

A Multi-Type Capacity Allocation Model for Field Hospital Location

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Abstract

This study presents a strategic optimization framework for post-disaster healthcare management in Istanbul, a metropolis facing significant seismic risks. The research develops a Mixed-Integer Linear Programming (MILP) model designed to bridge the gap between overwhelmed fixed medical infrastructures and the urgent need for temporary field hospitals. Beyond traditional facility location problems, the model incorporates spatial resource constraints to evaluate the trade-off between total patient volume and clinical urgency. The findings highlight a definitive operational threshold where the system shifts its priority to maximize survival rates for the most vulnerable casualties. By quantifying the balance between medical capacity and urban accessibility, this study offers a decision-support tool that enhances the resilience and life-saving potential of emergency healthcare networks in high-density urban environments. The study offers a decision-support framework for emergency planners to enhance the resilience and responsiveness of İstanbul healthcare systems under large-scale disaster scenarios.

Keywords

Earthquake Preparedness, Facility Location, Optimization Models.

1. Introduction

Earthquakes, which occur when the Earth's crust releases accumulated stress between tectonic plates through a sudden release of energy, are among the most destructive natural disasters affecting human systems. The North Anatolian Fault (NAF), one of the most active structures defining Turkey's seismic characteristics, has shaped the morphology and settlement fabric of the Anatolian landscape by periodically generating high-magnitude earthquakes throughout history. For a megacity like Istanbul, which hosts a high population density, a heterogeneous building stock, and critical industrial zones, this situation is not merely a seismic event but also carries the potential to evolve into a national security and public health crisis.

Projections of structural damage from the anticipated major Istanbul earthquake, combined with the complex nature of the urban fabric, necessitate strategic planning that goes beyond traditional emergency response protocols. Yurtlu et al. (2024) states that the first 72-hour period following the disaster, conceptualized in the literature as the "golden hours," constitutes the system's most critical phase in terms of maximizing survival rates. Yıldırım et al. (2018) claims that the time-sensitive nature of acute traumatic conditions—such as crush syndrome, hypovolemic shock, and multiple organ failure—transforms patient evacuation from a mere transportation activity into a dynamic optimization

problem that must be solved under constraints of limited time and resources. Istanbul's topographical challenges and the risk that viaducts, bridges, and narrow streets may become inaccessible during a potential disaster make this time constraint an even more critical parameter. Kişi et al. (2025) argues that risk management is of vital importance for ensuring public health security at the national and global levels, strengthening access to universal health care, and building the resilience of communities, countries, and health systems.

The nature of Istanbul's existing healthcare infrastructure's response to this massive surge in demand is the key determinant of the system's overall resilience. While the bed capacities and technological equipment of existing hospitals may appear on paper to meet a certain need, the operational continuity of these facilities during a disaster is at serious risk due to a lack of seismic isolation, disruptions in the medical supply chain, and power outages. Ekinci et al. (2024) indicates that hospitals' current capacities may prove insufficient during disasters. Modeling the potential bottlenecks of existing healthcare facilities using prior empirical data and capacity projections is essential to prevent system failures during a disaster. If the existing hospital network becomes isolated due to destroyed transportation arteries or is exposed to an influx of casualties far exceeding its capacity, the risk of triage processes becoming dysfunctional and preventable loss of life will be maximized.

The strategic mechanism that will bridge this operational gap and support urban resilience is field hospitals. In disaster logistics, field hospitals serve not only as temporary treatment areas but also as strategic buffer zones that alleviate the excessive burden on central hospitals. The rational and mathematically grounded placement of these units in areas where demand is highest but access to permanent healthcare facilities is limited directly increases the success of interventions within the "golden hours" by minimizing evacuation times. Consequently, selecting the right and optimal locations for field hospitals is of critical importance. Özkan et al. (2024) say that appropriate site selection is a critical factor for the effectiveness of healthcare services. Consequently, considering Istanbul's seismic risk profile, shifting disaster management to a proactive framework necessitates the integration of optimized field hospital site selection strategies developed through a detailed analysis of existing capacities and utilizing operations research techniques.

