

Location-Allocation of Relief Containers: A Case Study for Avcılar, Istanbul

Hasret Erdoğan and Şüheda Ercan

Student, Industrial Engineering Department
Abdullah Gül University, Kayseri, Türkiye

hasret.erdogan@agu.edu.tr, suheda.ercan@agu.edu.tr

Betül Çoban Yelken

Assistant Professor, Industrial Engineering Department
Abdullah Gül University, Kayseri, Türkiye

betul.coban@agu.edu.tr

Abstract

This study addresses the problem of pre-disaster preparedness by determining the optimal locations for a limited number of relief containers. These containers serve as mobile logistics units containing essential supplies such as tents, blankets, water, and hygiene kits for immediate post-disaster use. This research proposes a strategic placement model that distinguishes between candidate locations and demand points, acknowledging that not every demand site is suitable for installation and that a single candidate site may serve multiple demand areas. The decision-making process involves two simultaneous levels: selecting the optimal candidate sites and determining the number of containers to be allocated to each selected site, considering varying physical site capacities. A critical feature of the model is the service radius, which ensures that relief is not only available but also accessible within a specific distance. The proposed approach accounts for both satisfied and unsatisfied demand, aiming to achieve a balanced and efficient distribution of limited resources. The model is applied to a case study in the Avcılar district of Istanbul to demonstrate its effectiveness in enhancing urban disaster resilience and response efficiency.

Keywords

Disaster Logistics, Facility Location, Capacity Allocation, Relief Containers.

1. Introduction

Immediately following a disaster, rapid access to basic necessities such as shelter, water, and hygiene is critical for reducing human casualties and ensuring the effective conduct of the response process. Especially in large-scale disasters like earthquakes, waiting for aid supplies to reach the affected area after the disaster can cause delays and make it difficult to meet the urgent needs that arise in the initial hours. Therefore, strategically positioning aid supplies beforehand is considered a crucial step in disaster preparedness planning.

This study addresses the problem of placing a limited number of aid containers at suitable candidate locations as part of pre-disaster preparedness. The aim is to determine a deployment plan that will most effectively meet the expected demand for temporary shelter and basic needs after a disaster, under capacity and access constraints. In the system considered, containers are mobile logistics units containing essential kits such as tents, blankets, water, hygiene materials, and similar supplies to be used in the initial post-disaster phase. However, directly placing containers at all demand points is not economically and operationally feasible. Therefore, placing containers only at a certain number of suitable candidate locations is considered a more realistic approach. The problem structure includes two different

sets. The first represents the candidate locations where containers can be placed, and the second represents the demand points where aid requests arise. These two sets do not have to be the same. Not every demand point may be suitable for container placement, and each candidate point may serve not only its location but also multiple demand points in its vicinity. Therefore, candidate locations and demand points need to be evaluated separately in the model. The first decision to be made in this problem is which candidate points will be used to place containers. However, point selection alone is not sufficient. The number of containers to be placed at each selected point must also be determined. This is because some candidate points have the physical capacity to accommodate more than one container, while others have more limited capacity. Thus, the problem includes both location selection and capacity decision-making.

In this study, the concept of demand refers to the population that gathers in specific assembly areas after a disaster and needs emergency assistance. Therefore, demand does not directly represent the total population, but rather the segment of the population that needs temporary shelter and basic needs support after a disaster and heads to specific assembly areas. The number of households in need of temporary shelter for each settlement is used as the basis for determining the amount of demand. This value represents the total number of households that will need shelter support after a disaster. However, it is assumed that these households will not gather at a single point but will be distributed among different assembly areas within the relevant settlement. Therefore, the total number of temporary shelter households for each settlement is distributed proportionally to the physical size of the assembly areas within that settlement. In other words, it is assumed that larger assembly areas will accommodate more people, while smaller areas will generate a lower level of demand. Accordingly, the demand value for each assembly area is estimated based on the ratio of the size of that area to the total size of the assembly area within the settlement.

Following the 2023 Turkey-Syria earthquakes, container settlements were established in Türkiye to meet the need for temporary shelter (OCHA, 2023). This study aims to evaluate existing containers used after the 2023 earthquake, instead of using new containers as a resource for pre-positioned storage containers. Integrating existing container resources into the aid logistics system contributes to the intended pre-disaster response plan and, through resource reuse, promotes sustainability.

