Optimizing the Pre-disaster Emergency Response System of Istanbul

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Electronics and Computer Engineering.

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- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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Optimizing the Pre-disaster Emergency Response System of Istanbul

Muhammet Ali TAŞKIN

Abstract

Human history has been affected by the natural disasters and these disasters have shaped the flow of history with their magnitude. Modern living style of the 21st century increases the tendency to prefer urban life, and creates metropols with huge crowds. This preferred dense and jammed order lead to an increase on risk factor, and make large cities, like İstanbul, more vulnerable to natural disasters. In this context, deciding on the location and the service routes of warehouses before the disaster will minimize the delivery time for survivors while keeping the efficiency of each warehouse at top level. In this thesis, we develop a mathematical programming model to determine the locations of main warehouses and emergency response units at neighborhood level for İstanbul. In order to evaluate and compare on this domain, we employ three modified optimization models. Based on our results, we propose optimal locations for main and satellite warehouses as well as quantity of humanitarian materials to the survivors. We believe that insights incurred in this thesis will provide invaluable analytical guidance for policymakers.

Keywords: Humanitarian Logistics, Time Constrained Single Criteria Optimization

İstanbul'un Afetle Mücadele Sisteminin Optimizasyonu

Muhammet Ali TAŞKIN

Öz

İnsanlık, tarih boyunca türlü doğal afetlere maruz kalmıştır ve bu afetler etki derecesine göre tarihin akışını şekillendirmiştir. 21. yüzyıldaki modern yaşam, kent hayatına olan eğilimi arttırmış ve yoğun nüfuslu yapılaşmaları beraberinde getirmiştir. Tercih edilen bu yoğun ve sıkışık düzen risk faktörünü de yükseltmiş, İstanbul vb. metropolleri doğal afetlere karşı daha savunmasız hale getirmiştir. Bu bağlamda, afet öncesinde ana depoların koordinatlarına ve hangi bölgelere hizmet vereceğine karar verilmesi, afet anındaki yardıma ulaşma süresini en aza indirirken depo ve sığınakların en yüksek verimlilikle kullanılmasını sağlayacaktır. Bu tezde, benzeri çalışmaları da göz önünde bulundurarak, İstanbul ili için mahalle düzeyinde tek amaçlı karar verme modeli tasarladık. Farklı amaçların da göz önünde bulundurulması için 3 farklı model oluşturduk ve model çıktılarını karşılaştırdık. Çalışmamızda, ana ve yerel depoların nerede bulunması ve hangi mahallelere ne kadar miktarda yardım sağlanılması gerektiği sorularına cevap bulduk. Bu sonuçlar karar vericiler için değerli bir analitik rehber olacaktır.

Anahtar Sözcükler: İnsani Yardım Lojistiği, Süre Kısıtlı Karar Verme Modeli

to my family...

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Abbreviations

ERS	**E**mergency **R**esponse **S**ystem
ERU	**E**mergency **R**esponse **U**nit
OR	**O**perations **R**esearch
TEMS	**T**urkey **E**mergency **M**anagement **S**trategy
SU	**S**urvivor **U**nit
MIP	**M**ixed **I**nteger **P**rogramming

Chapter 1

Introduction

In the first chapter, we briefly explain the motivation of our study and our objectives in general. Firstly, we provide extensive information on the disaster statistics for various countries including Turkey since 1990 and present the consequences of various disasters in terms of population, economy, and society. We also include various several countries affected by similar disaster types as Turkey did. Additionally, we briefly discuss the works that study similar disaster response systems in literature, mention that the research community also developed a matching disaster response system in literature to mitigate outcomes which enlightens our thesis study. The last part of this chapter provides the organization of the upcoming chapters.

1.1 Turkey's Experience with Natural Disasters

Almost all territories and regions in the world faced brutal disaster experiences, and whereas Turkey's region was not an exception. Turkey's almost whole territory lays on the Asia which is the closest part of Asia to Europe and to Africa whereas the less part of the country belongs to continental Europe which makes the country neighbors with Bulgaria and Greece. The statistics on natural disasters of countries clearly show the geographic distribution of disasters by subtypes. We discuss the illustrative examples of Turkey and Japan. With the courtesy of UNISDR, we analyzed the disaster events in Turkey in the period of 1990-2014[1].

