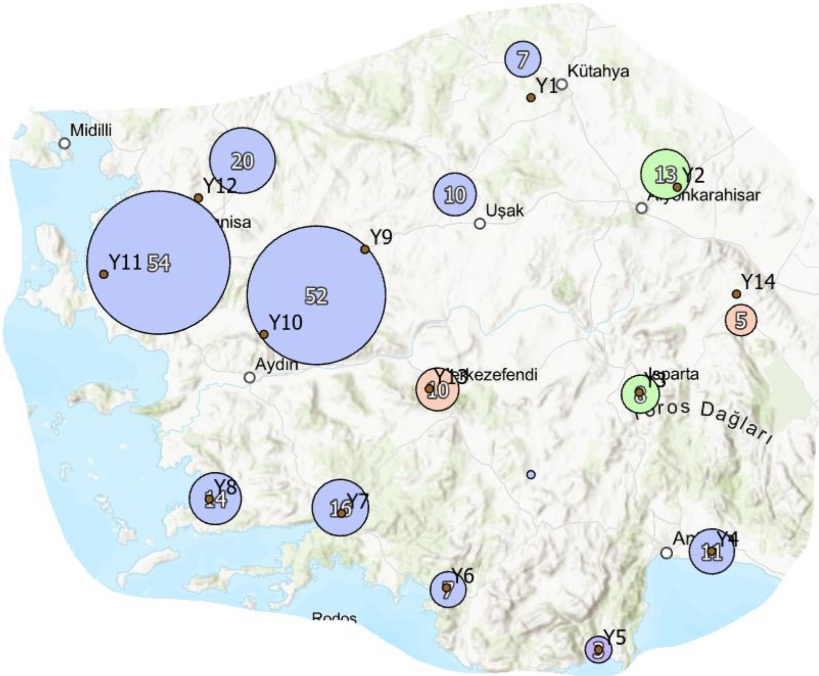


Figure 4. Number of Events Covered by Demand Sets.

The codes corresponding to the names of the demand points and their severity levels are shown in Table 3 below.

Table 3

Severity Levels of Set of Demand Poits and Number of Relevant Events

Candidate Points	Severity Level	Number of Events
Y (1)	3	7
Y (2)	6	13
Y (3)	5	8
Y (4)	5	11
Y (5)	2	3
Y (6)	3	7
Y (7)	7	16
Y (8)	6	14
Y (9)	4	10
Y (10)	9	52
Y (11)	10	54
Y (12)	8	20
Y (13)	4	10
Y (14)	1	5

3.4. Selection of Candidate Points

Candidate point selection varies according to regional characteristics. There may be many candidate points in a given region and each of them may have different characteristics. Since the aim is to ensure maximum coverage and to be able to evaluate each candidate point, its coverage capabilities, and its different characteristics such as ease of transportation, population density, geographical location, etc. among many alternative candidate points, in this study, candidate points have been selected close to each other and more than demand points.

Each disaster area has its own distinctive characteristics. In determining the candidate points, scores have been given according to the distinctive features determined based on expert opinions. While selecting the candidate locations, the opinions of experts at the TRC Disaster Coordination Center were consulted. As a result of the interviews and evaluations, the locations of facilities that can be established as disaster coordination centers within the territorial borders of the provinces under the responsibility of Izmir RDMC have been determined. Accordingly, 26 candidate points have emerged. In determining the candidate points the following criteria have been taken into consideration in determining the candidate points:

3.4.1. Proximity to Settlements (Geographic Location)

The proximity of RDMCs to settlements is an important criterion in terms of meeting local logistics needs. The following table is used in the evaluation of proximity to settlements. In Table 4, the distance of the selected candidate points to the settlements have been measured with the following values.

Table 4

Proximity To Settlements

Distance (km)	Score
284 -...	1
188-233	2
147-187	3
111-146	4
80-110	5
54-79	6
33-53	7
17-32	8
6-16	9
0-5	10

3.4.2. Proximity to the Disaster Scene

Since most of the disaster events in the responsibility area of Izmir MCC are in mountainous and terrain areas, the criterion of having disaster centers close to the event locations is also important. For this reason, the following table is used for the criterion. Candidate locations that have enough space for establishing a disaster center, are flat and meet the security requirements are evaluated with 10 points in terms of proximity to the incident scene, while locations that do not meet these requirements and are unsafe and open to theft and looting incidents are evaluated gradually with low points. According to the criteria in Table 5, the distance of the candidate points to be selected to the previous disaster events have been evaluated.

