LOGISTIC DEPOT LOCATION OPTIMIZATION FOR EMERGENCY PREPAREDNESS: A CASE STUDY IN BEŞİKTAŞ DISTRICT

(ACİL DURUMLARA HAZIRLIK İÇİN LOJİSTİK DEPO YERİ OPTİMİZASYONU: BEŞİKTAŞ İLÇESİ ÖRNEĞİ)

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In this thesis study, it was aimed to conduct a study that would contribute to disaster management regarding earthquakes, which is one of the biggest problems of Turkey and Istanbul. In the study, the location optimization of the logistics depot containing the materials that may be needed after the earthquake was studied, with the example of Beşiktaş district.

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ABSTRACT

Like many natural disasters, earthquakes occur unexpectedly and have major and devastating effects on human life. For this reason, it is of great importance to raise public awareness, take structural precautions and make emergency plans in earthquake risk areas. Turkey has 3 main fault lines covering many major cities and is among the countries with high earthquake risk. Among these fault lines, the North Anatolian Fault is known as the fastest and most active dextral fault line in the world. This fault line will greatly affect the Marmara Region, the most populous region of Turkey, and Istanbul, the most populous city, in a possible earthquake. Disaster management and emergency planning are as important as personal precautions to be taken before an earthquake. One of the important issues in disaster management is that post-disaster aid equipment is at the right points where people can reach it in a short time. In this study, the problem of locating depots containing materials that may be needed after the disaster in Beşiktaş district in case of any earthquake that may occur in the Marmara region is discussed. Two different binary integer programming (BIP) models have been proposed to minimize the demand-weighted distance in solving the problem. In mathematical models, it is decided whether depots that can meet the needs of the neighborhoods in Beşiktaş district will be opened in possible depot locations on the main arteries in the shortest distance. In the first model, it is assumed that the capacities of the depots can meet the needs in the districts. In the second model, the capacity of the depots was added to the mathematical model and the decision whether to open the depots was examined. The proposed mathematical models were applied to the Beşiktaş district earthquake storage problem.

Keywords: Humanitarian Logistics, Facility Location, Integer Programming, Optimization

ÖZET

Birçok doğal afet gibi depremler de beklenmedik şekilde meydana gelmekte ve insan hayatı üzerinde büyük ve yıkıcı etkiler yaratmaktadır. Bu nedenle deprem riski taşıyan bölgelerde kamuoyunun bilinçlendirilmesi, yapısal önlemlerin alınması ve acil durum planlarının yapılması büyük önem taşımaktadır. Türkiye, birçok büyük şehri kapsayan 3 ana fay hattına sahip olup, deprem riski yüksek ülkeler arasında yer almaktadır. Bu fay hatları arasında Kuzey Anadolu Fay hattı dünyanın en hızlı ve en aktif sağa atımlı fay hattı olarak bilinmektedir. Bu fay hattı olası bir depremde Türkiye'nin en kalabalık bölgesi olan Marmara Bölgesi'ni ve en kalabalık şehri İstanbul'u büyük ölçüde etkileyecektir. Deprem öncesi alınacak kişisel önlemler kadar afet yönetimi ve acil durum planlaması da önemlidir. Afet yönetiminde önemli konulardan biri de afet sonrası yardım ekipmanlarının insanların kısa sürede ulaşabileceği doğru noktalarda olmasıdır. Bu çalışmada, Marmara bölgesinde meydana gelebilecek herhangi bir deprem durumunda, afet sonrasında ihtiyaç duyulabilecek malzemeleri içeren depoların Beşiktaş ilçesinde konumlandırılması sorunu ele alınmaktadır. Problem çözümünde talep ağırlıklı mesafenin minimize edildiği, iki farklı ikili tamsayı programlama modeli önerilmiştir. Matematiksel modellerde Beşiktaş ilçesindeki mahallelerin ihtiyaçlarını karşılayabilecek depoların en kısa mesafede ana arterler üzerindeki muhtemel depo lokasyonlarında açılıp açılmayacağına karar verilmektedir. İlk modelde depoların kapasitelerinin ilçelerdeki ihtiyaçları karşılayabileceği varsayılmaktadır. İkinci modelde ise depoların kapasitesi matematiksel modele eklenerek depoların açılıp açılmama kararı incelenmiştir. Önerilen matematiksel modeller Beşiktaş ilçesi deprem depolama problemine uygulanmıştır.

Anahtar Kelimeler : İnsani Yardım Lojistiği, Tesis Yer Seçimi, Tam Sayılı Programlama, Optimizasyon

1.INTRODUCTION

Natural disasters are dangerous events that cause great loss of life and property and occur beyond the control of people. Hydrologically flood, tsunami, meteorologically drought, forest fires and geologically erosion, volcanic eruption and earthquake can be given as examples of natural disaster types. According to the World Meteorological Organization (WMO), the number of human deaths due to meteorological disasters has been recorded as 700,000 people in the world (MMO, 1999). Countries around the world are faced with different natural disasters due to their location and conditions. Natural disasters are divided into two as slowly progressing and sudden onset. Severe cold, drought and famine can be given as examples of slowly progressing natural disasters. Sudden natural disasters include fire, volcanic eruption, flood, avalanche, and earthquake. When these natural disasters will occur, the magnitude, severity and extent of the disasters cannot be known before they occur. Disasters leave people with physical effects such as death, disability and injury, and psychological effects such as shock and trauma. It can cause infectious and epidemic diseases. In addition to these effects, the natural disaster disrupts the infrastructure and economy of the region. There are also economic losses such as human losses and workforce shortages, providing the necessary financial resources for the repair of infrastructure and living spaces, and hindering the planned investments of the state. Many countries establish non-governmental organizations and disaster management departments for themselves to be cautious against disasters, reduce losses and control the situation after disasters.

Among the countries of the world, Turkey is frequently faced with natural disasters due to its tectonic, seismic, topographic, and climatic structure. Landslides, floods and overflows, fire, avalanche, and earthquake are the most common natural disasters in Turkey. Among these natural disasters, earthquakes are one of the most important natural disasters for Turkey. Turkey is located on the most geologically active seismic belt. There are 3 major fault lines, namely the North Anatolian Fault Line, the South Anatolian Fault Line, and the West Anatolian Fault Line. These 3 major fault lines affect many cities in our country. The North Anatolian Fault Line is known as the fastest moving fault line in the world, with a length of 1100 km, consisting of many parts from Van Gölü to the Saros Körfezi. Bingöl, Erzincan, Kocaeli, Istanbul and especially the Marmara Region and many other cities, which are affected by the North Anatolian Fault Line, are frequently faced with large earthquakes. The Turkish Ministry of Internal Affairs, Disaster and Emergency Management Presidency states that Turkey ranks third in the world in terms of loss of life in earthquakes and eighth in terms of the number of people affected.

According to TUIK data, the region with the highest population in Turkey is the Marmara Region and the most populated city is Istanbul. The abundance of industries, company headquarters and business areas in the Marmara Region also makes it an important location. The region with the highest population and economic benefit is located on the North Anatolian Fault Line. In the Marmara Region, the annual average maximum magnitude was 4.8 M, and the annual average risk was 63% (Sezer 2003). When the human losses and economic damages caused by the earthquake are revealed, it is seen that Turkey is facing a serious problem.