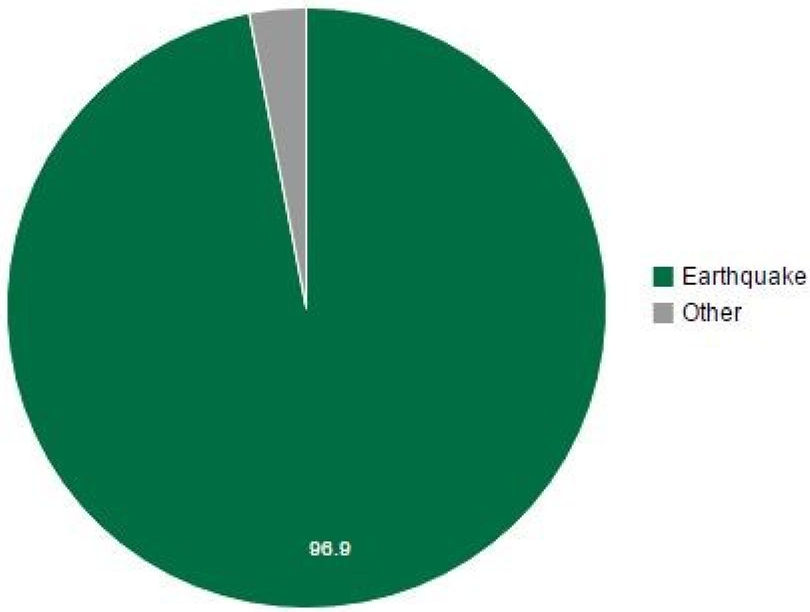

FIGURE 1.1: Disaster proportion of Turkey [1].

Figure clearly shows what types of disasters have been encountered in recent years in Turkey in terms of almost all occurrences. Geography defines the impact of weather which is the main reason of air based disasters like winds, turbines etc. Geology affects the catastrophe probability and frequency of disasters while also affecting the magnitude. The above figure depicts which part Turkey should focus on. Consequently, geological circumstance must be assessed and the precautions for related disasters must be determined to ease any unexpected event.

Japan, another vastly affected country of disasters through its history, is stated to be harmed primarily from earthquakes [1].

As the below figure depicts the ratio of mortal events between 1990 and 2014, earthquake leads the statistics with 91.1% where storm, extreme temperature, and other subtypes of disasters tolled to insignificant number when compared to earthquake. For the argument regarding the relationship of geography and disaster subtype, statistics of Japan and Turkey about disaster history may be taken as solid exemplifications.

Besides arguing results of past figures in terms of frequency, economic impact of those natural disasters in recent years should be discussed and lessons should be learned. To this end, we present related statistical figure representing economic loss for related years.

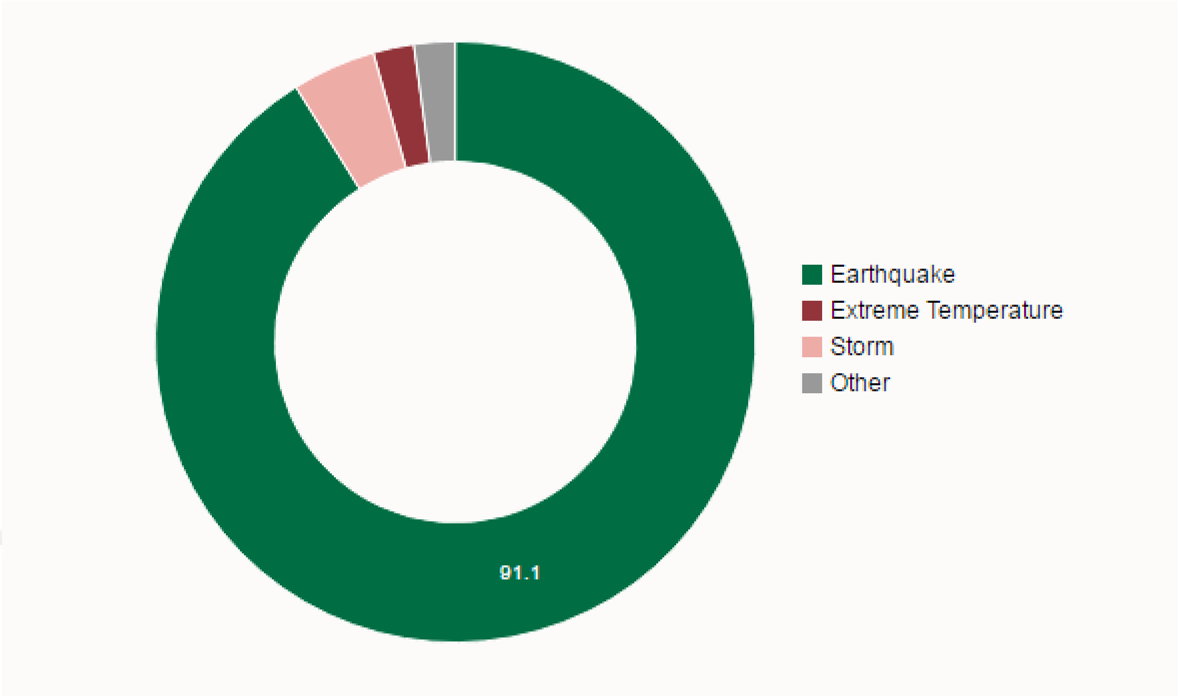

FIGURE 1.2: Disaster proportion of Japan [1].