One of the important elements of the problem is service range. It is assumed that each container point can only serve demand points within a certain distance. The service radius was determined by selecting a suitable distance so that individuals in need of post-disaster assistance could reach container points on foot. This situation requires not only the existence of capacity but also its accessibility. Therefore, candidate point selection is important in terms of both demand intensity and coverage success. Furthermore, it is assumed that each container has a specific and fixed capacity. As the number of containers placed at a point increases, the total service capacity of that point also increases. However, due to the limited total number of containers, the capacity must be distributed evenly and efficiently throughout the system. If the total demand exceeds the available capacity, unmet demand arises. Therefore, the problem structure considers not only the met demand but also the amount of unmet demand.

1.1 Objectives

The main objective of this study is to develop a location selection and capacity allocation model that will ensure the placement of a limited number of aid containers at the most suitable candidate points within the scope of pre-disaster preparedness. Firstly, it aims to create a decision structure that distinguishes between suitable candidate points for container placement and demand points where aid needs arise. Thus, the fact that not every demand point is directly suitable for container placement is reflected in the model. Secondly, it aims to determine how many containers should be assigned to the selected candidate points. In this way, not only location selection but also the capacity level that each point can carry is included in the decision-making process. Thirdly, the service radius constraint evaluates how many demand points around the container placement points will be covered. Fourthly, it aims to minimize the demand that cannot be met under limited resource conditions and to distribute the existing container capacity evenly and effectively among different neighborhoods in the district. Finally, it aims to provide decision-makers with an applicable and realistic planning proposal in terms of urban pre-disaster preparedness by applying the proposed model to the data.

2. Literature Review

In the field of humanitarian logistics, determining the strategic locations of storage facilities and the pre-positioning of relief items are critical for minimizing response time and maximizing the effectiveness of aid delivery. The literature

explores these issues through various modeling approaches, ranging from regional network designs to innovative mobile storage solutions.

A fundamental aspect of disaster preparedness involves evaluating regional constraints to identify optimal storage sites. Maharjan and Hanaoka (2017) addressed this by determining potential storage facility locations in Nepal. Their study evaluated the country's level of development, transportation accessibility, and disaster safety constraints while considering population densities at demand points. By building a model that incorporated variables such as road connections, earthquake-flood-landslide scenarios, and the Human Development Index, they tested storage coverage distances of 100 km, 200 km, and 300 km. Their results specifically showed that 26, 12, and 7 facilities were needed respectively for these scenarios, assuming unlimited capacity and utilizing real transportation data. Similarly, Lin et al. (2012) emphasized the necessity of decentralized distribution. Their study on the 1994 Northridge earthquake in Los Angeles demonstrated that relying on a central warehouse leads to low efficiency. By using a two-stage heuristic approach and HAZUS-MH-based demand data, they proved that a distributed network of temporary depots results in lower penalty costs and higher logistics performance compared to centralized structures.

Innovative approaches to storage have recently focused on the use of mobile units to increase flexibility. Şahin, Ertem, and Emür (2014) developed a mixed-integer programming model that utilizes shipping containers as temporary storage facilities. Their model determines the location, number, and type of aid materials to be stockpiled by analyzing earthquake risk in Türkiye, at-risk populations, and intercity distances. By balancing container capacity and destructiveness/risk indicators, they found that while some scenarios were impractical, feasible solutions led to the clustering of containers in high-risk areas. This concept of localized response is further supported by Yörük and Baykasoğlu (2025), who examined the use of containers as pre-disaster storage units specifically for the İzmir-Narlıdere region. Their study identified existing shortcomings in management processes and proposed a mathematical model to ensure disaster victims have direct access to materials before organized aid arrives. This approach consciously differs from a centralized warehouse structure, establishing a fast and accessible aid system that reduces response time in risky areas.

Istanbul's high seismic risk has led to specialized research on urban disaster logistics. Başkaya (2015) addressed the pre-positioning of items in Istanbul by establishing mixed-integer programming models that optimize location selection, stock quantity, and distribution. A significant contribution of this study was the evaluation of "lateral shipment" (stock sharing between centers) and the inclusion of sea transportation. Testing the model with real data, where warehouse capacities were determined by the number of classrooms in public schools, the study concluded that stock sharing significantly reduces average transportation distances and enables faster distribution. On the other hand, Kılçı, Kara, and Bozkaya (2015) shifted the focus to the problem of locating temporary shelter areas in the Kartal district. They criticized the traditional criterion-based ranking and developed a model that balances capacity utilization rates and population allocation. Their analysis revealed that occupancy difference constraints are decisive, and that the model's viability is highly sensitive to distance restrictions from health centers and main roads.