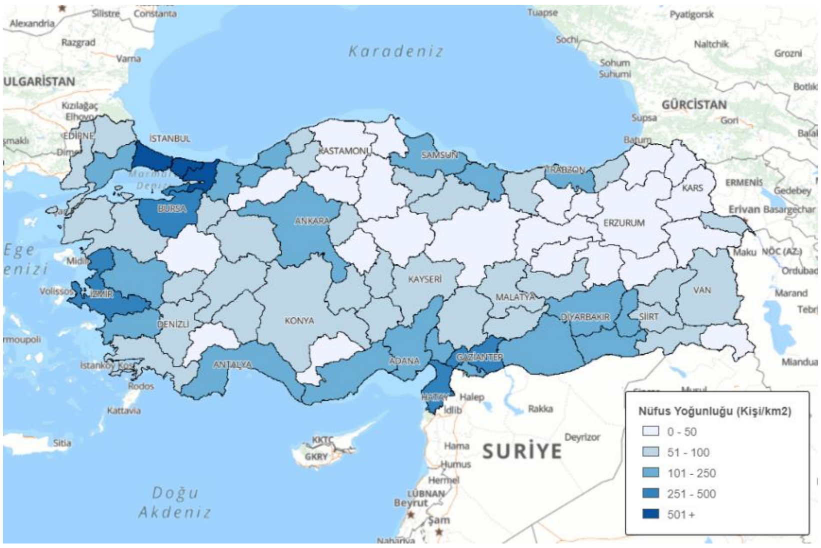

Figure 1.1: Population Density in Turkey

The most important reasons why earthquakes are a big problem for Türkiye are that their timing, size, and intensity are unknown. However, the damage to be faced can be minimized with effective and correct planning and management before, during and after the earthquake. When a disaster occurs in Turkey, the first response is made by the Disaster and Emergency Management Presidency (AFAD). Disaster and Emergency Management Presidency is an institution that plans, directs, supports, coordinates, and effectively implements the activities necessary to prevent disasters, reduce their damages, intervene and quickly complete post-disaster recovery works. For this purpose, it ensures cooperation between all institutions and organizations of the country, observes the rational use of resources and operates with a flexible and dynamic structure based on interdisciplinary work. Before an earthquake disaster occurs, precautions should be taken such as building earthquake-resistant structures and carrying out regular inspections, identifying buildings that do not comply with earthquake regulations and applying the necessary precautions, raising public awareness about what to do in case of an earthquake, preparing earthquake bags, and keeping the aid materials that may be needed after the earthquake in the right locations. Storing various aid materials, which are of critical importance and will help survive in disasters and emergencies, is of great importance so that people can access these materials in the fastest and easiest way after the earthquake. People who survive during and after the earthquake need to have quick access to basic needs such as tents, nutrition, water, and heating, as well as materials such as concrete crushers to be used in debris work. In this context, AFAD has located AFAD Logistics Depots in different parts of the country, as Turkey is an earthquake country. These depots contain tents, beds, bedding sets, heaters, and kitchen sets for people's most basic needs. For this reason, these urgent and important materials must be kept in the right locations.

In this study, the problem of positioning logistics depots, which is one of the precautions to be taken before the earthquake, is discussed. A mathematical model decides which depot should be opened among candidate depot locations so that all people who may need it can access the materials as quickly as possible and depot positioning is done at the least cost. This problem is implemented in the Beşiktaş district of the Marmara Region, which is located on the North Anatolian Fault Line, has a high population density and is an economically important region.

2. LITERATURE REVIEW

Over the years, many studies have been conducted on natural disasters and earthquakes that cause great losses in the world and in Turkey. Among these studies, humanitarian logistics and warehouse positioning problems have also been examined and many models have been proposed to reduce harm. Optimization models, heuristic algorithms and different methods have been put forward in the proposed models. In these models, objective functions are generally used to minimize the distance or time from the warehouse to the demand point, to minimize the total cost, or to meet the demand at the maximum level. The keywords used for literature review in this thesis study are disaster management, disaster logistics, humanitarian aid logistics and facility location selection. In this thesis study, 24 articles were examined for literature review.

In this thesis study, 24 articles were examined, and out of the 24 articles examined, deterministic modeling was observed in 14 of them and stochastic modeling was observed in 7 of them. While deterministic methods are widely used due to their simplicity and concrete results, stochastic methods are essential for modeling real-world uncertainties. In the other 3 articles, review and assessment models are discussed. Review and assessment articles play a crucial role in synthesizing knowledge, identifying research gaps, and guiding future studies. These studies clarify the effectiveness and limitations of both deterministic and stochastic methods. Among these articles, Ergin (2016) is the only article that uses the k-means clustering algorithm and the p-median model together. The majority of studies focus on various location selection methods using different optimization and mathematical models to determine the best locations for logistics warehouses and other facilities in disaster management. These studies include various approaches such as operations research models, mixed integer linear programming, maximum span location models, and stochastic programming models. These studies cover various disasters, especially earthquakes and floods, and reflect the importance of these events in terms of disaster management. When the articles are examined, it is particularly significant that 5 of the articles are about earthquake disasters and 4 of them are about flood disasters.

2.1 Review Papers

Safeer et al. (2014) provided a comprehensive review of modeling parameters for objective functions and constraints in humanitarian logistics distribution. The objective functions implemented in various humanitarian emergency operations aim to enhance the supply of relief aid. A classification-based review methodology is used to identify different cost functions and constraints for primary emergency operations in logistics, specifically casualty transportation and relief distribution problems. Drawing upon this classification, the article discusses potential areas for future research that would greatly assist decision-makers in planning logistics activities during emergency situations. Additionally, the article outlines recent trends, challenges, and research gaps within the field of Humanitarian Logistics.

Topal (2016) addressed how natural and human-induced triggers such as technological progress, population growth, and ecological imbalance led to various-scale disasters, causing significant economic damage. Effective management of logistics systems, crucial in disaster management, was essential to reduce these damages. Disasters could be devastating even with low intensity due to unplanned urbanization and lack of safety measures. Effective disaster response required well-planned logistics, with strategically located depots for rapid response, ultimately shortening the recovery period post-disaster.

Humanitarian logistics (HL) is crucial for effective disaster operations and management. Efficient HL operations are necessary to handle the uncertainties and complexities of disasters and minimize human and economic losses. Over the past two decades, numerous publications have focused on enhancing HL efficiency, proposing mathematical models and algorithms. Hezam et al. (2020) proposed a systematic literature review which was conducted to examine optimization models in HL. More than one hundred articles published between 2000 and 2020 were reviewed, primarily focusing on facility location problems, relief distribution, and mass evacuation. These areas contain both deterministic and non-deterministic models. The review aimed to provide a transparent and comprehensive analysis of the optimization models used in HL.

2.2 Deterministic Models

Balçık et al. (2008) addressed facility location decisions in a humanitarian relief chain for rapid-onset disasters. A model was developed to determine the optimal number and locations of distribution centers, as well as the necessary relief supplies at each center to meet the needs of affected populations. The variant of the maximal covering location model employed integrated facility location, inventory decisions, and considered multiple item types, along with budget and capacity constraints. The effectiveness of the model was demonstrated through computational experiments, which highlighted the impact of pre- and post-disaster funding on response time and demand satisfaction. Insights into managerial implications were concluded.

Görmez et al. (2011) studied the problem of locating disaster response and relief facilities in Istanbul, anticipating a major earthquake. The Metropolitan Municipality of Istanbul decided to establish facilities for prepositioning relief aid and executing post-disaster response operations. A two-tier distribution system was proposed, utilizing existing public facilities and new regional supply points. Mathematical models were developed to determine new facility locations, aiming to minimize the average-weighted distance between casualty locations and the nearest facilities, and to limit the number of facilities, considering distance limits and backup requirements under regional vulnerability. Trade-offs between these objectives under various disaster scenarios were analyzed. Results showed that a small number of facilities were sufficient, with robust locations across different parameters and modeling changes.

During flood disasters, shelters are sought by people in affected areas as safe places. These shelters, typically organized and provided by the government, serve not only as refuges for evacuees but also as distribution points for necessary supplies to those in surrounding affected areas. Chanta et al. (2011) proposed an optimization model to identify appropriate locations for temporary shelters in their article. The objectives were to maximize the number of flood victims who could access a shelter within a fixed distance and to minimize the total distance to the closest shelters. The bi-objective programming model was solved using the epsilon-constraint method, with a real case study based on data from the severe flooding in Thailand in 2011.

Liu et al. (2013) proposed the objective of their work as determining the location of emergency material warehouses. For the site selection problem, triangular fuzzy numbers were used for the demand at the demand node, the distance between the warehouse and demand node, and the cost of the warehouse. A bi-objective programming model was established to minimize the total cost and the distance between selected warehouses and the demand node. The fuzzy programming model was transformed into a deterministic bi-objective mixed-integer programming model using fuzzy number theories. A heuristic algorithm was designed and proven feasible and effective through a numerical example. Analysis results indicated that the warehouse location heavily depended on the degree α and weight w1, highlighting the need for accurate information before decision-making.