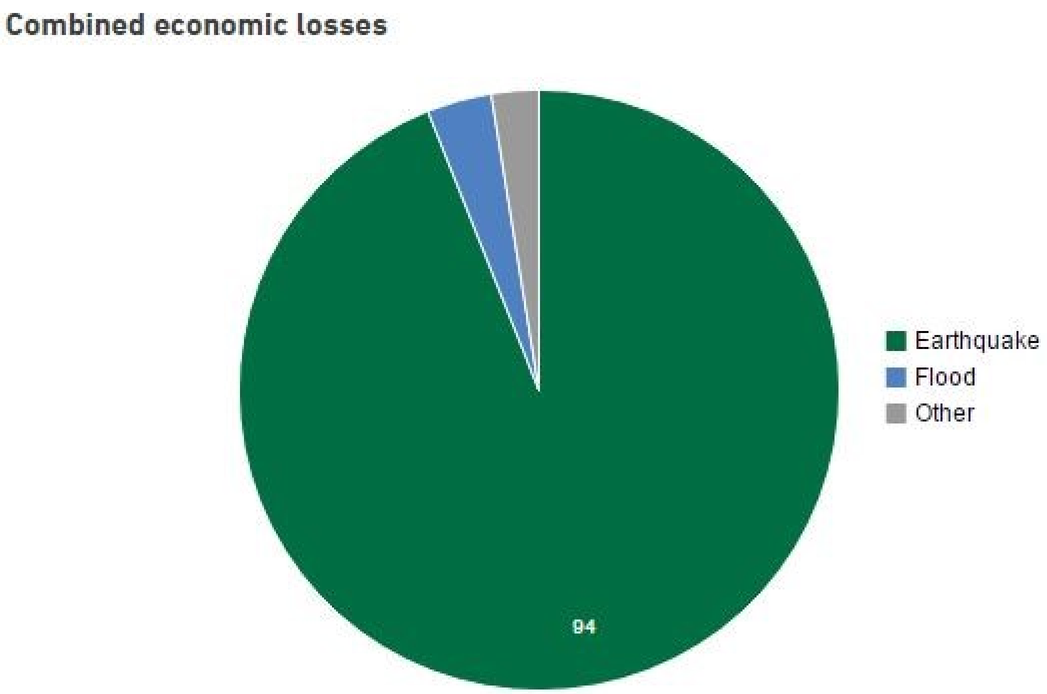

FIGURE 1.3: Combined economic losses [1].

Through combining the economic losses each year, it is estimated that natural disasters in recent years cost nearly 93 billion USD to Turkey [1]. When commenting on these economic results, it should be reminded that Turkey's last announced GDP is around 820 billion USD as well. Apparently, Turkey has been dramatically affected from earthquakes economically and vitally, and its side effects have been continuing for many years after a disaster happens.

1.2 Disaster History and Istanbul

Istanbul is the most prominent city of Turkey with its huge population of nearly 20 million and with its huge economic scale if compared to remaining cities [2]. Research findings suggest that Istanbul is also amongst the highly developing cities which are also nominated to top 25 cities in 2025 [3]. Gezici et al. underlines the impact of the culture, tourism and other intangible factors to the development of a city exampling with Istanbul. Authors also review the strong suggestion that Istanbul will continue to shine in between the Middle East and East Europe while pushing the limits of being financial, technological and socio-economic leader in the region [4].

Turkey pushes forward its crowded precious city by integrating trade routes from Europe to Asia by tens of mutual agreements and by exploiting its dense population where 2.542 citizen per square meter live in its territory. While it's a great potential for Istanbul to be assertive with its huge population and infrastructure, high risk of losing reputation would come with an unexpected emergency situation.

By the definition of what may have been called as a hazard to a urban settlement by International Federation of Red Cross and Red Crescent Societies; earthquakes, floods, great fires, landslides, tsunamis, volcanic activities, storms, droughts are nominated to have responsibility for collapsing the cities and extinction of many tribes through human history [5].

As well as natural hazards keep the high rank of death rate among hazard types to society, in recent centuries, technological hazards arise as another lethal type of hazards to human kind as well. Industrial accents, nuclear explosions, unconditioned urban settlements have been accepted as the top influential subtypes of technological hazards. Tech perils, also reputed as man-made hazards that clearly underlines why the unexpected situation occurs, lead the death toll flag and are not the prior goal of this research on Istanbul emergency case [6].

From Munich to Tokyo, natural disasters kept to be catastrophe on all over the world. Disaster subtypes still exist at certain occurrence probability. If past history of disaster statistics of countries are to be reviewed it will be noticed that for instance, Tokyo keeps the high likelihood to have earthquakes rather than flood or any other hazard types. A trusted research facility, Munich RE underlines that more than 980 loss events had been occurred in 2014 where meteorological events dominate the results [7]. Statista, another reliable statistics resource, shares that top apocalyptic disaster between 1980 and 2015 is Thailand Earthquake in 2004 with 220.000 death toll and Haiti earthquake follows it with 159.000 bodies and millions of wounded civilians and refugees [8]. Among various types of disasters, earthquake holds the leadership with 6 events out of top 10 events. Statistics clearly shows how mortal a disaster could be. Further reliable authority in emergency and disaster domain, The United Nations Office for Disaster Risk Reduction presents that 0.7 million people have died in the apocalyptic disasters in last 10 years where 1.7 billion people have been affected and 1.4 trillion dollar economic damage have occurred [1].