Furthermore, the necessity of flexible network designs is highlighted by Temur et al. (2019) in their study of the Ümraniye district. By integrating demand distributions corresponding to different damage levels, they formulated a mixed-integer linear programming model that showed how warehouse placement and distribution strategies vary significantly depending on the earthquake scenario. Finally, the importance of incorporating geotechnical risk into these logistical decisions is demonstrated by Cranswick et al. (2000). Their investigation in the Avcılar region after the 1999 Kocaeli earthquake showed that building damage was ten times higher in certain areas due to the overlap between low-frequency seismic wave amplification and the natural frequency of buildings. This finding suggests that disaster planning and logistics must look beyond simple geographical location and consider soil characteristics and wave propagation as critical factors in facility placement.

In his study, Arslan (2017) addressed the optimal placement of disaster containers to increase the probability of survival in post-disaster response processes. The study modeled the optimal placement of six disaster containers within a 3 km coverage distance for 56 settlements in the Düzce city center. The modeling process utilized p-median, fixed-cost facility site selection without capacity, and maximum coverage models. The Lagrange approach from classical methods and the genetic algorithm from modern methods were applied for the solution. Furthermore, criteria such as population size, distance to health facilities, distance to the disaster coordination center, and access to main roads were considered in the model. The findings show that different optimization methods provide similar coverage rates and that all demand points can be covered 100% with appropriate placement.

Yoruk et al. (2023) addressed the positioning of neighborhood disaster stations and the determination of replenishment distribution routes from the main depot to these stations to support rapid response after a disaster. In this context, a multi-objective mixed-integer linear programming model was developed that comprehensively examines the positioning and replenishment problems, thus contributing to a significant gap in literature. The first objective of the model is to increase accessibility by minimizing the maximum distance between post-disaster assembly areas and the nearest disaster station, and the second objective is to minimize the total transportation cost during the replenishment process. The model was tested using real data from the Buca district of Izmir province. The findings show that the appropriate positioning of disaster stations significantly increases accessibility and that operational costs can be effectively controlled by optimizing replenishment routes. Furthermore, it was determined that increasing the number of containers reduces access distance but increases costs, revealing a significant cost-service balance.

Studies in the literature generally focus on placing disaster containers at appropriate locations, reducing access distances, pre-positioning aid materials, or minimizing transportation costs during replenishment processes. This study, however, differs from these approaches by analyzing how a limited number of containers can be allocated to demand points under realistic capacity constraints and different container scenarios, and the impact of this allocation on met and unmet demand. In the model, candidate container locations and demand points are treated as separate clusters, the maximum number of containers that can be placed is determined according to the spatial capacity of each candidate point, and container capacity is physically justified based on aid kit volume and container internal volume. Furthermore, by comparing scenarios with 100, 200, 300 and 400 containers under a 2 km service radius, the impact of changes in resource quantity on the number of opened candidate points, met demand, unmet demand, and overall response rate is revealed. In this respect, the study goes beyond merely presenting an accessibility-based site selection model; it develops a practical decision support approach that evaluates capacity adequacy and the impact of resource increases on service levels in pre-disaster container planning.

In their study, Şahin, Ertem, and Emür (2014) examined the pre-positioning of aid materials in containers instead of permanent warehouse structures in humanitarian aid logistics. The study developed a mixed integer linear programming model to strategically place containers before a disaster, determine the number of containers, and simultaneously optimize the type and quantity of aid materials to be stored at each point. The model was tested using AFAD data for Turkey as a whole, considering earthquake risk, potentially affected population, and intercity distance data. The objective function focused on minimizing the total distance between demand points and container locations. The findings showed that positioning containers near high-risk areas enabled service to disaster victims from a shorter distance and that the mobile storage approach offered a flexible alternative to traditional fixed warehouse systems.