Gösling et al. (2014) proposed a framework to aid decision-makers in humanitarian logistics in comparing various operational research (OR) models available for decision support. The framework suggested three comparison approaches: based on the decisions they supported, the criteria and metrics they employed, and their underlying methodology and assumptions. The article illustrated this framework by comparing two OR models for specifying stationary depots in relief logistics. Ultimately, the goal was to develop a methodological toolkit to guide users in selecting the most suitable OR model for their specific decision problem in humanitarian logistics.

A mixed-integer linear programming (MILP) methodology was proposed in this study for the selection of temporary shelter site locations by Kılcı et al. (2014). The main objective was to maximize the minimum weight of open shelter areas, considering the decision-making process, population assignments, and utilization control. Real data from Kartal, Istanbul, Turkey was utilized to validate the mathematical model, with a base case scenario generated for analysis. Sensitivity analysis was conducted to examine the impact of model parameters, and the results were discussed. Furthermore, a case study using data from the 2011 Van earthquake was performed to evaluate the model's performance in a real-world setting. This study contributed to the field by providing insights and practical implications for selecting shelter locations, particularly in emergency scenarios.

Manopiniwes et al. (2014) addressed the critical issue of shortages and delays in humanitarian logistics, emphasizing the impact on survivors. They advocated for sufficient budgets to prevent these issues, proposing a strategic model to minimize logistics costs and meet total relief demand. The model integrated facility location and inventory decisions, considering capacity constraints and time restrictions. Applied to a real flood case in Thailand, the mixed-integer programming problem offered valuable insights through sensitivity analysis and managerial implications for effective relief operations.

Facility location problems are strategic decisions with long-term economic outcomes, often challenging to solve. Ergin (2016) focused on the disaster depot location selection problem in Turkey, aiming to identify suitable storage areas for urgent needs during disasters. The k-means algorithm, a cluster analysis method, was used to determine optimal depot locations within geographical regions, considering depot service capacities. The problem was formulated as a P-median 0-1 integer programming model, incorporating setup costs, socio-economic development values, distance distributions, and the desired number of depots. The study successfully determined the most suitable depot locations and the cities covered by each depot.

Boonmee et al. (2017) aimed to conduct a comprehensive survey on facility location problems related to emergency humanitarian logistics, considering both data modeling types and problem types. The research focused on pre-disaster and post-disaster situations, including the placement of distribution centers, depots, shelters, debris removal sites, and medical centers. Four main problem categories were examined: deterministic, dynamic, stochastic, and robust facility location problems. For each problem category, the article evaluated facility location types, data modeling types, disaster types, decision-making processes, objectives, constraints, and solution methods. Real-world applications and case studies were presented to provide practical insights. The survey also identified research gaps that needed to be addressed in future studies to enhance disaster relief operations. By combining an exact algorithm and a heuristic algorithm, the article emphasized the significance of an exact algorithm in improving emergency humanitarian logistical facility location problems.

Aydın et al. (2017) addressed the location selection problem of disaster logistics depots in Turkey, where earthquakes accounted for approximately 70% of all disasters. The aim was to minimize the impact of disasters by effectively managing pre-disaster, during-disaster, and post-disaster needs. An integrated two-stage model was proposed for this purpose. In the first stage, a set covering model was developed to determine the minimum number of alternative depots within a specific coverage area. The second stage introduced a p-median model to minimize demand-weighted distance. The model was further extended by incorporating capacity constraints for the depots. Various analyses were conducted considering different capacity levels, numbers of victims, and coverage distances. To illustrate the application of the proposed model, Maltepe district was chosen as a case study for determining the optimal location of a disaster logistics depot. This research contributed to effective disaster management efforts in Turkey, ensuring the prompt and efficient delivery of emergency supplies to affected areas.

Abbasoğlu (2019) focused on effective disaster management planning in Turkey, considering earthquakes as one of the most devastating and unpredictable disasters. The main objective was to determine optimal locations for humanitarian aid facilities to control the implications of earthquakes. The research addressed a three-stage problem. Firstly, past earthquake records were analyzed to estimate the number of people who would be affected by seismic impacts in a selected region. Secondly, future earthquake risks were determined using the Gutenberg-Richter method based on these records. Lastly, a two-stage disaster supply logistics model was developed, considering the level coverage model. The proposed model was applied to the location problem of logistics depots in Bursa during the disaster management preparation stage. This study aimed to provide valuable insights and guidelines for decision-makers involved in disaster management planning, specifically regarding the storage and distribution of essential supplies in earthquake-prone areas.

Dönmez et al. (2021) presented a comprehensive review of research on facility location problems under uncertainty in humanitarian contexts. The primary aim was to summarize and structure this increasingly prominent topic in the scientific community. The review considered various perspectives, including types of facilities, decision-making processes, optimization criteria, uncertainty-capturing paradigms, and solution methods. The detailed analysis helped identify distinctive features and current trends, expectations, and gaps in existing knowledge, outlining relevant research directions.

Ayuhdya (2023) addressed challenges in Nong Khai and Udon Thani provinces, situated on the south bank opposite Vientiane, where monsoon-induced floods posed significant issues due to incomplete drainage infrastructure. A comprehensive response, mitigation, and recovery plan was deemed imperative. The focus lay on identifying optimal locations for emergency flood shelters, aiming to minimize transportation costs. Using a scenario-based facility location model incorporating historical data on detour routes and population size, two scenarios were evaluated using 2017-2019 data. The results indicated that Mueang Udon Thani and 3-Nong Han were crucial districts for effective emergency flood shelter placement.

Baldomero-Naranjo et al. (2024) introduced a hierarchical facility location model with three levels: first-level facilities that manufactured various products, second-level facilities serving as warehouses, and a third level comprising clients who demanded the manufactured and stored products. The model, termed the multi-product maximal covering second-level facility location problem (SL-MCFLP), aimed to determine the optimal locations for the second-level facilities and the products to be stored in each, maximizing overall client satisfaction in terms of coverage. A Mixed Integer Linear Program (MILP) was formulated, reinforced by families of valid inequalities. Due to the exponential number of constraints, separation algorithms were proposed. Additionally, three variants of a metaheuristic procedure were developed. Computational studies demonstrated the formulation's potentials and the heuristic's effectiveness.

2.3 Stochastic Models

Mete et al. (2009) proposed a stochastic optimization approach for the storage and distribution of medical supplies for disaster management, addressing a range of possible disaster types and magnitudes. A stochastic programming model was developed to select storage locations and inventory levels for various medical supplies, incorporating disaster-specific information and potential effects through disaster scenarios. This model balanced preparedness and risk despite uncertainties. The subproblem could suggest vehicle loading and routing for medical supply transport during disaster response, based on up-to-date field information. A case study demonstrated this approach for earthquake scenarios in Seattle, aiding interdisciplinary agencies in preparing for and responding to disasters efficiently by considering risk.

Rawls et al. (2010) proposed a model for the pre-positioning of emergency supplies was explored as a method to enhance preparedness for natural disasters. An emergency response planning tool was developed to determine the locations and quantities of various supplies to be pre-positioned, given the uncertainty regarding the occurrence and location of natural disasters. A two-stage stochastic mixed integer program (SMIP) was presented to offer a pre-positioning strategy for hurricanes or other disaster threats. This SMIP was designed to account for uncertainties in supply demand and transportation network availability. To address computational complexity, a heuristic algorithm known as the Lagrangian L-shaped method (LLSM) was created to solve large-scale problems. The model's application was demonstrated through a case study in the Gulf Coast area of the US.

Döyen et al. (2011) developed a two-stage stochastic programming model for a humanitarian relief logistics problem. Decisions were made regarding pre- and post-disaster rescue centers, the stocking of relief items at pre-disaster centers, relief item flows at each echelon, and relief item shortages. The objective was to minimize the total costs, which included facility location, inventory holding, transportation, and shortage costs. The deterministic equivalent of the model was formulated as a mixed-integer linear programming model and solved using a heuristic method based on Lagrangean relaxation. Results from randomly generated test instances indicated good performance of the proposed solution method for up to 25 scenarios. The model was validated by calculating the value of the stochastic solution and the expected value of perfect information.