1.1 Objectives

This study addresses the issue of "strategic site selection and capacity of field hospitals" with the aim of enhancing the effectiveness of the post-disaster emergency medical response network under the scenario of the anticipated large-scale Istanbul earthquake. The primary focus of the research is to minimize unmet demand for patient evacuation during the critical post-disaster phase and to minimize the total access distance between demand points and medical units. The developed mathematical model defines the operational capacities of Istanbul's existing hospital inventory and the logistical capacity limits of the planned field hospitals as primary constraints. Under these constraints, a framework has been designed to simultaneously optimize the objectives of "maximum coverage area" and "distance minimization" to enhance the system's overall accessibility.

The developed model aims to determine the optimal locations for field hospitals within a scientific analytical framework. The fundamental value of this study compared to theoretical models in literature lie in the fact that it allocates capacity in field hospitals by considering injured patients requiring intensive care, and that it was conducted on an empirical basis using Istanbul's actual healthcare infrastructure data and current spatial coordinates rather than hypothetical scenarios. It is believed that the findings will provide decision-makers with data-driven insights for disaster logistics planning.

2. Literature Review

Disaster management is a vital challenge for modern society, especially when dealing with large-scale events like earthquakes. In the immediate aftermath of a disaster, the success of the emergency medical response determines survival rates during the "golden hours." To manage this crisis, it is essential to treat disaster response not just as a series of isolated actions, but as a coordinated system. Beamon and Kotleba (2006) showed that the foundation of an effective response lies in how well medical resources and facilities are positioned before and during the crisis. Many studies emphasize that the main goal of these logistics systems is to provide life-saving services as quickly as possible. For instance, Caunhye et al. (2012) reviewed various optimization models and explained how analytical tools can help balance speed and cost in emergency situations. Furthermore, Galindo and Batta (2013) argued that a well-planned facility network is the first step toward a time-efficient medical response. Therefore, building a scientific framework for site selection is not just a mathematical task but a necessity for saving lives.

The strategic deployment of temporary medical units, specifically field hospitals, constitutes a vital component of disaster preparedness and response strategies. Research in this domain has evolved from basic location-allocation models to sophisticated frameworks that prioritize rapid accessibility and geographical coverage. For instance, Boonmee et al. (2017) developed the SC network with uncertainty in their comprehensive review, noting that facility location is the most critical strategic decision in humanitarian aid. Furthermore, Rath and Gutjahr (2014) developed the SC network with uncertainty by integrating warehouse location and inventory planning, establishing the importance of multi-level facility networks. While these studies provide a foundation for temporary facility placement, the dynamic nature of seismic events requires models that can adapt to high-density urban environments where space and time are severely constrained.

In recent years, the focus has shifted toward more specialized networks that consider the logistical constraints of post-disaster zones. Vargas-Florez et al. (2015) developed the SC network with uncertainty by emphasizing the resilience of access routes between demand points and medical units, highlighting that a site's effectiveness is often dictated by its connectivity. Additionally, Loretto and Chiarini (2020) developed the SC network with uncertainty to address the operational challenges of setting up field hospitals in immediate response phases, noting the trade-off between deployment speed and long-term stability. As noted by Kunz and Gold (2017), who developed the SC network with uncertainty in the context of humanitarian supply chains, the lack of coordination between existing infrastructures and temporary facilities remains a primary bottleneck. This underscores the necessity for a model that bridges the gap between fixed hospital inventories and mobile field units.

A significant challenge in disaster medical logistics is the accurate allocation of facility capacities to reflect the varying severity of patient injuries. In this context, Salman and Gül (2014) proposed a multi-period integer programming model to simultaneously optimize capacity allocation and casualty evacuation decisions, focusing on the size and location of field hospitals to meet surge demand. While their work established a critical foundation for capacity planning, the broader literature still frequently treats hospital beds as generic resources. For instance, Bozorgi-Fard et al. (2020) argued that neglecting injury severity leads to inefficient resource allocation, particularly when dealing with multi-priority casualties. This problem is more pronounced in large urban settings like Istanbul, where the demand for specialized care often surpasses available capacity. Although studies by Ghasemi et al. (2022) and He and Liu (2021) have integrated triage-based classifications and hierarchical systems, they primarily focused on general medical supplies or general facility performance rather than differentiated intensive care unit (ICU) capacities.