Table 5

Proximity To the Disaster Scene

Distance (km)	Score
301-380	1
231-300	2
171-230	3
121-170	4
81-120	5
51-80	6
31-50	7
16-30	8
6-15	9
0-5	10

3.4.3. Population Density

It is obvious that disaster centers to be established in densely populated regions will provide the opportunity to reach more disaster victims. The more population the disaster center covers, the more disaster victims can be reached. Therefore, the existence of this criterion is important. During the evaluation, the location of the unit point has been taken as the center and the population density within a radius of 10 km has been taken into consideration.

In Table 6, the candidate points to be selected are ranked based on population density. Although the populations of the provinces are given below, the selected candidate points are ranked according to the population rate of the region where they are located.

Table 6

Population Density

Population	Score
1.000 and less	1
1.001-10.000	2
10.001-25.000	3
25.001-50.000	4
50.001-10.000	5
100.001-250.000	6
250.001-500.000	7
500.001-750.000	8
750.001-1.000.000	9
1.000.001 and more	10

Figure 5 shows the set of candidate points for new RDMCs that can be optimally located using the GIS.

Figure 5. Set Of Candidate Points

Considering the same criteria for all candidate points within Izmir RMDC, the regional characteristic coefficients have been created as shown in Table 7.

Table 7

Regional Characteristic Coefficients of Candidate Points

Candidate Points X (n)	Geographic Location (G_j)	Population Density (P_j)	Proximity to Disaster Scene (O_j)
X (1)	8	10	7
X (2)	7	10	9
X (3)	2	3	8
X (4)	8	4	10
X (5)	8	7	7
X (6)	8	7	7
X (7)	9	6	9
X (8)	5	7	8
X (9)	6	8	7
X (10)	5	8	7
X (11)	4	1	6
X (12)	6	5	7
X (13)	10	5	8
X (14)	7	7	7
X (15)	10	6	8
X (16)	5	2	7
X (17)	6	2	8
X (18)	3	4	7
X (19)	9	6	9
X (20)	9	3	6
X (21)	4	1	9
X (22)	7	9	7
X (23)	7	9	10
X (24)	3	2	10
X (25)	1	2	10
X (26)	4	1	6
Average	$V_G = 6{,}19$	$V_P = 5{,}19$	$V_O = 7{,}85$

3.5. Proposed Mathematical Model

The objective of the model is to ensure that the identified candidate points cover the set of maximum demand points.

The mathematical model formulation is shown below.

Indices:

i : Demand points; $i = 1, \dots, m$

j : Candidate points; $j = 1, \dots, n$

Parameters:

h_i : Number of diasater events occuring at node i

d_{ij} : Distance between points i and j

p : Number of RDMCs to be placed.

S : Coverage distance

$$d'_{ij} = \begin{cases} 1, & \text{if } d_{ij} \leq \text{S} \\ 0, & \text{if } d_{ij} > \text{S} \end{cases}$$

C_j : Geographic location

N_j : Population density

O_j : Proximity to the disaster scene

V_c : Minimum average value to ensure geographical standards.

V_N : Minimum average value to ensure population density standards.

V_O : Minimum average value to meet the standard of proximity to the disaster scene.

Decision Variables:

$$X_i = \begin{cases} 1, & \textit{if potential candidate point j is placed} \\ 0, & \textit{otherwise} \end{cases}$$

$$y_i = \begin{cases} 1, & \textit{if node i is covered} \\ 0, & \textit{otherwise} \end{cases}$$

Mathematical Model:

$$\text{Max Z} = \sum_{i=1}^{m} h_i y_i \tag{6}$$

s.t.

$$y_i \le \sum_{j=1}^{n} X_j \;\; i = 1, \dots, m \tag{7}$$

$$\sum_{j=1}^{n} X_j \le P \tag{8}$$

$$\sum_{j=1}^{n} C_j X_j \ge V_c \sum_{j=1}^{n} X_j \tag{9}$$

$$\sum_{j=1}^{n} N_j X_j \ge V_N \sum_{j=1}^{n} X_j \tag{10}$$

$$\sum_{j=1}^{n} O_j X_j \ge V_O \sum_{j=1}^{n} X_j \tag{11}$$

$$X_j \in \{0,1\} \qquad \forall_j \in J \tag{12}$$

$$y_i \in \{0,1\} \qquad \forall_i \in I \tag{13}$$

The objective function (6) shows that candidate points cover the number of disaster events within the range of coverage distance. Constraint (7) specifies which candidate points are covered within a reasonable service distance. Node

i is considered covered if the RDMC is placed at any node j within the coverage target area of node i. Constraint (8) limits the number of RDMCs that can be placed. Constraints (9-11) are related to the geographical location, population density and proximity to the disaster scene, respectively. Constraint (9) ensures that the sum of the geographical location scores of the candidate points to be selected is greater than the average geographical location scores of all candidate points. Constraint (10) ensures that the sum of the population density scores of the candidate points to be selected is greater than the average population density scores of all candidate points. Constraint (11) ensures that the sum of the proximity to disaster scene scores of the candidate points to be selected is greater than the average disaster scene scores of all candidate points. Constraints (12) and (13) represent descriptive constraints (0-1) for the decision variables.