Rawls and Turnquist (2010) developed an optimization model for positioning aid supplies before a disaster in post-disaster response processes. The study emphasizes that traditional deterministic approaches are insufficient due to the uncertainty surrounding when, where, and the magnitude of natural disasters will occur, and proposes a stochastic approach to model this uncertainty. A two-stage stochastic mixed integer programming model was developed in the study. The first stage covers warehouse location and stock levels, while the second stage covers distribution decisions based on the actual scenario. Uncertainty was modeled considering different disaster scenarios and probabilities, as well as facility damage and disruptions in the transportation network. The model was tested with a case study on hurricane risk in the southeastern United States. The analysis results show that positioning aid supplies at appropriate locations before a disaster reduces response time and provides more efficient access to demand points. Furthermore, the model was shown to produce cost-effective solutions by balancing stock levels with the costs of unmet demand. Boonmee, Arimura, and Asada (2017) presented a review of facility location problems in disaster logistics, highlighting the critical role of locating distribution centers, warehouses, and shelters in disaster management. In the study, facility location problems for disaster logistics were classified into four main categories: deterministic, stochastic, dynamic, and robust models, and how these models are applied at different levels of data uncertainty was analyzed. The majority of the studies examined used mixed integer linear programming models involving facility location, demand assignment, and capacity decisions, and the objective functions generally focused on minimizing total cost, transportation distance, or unmet demand. The findings indicate that an integrated approach to pre- and post-disaster decisions allows for more effective and realistic logistics planning.

Balcık and Beamon (2008), in their study, emphasized that factors such as demand uncertainty, limited resources, and the need for rapid response in disaster logistics create a more complex structure compared to classical facility location problems. Accordingly, they used a mixed integer programming method based on a maximum coverage model to

optimize the number, location, and stock levels of distribution centers together. In the developed model, different types of aid materials were considered along with capacity and budget constraints, and the goal was to meet demand points within a specific service time. The model was tested on a scenario-based dataset created using global earthquake data and showed that the location of distribution centers had significant effects on response time and demand fulfillment rate. The findings reveal that stocking aid materials at appropriate locations before a disaster increases the speed of response and enables the fulfillment of greater demands.

Demirbaş and Ertem (2021) present a study addressing the concept of equivalent warehouses in humanitarian aid logistics. The study highlights that container-based warehouses storing different types of aid materials (e.g., tents, beds, blankets) before disasters suffer from unbalanced resource structures, leading to delays in post-disaster response operations. To address this problem, the authors propose reallocating existing resources and converting selected warehouses into equivalent warehouses containing a balanced mix of all aid materials. The proposed model is formulated as a location reallocation problem and solved using a mixed integer programming approach. The model was tested using historical earthquake data from Türkiye and evaluated under different disaster scenarios. The results show that the equivalent warehouse approach significantly improves response performance, especially in large-scale disaster scenarios. Furthermore, the study demonstrates that it is not necessary to convert all warehouses; instead, converting a limited number of strategically selected warehouses into equivalent warehouses is sufficient to achieve significant improvements in operational efficiency

3. Mathematical Model

Sets

i : Demand locations

j : Candidate container locations

Parameters

c_i : Estimated demand at demand point i

D_{ij} : Distance between demand point i and candidate location j

Q : Capacity of one relief container

U_j : Maximum number of containers that can be placed at candidate location j

H : Total number of available containers

R : Maximum service radius

Variables:

y_j : 1 if candidate location j is opened, 0 otherwise

n_j : Number of containers placed at candidate location j

x_{ij} : Amount of demand at point i served by candidate location j

t_i : Unmet demand at demand point i

The proposed mathematical model is a single-objective mixed-integer linear programming model formulated to decide the placement of pre-disaster relief containers in the Avcılar district and the provision of services from these containers to post-disaster demand points. In the model, demand points represent assembly and tent areas where post-disaster aid may be needed; candidate points represent potential sites suitable for container placement. The main objective of the model is to minimize the total unmet demand by allocating a limited number of containers to selected candidate sites. Each demand location can only receive services from candidate points within the determined maximum coverage distance R , and the number of containers that can be placed at each candidate point is limited by an upper limit U_j determined based on the physical capacity of the relevant area. In addition, the amount of service that can be provided from candidate points to demand points is controlled by capacity constraints, taking into account the fixed aid capacity Q of each container. Thus, the model helps improve access to aid after a disaster and while making effective use of the available container capacity.