This study brings together the critical elements discussed in literature to create a practical solution for Istanbul. Unlike many theoretical models, this research focuses on the actual capacity of existing hospitals and the specific needs of intensive care (ICU) patients. By combining "maximum coverage" with "minimum distance" in a single framework, the developed model offers a realistic way to place field hospitals. The main value of this work is its empirical basis; it uses real spatial data and current healthcare infrastructure instead of hypothetical numbers. As a result, the findings provide a data-driven guide for decision-makers to improve the effectiveness of the emergency medical response during a large-scale Istanbul earthquake.

3. Mathematical Model

The Field Hospital Allocation Model is based on the principle of managing limited medical resources in a way that maximizes social benefit within Istanbul's seismic risk profile. The model's basic structure is designed to organize complex network relationships among the nodes where patient demand arises (i), existing healthcare centers that ensure operational continuity (j), and candidate field hospital locations planned for strategic placement (h). Unlike standard facility site selection models in literature, this formulation addresses service capacity within a heterogeneous structure. In this context, service capacities are divided into two main categories: general care and highly equipped intensive care services for critical injuries. This distinction enables the model to prioritize resource allocation for the most critical cases in accordance with its triage logic.

The operational framework of the proposed mathematical model is built upon a set of deterministic parameters that balance post-disaster healthcare demand with existing and temporary medical resources. The model's prioritization mechanism is controlled by the weight coefficient w_t which determines the importance of unmet demand based on service types. Regarding logistical capacity management, the maximum service capacities of existing hospitals C_{ij} and candidate field hospitals M_{ht} serve as fundamental thresholds limiting the system's demand-fulfillment capability. In the field hospital establishment process, the physical suitability of candidate locations is monitored through the total

available area A_h and the required unit area per bed type G_t ; this approach ensures that square-meter-based physical constraints are rationally converted into medical capacity. While geographical accessibility is optimized through distance data between demand points and hospitals D^1_{ij} or potential field hospital locations D^2_{ih} , the total number of facilities to be established F is integrated into the model.

The proposed mathematical model manages the complex post-disaster healthcare network through a coordinated set of binary and continuous decision variables. The variable y_h determines the strategic opening of a potential field hospital at candidate location h , while the assignment of specific demand points to the existing healthcare infrastructure or the newly established field hospitals is governed by x_{ij} and z_{ih} , respectively. These binary decisions establish the foundational links between injured populations and medical facilities. The operational capacity for each specific service type at a field hospital is defined by p_{ht} , which ensures that the available space is rationally distributed between general and intensive care. The movement of patients is precisely tracked through n_{ijt} representing the volume of people assigned from demand point i to hospital j for service type t , and m_{iht} , which captures the corresponding flow to field hospitals. Finally, the model monitors the efficiency of the entire system through u_{it} , a critical variable that quantifies the unmet demand for each service type at every location.

Sets

I : Demand locations

J : Existing hospitals

H : Potential field hospitals

T : Types of service support type (normal bed and intensive care bed)

Parameters

W_t : Weight of the unmet demand for service type t

D_{it} : Number of people requiring type t service support type at demand point i

C_{jt} : Maximum service capacity for t service support type of hospital j

M_{ht} : Maximum service capacity for t service support type of field hospital h

A_h : Total available area of potential field hospital h (m²)

D^1_{ij} : Distance between demand point i and hospital j

D^2_{ih} : Distance between demand point i and field hospital

G_t : Required area (m²) per unit of type t bed

F : Number of field hospitals to be established

Variables

x_{ij} : 1 if demand point i is assigned to hospital j , 0 otherwise

z_{ih} : 1 if demand point i is assigned to potential field hospital h , 0 otherwise

y_h : 1 if potential field hospital h is opened, 0 otherwise

p_{ht} : Capacity of type t service at field hospital h

n_{ijt} : Number of people assigned to hospital j from demand point i for service type t

m_{iht} : Number of people assigned to field hospital h from demand point i for service type t

u_{it} : Unmet demand for service type t at demand point i

The proposed mathematical model is based on a Weighted Mixed-Integer Linear Programming framework designed to manage the medical response process following an earthquake in Istanbul. Within this framework, the model establishes a strategic balance between the primary objective Z_1 of minimizing total unmet demand and the secondary objective Z_2 of minimizing the total distance to meet demand. The model's uniqueness lies in its ability to determine intervention priority through the weight coefficients assigned to these objectives; by assigning a higher weight coefficient (W_t) to the unmet demand for critical cases requiring intensive care, it ensures that limited resources are prioritized for individuals in life-threatening situations. Simultaneously, by ensuring the transport of injured patients to the nearest field hospitals or existing healthcare centers in accordance with the distance minimization objective.