In recent years, frequent emergencies become a significant factor influencing social development. The storage of emergency resources is recognized as crucial for smooth disaster relief operations. However, the construction of emergency resources storage is a complex project. Wang et al. (2012) aimed to study regional emergency resources storage, analyzing its necessity and focusing on region division as the initial step. A two-stage stochastic programming model was proposed to address the region division problem. A case study was presented to demonstrate the efficiency of the proposed solution strategy.

Garrido et al. (2015) focused on meeting post-flood emergency relief demands with tools such as inventory levels to ensure a certain probability of meeting those demands. The demand was calculated as the amount of necessary relief supplies, establishing a stochastic relationship with the severity of the flood disaster. A mixed-integer programming model was developed to minimize two logistic parameters: cost and time. The uncertainty in demand was addressed using the Monte Carlo simulation method. The model was transformed into a linear form and solved using deterministic methods.

Dufour et al. (2017) analyzed the potential cost benefits of adding a regional distribution center in Kampala, Uganda, to the existing The United Nations Humanitarian Response Depot (UNHRD) network to improve responses to humanitarian crises in East Africa. Fieldwork, simulation, network optimization, and statistical analyses were used to assess the costs of prepositioning high-demand non-food items in Kampala and propose a robust stocking solution. Results showed that adding a regional depot in Kampala would be cost-efficient, even with varying UNHRD transport costs. The proposed solution, now being implemented by UNHRD, should result in a mean cost reduction of around 21% over 5000 demand scenarios.

Liu et al. (2022) addressed the uncertainty of relief supplies. However, the destruction from disasters could not be estimated accurately and timely, leading to uncertain relief demands. Thus, a post-disaster relief scheduling problem in sustainable humanitarian supply chain (SHSC) considering both uncertain relief supplies and demands was examined. The objective was to minimize the expected total unsatisfied demand rate, adverse environmental impact, and economic cost, while maximizing survivors' perceived satisfaction. A new stochastic bi-level optimization model was proposed. A hybrid solution approach, including sample average approximation, prime-dual algorithm, linearization technique, and global criteria method, was developed. A case study was conducted.

Grouping all these studies according to objective functions clarify the various priorities and approaches used in logistics warehouse space optimization and disaster management. Minimizing distance or time and minimizing cost are common goals that reflect the importance of efficiency and cost-effectiveness in disaster response. Maximizing coverage provides extensive service access, and addressing uncertainty makes models more robust and realistic.

Grouping the studies by solution methods highlights the various techniques used in disaster management and logistics warehouse space optimization. Linear programming and mixed integer linear programming are common in their ability to handle sensitivities and constraints. Stochastic programming is crucial for managing uncertainty; Heuristic methods, on the other hand, provide practical solutions for complex problems. Simulation and multi-objective optimization provide valuable information about system performance and trade-offs. Systematic literature reviews and statistical methods provide fundamental knowledge and analytical insights. Table 2.1 shows which disasters the articles examined in disaster management are specifically about. All articles examined in Table 2.2 are classified in terms of the mentioned aspects.

Table 2.1: Literature Classification According to Disaster Type

Disasters	**Authors**
Earthquake	Mete et al. (2009), Görmez et al. (2011), Kılcı et al. (2014), Aydın et al. (2017), Abbasoğlu (2019)
Flood	Chanta et al. (2011), Manopiniwes et al. (2014), Garrido et al. (2015), Ayuhdya (2023)
General Humanitarian Logistics / Multiple Disasters	Balçık et al. (2008), Rawls et al. (2010), Döyen et al. (2011), Wang et al. (2012), Liu et al. (2013), Gösling et al. (2014), Safeer et al. (2014), Topal (2016), Ergin (2016), Boonmee et al. (2017), Dufour et al. (2017),

	Hezam et al. (2020), Dönmez et al. (2021), Liu et al. (2022), Baldomero-Naranjo et al. (2024)

Table 2.2: Literature Classification

Authors	**Objective Function**	**Solution Method**	**Problem Type**
Balçık et al. (2008)	Minimizing distance or time, maximizing coverage	Maximal Covering Location Model	Facility Location Problem
Mete et al. (2009)	Minimizing cost	Stochastic Programming, Multi-Objective Optimization	Facility Location Problem, Inventory Management Problem
Rawls et al. (2010)	Minimizing expected cost	Two-stage stochastic mixed integer programming	Facility Location Problem
Görmez et al. (2011)	Multi-objective optimization	Multi-Objective Optimization	Facility Location Problem
Chanta et al. (2011)	Minimizing distance, time	Bi-objective Programming	Facility Location Problem
Döyen et al. (2011)	Minimizing cost, maximizing coverage,	Stochastic Programming, Multi-Objective Optimization	Facility Location Problem
Wang et al. (2012)	Minimizing cost	A Two-stage Stochastic Programming	Model for Emergency Resources Storage Region Division
Liu et al. (2013)	Minimizing total cost and distance	Linear Programming	Facility Location Problem

Safeer et al. (2014)	Modeling parameters for various objective functions	Metaheuristic Methods, Statistical and Analytical Methods	Inventory Management Problem
Gösling et al. (2014)	Minimizing distance	Linear Programming	Network Design Problem, Routing Problem
Kılcı et al. (2014)	Maximizing minimum weight of open shelter areas	Mixed-Integer Linear Programming	Facility Location Problem
Manopiniwes et al. (2014)	Minimizing cost	Mixed-Integer Linear Programming, Simulation	Network Design Problem, Routing Problem
Garrido et al. (2015)	Minimizing cost	Stochastic Programming	Facility Location Problem
Ergin (2016)	Minimizing cost	k-means Clustering, P-Median Model, Mixed-Integer Linear Programming	Facility Location Problem
Topal (2016)	Maximizing coverage	Simulation	Review and Assessment
Boonmee et al. (2017)	Minimizing distance, time, maximizing coverage	Mathematical Programming	Facility Location Problem
Aydın et al. (2017)	Minimizing cost	Mixed-Integer Linear Programming	Facility Location Problem
Dufour et al. (2017)	Minimizing the logistic costs	Stochastic Programming	Logistics service network design
Abbasoğlu (2019)	Maximizing coverage	Statistical and Analytical Methods	Facility Location Problem

		(Gutenberg-Richter Method)	
Hezam et al. (2020)	Systematic Literature Review	Systematic Literature Review	Review and Assessment
Dönmez et al. (2021)	Minimizing distance, time	Mathematical Programming, Stochastic Programming	Facility Location Problem
Liu et al. (2022)	Minimizing the expected total unsatisfied demand rate	Stochastic Programming, Bi-level Optimization Model	Post-disaster Relief Scheduling Problem
Ayuhdya (2023)	Minimizing transportation costs	P-Median Model, Mixed-Integer Linear Programming	Facility Location Problem
Baldomero-Naranjo et al. (2024)	Minimizing cost, maximizing coverage	Hierarchical Facility Location Model	Facility Location Problem

The Marmara Region is located on the North Anatolian Fault Line and is the region with the highest population density and earthquake risk in Turkey. When the earthquake risk literature and earthquake reports are examined, it is highly likely that many cities and districts will be damaged in a possible earthquake in the Marmara Region. Keeping aid materials ready in a depot in disaster management ensures that post-earthquake aid reaches disaster victims quickly. The mere storage of these aid materials does not mean that these aids will be effective. Depots must be in the right number, in the right locations and with capacities to fully meet the demands. In this study, the problem of where depots should be opened in Beşiktaş district of the Marmara Region, and through which depots the neighborhoods can access aid materials is emphasized. Looking at the research in the literature, in these problems, the opening of depots is determined as a parameter and neighborhoods are assigned to depots. In this study, unlike the examples in the literature, a mathematical model decides which depots will be opened or not. The decision is made in line with the objective function that minimizes the demand-weighted distance, and the cost of the depot can be kept in balance within the constraints of the model. With this solution, it is of great importance from an economic perspective by preventing the opening of unnecessary depots, and from a humanitarian perspective, as all demands will be met.