Mathematical Model:

$$\min Z = \sum_{i \in I} t_i \quad (1)$$

Subject to

$$\sum_{j \in J} x_{ij} + t_i = c_i \quad \forall i \in I \quad (2)$$

$$\sum_{i \in I} x_{ij} \leq Q n_j \quad \forall j \in J \quad (3)$$

$$n_j \leq U_j y_j \quad \forall j \in J \quad (4)$$

$$n_j \geq y_j \quad \forall j \in J \quad (5)$$

$$\sum_{j \in J} n_j \leq H \quad (6)$$

$$y_j \in \{0,1\} \quad \forall j \in J \quad (7)$$

$$n_j \in \mathbb{Z}_+ \quad \forall j \in J \quad (8)$$

$$x_{ij} \geq 0 \quad \forall i \in I, j \in J \quad (9)$$

$$t_i \geq 0 \quad \forall i \in I \quad (10)$$

The objective function in Equation (1) aims to minimize the demand of demand points. Constraint (2) shows the demand balance. The sum of unmet demand and met demand is the demand of the demand point. Constraint (3) limits the amount of demand that a candidate point can meet based on the number of containers at each candidate location and the capacity of a single container. Constraints (4) and (5) ensure that containers are placed only in open spaces and that each open space can accommodate at least one container. Constraint (6) limits the total number of containers that can be placed based on the container upper limit defined in the scenario. Constraints (7)-(10) allow decision variables to be defined as binary, integer, and non-negative continuous variables.

4. Case Study for Avcilar District in Istanbul

Avcilar, one of Istanbul's districts with a high earthquake risk, was selected as the application area for this study. Due to its high population density, building stock characteristics, and soil structure, the district is at risk in the event of a major Istanbul earthquake. Earthquake scenario studies conducted by the Kandilli Observatory and Earthquake Research Institute indicate that Avcilar is among the districts with a high risk of damage and loss. Therefore, the strategic placement of pre-disaster aid containers is important for the Avcilar district disaster response plan (Erdik et al., 2003).

The data used in this case study were compiled from various sources. First, candidate locations for placing aid containers were identified, considering open spaces, assembly areas, suitable public areas, and other physically suitable areas for container placement. Demand points were defined as assembly areas where individuals are expected to gather after a disaster. In this context, spatial data and area information regarding assembly areas were obtained from the disaster information system provided by Avcilar Municipality. The dataset was created using the assembly area lists and maps available in the system. In this study, a total of 148 demand points and 143 candidate container locations were identified. The distances between candidate points and demand points were calculated using the geographical coordinates of these areas. Considering the latitude and longitude values of each point, the distance between two points is obtained using the Haversine formula. Thus, a distance matrix representing the distances between candidate locations and demand points is created.

In this study, demand data was generated based on an assumption about the number of households predicted to become homeless after a potential earthquake. The data used was obtained from an earthquake scenario study prepared jointly by the Istanbul Metropolitan Municipality and the Kandilli Observatory and Earthquake Research Institute, which estimates building damage and temporary shelter needs at the neighborhood level (Istanbul Metropolitan Municipality 2019). As shown in Table 1, This study presents the damage, loss, and shelter needs values that could occur for each neighborhood under a scenario earthquake of magnitude Mw=7.5.

Based on this data, the estimated total number of homeless households in each neighborhood was distributed to the designated assembly areas within that neighborhood. The distribution was carried out proportionally based on the surface area (m²) of each assembly area. The sizes of the assembly areas were determined using geographical measurements obtained from Google Earth.

Table 1. Neighborhood-Based Temporary Shelter Need Values for the Mw 7.5 Scenario Earthquake

NEIGHBORHOOD NAME	TEMPORARY SHELTER NEED (NUMBER OF HOUSEHOLDS)
Ambarlı	3.699
Cihangir	5.464
Denizköşkler	4.086
Firuzköy	2.073
Gümüşpala	3.833
Merkez	2.751
Mustafa Kemalpaşa	3.863
Tahtakale	2.247
Üniversite	1.617
Yeşilkent	5.308

The capacity parameter used in the model is determined based on the volume of aid containers and the volumetric requirements of aid kits. Each aid kit is designed to serve one family. The kit consists of materials that provide basic shelter and life support; these include a family tent, blankets, drinking water, a flashlight, and a hygiene kit. This content is considered a standard aid package to meet the basic needs of families in the initial stages of a disaster. To determine the capacity of an aid container, the dimensions and usable internal volume of the container are considered first. Then, the approximate space volume occupied by each aid kit is calculated, and the total number of kits that can fit inside a container is estimated. Assuming that each kit represents a family, the number of kits per container also indicates the number of families that the container can serve. This value is used as the capacity of a container in the model. Thus, the capacity parameter is defined as a quantity based on the logic of physical storage.