Mathematical Model:

$$\text{Min } z_1 = \sum_i \sum_t W_t u_{it} \quad (1)$$

$$\text{Min } z_2 = \sum_i \sum_j D^1 x_{ij} + \sum_i \sum_h D^2_{ih} z_{ih} \quad (2)$$

Subject to

$$u_{it} = D_{it} - \sum_j n_{ijt} - \sum_h m_{iht} \quad \forall i, t \quad (3)$$

$$n_{ijt} \leq x_{ij} C_{jt} \quad \forall i, j, t \quad (4)$$

$$\sum_i n_{ijt} \leq C_{jt} \quad \forall j, t \quad (5)$$

$$\sum_i m_{iht} \leq p_{ht} \quad \forall h, t \quad (6)$$

$$m_{iht} \leq z_{ih} M_{ht} \quad \forall i, h, t \quad (7)$$

$$z_{ih} \leq y_h \quad \forall i, h \quad (8)$$

$$\sum_t p_{ht} G_t \leq A_h \quad \forall h \quad (9)$$

$$\sum_h y_h \leq F \quad \forall h \quad (10)$$

$$p_{ht} \leq y_h M_{ht} \quad \forall h \quad (11)$$

$$x_{ij}, z_{ih} \text{ and } y_h \in \{0,1\} \quad (12)$$

The constraints defining the operational limits of the developed mathematical model have been designed within an integrated framework to ensure the system's medical and logistical sustainability. Constraint (3), which forms the basis of the model, dynamically defines the unmet demand for general treatment and intensive care at each demand point; Constraints (4) and (5) prevent system overloading by ensuring that the assignment of casualties to existing hospitals does not exceed these institutions' maximum service and intensive care capacities. The operational framework for field hospitals is defined by Constraints (6) and (7); these constraints mandate that the total number of casualties assigned to each temporary medical unit must remain within the upper limits specified for the relevant service type. In terms of the system's logical consistency, Constraint (8) requires that a field hospital must first be established at a location before casualties can be transported there, while Constraint (9) ensures that the operational capacity allocated to field hospitals does not exceed the permitted maximum values. Within the scope of strategic resource management, Constraint (10) limits the total number of field hospitals to be established to a specified upper limit; Constraint (11) ensures that if a field hospital is opened at a candidate location, its capacity does not exceed its maximum capacity. Finally, Constraint (12) completes the mathematical validity of the model by specifying that all decision variables must be non-negative and conform to binary (0-1) logic rules.

2.1) Solution Methodology

In the solution process of this study, Weighted Multi-Objective Mixed-Integer Linear Programming was used to manage two conflicting primary objectives. Stanimirović (2012) say that the lexicographic approach has been used to optimize objectives in a sequential manner by establishing a priority order among the objective functions. Using this method, the problem was solved by assigning weight coefficients (W_t) to the first objective function (Z_1) based on their importance levels. Given the critical importance of cases requiring intensive care ($t=2$), a higher priority weight was assigned to this demand type within the z_1 function. As a result, the model generates solutions that aim for the highest survival rate by operating a rational triage mechanism under limited capacity conditions. The optimal assignment results obtained from the primary objective function (Z_1) and the volume of unmet demand were accepted

as input data, resulting in the addition of two new constraints. These constraints were derived by distinguishing two different demand types from the output of the (Z_1) function.

$$\sum_i u_{i1} \leq z_1 \quad (12)$$

$$\sum_i u_{i2} \leq z_1 \quad (13)$$

Within these constraints, logistics efficiency has been maximized by minimizing the total travel distances (Z_2) to the facilities to which the injured have been assigned.