3. MATERIAL AND METHODS

In this study, a mathematical model was proposed that optimizes the decision whether to open depots by minimizing the demand-weighted distance from possible logistics depot locations in Beşiktaş district. It is concluded which neighborhood in Beşiktaş District will receive help from which possible depot, and which of these possible depots should be opened according to demand and distance. In disasters with devastating effects, such as earthquakes, it is very important that people can access relief materials as quickly and easily as possible. For this reason, possible logistics depot locations were selected from large areas such as parks, gardens and gathering areas on the main arteries in Beşiktaş district. The reasons for choosing possible depot locations on the main artery are that in case of a possible congestion or destruction on the side roads in case of a disaster, the depot may lose its function and it will not be possible for people to use it. These potential depot locations located on major arteries are much less likely to be damaged. The 13 possible depot locations selected in Beşiktaş district are shown in Figure 3.1 below.

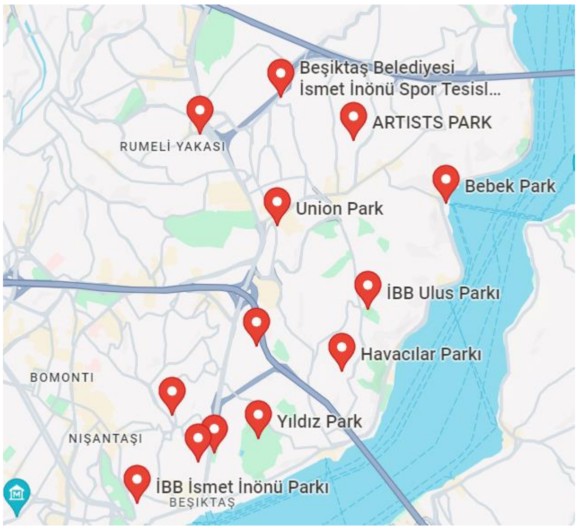

Figure 3.1: Possible Depot Locations on Google Maps

Table 3.1: Numbers and Names of Possible Depots

Depot Number	Depot Name
1	Çeliktepe İETT Garajı
2	Beşiktaş Belediyesi İsmet İnönü Spor Tesisleri
3	Sanatçılar Parkı
4	Birlik Parkı
5	İBB Bebek Parkı
6	İBB Ulus Parkı
7	Balmumcu Parkı
8	Havacılar Parkı
9	Yıldız Parkı
10	Azerbaycan Dostluk Parkı
11	Abbasağa Parkı
12	İBB Yahya Kemal Parkı
13	İBB İsmet İnönü Parkı

In this study, the night scenario at the time of the earthquake was taken as basis. When a disaster occurs, not all members of the society are affected by this disaster in the same way. While some people lose their lives, some are injured, and some remain completely healthy. The same situation is seen in earthquake disasters. While some people lose their lives, some are injured and survive thanks to aid, and some continue their lives in completely intact homes and conditions. Considering this situation, it is not correct and realistic to consider the entire population in the parameter called demand in this study. "Possible Earthquake Loss Estimates Booklet" for each district of Istanbul has been prepared by Istanbul Metropolitan Municipality and Kandilli Observatory and Earthquake Research Institute. According to this study, the number of households that will need temporary shelter after a possible major earthquake in each neighborhood in Beşiktaş district and the number of people who may need temporary shelter in each neighborhood were determined, assuming that the average number of people living in each household is 3 people. In the proposed mathematical model, these number of people are taken as basis in the demand parameter. The numbers of households and people who may need temporary shelter in a possible earthquake, determined by

Istanbul Metropolitan Municipality, and Kandilli Observatory and Earthquake Research Institute, are shown in Table 3.2 below.

Table 3.2: Number of People in Need of Temporary Shelter in Neighborhoods

Neighbourhoods	Number of Households in Temporary Shelter Need	Number of People in Temporary Shelter Need
Konaklar	230	690
Dikilitaş	207	621
Akat	329	987
Gayrettepe	178	534
Nisbetiye	143	429
Etiler	201	603
Mecidiye	525	1575
Türkali	333	999
Ortaköy	143	429
Ulus	125	375
Levazım	74	222
Vişnezade	214	642
Bebek	114	342
Yıldız	169	507
Muradiye	69	207
Kültür	64	192
Abbasağa	136	408
Cihannüma	119	357
Arnavutköy	90	270
Balmumcu	84	252
Levent	105	315
Kuruçeşme	74	222
Sinanpaşa	147	441

In this thesis study, AFAD logistics depots are used as the basis for depots that people can reach quickly and easily in case of disaster. AFAD logistics depots contain tents, beds, bedding sets, heaters, and kitchen sets, and periodic maintenance of the materials is carried out. (Topal, 2016) In this study, it is assumed that the same materials are located in the depots. Table 3.3 shows the quantities of materials in a depot. When we look at the number of materials in the AFAD depot, it is seen that 1 depot will serve 1200 people, considering the number of single beds. For this reason, in the mathematical model, the parameter of 1 depot capacity is taken as 1200. Depending on the area size and suitability of the possible depot locations, the capacity parameter is taken as 1200 and its multiples depending on the establishment of more than one depot. The average price of such empty depots that can be filled with aid materials varies between 2000-6000. The reason for these prices to change depends on factors such as the material quality of the depot, its size, and the sheet thickness used.

Table 3.3: Aid Materials and Quantities in the Depot

Relief Material	Quantity in Depot
Tent	100
Bed	1200
Blanket	2000
Heater	720
Kitchen Set	1440

In the proposed mathematical model, while the demand-weighted distance is minimized, the distances between depots and neighborhoods are also entered as parameters. While calculating these distances, first the locations of the depot locations and neighborhood centers were determined with Google Maps, and then the Euclidean distances between the depot locations and neighborhood locations were calculated. Euclidean distances in meters were used in the mathematical model.

In the first proposed mathematical model, it was assumed that the capacities of the depots could meet the entire demand. In the second proposed mathematical model, the capacities of the depots were also added to the mathematical model. Since all decision variables are binary variables, the model is called binary integer programming model.

3.1 Noncapacitated Mathematical Model

Indices:

i: Index of neighbourhoods (i=0…. 23)

j: Index of depots (j=0…. 13)

Parameters:

d_i = The amount of demand in neighbourhood i

c_{ij}= The distance between neighbourhood i and depot j

K_j= Fixed cost of opening depot j

$Kmax$ =The maximum cost of opening depot

Decision Variables:

$$X_{ij}= \begin{cases} 1, & \text{if neighbourhoood i get help from depot j} \\ 0, & \text{otherwise} \end{cases}$$

$$Y_j= \begin{cases} 1, & \text{if depot j open} \\ 0, & \text{otherwise} \end{cases}$$

Objective Function:

$$\text{Min } \sum_{i=1}^{23} \sum_{j=1}^{13} X_{ij} c_{ij} d_i \qquad (1)$$

Constraints:

$$\sum_{j=1}^{13} X_{ij} = 1 \qquad \forall i \quad (2)$$

$$\sum_{i=1}^{23} X_{ij}\, d_i \;\le\; MY_j \qquad \forall j \quad (3)$$

$$\sum_{j=1}^{13} K_j Y_j \;\le\; Kmax_j \qquad (4)$$

$$X_{ij}, Y_j \in \{0,1\} \qquad \forall i,j \quad (5)$$

3.2 Capacitated Mathematical Model

Indices:

i: Index of neighbourhoods (i=0…. 23)

j: Index of depots (j=0…. 13)

Parameters:

d_i = The amount of demand in neighbourhood i

c_{ij}= The distance between neighbourhood i and depot j

K_j= Fixed cost of opening depot j

C_j= The capacity of depot j

$Kmax$ =The maximum cost of opening depot

Decision Variables:

$$X_{ij} = \begin{cases} 1, & \text{if neighbourhoood i get help from depot j} \\ 0, & \text{otherwise} \end{cases}$$

$$Y_j = \begin{cases} 1, & \text{if depot j open} \\ 0, & \text{otherwise} \end{cases}$$