Table 2. Capacity Estimation for One 20 ft Relief Container

Component	Quantity per Family Kit	Unit Volume Used in Calculation	Volume per Family Kit
Family tent	1	0.04400 m ³	0.04400 m ³
Synthetic blanket	3	0.02340 m ³	0.07020 m ³
Flashlight	1	0.00025 m ³	0.00025 m ³
5 L water and hygiene kit	1	0.00972 m ³	0.00972 m ³
Total volume of one family relief kit			0.12417 m ³
20 ft container nominal internal volume	1	33.2 m ³	
Operational usable volume ratio		36.5%	12.118 m ³
Estimated container capacity			97 kits/container

The container capacity parameter used in the model was estimated based on the packed volume of the items included in the family aid kit presented in Table 2. The volume of the family tent is calculated according to UNHCR's family tent packing dimensions of 110 × 25 × 16 cm, with a volume of 0.044 m³. The blanket volume is estimated at

approximately 0.023 m³ per blanket, considering the dimensions of UNHCR's high-heat-resistant synthetic blanket bale of 85 × 55 × 75 cm for 15 blankets. The nominal internal volume of a standard 20 ft container is 33,200 m³. For the flashlight and 5 L water and hygiene kit, there are no standardized dimensions, therefore approximate volume assumptions were used. Since the container volume cannot logically be fully utilized, an assumption of a usable volume ratio of 36,500% is applied, taking into account loading spaces, access area, and stacking inefficiencies. Based on these calculations, the model assumed that one 20-foot container would hold 97 family aid kits.

The maximum number of containers for candidate locations was determined by considering area size, physical suitability, and operational constraints. The maximum number of containers that can be placed at each candidate location is determined based on the physical size of the area. Since candidate locations mostly consist of public open spaces such as schoolyards, parks, market areas, squares, and designated gathering areas, it is not feasible to use all of these areas for container placement. Therefore, it is assumed that only 10% of the total area of each candidate location will be used for container placement. This usable area is then divided into 30 m² of operational space, assumed to be required for one container, and the maximum number of containers for each candidate location is determined. The resulting dataset consists of demand points, candidate settlement points, distance matrix, service radius, kit capacity per container, maximum number of containers per location, and estimated aid demand based on assembly area. This data structure makes it possible to apply the proposed model to a real urban disaster preparedness problem and to interpret the results from an operational perspective.

5. Results and Discussion

In this section, the proposed mathematical model is evaluated for different container numbers under a 2 km service radius. The demand met, unmet demand, number of candidate points opened, and capacity utilization are analyzed by increasing the container number from 100 to 400.

In the present study, scenarios with service radius of 2 km, 5 km, and 10 km and different container numbers were tested. It was concluded that a service radius of 2 km is sufficient in terms of access to demand points. Therefore, no significant change was observed in assignment when the service radius was increased to 5 km and 10 km. The model did not shift to more distant candidate points because it could fulfill the demand from nearby candidate points.

Table 3. Summary of Demand Coverage Results under Different Container Availability Scenarios

Indicators	2 km - 100 containers	2 km - 200 containers	2 km - 300 containers	2 km - 400 containers
Number of opened candidate locations	36	46	68	87
Total used containers	100	200	300	369
Total demand	34,941	34,941	34,941	34,941
Served demand	9,700	19,400	29,100	34,941
Unmet demand	25,241	15,541	5,841	0
Overall coverage rate (%)	27.76%	55.52%	83.28%	100.00%
Fully served demand points	57	86	108	148
Partially served demand points	15	16	9	0
Unserved demand points	76	46	31	0
Maximum service distance	≤ 2 km	≤ 2 km	≤ 2 km	≤ 2 km

In this study, a mixed integer linear programming (MILP) model was developed in the GAMS 53.5.1 environment and solved using the CPLEX 22.1.2 solver on the NEOS Server. In the largest scenario, with a service radius of 2 km and 400 aid containers, the model uses 727 constraints, 21,599 decision variables, and 64,642 non-zero coefficients. 286 of the variables are discrete (binary or integer) variables. The model was solved optimally with zero optimality gap, and the total solution time was approximately 0.21 seconds. This model analyzes four different scenarios involving 100, 200, 300, and 400 aid containers. Since the model structure remains the same between scenarios, the calculation statistics are based on the largest scenario, which involves 400 containers.