4. Case Study for Istanbul

In this section, a comprehensive case study was conducted using Istanbul earthquake scenario to test the validity of the developed model. The study involved designing the allocation of disaster-related demand points to hospitals and deployment of field hospitals considering the need for medical evacuation, based on Istanbul's seismic risk profile and demographic data.

4.1. Data Sources and Demand Forecasting

The primary dataset for this study is based on current earthquake risk reports obtained from the "Potential Earthquake Loss Estimation Booklets" (Istanbul Metropolitan Municipality (IMM) 2019), a joint study conducted between the Istanbul Metropolitan Municipality (İBB) and the Kandilli Observatory and Earthquake Research Institute. Using the damage estimates and demographic data presented in these reports as a reference, injury estimates were generated for Istanbul's 35 districts and the 952 neighborhoods within them. Demand points (i) were defined in the system as the geographic centers of the neighborhoods, and the potential number of casualties for each point was parametrically incorporated into the model.

4.2. Casualty Categorization and Medical Service Types

Disaster literature and relevant institutional reports generally classify post-earthquake medical cases into four primary groups: total number of casualties, seriously injured, those requiring treatment in the hospital, and slightly injured (Istanbul Metropolitan Municipality 2019). However, to manage resources in the most efficient and life-saving manner within the scope of disaster logistics, this study focuses on two critical categories that directly occupy hospital capacity and require professional intervention. Based on the analyses conducted, it has been determined that certain groups within the "Treatment in the Hospital" and general "Number of Seriously Injured" categories must be directed to medical facilities for professional care. Therefore, the strategic capacity allocation and field hospital location selection model is constructed upon these two fundamental demand types (t), where medical resources are most likely to encounter a bottleneck:

- **Type 1 - General Treatment (Normal):** This represents patients whose lives are not immediate danger, but who require surgical intervention, dressing, or stabilizing treatment by medical professionals. This group constitutes the primary patient profile utilizing the general service capacities of field hospitals.
- **Type 2 - Intensive Care (ICU):** This covers critical patients whose vital functions are at risk and who require emergency Intensive Care Unit (ICU) intervention and life support systems due to causes such as Crush syndrome or severe internal organ damage.

The model classifies the health services provided by both existing hospitals and planned field hospitals into two main capacity types: General Service and Intensive Care corresponding to these two distinct demand types ($t=1$ and $t=2$). This classification is a triage-based optimization strategy aimed at prioritizing the transport of limited medical personnel and technical equipment to critical cases (Type 2) with the highest clinical urgency.

4.3. Field Hospital Capacity

The requirements for the planned field hospitals were determined based on international humanitarian aid standards and references from similar disaster management studies. Vafaei (2014) claims that sufficient medical supplies must be available due to increased population density before disasters such as earthquakes. A model that addresses the decision of locating and relocating mobile hospitals using various disaster scenarios is proposed in (Acar and Kaya 2019). The operational limits of the field hospitals and the other parameter values utilized in the model are summarized below:

- **Required area (m^2) per unit of type t bed (G_t):** To ensure operational sustainability, the capacity for each candidate location is defined by the allocated bed area. For intensive care services ($t=2$), the area is fixed at

25 m² per bed, while for general treatment services ($t=1$) (O’Connell and Humphreys 2000). It is defined as 12 m² per bed (The Facility Guidelines Institute, 2010).

- **Number of Facilities (F):** Stadiums, event venues, and fields are suitable locations for these temporary hospitals. Due to logistical constraints and medical personnel limitations, we define the candidate locations for field hospitals to be established and the maximum number of field hospital candidate locations are restricted to 29 (Kömürcü 2020).
- **Distance Parameters (D^1_{ij}, D^2_{ih}):** The distances between demand points and facilities were calculated using as the crow flies distance data and integrated into the model as a constraint to minimize emergency response and access times.

5. Results and Discussion

In this section, the numerical results obtained from the mathematical model are analyzed under various scenarios to evaluate the impact of resource allocation on casualty evacuation. The primary focus of this analysis is to examine the sensitivity of the model to the α (α parameter) which is utilized to weight and prioritize intensive care patients ($t = 2$) over normal patients ($t = 1$). The trade-off between unmet demand rates and the number of established field hospitals is presented in result table.