Catastrophic events are also destructive for business world. Directly and indirectly, it is claimed that those disasters that have taken place since 2000 cost 2.5 billion dollar globally which is highly above the global domestic product of almost all countries. To sum up, we summarized major impacts of disasters to countries and exerted to show that how high the death figures. In society, it is also believed that natural disaster are the top harming incidents to a country when necessary precautions have not been taken.

1.3 The Motivation

The motivation behind the adoption of operations research (OR) methods mainly lies on the structural similarity between emergency management and OR. Efficient mathematical modeling and solving those alike occasions would probably benefit millions of human beings which underlines and motivates the researchers to work in. We connect OR methodology with the disaster management cycle stated in detail below.

Disaster vulnerability of huge cities are proven according to disaster statistics database and the illustrative examples we presented. Leading cities of countries in terms of economy, social status, and development clearly owe their high ranking positions in part to agile response of disaster conditions. As well as this readiness condition of cities that is crucial to maintain its position, it is noteworthy that planning of disaster response belongs to disaster management cycle which is proposed by Tufekci [9].

According to disaster management cycle, disaster response managers should consider efficient response of emergency situation in four main phase that are recovery, mitigation, preparation, and response. Whereas mitigation and preparation phases belong to before disaster part, after disaster part includes response and recovery phases. Educating civilians, deploying emergency warehouses, authorizing officials to build emergency infrastructure are the basic major duties carried out in the pre-disaster phase.

FIGURE 1.4: Disaster management cycle [9].

In our thesis, we aim to develop an analytical model to assign and pre-allocate the resources before emergency situation occurs. Hence, proposed mathematical model presents the results of optimized assignment for warehouses to demand points, if such a case happens. Another contribution of our study is that, we imported the longitude-latitude coordinates of each demand point of Istanbul, and it clearly fills the gap in previous research on Istanbul. There are also humanitarian logistics efforts done on Istanbul. But, most of them focus on post-disaster case which employs the effects of disaster with certain parameters.

1.4 Outline of Thesis

In Chapter 2, we review the literature in humanitarian logistics domain especially those which employ operations research. We state the similarity of supply chain logistics and humanitarian logistics arguing that similar approaches done in supply chain field may be applied on humanitarian logistics as well. We stress the OR methodology applied from 90s to present days by classifying them into single objective and multi objective approaches. Stochastic, fuzzy approaches with their targets and the results have also been included in second chapter. Lastly, we state the fuzzy approach which is the modern solution method of time consuming OR problems.

Chapter 3 presents the acknowledged modern logistics concepts and how they are connected to humanitarian logistics and supply chain logistics. We briefly explain the interdisciplinary approaches to humanitarian logistics in a way researchers apply to supply chain management. Then we propose our Emergency Response System and state the relation between modern response systems of disaster operations management. We outline the modern approach in basics and charted the relation of each part with our proposed ERS.

Chapter 4 explains Turkey's Emergency Management Strategy (TEMS) and its relation to our proposed emergency response plan. We share the mutual link of each sub-part of TEMS with our study. For instance, we share why logistics team is related to assignment table.

Chapter 5 presents proposed methodology for the emergency management problem in Istanbul and includes the details of the linear program with objective functions, constraints, indices, and parameters. We explain each detail located in linear program and shared the objectives of each part. Lastly, we share the assumptions we made on the model.

In the sixth chapter, we share the outline of database and how we create and design it regarding our parameters in model. Then, results of our methods are presented. Suggested ERU centers and warehouses with expected capacity usages are discussed. We also present three models with their differences and show how the results are differentiated. Each model is run with the time constraint and without time constraint. Lastly, the sensitivity analysis of models is discussed and we present our suggestions for policymakers in terms of which warehouse, ERU center, and neighborhood link they should use, what amount should be transferred, which ERU center should be located in which neighborhood, and which warehouse should be located in which district. We also include the maximum time consuming delivery of layer 1 and layer 2 as well as the average transfer time of all.

In the last chapter, we include the overall structure and objective of our thesis concretely. We include that how our study should be utilized by appliers and stated our suggestion briefly. Furthermore, we share pointers for future research.

1.5 Contributions

Our contributions could be stated as follows;

1. We developed an emergency response system which serves the objectives of TEMS plan.
2. We provide first two-tier emergency distribution model in Istanbul.
3. We suggest the main warehouse and ERU warehouse locations as well as total number of them.
4. Our model meets the demand of each neighborhood in Istanbul.
5. We provide sensitivity analysis to guide policymakers for their decisions.

Chapter 2

Literature Review

In second chapter, we present relevant literature and results on related topics. Firstly, we discuss that how similar the supply chains and disaster management systems when they function. Various literature review efforts have been carried out by a group of researchers to showcase the research methods applied on humanitarian logistics.

Modeling of disaster response circumstances has been divided into two categories as single criteria modeling and multi criteria modeling. Single criteria modeling addresses the objective chosen by model builder to optimize overall status. Multi criteria modeling optimizes multiple goals whose ranking is aligned by decision maker. Because of computational burden of multi-objective approaches on emergency situation, heuristics and metaheuristic principles have been applied on humanitarian logistics to improve solution efficiency.