Objective Function:

$$\text{Min } \sum_{i=1}^{23} \sum_{j=1}^{13} X_{ij} c_{ij} d_i \qquad (6)$$

Constraints:

$$\sum_{j=1}^{13} X_{ij} = 1 \qquad \forall i \quad (7)$$

$$\sum_{i=1}^{23} X_{ij}\, d_i \le Y_j C_j \qquad \forall j \quad (8)$$

$$\sum_{j=1}^{13} K_j Y_j \le Kmax \qquad (9)$$

$$X_{ij}, Y_j \in \{0,1\} \qquad \forall i,j \quad (10)$$

Equations (1) and (6) are the objective functions of mathematical models. Both functions are the same and aim to minimize the demand-weighted distance sum. That equation consists of the product of demand, distance parameters and the decision variable indicating which depot will be assigned to which neighborhood. Equations (2) and (7) are the same and are constraints of mathematical models. This restriction ensures that each neighborhood must get help from 1 depot. Equations (3) and (8) are constraints of mathematical models. Equation (3) states that if a depot is opened, it meets all demand with a big M value, without capacity restrictions, regardless of the demand amount of the neighborhoods to which that depot is assigned. Equation (8) states that depots are assigned to neighborhoods to the extent that they can meet the demand of the neighborhoods, based on their capacities. Equations (4) and (9) are the same and are constraints of mathematical models. This constraint ensures that the total cost of the depots to be opened does not exceed the total budget. Equations (5) and (10) are constraints stating that the decision variables are binary variables.

4. RESULTS

Two different mathematical models are presented to determine which neighborhood will receive help from which depot by minimizing the demand-weighted distance from possible depot locations in Beşiktaş district. In solving the problem, results were obtained with the GAMS code for both mathematical models. The data in Table 3.2 was used for the demand parameter in the mathematical model. The distances between neighborhoods and depots are used as parameters in the model by calculating Euclidean distances in the GAMS code. Assuming that a depot of average size and quality is used in the problem solution, the cost of a depot is taken as $4000. Since a depot can provide aid to 1200 people, the capacity of a depot is taken as 1200. More than one depot was positioned according to the area size and characteristics of the possible depot locations, and depot capacities and depot costs were determined accordingly. After entering the total budget parameter, results were obtained from the GAMS code of the model. Table 4.1 and Table 4.2 shows the optimal results obtained with the GAMS code, which depots should be opened, and which neighborhood should receive help from which depot, in line with the parameters and objective function.

Table 4.1: Non-capacitated Mathematical Model Results

X_{ij}	1	2	3	4	5	6	7	8	9	10	11	12	13
Konaklar	0	1	0	0	0	0	0	0	0	0	0	0	0
Dikilitaş	0	0	0	0	0	0	0	0	1	0	0	0	0
Akat	0	0	1	0	0	0	0	0	0	0	0	0	0
Gayrettepe	0	0	0	0	0	0	0	0	0	1	0	0	0
Nisbetiye	0	0	0	1	0	0	0	0	0	0	0	0	0
Etiler	0	0	1	0	0	0	0	0	0	0	0	0	0
Mecidiye	0	0	0	0	0	0	0	0	1	0	0	0	0
Türkali	0	0	0	0	0	0	0	0	0	0	1	0	0
Ortaköy	0	0	0	0	0	0	0	1	0	0	0	0	0
Ulus	0	0	0	0	0	0	0	1	0	0	0	0	0
Levazım	0	0	0	0	0	0	0	1	0	0	0	0	0
Vişnezade	0	0	0	0	0	0	0	0	0	0	1	0	0
Bebek	0	0	0	0	1	0	0	0	0	0	0	0	0
Yıldız	0	0	0	0	0	0	0	0	1	0	0	0	0
Muradiye	0	0	0	0	0	0	0	0	0	0	1	0	0
Kültür	0	0	0	0	1	0	0	0	0	0	0	0	0
Abbasağa	0	0	0	0	0	0	0	0	0	0	1	0	0
Cihannüma	0	0	0	0	0	0	0	0	0	0	1	0	0
Arnavutköy	0	0	0	0	1	0	0	0	0	0	0	0	0
Balmumcu	0	0	0	0	0	0	0	0	1	0	0	0	0
Levent	0	0	0	1	0	0	0	0	0	0	0	0	0
Kuruçeşme	0	0	0	0	0	0	0	1	0	0	0	0	0
Sinanpaşa	0	0	0	0	0	0	0	0	0	0	1	0	0

Y_j	1	2	3	4	5	6	7	8	9	10	11	12	13
Open or Not?	0	1	1	1	1	0	0	1	1	1	1	0	0

Objective Function Value: 6969293.920

Table 4.2:Capacitated Mathemtical Model Results

X_{ij}	1	2	3	4	5	6	7	8	9	10	11	12	13
Konaklar	0	1	0	0	0	0	0	0	0	0	0	0	0
Dikilitaş	0	0	0	0	0	0	0	0	1	0	0	0	0
Akat	0	0	1	0	0	0	0	0	0	0	0	0	0
Gayrettepe	0	0	0	0	0	0	1	0	0	0	0	0	0
Nisbetiye	0	0	0	0	0	0	1	0	0	0	0	0	0
Etiler	0	0	1	0	0	0	0	0	0	0	0	0	0
Mecidiye	0	0	0	0	0	0	0	0	1	0	0	0	0
Türkali	0	0	0	0	0	0	0	0	0	0	1	0	0
Ortaköy	0	0	0	0	0	0	0	1	0	0	0	0	0
Ulus	0	0	0	0	0	0	0	1	0	0	0	0	0
Levazım	0	0	0	0	0	0	1	0	0	0	0	0	0
Vişnezade	0	0	0	0	0	0	0	0	0	0	1	0	0
Bebek	0	0	0	0	1	0	0	0	0	0	0	0	0
Yıldız	0	0	0	0	0	0	0	0	1	0	0	0	0
Muradiye	0	0	0	0	0	0	0	0	0	0	1	0	0
Kültür	0	0	0	0	1	0	0	0	0	0	0	0	0
Abbasağa	0	0	0	0	0	0	0	0	0	0	1	0	0
Cihannüma	0	0	0	0	0	0	0	0	0	0	0	1	0
Arnavutköy	0	0	0	0	1	0	0	0	0	0	0	0	0
Balmumcu	0	0	0	0	0	0	1	0	0	0	0	0	0
Levent	0	1	0	0	0	0	0	0	0	0	0	0	0
Kuruçeşme	0	0	0	0	0	0	0	1	0	0	0	0	0
Sinanpaşa	0	0	0	0	0	0	0	0	0	0	0	1	0

Y_j	1	2	3	4	5	6	7	8	9	10	11	12	13
Open or Not?	0	1	1	0	1	0	1	1	1	0	1	1	0

Objective Function Value: 7252042.417

Figure 4.1: Depot-neighborhood Diagram for Non-capacitated Model

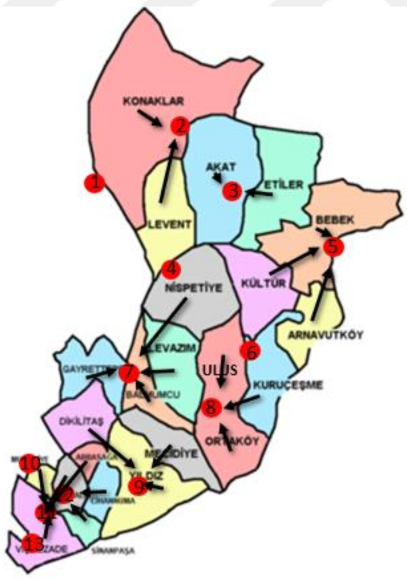

Figure 4.2: Depot-neighborhood Diagram for Capacitated Model

In this study, the total budget was taken as $75,000. In line with the results obtained depending on this budget value, the question arises as to what effect any change in the budget value will have on the model. It was examined how the budget constraint affects the decision variables regarding whether to open depots or not. This analysis was made by running the GAMS code with different budget values through the capacitated mathematical model. The change of the decision variable expressing which depots will be opened or not in line with different budget values is seen in Table 4.3.