Table 1 reveals how the weight coefficient α (α parameter) and the number of established field hospitals dramatically alter the unmet demand rates across different casualty categories. When examining result table, it is observed that in the scenario where 10 field hospitals are established, the unmet demand rate for intensive care ($t = 2$) casualties remains constant at a high level of 55% for α values ranging from 0.50 to 0.65. However, upon reaching the critical tipping point of $\alpha=0.70$ the model's prioritization logic is activated, reducing this rate to 7.81% for type 2 ($t = 2$); conversely, the unmet demand for type 1 ($t = 1$). patients increase from 16.24% to 36.31%. This numerical shift mathematically confirms that the model successfully channels limited capacity toward the most severe cases.

The analysis of capacity expansion indicates that increasing the number of field hospitals to 15 and 20 plays a decisive role in system performance. In the 15-field-hospital scenario, for $\alpha \geq 0.70$ the unmet demand rate for type II patients is eliminated (0%), while the rate for type I patients remains at 32.03%. In the most optimistic scenario involving 20 field hospitals, the intensive care demand is again reduced to 0%, while the unmet demand for Type I patients drops to 24.43% due to the increased capacity. These results clearly demonstrate that simply increasing the number of facilities in a metropolis like Istanbul is insufficient; rather, managing intensive care units with a significant weight factor $\alpha \geq 0.65$ is essential to maximizing survival chances for the most critical injuries, such as crush syndrome.

Table 1. Detailed Results for Various Field Hospital Number for Various α Values

		Unmet Demand Rate					
Field Number	Hospital	10		15		20	
		Type I (%)	Type II (%)	Type I (%)	Type II (%)	Type I (%)	Type II (%)
α	0.5	16.24	55.00	8.64	55.0	1.04	55.0
	0.60	16.24	55.00	8.64	55.0	1.04	55.0
	0.65	16.24	55.00	8.64	55.0	1.04	55.0
	0.70	36.31	7.81	32.03	0	24.43	0
	0.75	36.31	7.81	32.03	0	24.43	0
	0.80	36.31	7.81	32.03	0	24.43	0

Due to the analysis results, it was determined that the range where the α weight coefficient increases from 0.65 to 0.70. To observe the radical changes occurring within this range more clearly, values between 0.65 and 0.70 were simulated on a micro scale and results are shown in Table 2.

Table 2. Detailed Results for 10 Field Hospital for α Between 0.66 and 0.69

Field Hospital Number	α	Unmet Demand Rate for Type I (%)	Unmet Demand Rate for Type II (%)
10	0.66	16.24	55.00
	0.67	16.24	55.00
	0.68	36.31	13.07
	0.69	36.31	13.07

The findings reveal that, up to the 0.65 level, the system focuses on normalizing Type 1(normal) cases with high patient volume and maintaining overall evacuation efficiency; however, starting from the 0.68 threshold, it was observed that the mathematical priority shifts entirely to Type 2 (intensive care) cases.

Numerical comparisons within this sensitive range indicate that, regardless of the number of field hospitals, the greatest reduction in the unmet demand rate for intensive care occurs in the 0.66 to 0.67 range. For example, in a scenario with 10 field hospitals, while 55% of intensive care demand remained unmet at an α value of 0.66, increasing the coefficient by just 0.02 units to 0.68, reduced this loss to as low as 13%. This demonstrates that the model strategically diverts limited medical personnel and intensive care equipment from general surgical units at a rapid pace to focus on the most critical patients. Consequently, this analysis presents maintaining the α parameter at a minimum level of 0.68 as a scientific imperative for disaster managers seeking to maximize survival rates in a metropolis like Istanbul as this value represents the most delicate balance point between the system's capacity utilization efficiency and the absolute protection of critically ill patients.