Since facility location problems are NP-Hard (NP-Complete for decision problems), it may be difficult to find the optimal solution as the size of the problem increases. NP-Hard is a term used to classify optimization problems. To date, no polynomial-time algorithm has been developed for this type of problem. Finding the optimal solution to NP-Hard problems is possible through an exponential-time algorithm (which may take a very long time) (Garey and Johnson, 1979).

Exact and heuristic techniques solve facility location problems. Exact techniques include mixed integer programming, the most vital optimization technique. The goal is to optimize the cost function with service constraints using the Simplex algorithm and Branch and Bound technique applied to relaxed integer programming. There are commercial software programs for solving integer problems, while heuristic techniques provide faster near-optimal solutions. Heuristic techniques are used when finding optimal solutions is time-consuming. The key heuristic technique is Lagrangian based heuristic. While the results of this method are less mathematically formulated than integer programming, the solution can be more challenging. Some heuristic techniques for location problems include Exchange Heuristics, Drop Heuristics, Sequential Location and Allocation, Simulated Annealing, Tabu Search, and Genetic Algorithms.

4. Implementation and Findings

4.1. Creation of Scenarios

One of the most important factors affecting timely response to disasters is transportation. Transportation can be provided by land and air routes: First three coverage scenarios have been created based on the road distances from the candidate points to the demand points.

In the disaster literature, it is envisaged to reach the disaster location within two hours when a disaster call is received. Since the transportation time from one location to another may vary depending on the road condition, our first scenarios heve been created based on three different road distances.

Based on the assumption that maximum speed values that freight transportation vehicles can reach on a road and the condition of the roads, distances of 120 km, 150 km and 180 km have been determined as the road coverage distance constraints of our initial scenarios. Based on the conditions of the roads in mountainous and coastal areas, the maximum speed that a freight transport vehicle can reach is 60 km/h and our first scenario is created. The maximum speed of a cargo transport vehicle traveling on both mountainous and flat roads was taken as 75 km/h and our second scenario was created. Our last scenario, which is based on road distance, is based on the maximum speed of a freight vehicle traveling on a normal straight road as 90 km/h and the third scenario has been created.

The second type of scenario we consider is the geodetic distances which are obtained based on measurements made on large pieces of land, taking into account the curvature of the earth. Disasters such as fires and floods in recent years have brought transportation difficulties. With the increasing helicopter inventory in our country, its use in different and strategic missions, especially in health, the development of technology day by day, the road and communication distances and carrying capacities of unmanned aerial vehicles are increasing, and these technologies can also be used in disaster logistics, as it is anticipated that these values will increase in the future. With this prediction, geodetic distances of 200 km, 300 km and 400 km are the second group scenarios that we have cosidered. These scenarios mentioned above are numbered as follows:

Scenario 1: Road distance 120 km.

Scenario 2: Road distance 150 km.

Scenario 3: Road distance 180 km.

Scenario 4: Geodetic distance 200 km.

Scenario 5: Geodetic distance 300 km.

Scenario 6: Geodetic distance 400 km.

4.2. Scenario Solutions

In this section, the solution of the scenarios and the evaluations related to the solution have been described. It is essential that only one RDMC provides service to any disaster or disasters that may occur anywhere in the responsibility area. For this reason, (0/1) integer variables have been used in the model.

For each scenario, the solution of the model has started with at least one RDMC that can be deployed for the districts, and this number has been increased by one until 100% coverage has been achieved.

Thus, it has been tried to determine the minimum number of RDMCs serving the highest number of disaster victims. The solutions of these scenarios have then been compared with each other, and these solutions can be presented to the decision maker as a solution alternative to the current situation in the Izmir RDMC area of responsibility.

Finally, the solutions have been solved by changing the problem parameters and the changes in the results have been analyzed. The developed model has been solved using ArcGIS Route Solver software. ArcGIS Route Solver, which is part of the ArcGIS platform developed by Esri that produces worldwide solutions in GIS, works as an optimisation module that performs mathematical and geographical analyses to determine the best route or routes for a specific facility location problem. Within this solver, there is a platform that can make distance measurements in the most accurate way due to the geoid structure of the world and plan transport times in the most appropriate way. The most appropriate solution can be provided with models of facility location methods. As many variables and constraints as needed can be added to the system to ensure that the process is operated close to reality.