2.1 Disaster and Supply Chain Similarity

A disaster has been acknowledged as an extraordinary situation that certain basic requirements must be routed and delivered to the vulnerable. For that reason, it is obvious that applying the state of art engineering principles on this domain will generate efficient strategies for disaster logistics.

Supply chain management is a principal research and an application area where certain factors is under control to serve each stakeholders with maximum value [10]. Under the catastrophic situations, several factors must be kept above pre-specified limits so as to preserve disaster logistics efficient and serve the disaster-victims efficiently.

Supply chains have been created, maintained, and sustained solely to maximize gross profit as each company does. Compiling those capable management approaches to disaster organizations yields a motivation to apply similar methodologies to humanitarian logistics. Researchers who primarily focus on relief operations name their area as operations research. Cornell University defines operations research as planning and routing resources so as to maximize certain metrics delimited by executives [11]. Operations research is an area to apply constrained mathematical model under privileged circumstances which also could be disasters, and it is easy to have direct relationship between them. Their philosophy relies on delivering resources as quickly as possible while sustaining additional limits. Hence, one may conclude humanitarian logistics as a suitable extent to be focused by operations researchers.

2.2 General Introductory Insights in Articles

It is noteworthy to realize that operations research society has already focused on this field from 90s [12]. Almost all researches done in this field state the importance of emergency logistics in their introductive phase by compiled figures. Emphasizing the vitality of humanitarian logistics research by providing most recent events occurred all over the world creates an attraction on readers. Quantitative data usage also widens the perspective of mathematical model implementation.

Humanitarian logistics, a.k.a. disaster logistics, is an area that hundreds of qualitative researches have been applied. Those researchers state further factors such as the significance of involvement of government in relief operations, education of staffs involved primarily in this area and cooperation of entire relief foundations to achieve their goals. After acknowledging the importance of qualitative research approach, the requirement of handling the results initiates the worth of quantitative approaches to the field as well.

2.3 Review Efforts

Kunz and Reiner provide a comprehensive review on humanitarian logistics by including both qualitative and quantitative efforts [13]. More specifically, they reviewed 174 articles published between 1993 and 2011. They pointed out that the trend of this topic has instantly grown in recent years. In order to assess the research papers both on qualitative and quantitative data, they have developed useful metrics. Authors have counted and classified the words contained in research articles as government, socio-economic, infrastructure and environment word phrases. In conclusion, grouping of words depicts the information revealed in those researches and draws a path for future research studies.

Li et al. introduced emergency medical services as a distribution of services to relief demand points and reviewed recent developments in EMS [14]. They have listed the approaches in literature as heuristics and classic algorithms. Genetic algorithm and tabu search are listed as widely used modern heuristic approaches for multi criteria modeling. Authors also pointed out a database which have been intensely used by geographic information system. They emphasize the integration of quality metrics and priorities in their mathematical models.

Caunhye et al. investigated related articles in humanitarian logistics and devised a framework [15]. They state that research efforts divided into pre-disaster and post-disaster categories. Relationship diagram highlights the strong connection between those modules which are relief distribution, evacuation and casualty distribution. Reviewers pointed out that further research directions should be focused on cost-effectiveness.

L.V. Wassenhove and A. P. Martinez introduced the efforts focused on cost trade-off analysis and standard replacement policies [16]. The paper illustrates the adaptation of supply chain models into operations research. While highlighting the basic features and superiority of supply chain management, they conclude the probable implementation feasibility of similar domains such as humanitarian logistics.

2.4 Heuristics

Optimization problems fall into category of none polynomial time algorithms which motivates researchers into heuristic approaches. Amiri et al. applied a meta-heuristic solution approach which named as particle swarm optimization [17]. Robust optimization has been considered primarily in their efforts which minimizes the difference incurred from variability. Minimizing total cost was the objective function of model with cost variability. Capacity of relief distribution centers are welcomed as constraints in model.

Authors compared the identical algorithms in two different methods that are branch and bound, particle swarm optimization (PSO). Results are depicted graphically, which emphasize the instant increment with exact problem set size. PSO clearly outperforms the previous method, branch and bound, and clearly constitutes a path for researchers directing them to heuristic algorithms which enables them to obtain data in less amount of time. They attained the results on LINGO software, which enable them to work for branch and bound but not for PSO. Effectiveness of PSO on large domains is the crucial conclusion of their research.

After underlining the importance of relief items' urgent delivery to victims, Wang et al. constructed the dynamic modeling which closes the gap between application and theoretical efforts, where authors also introduced the weights for several commodity to be supplied [18]. Their solution approach was heuristics and named as Lagrange Relaxation. Similar to optimization research completed in this workspace, they advise that future research should focus on obtaining robust results in reasonable time.

Ozdamar et al. stressed the effectiveness of obtaining heuristic approaches in multi modal cases such as rails, truck, air transportations etc. [19]. As stated before, logistics optimization research done in this field fall into the main category of commodity routing. As known by investigators, vehicle routing problem can be solved under non polynomial time which drags solvers to heuristics approaches. They have applied their model on Istanbul earthquake which occurred on 1999. Results demonstrate the success of LaGrange relaxation-supported heuristics model.