The sensitivity of the model to the α parameter is inherently linked to the physical area constraints (G_t) defined for field hospitals. The following logic explains the radical shift observed at the critical α threshold:

- **Low α Values:** At lower α values, the objective function aims to maximize the total number of survivors (quantity). Since a normal bed requires 12 m² and an intensive care (ICU) bed requires 25 m², the model mathematically prioritizes Type I patients. In this scenario, placing two normal beds in a 25 m² area to save two individuals is seen as more "efficient" than allocating the same space to a single ICU bed for one person.
- **The Critical α Threshold:** As the weight of the ICU demand (W_t) increases, the model reaches a tipping point where saving a single life in Type II becomes mathematically more valuable than saving multiple individuals in Type I. This transition represents the shift from a "volume-based" strategy to a "criticality-based" intervention.
- **Operational Transformation:** The direct correlation between the prioritization coefficient and the area constraints forces the model to transform its capacity allocation strategy. Once the threshold is crossed, the model reconfigures the field hospital layouts to prioritize ICU units, acknowledging that while intensive care is more resource-intensive in terms of space, its clinical weight outweighs the numerical superiority of general treatment cases (Table 3).

Table 3. Detailed Results for Various Field Hospital Number for $\alpha=0.65$

Number of field hospitals	Unmet Demand		Assignment Rate (%)	
	Type I	Type II	Type I	Type II
0	14211	4394	63.69	45
5	10539	4394	73.07	45
10	6356	4394	83.76	45.00
15	3381	4394	91.36	45.00
20	406	4394	98.96	45.00
23	0	3733	100	53.27
29	0	2244	100	71.91

Table 4. Detailed Results for Various Field Hospital Number for $\alpha = 0.70$

Number of field hospitals	Unmet Demand		Assignment Rate (%)	
	Type I	Type II	Type I	Type II
0	14211	4394	63.69	45
5	14211	2632	63.69	67.05
10	14211	624	63.69	92.19
15	12536	0	67.97	100
20	9561	0	75.57	100
23	7776	0	80.13	100
29	4675	0	88.06	100

Table 3 and Table 4 reveals how sensitive the model is to the priority parameter, α . In Table 3, $\alpha = 0.65$, the system prioritizes Type I (General Treatment) casualties, reducing their unmet demand by 97.1% before Type II (ICU) cases receive any additional capacity. Conversely, Table 4 ($\alpha = 0.70$) shifts the priority toward critical cases, ensuring that Type II patients reach a 100% assignment rate with only 15 field hospitals, while Type I patients remain at their baseline service level. While the $\alpha = 0.70$ scenario provides earlier security for high-risk patients, the $\alpha = 0.65$ strategy proves more efficient in terms of total system volume, leaving only 2,244 patients unassigned at 29 facilities compared to 4,675 in the latter case. This trade-off suggests that while a higher α protects the most vulnerable, it may result in a higher overall number of untreated casualties. Finally, it is assumed that any remaining casualties who cannot be accommodated within this network are transferred to healthcare facilities in neighboring provinces for further treatment.