Analysis of Scenario 1

In this scenario, full (100%) coverage cannot be achieved with the current constraints (regional characteristics) added to the mathematical model. Instead, with five RDMCs to be located, 42% coverage is achieved. It is evaluated that an effective response to disasters will not be sufficient with this scenario. The fact that locating more RDMCs will cost the decision makers more, hence this option doesn't seem desirable. Table 8 shows the solution results for Scenario 1 for locating different numbers of candidate points.

Table 8

First Scenario Solutions for Locating Different Number of Candidate Points (Road Distance 120 Km)

Number of RDMC	Selected Candidate Points	Covered Demand Points	Number of Demands	Coverage Ratio (%)
1	X2	Y11	54	24
2	X2, X7	Y11, Y13	64	28
3	X2, X7, X15	Y2, Y11, Y13	77	33
4	X2, X7, X15, X19	Y2, Y3, Y11, Y13	85	37
5	X2, X7, X15, X19, X23	Y2, Y3, Y4, Y11, Y13	96	42

Analysis of Scenario 2

In this scenario, full coverage cannot be achieved. However, with five RDMCs to be located, 53% coverage is achieved. The same logic applies to this scenario in terms of coverage ratio. Table 9 shows the solution results for Scenario 2 for locating different numbers of candidate points.

Table 9

Second Scenario for Locating Different Number of Candidate Points (Road Distance 150 Km)

Number of RDMC	Selected Candidate Points	Covered Demand Points	Number of Demands	Coverage Ratio (%)
1	X2	Y11, Y12	74	32
2	X2, X7	Y11, Y12, Y13	84	37
3	X2, X7, X15	Y2, Y11, Y12, Y13, Y14	102	44
4	X2, X7, X15, X19	Y2, Y3, Y11, Y12, Y13, Y14	110	48
5	X2, X7, X15, X19, X23	Y2, Y3, Y4, Y11, Y12, Y13, Y14	121	53

Analysis of Scenario 3

In the scenarios created according to road distances, it is seen that coverage rates increase as the road distance increases. It is considered that 84% coverage rate for five RDMCs to be opened is a reasonable and preferable option in terms of response to disaster events. Table 10 shows the solution results for Scenario 3 for locating different numbers of candidate points.

Table 10

Third Scenario Solutions for Locating Different Number of Candidate Points (Road Distance 180 km)

Number of RDMC	Selected Candidate Points	Covered Demand Points	Number of Demands	Coverage Ratio (%)
1	X2	Y10, Y11, Y12	126	55
2	X2, X7	Y9, Y10, Y11, Y12, Y13	146	63
3	X2, X7, X15	Y1, Y2, Y9, Y10, Y11, Y12, Y13, Y14	171	74
4	X2, X7, X15, X19	Y1, Y2, Y3, Y9, Y10, Y11, Y12, Y13, Y14	179	78
5	X2, X7, X15, X19, X23	Y1, Y2, Y3, Y4, Y5, Y9, Y10, Y11, Y12, Y13, Y14	193	84

Analysis of Scenario 4

In the fourth scenario, the demand points within a 200 km radius of the candidate points that meet the constraints are analyzed and the points covered are indicated in percentage. The set of demand points covered by the four different candidate points is 230 and 100% coverage is achieved. Table11 given below illustrates the solution results for Scenario 4 for locating different numbers of candidate points.

Table 11

Fourth Scenario Solutions for Locating Different Number of Candidate Points (Geodetic Distance 200 km)

Number of RDMC	Selected Candidate Points	Covered Demand Points	Number of Demands	Coverage Ratio (%)
1	X2	Y8, Y9, Y10, Y11, Y12	150	65
2	X2, X7	Y1, Y2, Y3, Y5, Y6, Y7, Y8, Y9, Y10, Y11, Y12, Y13	214	93
3	X2, X7, X15	Y1, Y2, Y3, Y5, Y6, Y7, Y8, Y9, Y10, Y11, Y12, Y13, Y14	219	95
4	X2, X7, X15, X19	Y1, Y2, Y3, Y4, Y5, Y6, Y7, Y8, Y9, Y10, Y11, Y12, Y13, Y14	230	100

Within a 200 km geodetic range, the selected candidate points and their coverage areas are shown in the figure below.