Table 4.3: Different Total Budget Values Scenarios for Capacitated

Budgets	Objective Function	1	2	3	4	5	6	7	8	9	10	11	12	13
105000$	5999598.615	0	1	1	1	1	1	1	1	1	0	1	1	1
90000$	6142126.615	0	1	1	1	1	0	1	1	1	0	1	0	1
75000$	7252042.417	0	1	1	0	1	0	1	1	1	0	1	1	0
60000$	8502449.141	0	0	1	0	1	0	0	1	1	0	1	0	1
45000$	1.123179E+7	0	1	0	0	1	0	0	0	1	0	0	0	1

5. DISCUSSION

In this thesis study, two mathematical models are proposed in which the capacities of the depots are assumed to be infinite, and the capacities of the depots are added as parameters. These mathematical models are solved in GAMS. In line with the entered parameters, the objective function of the non-capacitated mathematical model, that is, the minimum value of the demand-weighted distance, is 6969293.920. In this first model, where depot capacities are ignored, it is seen that the 2nd, 3rd, 4th, 5th, 8th, 9th, 10th, and 11th depots should be opened according to the decision variables that minimize the objective function. In such a case, which neighborhood will receive help from which depot is shown in Table 4.1. In line with the entered parameters, the value of the objective function of the capacitated mathematical model is 7252042.417. When we look at the decision variables that minimize the objective function, it is seen that the 2nd, 3rd, 5th, 7th, 8th, 11th, and 12th depots should be opened. In such a case, which neighborhood will receive help from which depot is shown in Table 4.2.

When looking at these two models, it is seen that the value of the objective function is lower when the capacity constraint is not considered, and the value of the objective function is higher when the capacity constraint is added. This is since when the capacity constraint is added to the model, it makes the problem more complicated, and it is more difficult to minimize the demand-weighted distance due to the capacity constraint. When we look at the depots, it is seen that the 1st, 6th, and 13th depots are not opened in line with the parameters entered in both models. This is because while the demand-weighted distance is minimized in the objective function, these depots are at more extreme points of the region compared to other depots and their demand-weighted distances are higher, and therefore the model prevents minimizing the demand-weighted distance. At the same time, the reason why the 2nd, 3rd, 5th, 8th, and

11th depots are opened in both models is that the demand-weighted distance decreases with the other selected depots in the conditions when these depots are opened, and the objective function takes a smaller value compared to other scenarios. Table 4.1 and Table 4.2 show that each neighborhood is assigned to a depot. Optimal results were achieved in line with the parameters obtained to solve this problem with the two proposed mathematical models. Looking at these two mathematical models, the capacitated mathematical model would prove infeasible in a different scenario if the total depot capacity was less than the total demand and heuristic methods might have to be used. In another scenario, although unrealistic, if the total budget was smaller than the cost of a depot, the model would still give infeasible results.

5.1 Sensitivity Analysis

In this thesis study, capacitated mathematical model results were examined with different total budget values. The total budget value taken in the actual study is \$75000. This total budget value was increased and decreased by 20% and 40%, these values were taken as parameters and the capacitated mathematical model was run again in the GAMS code. In this case, while the actual total budget value is 75000\$, it is examined how the capacitated mathematical model results change in scenarios where the total budget value is 105000\$, 90000\$, 60000\$ and 45000\$.

Table 4.3 shows the objective values obtained as a result of the solution of the capacitated mathematical model with different total budget values and the optimal values of the decision variable indicating which depot is opened or not. Looking at the obtained scenarios, it is seen that the objective value decreases as the total budget value increases. As the total budget increases, the model can open more depots, further minimizing the demand-based distance. However, as the total budget value decreases, the model must open fewer depots and therefore it can only minimize the objective value within the framework of these constraints. For this reason, as the total budget value decreases, the objective value becomes higher as it is more difficult to minimize. Likewise, when looking at whether the depots are opened or not, as the total budget increases, the model opens more depots to cover the depot cost and to minimize the demand-based distance. For this reason, as the total budget decreases, fewer depots are opened.

The analysis shows that a 20% reduction in the budget from the initial \$105,000 to \$90,000 has a relatively modest impact on the objective function, while further reductions lead to increasingly larger increases in the objective function and reduced efficiency in warehouse placement. The percentage change in the objective function value when the maximum total budget value is compared to all other budget values is shown in Table 5.1.

Table 5.1: Objective Function Percentage Change When the Maximum Budget Value and The Other Budget Values

Budget Values	**Objective Function Increase Rate**
105000\$ - 90000\$	2.4 %
105000\$ - 75000\$	20.9 %
105000\$ - 60000\$	41.7 %
105000\$ - 45000\$	87.2 %

Changes are observed in the objective function depending on the 20% and 40% progressive increases and decreases in budget values. The analysis shows the percentile change in the objective function as the budget decreases:

1. From \$105,000 to \$90,000: There is a 2.4% increase in the objective function, indicating a modest impact on the optimization solution when the budget is reduced by 20%.
2. From \$90,000 to \$75,000: The objective function increases by 17.2%, showing a more significant impact as the budget is further reduced by 20%.
3. From \$75,000 to \$60,000: The objective function sees a 18.1% increase, indicating a continued substantial impact on the optimization results with further budget reduction.
4. From \$60,000 to \$45,000: The objective function increases by 32.1%, demonstrating a drastic impact on the optimization results due to the significant budget cut.

This step-by-step analysis highlights how each incremental reduction in budget affects the efficiency of the depot placement optimization. Initial reductions have a moderate impact, but as the budget continues to decrease, the efficiency of the optimization decreases significantly, emphasizing the importance of maintaining a higher budget for effective disaster management. This shows that it is vital to maintain a higher budget to optimize the placement of logistics warehouses for emergency preparedness and that significant budget cuts can greatly impact the efficiency and effectiveness of disaster management strategies.

Table 5.2: Objective Function Percentage Change When the Budget Value Change

Budget Values	**Objective Function Increase Rate**
105000$ - 90000$	2.4 %
90000$ - 75000$	17.2 %
75000$ - 60000$	18.1 %
60000$ - 45000$	32.1 %

6. CONCLUSION

As a conclusion, this thesis presents a comprehensive study on logistic depot location optimization for emergency preparedness, specifically focusing on the Beşiktaş district in Istanbul, Turkey. Given Turkey's high sensitivity to earthquakes, especially in the densely populated and economically significant Marmara Region, the study aims to enhance disaster management by optimizing the placement of emergency supply depots.

The research addresses a critical need for strategic planning in disaster preparedness, emphasizing the importance of locating logistic depots that can ensure quick and efficient distribution of aid materials following an earthquake. It is necessary to know the precautions to be taken before the earthquake, what to do during the earthquake, and to take precautions to survive after the earthquake. It is necessary to build durable buildings, raise public awareness, carry out regular building and infrastructure inspections, and make preparations for what may happen after the earthquake. If these precautions are not taken, very destructive effects of earthquakes can be seen. It is necessary to combat many problems such as injuries and loss of life, losses of many buildings, residences, workplaces, hospitals, historical and cultural heritage, epidemic diseases and environmental pollution. It is possible to take many measures on these issues at the state, institutions and individual level. For this reason, in this study, the problem of positioning logistics depots, which is one of the precautions to be taken against the problems that may occur after the earthquake, was studied. By implementing two binary integer programming (BIP) models, a non-capacitated model and a capacitated model, this study provides a framework for depot location optimization. The non-capacitated model assumes that depot capacities are unlimited, while the capacitated model incorporates capacity constraints, making the problem more realistic and complex. The optimal depot locations were determined using GAMS, considering the demand-weighted distance. Sensitivity analysis was made based on the budget value in line with GAMS outputs. The non-capacitated model identified the optimal locations for depots without considering capacity constraints, resulting in a lower objective function value. The depots selected were able to serve the needs of all neighborhoods efficiently based on distance. Incorporating capacity constraints, the capacitated model provided a more realistic scenario where each depot has a limited capacity to serve the population. Although the objective function value was slightly higher, the model ensured that depots were not overloaded and could effectively manage the distribution of aid materials.