2.5 Single Criteria Models

Jin et al. focused their efforts into efficient transferring and assignment of disaster victims to appropriate on-site clinics and hospitals [20]. Their mathematical model consists of single objective function which includes survival probability of victims related to patient type of theirs. Incorporating the location distance between disaster area, on-site clinics and hospitals, the model maximizes the total number of survivors under the constraint of patient- doctor assignment. Having the results for both objective functions that are total cycle time and surviving patients, they implement their model in a computational environment considering single disaster area, multiple disaster area, less demand and large demand cases.

Results obtained for several situations, also for total cycle time and total surviving patients, imply that the maximization of the number of survival patients would lead to efficient results where patients are categorized and assigned to best procurement stage. A routing optimization under the catastrophic situations is developed and applied on Istanbul and then results are presented by Ozdamar [21]. Proposed route planning system effectively transforms inputs into outputs by traditional approaches.

Risk mitigation is the key point that differentiates Ben-Tal et al.'s work from similar efforts [22]. Main advantage of their work supported by dynamic programming is each time points have been maximized regarding previous ones. Adjustable Robust Counterpart (ARC) approach has also been introduced to the problem domain as dynamic programming approach which is a rarely utilized methodology.

2.6 Multi Criteria Models

Apart from single objective approaches, Amiri et al. achieves the incorporation of different layers of decision as tactical, strategic and operational [12]. Their models' superiority also lies in considering uncertainty variables with decision variables. As well as considering ordinary processing of pre-disaster and the post disaster, their mathematical model also includes the disruption of transportation of network after the disaster. Compiling the model with its variables and constraints, they have applied and got the results for earthquakes in Tehran capital city. Maximum shortage, travel time and total cost are the objective functions to be minimized in their solution, Amiri, used constraint method to compile those three functions into single function so as to benefit the solution procedures of regular methods as simplex, branch and bound and so on. Results have been obtained with the GAMS software and CPLEX solver. Pareto optimal solution for binary objective relations is depicted as part of the results.

Vitorino et al. compiled a large number of studies done in this field [23]. They clearly define the attributes included in the multi criteria optimization models. Cost, time, equity, priority, reliability are listed as primary consideration for model builders. They pointed out the aggregation of objectives so as to serve each metric. With clear charts depicting each objective function, the dissimilarity between single and multi-criteria case is obvious. They have applied their model on an illustrative example of Haiti disaster in 2010. They have combined their objective functions into single one with goal programming.

F. Barzinpour and V. Esmaeili have built their mathematical models on multi-criteria [24]. Maximizing the meeting rate of total demand is their initial objective function whereas the second one stands for minimizing the total cost occurred by processing of facilities, and the last one aims to minimize total transportation and shortage costs. Acknowledging the equal significance of those models, goal programming method has been developed to prioritize objectives in order. Main insight in goal programming lies on penalizing the variance from objective function. Each objective function is involved in main objective function. Representative application has been done on the earthquake in Tehran, Iran which is divided into 10 sub-regions to inspect success rate in each. Covered people denotes the figures that the ratio of survival rate similar to other models, almost all yield full coverage. Shortage of units and stored equipment constitutes total cost for the third objective, and also included in their model. In order to benefit from the solver practically on linear programs, each nonlinear equation transformed into linear equation by linearization technique. Data and parameters for model are mainly imported from GIS database which has been fed by municipalities.

Mirzapour et al. constructed a multi objective stochastic programming model so as to distribute relief under uncertainty [25]. Apart from similar approaches in this domain, there also exists another solution procedure called Compromise Programming. Goal programming, reference point method, and compromise programming is the most frequently used solution approaches in multi criteria decision making. Shared principle among these solution procedures is combining several objective functions into single statement, and then initiating the solution progress.

As similar investigations done in this field, Mirzapour et al. have also implemented their models on Tahran which is a suitable data application area for emergency management [25]. They obtain results with LINGO running on a PC. Several model types are presented in the paper according to demand, supply, or cost uncertainty. According to results, deterministic model provides the maximum cost among all.

Sheu also expressed the importance of dynamic programming and allocation of scarce resources in emergency situations in his further article [26]. Under the condition of sudden catastrophic affects in disaster area, communication and information services would be lost due to disruptions in networks. Insufficient data and information issue would be fixed by data fusion methodology whereas compiling the results and running the related model must be done under the heuristics model so as to obtain results in reasonable time as they did.

Data fusion methodology stands for completing the insufficient parts of multiple data statements to gain single, least damaged data. Several scenarios have been also presented to compare their effects on their model whereas numerous data points are also introduced.

Hu devised an optimization model for emergency logistics which minimizes the total shortage cost while including total transportation costs as well [27]. Computational simulations are performed on Dash Xpress optimization software which yields the results in less than 1 second. The author stated that further studies may be developed on considering multiple disaster points and capacity of logistics model.

2.7 Stochastic Models

Doyen et al. conducted a stochastic modeling study on disaster management [28]. First of all, they have taken probabilities into consideration and placed into the model both in objective functions and constraints. After emphasizing the difficulty of solving NP-Hard problems such as TSLP problems, they propose a heuristic model to obtain results which is Lagrange relaxation. Solution of model is also supported by local search algorithm.