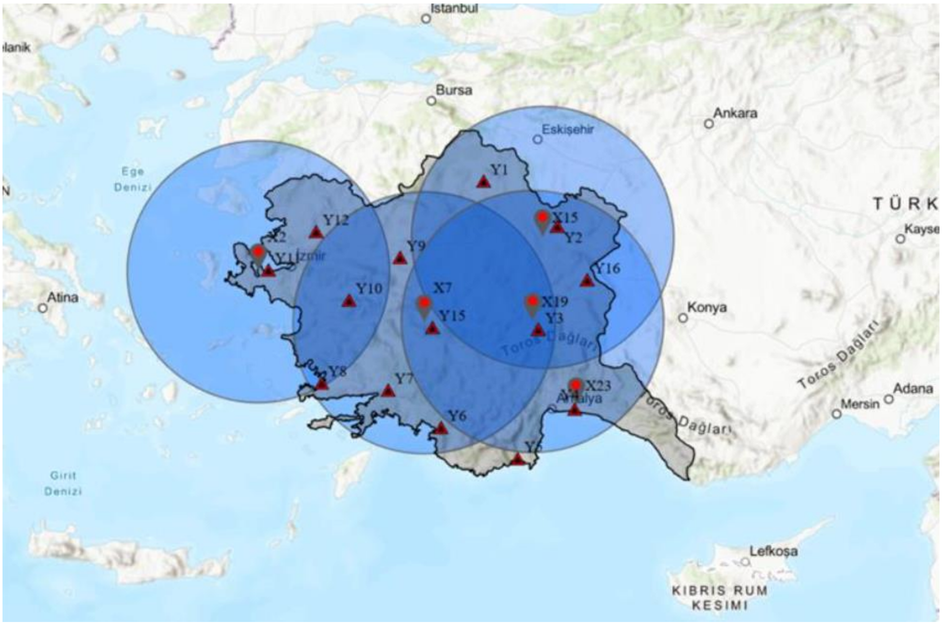


Figure 6. Selected Candidate Points and Coverage Areas (200 Km Geodetic Distance)

Analysis of Scenario 5

In the fifth scenario, the demand points within a geodetic distance of 300 km of the candidate points that meet the constraints are analyzed and the points covered are indicated as percentages. According to this scenario, only one candidate point (X7) needs to be located to achieve 100% coverage. Table 12 shows the solution results of Scenario 5 for locating different number of candidate points.

Table 12

Fifth scenario solutions for locating different number of candidate points (Geodetic distance 300 km)

Number of RDMC	Selected Candidate Points	Covered Demand Points	Number of Demands	Coverage Ratio (%)
1	X7	Y1, Y2, Y3, Y4, Y5, Y6, Y7, Y8, Y9, Y10, Y11, Y12, Y13, Y14	230	100

Within a 300 km geodetic range, the selected candidate points and their coverage areas are shown in the figure below.

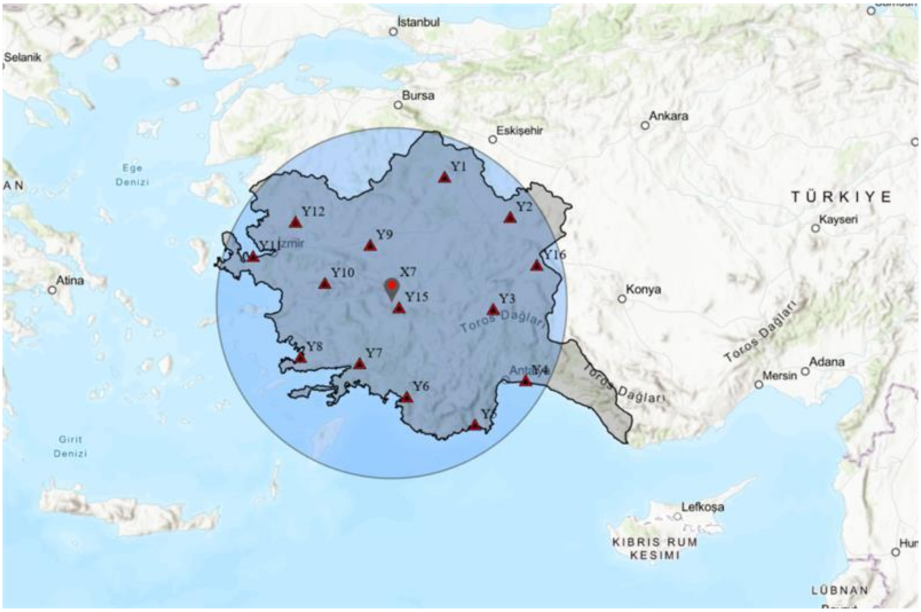


Figure 7. Selected Candidate Points and Coverage Areas (300 Km Geodetic Distance)

Analysis of Scenario 6

In the sixth scenario, the demand points within a 400 km radius of the candidate points meeting the constraints are analyzed and the percentage of points covered is indicated. Any of the three different candidate points (X7, X15, X19) can cover all demand points. Table 13 shows the solution results of Scenario 6 for locating different number of candidate points.