The findings of this study have significant implications for disaster management and urban planning. By optimizing depot locations, emergency management agencies can ensure that resources are allocated efficiently, minimizing response times and potentially saving lives. Strategic depot placement can reduce the overall cost of disaster response by ensuring that fewer depots are needed while still meeting the demand, thereby optimizing budget utilization. The study provides a valuable framework that can be adopted by policymakers for planning and improving disaster preparedness strategies not only in Istanbul but also in other earthquake-prone regions.
Despite the methodology, there are several limitations to this study that should be considered. The models assume static demand and supply conditions, which may not reflect the dynamic nature of disaster scenarios. Real-time data and adaptive models could enhance accuracy. The study focuses on Beşiktaş district. Extending the analysis to a larger geographical area or incorporating inter-district dependencies could provide a more comprehensive understanding.

6.1 Thesis Contribution

In this study, the positioning of logistics depots was studied so that people who survived the earthquake could access the materials they may need as soon as possible. This study was conducted based on Beşiktaş District. Possible depot locations on main arteries have been determined. The number of people who may need temporary shelter and aid materials after a possible earthquake in the neighborhoods of Beşiktaş district has been determined. AFAD logistics depots were taken as basis for the depots to be located, and depot capacity and costs were determined. The total budget allocated to take these depot positioning measures has been determined. The aim of this study is to ensure that people can access relief materials as soon as possible via main roads after the earthquake. One of the most important points here is that the amount of aid materials in the depots are sufficient for people. For this reason, the capacities of the depots were also taken into consideration. Within the scope of this problem, two different mathematical models, non-capacitated and capacitated versions, have been proposed that minimize the demand-weighted distance.

Optimal results were obtained by coding the two proposed mathematical models in GAMS. With these results, the optimal locations of the depots were determined, where people who survived the earthquake and needed help could reach sufficient relief materials in the shortest distance. According to these results, it was determined which of the possible depot locations should be placed and which neighborhood should receive help from which depot. The total budget constraint in the mathematical model constraints also affects variables such as how many depots will be opened and therefore which neighborhood will be assigned to which depot, and ultimately the objective function. After the optimal results were found, the effects of different total budget values on the optimal results were also examined. Having a higher total budget will make it easier to open more depots and will also provide space to minimize the objective value, which represents the demand-based distance. It is revealed that when the total budget decreases, the objective value, which expresses the demand-weighted distance, is higher by opening fewer depots compared to other scenarios.

6.2 Future Work

In future studies, multi-purpose mathematical models can be created. In this study, there is a single objective function that minimizes the demand-weighted distance, but a mathematical model can be created with two different objective functions that minimize both the demand-weighted distance and the total cost. In this study, possible depot locations and distances between neighborhoods were calculated based on Euclidean distance. In further studies, distance calculations can be made that include intermediate roads instead of Euclidean distances. In this study, demand is specific and taken as a parameter in the mathematical model. In future studies, stochastic models can also be developed by taking demand as uncertain.

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APPENDICES

Appendix A.

```
sets
i neighbourhood   / Konaklar, Dikilitas, Akat, Gayrettepe, Nisbetiye,
                    Etiler, Mecidiye, Turkali, Ortakoy, Ulus,
                    Levazim, Visnezade, Bebek, Yildiz, Muradiye,
                    Kultur, Abbasaga, Cihannuma, Arnavutkoy, Balmumcu,
                    Levent, Kurucesme, Sinanpasa  /
j depot           / 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 /;
parameters
d(i) demand       /Konaklar 690, Dikilitas 621, Akat 987, Gayrettepe 534,
                   Nisbetiye 429, Etiler 603, Mecidiye 1575, Turkali 999,
                   Ortakoy 429, Ulus 375, Levazim 222, Visnezade 642,
                   Bebek 342, Yildiz 507, Muradiye 207, Kultur 192,
                   Abbasaga 408, Cihannuma 357, Arnavutkoy 270,
                   Balmumcu 252, Levent 315, Kurucesme 222, Sinanpasa 441/
K(j) fixed cost of opening depot     / 1 12000, 2 8000, 3 8000, 4 8000,
                                       5 8000, 6 12000, 7 8000, 8 8000,
                                       9 16000, 10 8000, 11 8000, 12 8000,
                                       13 12000  /
 C(j) capacity of depot              / 1 3600, 2 2400, 3 2400, 4 2400,
                                       5 2400, 6 3600, 7 2400, 8 2400,
                                       9 4800, 10 2400, 11 2400, 12 2400,
                                       13 3600   /
maxDepot max depot openning cost     / 105000/
M    a very large number             / 1e10 /  ;
```

parameters

```
neighbourhood_x(i)      /  Konaklar    41.09532708, Dikilitas    41.05578305
                           Akat        41.08606952, Gayrettepe   41.06303173
                           Nisbetiye   41.07252992, Etiler       41.08475193
                           Mecidiye    41.05277442, Turkali      41.04717937
                           Ortakoy     41.05430685, Ulus         41.06366161
                           Levazim     41.06236955, Visnezade    41.04088392
                           Bebek       41.07910621, Yildiz       41.04885397
                           Muradiye    41.04823954, Kultur       41.07331252
                           Abbasaga    41.04970411, Cihannuma    41.04690121
                           Arnavutkoy  41.06954194, Balmumcu     41.05923893
                           Levent      41.08141868, Kurucesme    41.0608165
                           Sinanpasa   41.0428423    /
neighbourhood_y(i)      /  Konaklar    29.01380285, Dikilitas    29.01380285
                           Akat        29.0263252,  Gayrettepe   29.00687208
                           Nisbetiye   29.02212237, Etiler       29.03646491
                           Mecidiye    29.01941456, Turkali      29.00192672
                           Ortakoy     29.02737999, Ulus         29.02716421
                           Levazim     29.01936302, Visnezade    28.99833111
                           Bebek       29.04328684, Yildiz       29.01431829
                           Muradiye    28.99889785, Kultur       29.0332235
                           Abbasaga    29.00510895, Cihannuma    29.00814724
                           Arnavutkoy  29.04296986, Balmumcu     29.01550908
                           Levent      29.01694088, Kurucesme    29.03386612
                           Sinanpasa   29.0050072   /
depot_x(j)              /  1 41.08395108, 2  41.09135137,
                           3 41.08735106, 4  41.07673367,
                           5 41.07919583, 6  41.0651719,
                           7 41.06320032, 8  41.06012186,
                           9 41.05257547, 10 41.05519247,
                          11 41.04949651, 12 41.04991732,
                          13 41.04447993          /
depot_y(j)              /  1 29.00628914, 2  29.01841221,
```

```
                         3 29.03045652, 4  29.01943291,
                         5 29.04372568, 6  29.03150996,
                         7 29.01498341, 8  29.02723187,
                         9 29.01588931, 10 29.00159945,
                        11 29.00568227, 12 29.00863292,
                        13 28.99661663          /
parameters  dist(i,j);
dist(i,j) = 111111*sqrt(power(neighbourhood_x(i) - depot_x(j), 2) +
power(neighbourhood_y(i) - depot_y(j), 2))

variable
z      objective function value

binary variables
x(i,j)  neighbourhood i connected to depot j
y(j)    depot j is openned

equations
obj     objective function
cst1(i) each neighbourhood must be served by exactly one depot
cst2(j) depot openning constraint without capacity
cst3(j) depot openning constraint with capacity
cst4    total depot opening cost constraint ;

obj..          z =e= sum((i,j), d(i)*dist(i,j)*x(i,j));
cst1(i)..      sum(j, x(i,j)) =e= 1;
cst2(j)..      sum(i, d(i)*x(i,j)) =l= y(j)*M;
cst3(j)..      sum(i, d(i)*x(i,j)) =l= y(j)*C(j);
cst4..         sum(j, K(j)*y(j)) =l= maxDepot

model alloc_no_cap /cst1, cst2, cst4, obj /
      alloc_cap / cst1, cst3, cst4, obj /;
```

```
solve   alloc_no_cap using mip minimizing z;
display z.l, x.l, y.l;

solve   alloc_cap using mip minimizing z;
display z.l, x.l, y.l;

display dist
```