Table 3 shows that the increase in the number of containers directly affects the met demand. In the 100-container scenario, only 27.76% of the total demand was met, while in the 200-container scenario, 55.52% was met, and in the 300-container scenario, 83.28% was met. In the 400-container scenario, the model met all the demand using only 369 containers, and the unmet demand dropped to zero (Table 4).

Table 4. Comparison of Service Radius Scenarios for 400 Containers

Radius	Open Sites	Coverage
2 km	88	100%
5 km	99	100%
10 km	94	100%



Figure 1. Avcılar container candidate locations placement for 2 km service radius and 400 container scenario

Figure 1 shows the candidate locations and representative demand assignments opened for a 2 km service radius and 400 container scenario. Blue dots represent active candidate locations and the number of containers, while red dots represent demand points. The results show that containers are not concentrated in a single area but are distributed in varying numbers across different neighborhoods and according to neighborhood capacity. The results indicate that the

number of containers is a decisive decision variable in pre-disaster relief material placement planning. When the number and capacity of containers are insufficient, a significant portion of the demand cannot be met, while when sufficient capacity is reached, all demand can be met.

6. Conclusion

This study applies a mixed-integer linear programming model to the placement and assignment of pre-disaster relief containers to demand points in the Avcılar district. The model determines the candidate container locations to be selected, the number of containers to be assigned to each selected location, and the demand points to be served within the defined service radius. Scenario results show that increasing the number of containers significantly reduces unmet demand. In a scenario with 400 containers and a service radius of 2 km, it was observed that a total of 34,941 units of demand could be fully met using 369 containers. The unique contribution of this study is that it adapts the location assignment-based optimization approach to the district-scale disaster relief container placement problem by considering local demand levels, candidate location capacities, container capacities, different container number scenarios, and service radius constraints together. The proposed model can support local governments in planning pre-disaster relief resources in a more systematic and data-driven manner.

6.1 Limitations

While the developed model provides a robust framework for disaster response logistics, its practical application is bounded by some simplifying assumptions and data constraints:

- **Proportional Demand Distribution:** The model assumes that population and subsequent relief demand are distributed uniformly or proportionally across specified geographic areas. In reality, demographic density and localized vulnerability factors can cause demand to cluster unpredictably.
- **Fixed Kit Volume and Rigid Usable Ratios:** A static volume was assumed for the relief kits, combined with a strict 36.5% usable volume ratio for storage efficiency. This does not account for potential variations in packaging sizes or alternative stacking configurations that could optimize space.
- **Conservative Candidate Area Constraints:** The available space for establishing distribution centers was restricted to a 10% usable candidate area to account for zoning and immediate post-disaster land constraints. While pragmatic, this strict threshold may prematurely exclude viable logistics sites.
- **Distance Metrics:** Transportation and allocation calculations rely on Euclidean distance rather than actual road network distances. This geometric simplification inherently underestimates travel times and fails to account for real-world routing barriers, traffic congestion, or post-earthquake infrastructure damage.

6.2 Future Research

To bridge the gap between this strategic model and real-world operational complexities, several avenues for future research are proposed:

- **Multi-Objective Formulations:** Future iterations should evolve from a single-objective focus (such as cost or distance minimization) to multi-objective optimization. This would allow decision-makers to explicitly evaluate the trade-offs between financial efficiency, operational speed, and social equity (e.g., ensuring underserved populations receive equal priority).
- **Stochastic Demand and Varying Earthquake Magnitudes:** Rather than relying on deterministic demand profiles, integrating stochastic (probabilistic) demand variations would better reflect reality. Modeling demand as a function of different earthquake magnitudes and epicenter locations will allow for dynamic scenario planning and more resilient supply chain networks.

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Biographies

Betül ÇOBAN YELKEN is an Assistant Prof. of Industrial Engineering at Abdullah Gül University, Kayseri. She completed his BS and MS education at TOBB ETÜ, Ankara and PhD at University of Kent. Her research interests include optimization theory and algorithms and their applications in disaster management and humanitarian logistics systems. Her specialties include optimization, mixed-integer programming models and theory and algorithms.

Hasret ERDOĞAN is an undergraduate student in the Department of Industrial Engineering at Abdullah Gül University, Kayseri. Her research interests include data science, business analytics, optimization, and decision support systems.

Şüheda ERCAN is also an undergraduate student in the Department of Industrial Engineering at Abdullah Gül University, Kayseri. Her research interests include optimization, operations research, logistics planning, and decision support systems.