Table 13

Sixth scenario solutions for locating different number of candidate points (Geodetic distance 300 km)

Number of RDMC	Selected Candidate Points	Covered Demand Points	Number of Demands	Coverage Ratio (%)
1	X7	Y1, Y2, Y3, Y4, Y5, Y6, Y7, Y8, Y9, Y10, Y11, Y12, Y13, Y14	230	100
1	X15	Y1, Y2, Y3, Y4, Y5, Y6, Y7, Y8, Y9, Y10, Y11, Y12, Y13, Y14	230	100
1	X19	Y1, Y2, Y3, Y4, Y5, Y6, Y7, Y8, Y9, Y10, Y11, Y12, Y13, Y14	230	100

Within a 400 km flight range, the selected candidate points and their coverage areas are shown in the figure below.

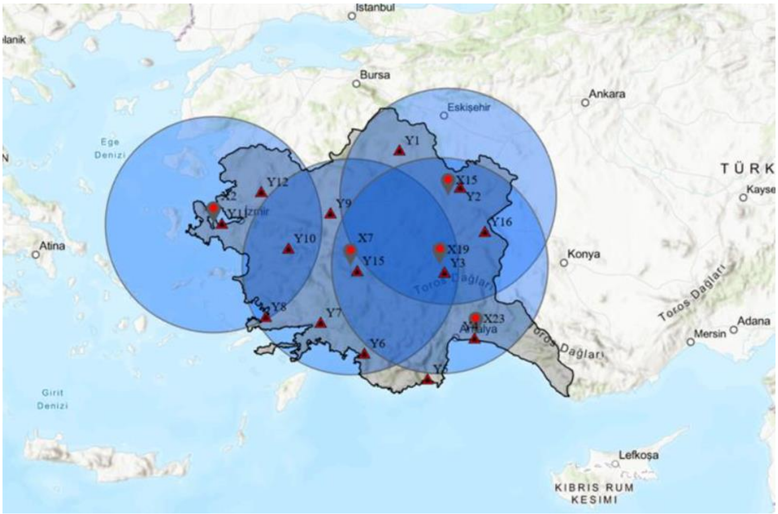


Figure 8. Selected Candidate Points and Coverage Areas (300 Km Geodetic Distance)

5. Computational Analysis

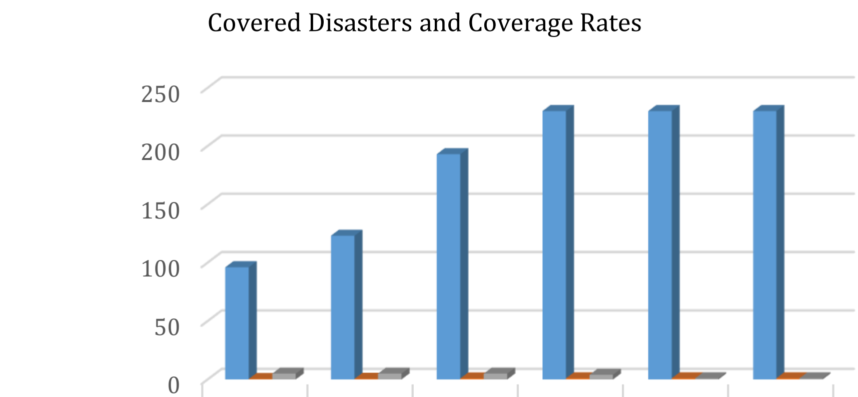
In this study, the MCLP technique has been used to determine the disaster distribution locations based on the disasters experienced in the last two decades in the Izmir Regional Disaster Area of TRC. However, since the problem is NP-Hard, full coverage could not be achieved in some scenario solutions. After finding an optimal solution to a mathematical problem, it is crucial to conduct sensitivity analysis to assess how changes in model parameters affect the solution. While sensitivity analysis is straightforward in linear programming problems, it does not yield accurate results in integer programming models like the one used here. In these models, the problem has been solved by adjusting the model parameters for each scenario and comparing the results. Parametric analysis is then conducted on the obtained results.