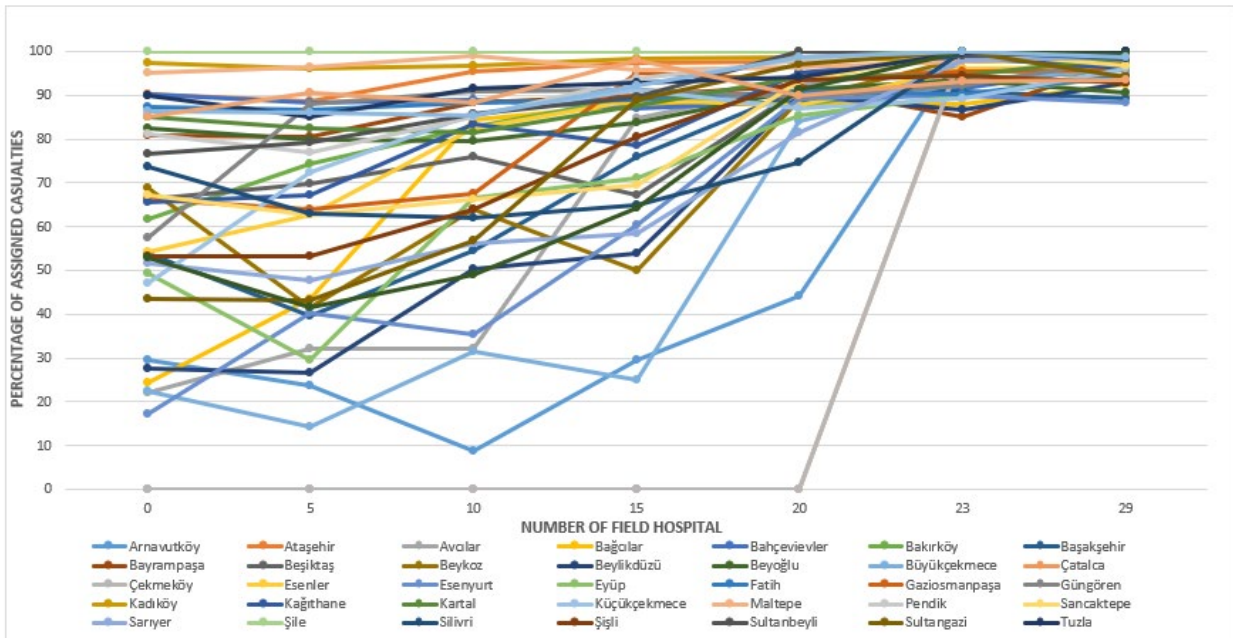


Figure 1. Total assigned casualties for $\alpha = 0.65$

The graph shown in Figure 1 analyzes the total assignment rates of earthquake victims in Istanbul to both existing hospitals and established field hospitals on a district-by-district basis (Percentage of Assigned Casualties). These data reveal the following regarding the capacity adequacy of the healthcare system post-disaster and the need for strategic expansion: The "0" column in the table shows the current hospital capacity to meet demand in the absence of an additional field hospital. The fact that this rate is 0% in districts like Çatalca and Çekmeköy proves that the existing fixed-facility hospitals will be completely inadequate to handle the earthquake load in these areas and that the region is in need of external aid. In contrast, Şile's 100% rating in every scenario indicates that its existing infrastructure is sufficient to meet local demand.

As the number of field hospitals increases, a significant improvement in rates is observed in districts such as Avcılar, Bağcılar, and Esenyurt. For example, in Esenyurt, the appointment rate, which was only 17.1% with existing hospitals, rises to 89.2% with 20 field hospitals. This finding confirms that the model optimizes the system's total life-saving capacity by deploying field hospitals in "critical bottleneck" areas where existing hospital capacity is most limited. When the data is examined, it is seen that the establishment of 23 field hospitals resulted in 100% rates even in remote districts such as Çatalca and Çekmeköy, which previously had no healthcare services (0% rate).

Consequently, this figure numerically documents that relying solely on existing hospitals during an earthquake would lead to significant human loss. In particular, districts such as Arnavutköy, Avcılar, Büyükçekmece, Çatalca, Çekmeköy, and Esenyurt are unable to provide healthcare services to a large portion of their populations without field hospital support. In the 29-field hospital scenario, all districts achieving an assignment rate of 88% or above demonstrate how effective the developed model is as a planning tool for ensuring urban resilience.

6. Conclusion

This study developed a Weighted Mixed-Integer Linear Programming model with lexicographic approach to optimize the strategic deployment of field hospitals and the allocation of casualties in Istanbul following a major earthquake scenario. Unlike traditional location models, the proposed framework integrates a triage-based prioritization mechanism by distinguishing between intensive care (Type II) and general treatment (Type I) demands. The results clearly demonstrate that Istanbul's existing healthcare infrastructure is insufficient to cope with the projected casualty volume, necessitating the establishment of temporary field hospitals to bridge the critical capacity gap.

A key finding of this research is the significant impact of the prioritization coefficient (α) and physical area constraints (G_t) on survival outcomes. The sensitivity analysis revealed a critical threshold between $\alpha = 0.65$ and $\alpha = 0.70$, where the model transitions from a volume-oriented approach to a life-saving, criticality-based strategy. By quantifying the opportunity cost of hospital space where one ICU bed (25 m²) is balanced against two general beds (24 m²), the model provides a mathematically grounded decision-support tool. It successfully demonstrates that with a strategic allocation of at least 15 field hospitals, even the most critical intensive care demands can be fully met, provided that the prioritization logic is correctly tuned to favor high-risk casualties.

Overall, this study emphasizes that effective disaster response in a high-density metropolis like Istanbul requires more than just increasing facility numbers; it demands real data-driven resource scaling and precise triage management. The proposed model offers emergency planners and policymakers a practical framework to enhance the resilience of the urban healthcare system.

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