Computational consequences mainly include the comparison of CPLEX and Lagrange heuristics (LH). Finally, they conclude that LH is capable of solving models up to 25 scenarios where each one stands for different probabilities for each case. Stochastic model involved mathematical models incorporating uncertainty which closes the gap between the real world and academia. For that reason, computationally effective stochastic model building and solution is the key for the progress in emergency research area.

2.8 Fuzzy Approach

Sheu proposed a novel method where the author approached to emergency optimization with fuzzy logic solution procedure, and concluded 30% potential system improvement overall [29].

B. Adivar and A. Mert evaluated their models' performance on fuzzy credibility metrics [30]. They have also supported their model by real case data obtained externally. Solution also paves the way for analyzing process flows under the disaster occurrence. Minimized the total function includes fuzzy-involved terms and lets researchers to deeply analyze the results defining the lower and upper boundaries for decision variables.

2.9 Humanitarian Logistics Studies on Istanbul

Ozkapici et al. state that intermodal transportation in humanitarian logistics could improve the delivery time [31]. Their research includes mixed integer programming (MIP) model of two-layer transportation. First layer of transportation is for delivering materials from main docks to sub-ports, and second layer connects sub-ports to relief facilities which are located in district centers. Baskaya et al. develop a two-layer MIP model for lateral transshipment which transfers materials to districts from main warehouses [32]. Their model serves the district centers at the last stage. Lateral shipment option is also considered in another model so that they can benchmark the differences. They state that using lateral shipment improves the delivery time. Kilci and Yetis create a two-layer MIP model which aims to deliver shelters from district centers to neighborhoods [33]. They apply their model on Kartal and Van. Renkli and Duran suggest the relief facility locations for Istanbul by their two-layer MIP model [34]. They include material types and vulnerability of earthquakes. Salman and Yucel utilize tabu search algorithm in their two-layer model which aims to decrease algorithm complexity [35]. Model yields a slight improvement of computational time. Their model delivers aid material to 186 neighborhoods from relief warehouses determined by model. Salman and Gormez develop two models and solve with e-constraint method [36]. The first model delivers to district centers from potential relief facilities and the second model transfers from district centers to neighborhoods. Table 2.1 shows the studies conducted on Istanbul in terms of humanitarian logistics.

Researchers apply mixed integer models to deliver materials. they aim to serve district centers at the last stage, whereas Istanbul needs inclusive delivery network. Except Gormez's work [36], there is no model which aims to serve all neighborhoods. Our model aims to serve all neighborhoods of Istanbul. Salman's work is not optimizing the three layer transfer, it aims to optimize two different models. They assume that all neighborhoods would receive materials from solely their districts. On the other hand, our model allows neighborhoods to receive materials from any relief centers in order to optimize model's objective. Whereas Gormez's research is a frontier line analysis employing multiobjective programming, our approach is a better solution for delivering materials as fast as possible regarding constraints and parameters.

Humanitarian logistics has been acknowledged as a hot area for investigators and for policy makers as well as researchers from academia. From the early 90s, operations research basic modeling and solving methodology have been applied on emergency logistics which led to many effective results.

Similar to modelling efforts done in other researches, defining the objective function lies at the core of mathematical modeling and transformation of emergency case. As well as defining objective, placing constraints into model requires their adaptation to whole model infrastructure.

Solution methodologies construct the core of efforts done in this area to obtain results for problem domain. Classical approaches such as simplex or branch and bound mostly yield inefficient computational results at the hand. After a certain limit, related computer program becomes inefficient to give a result. The main reason why it becomes so time-consuming is forcing the processor to do vast amount of arithmetic calculations for each included case.

TABLE 2.1: Humanitarian logistics applications on Istanbul

Authors	**Objective**	**Technic**	**Database**	**Domain**
Ozkapici, D.B., Ertem, M.A., Aygunes, H.	Maritime based intermodal HL	MIP - 2 layers- ship to port to districts	TUIK	Istanbul
Baskaya, S., Ertem, M.A., Duran, S.	Lateral transshipment applications on HL	MIP - 2 layers - warehouse (district candidate) to districts	JICA report-2002	Istanbul
Kilci, F. , Yetis, B.	Delivering shelter	MIP - 2 layers - sub district to neighborhood	TUIK	Kartal, Van
Renkli, C. , Duran S.	Suggest disaster response facility locations	MIP - 2 layers - warehouse (district candidate) to districts	JICA report-2002	European side
Salman, F.S. , Yucel, E.	Demand & storage linkage	Tabu Search	JICA report-2002	Istanbul
Salman, F.S. , Gormez, N.	Locating facilities	MIP - 3 layers - 2 optimization model - e consraint method	JICA report-2002	Istanbul

In modern heuristics approach, even the best solution is not guaranteed. It clearly removes the superiority of classical approaches by having the results quickly. It is widely acknowledged and accepted as a case in research area that after a certain problem size, heuristic approaches must be introduced so as to have results in reasonable time.