First of all, candidate points for distribution centers have been evaluated with three different constraints. The candidate points determined in accordance with these constraints have been solved with six different scenarios. Creating scenarios presents options to the decision maker, generating alternative options that cover multiple demand points at varying distances. Each scenario identifies coverage ratios by finding demand points covered by those that meet model constraints.

Firstly, three different solutions have been obtained according to the road distances. In the first scenario, the demand points located within a 120 km radius of the road distance of the candidate points suitable for the constraints have been solved and the coverage rates have been determined. In the second scenario, the objective is to find the demand points within a 150 km radius of the candidate points that meet the constraints. In the third scenario, the objective is to find the demand points within a 180 km radius of the candidate points that meet the constraints.

To deliver essential items during a disaster, geodetic distances have been calculated thanks to ArcGIS Route Solver. With advancing technology and transportation capacities of unmanned aerial vehicles, emergency nutrition and shelter materials can be used for disaster logistics. The fourth scenario analyzed demand points within a 200 km flight distance, determining coverage and percentages. Four candidate points cover 230 demand points, achieving full coverage. In the fifth scenario, analysis has been done on demand points within 300km flight distance of the candidate points meeting constraints. This analysis determines their coverage and percentages. The candidate disaster center covers 230 demands, ensuring full percent coverage. In scenario six, demand points within a 400 km flight distance of the candidate points are analyzed for coverage and percentages. Any of the 3 candidate points can meet all demands.

When the solutions are compared, the objective function value and the coverage percentages of the disaster points vary for the solution of each scenario. The lines colored in blue in Figure 9 show the number of disasters covered for each scenario, while the lines colored in orange show the coverage rates.



	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Number of Events	96	123	193	230	230	230
Coverage Rate	42%	53%	84%	100%	100%	100%
Candidate Points	5	5	5	4	1	1

Figure 9. The Number of Disasters Covered and Coverage Rates for Each Scenario.

Following the solutions obtained, the number of candidate points selected, and the number of demand points covered for each scenario are shown in Figure 10. With five candidate points, five demand sets can be covered in the first scenario, seven in the second scenario and eleven in the third scenario. In the fourth scenario, four candidate points cover fourteen demand sets and provide full coverage. In the fifth and sixth scenarios, full coverage has been achieved with only one candidate point.

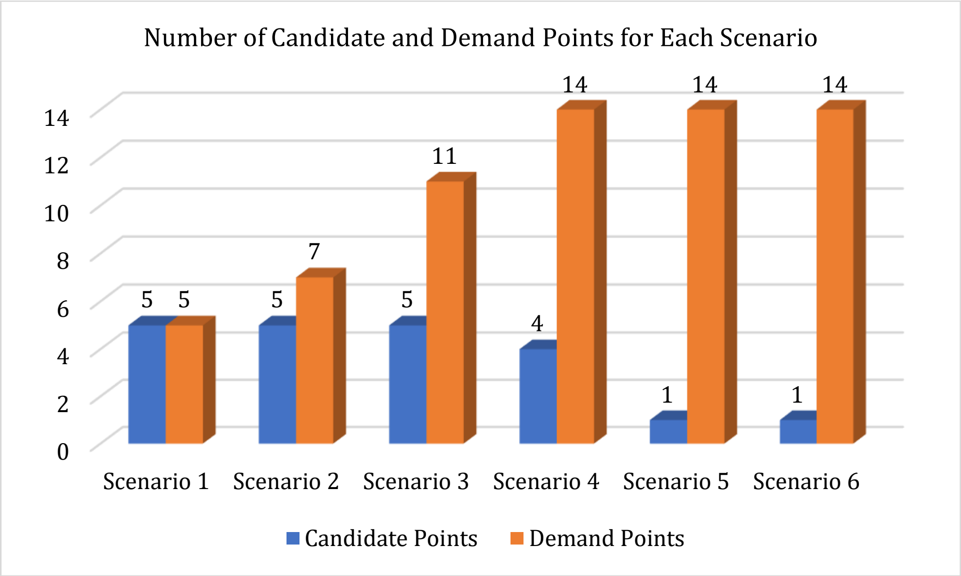


Figure 10. Number of Candidate and Demand Points for Each Scenario

In the scenario solutions, it has been emphasised that as the distances between the candidate points and the demand points increase, the coverage rates decrease, and additional facilities need to be built. In the first four scenarios, it has been observed that full coverage cannot be achieved even with five candidate points, but since it is not sustainable to open more than five facilities, no attempt has been made to select more candidate points.

Figure 11 shows the comparative number of disasters covered by the selected candidate points for each scenario.

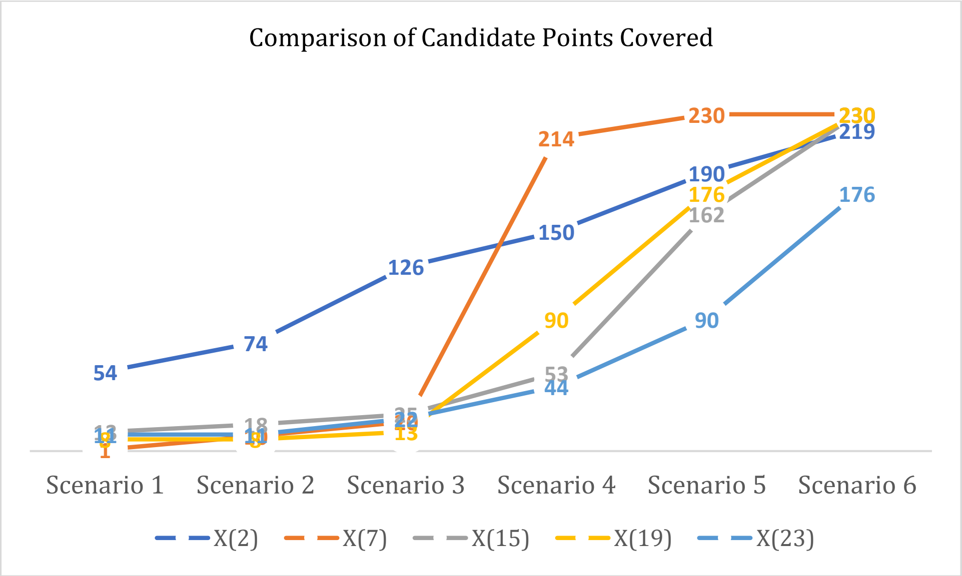


Figure 11. Comparison of Candidate Points Covered According to Different Scenarios.

6. Conclusion

Disasters are defined as events that occur in both human and natural resources and affect living life and activities negatively. Disaster management is a process that involves planning and coordinating the activities to be carried out before, during and after the disaster. The concept of disaster management consists of four phases: risk and mitigation, preparation, response, and recovery. Here, the problem of determining the location of disaster logistics warehouses, which is one of the activities belonging to the pre-disaster preparation phase, is addressed.

The problem of determining Izmir RDMC locations has been modeled using MCLP method. Demand sets have been created by analyzing past disasters in the region and candidate points have been identified to serve these demands efficiently, considering regional characteristics. Six scenarios have been created for the model. The model has been solved using ArcGIS Route Solver on a computer. After obtaining solutions for each scenario, parametric analysis has been applied to figure out how the optimal solutions changed based on the criteria used.

The results of solving the scenarios give the decision maker different options, showcasing the flexibility of the mathematical model. The effectiveness and value of the model depend on accurately reflecting the actual situations. This is crucial, especially when determining regional candidate scores, to consider the opinions of staff with regional expertise and subject matter knowledge. The model accurately depicts and is easily applicable in any area.

In the model, coverage distances have been determined based on the capacities and capabilities of RDMCs and the terrain and road conditions of the region. Developing technology and changing conditions will change the capacity and capabilities of RDMCs. Therefore, it should be taken into consideration that the coverage distance of each RDMC will also change according to the changing conditions.

Other studies that can be done for the problem examined here can be listed as follows:

In this study, RDMCs must respond to the maximum number of disaster events within a set response time. This requires using the 'Maxisum' objective function to solve the problem. An alternative approach is to determine response times based on event urgency and maximize the number of events responded to in the shortest time. Alternatively, the problem can be solved using the "Maximin" objective function. Once the RDMCs are deployed, the response route to disaster events can be determined and in case of multiple coverage, a shortest path algorithm can be used to determine which demand point should be assigned to which service center. After obtaining the optimal solution, a simulation can validate and test it. The selection of candidate points on road networks may allow for a reasonable set of candidate points and the use of a different facility location model for the problem.

Here, this application of the model is limited to Izmir RDMC, but it can be applied to other regions by determining regional feature coefficients. It can also be extended to more complex scenarios with different assumptions and parameters. The (0/1) integer programming model has been solved using ArcGIS Route Solver software. Due to the NP-hard nature of the problem, larger problems may take time to solve or may not be solved at all. In this case, heuristic methods are appropriate.

Contribution of Researchers

In this study, Murat KOÇ contributed to the collection of data, determination of the method, application, and numerical analysis, Hüseyin Ali SARIKAYA contributed to the creation of the article, review of scientific literature, conclusions, and recommendations.

Conflict of Interest

No conflict of interest is declared by the authors.

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