Defining the structure of objective functions is not sufficient for obtaining the results. The proper selection of solution approach must be introduced so as to have effective outcomes. False assignment of solver approach to certain problem domains would result in time consuming and unresponsive computer programs. Fuzzy approach, stochastic approach, and dynamic approach are those approaches which are developed to improve algorithm efficiency.

Chapter 3

Humanitarian Logistics

In this chapter, we introduce the concepts of logistics and its main operation areas. A crucial type of logistics, humanitarian logistics has been introduced from various perspectives. We express the distinction on logistics by profit based and non-profit based approaches and we aim fast delivery of materials and cost minimization. Lastly, we propose our Emergency Response System that captures the modern disaster response idea in research community by our mathematical optimization approach.

3.1 Logistics

According to the definition, logistics has been stated as the interaction and management of multiple tasks that are directly or indirectly related to operations of transportation such as sourcing, warehousing, educating, management [37]. In this context, logistics has various relations with multiple parts of an ongoing business. As well as having multiple relations, it has also multiple definitions because of its versatile structure.

Logistics has been also defined as efficiently planning and coordination between various product types, vast amount of products and wealth that occurs from flow of those [38]. Essentially, coordination among distinct members of a supply chain is the core meaning in almost each explanation of the logistics term.

The way logistics used may be affected by the intention of users of that system. There are various types of logistics where the structure of logistics consisted according to the objective of system's founders such as humanitarian logistics (HM), reverse logistics, military logistics, business logistics, procurement logistics and green logistics.

3.2 Humanitarian Logistics

In this study, a crucial type of logistics, humanitarian logistics is investigated on Istanbul city of Turkey in terms of involving fast and effective algorithms to respond the core needs of affected community at disaster times.

Humanitarian logistics has been defined as the overall progress of arrangement and dynamic coordination of emergent products between warehouses and demand points [39]. This progress involves multiple pieces that build a powerful supply chain system. Cost efficient acquirement of goods, agile responding movement of products, least occupying stock holding strategies, trailing the behaviors of that system and intervention to ongoing process are key parts of a productive humanitarian logistics structure.

Unfortunately, natural disasters have become more and more harmful to humankind in terms of floods, storms, droughts, extreme temperatures over the years [1]. At this point, humanitarian logistics mainly targets to relieve natural disasters in community with its planning-based approach.

Because of increased frequency and impact of catastrophes, researchers from various areas have concentrated their efforts on humanitarian logistics. Cooperation of shareholders to resolve emergency situation after disaster occurs is the uncomplicated way of efficient working. Contrarily, weak design and operation of humanitarian logistics would result in unanswered calls of citizens.

Due to disasters affecting more the humanity, working closely with various industry units and creating partnerships with private business is increasing efficiency. Main objective of this thesis is to discover inclusive cooperation among these business units [40]. From this point of view, we analyzed the literature and found vital implications on this domain. Altay et al. specified the major actions taken during the phases of disaster management which we clearly mentioned in "The Motivation" subsection [41].

3.3 Humanitarian Warehouse Location

Typical activities during various phases of disaster response have been compiled by Altay et al. to classify micro-level actions together [15]. We aim to develop a system of locating humanitarian warehouses to maximize survivor benefit while meeting the objectives of officials in the field. We call our suggested system as emergency response system. Emergency response system (ERS) is designed in which all supply chain units are included to respond emergency situations as efficiently as possible and involves micro activities mentioned in disaster response system. Numerous activities could be exemplified in a disaster response system such as authorizing the personnel to create volunteer groups, budgeting the response plan, purchasing the required materials, supplying related commodities, preparing the planned warehouses and so on.

As easily noticed in sample micro level actions, those are the activities that should be done before the disaster occurs. On the other hand, ERS also involves activities for post-disaster phase. Concisely, ERS is the management philosophy of emergency response situation. The study of ours is a preliminary introduction to ERS so as to determine system which warehouses, emergency response units and demand points linked and which amount should be transferred to each. Efforts belonging to this thesis could also be considerded as significant portion of ERS in terms of optimized allocation of resources and sensitivity analysis which paves the way of efficient model builders and policymakers to design Istanbul's emergency action plan.

Locating huge capacity humanitarian warehouses, district based emergency response units and exact coordinates of cumulated demands is preliminary part of an efficient ERS system whereas a linear program based mathematical model representing Istanbul structure and optimized results of that particular model is subsequent component of ERS system. We present sensitivity analysis which is another significant reporting structure in ERS system that creates potential to diagnose differences based on what-if analysis. As an example, policymakers would be able to display the effects if they choose to have different delivery time limits.

Our proposed emergency response system constitutes powerful part of disaster management system which is evidently defined in the next section. We also depicted the general scheme of disaster management system whereas our proposed emergency response system is significant portion of that system which is closely linked to 2 main phases that are preparedness and response. As depicted in the scheme, our suggested ERS is a tailored model for Istanbul based emergency concern which involves a city representing mathematical model that includes enormous effort on its own in terms of 39 districts, 960 neighborhoods and its exact locations. This part of our ERS model closely linked to preparedness phase of disaster management system. The reason for the tight connectivity is that with models, solutions and suggestions, even this thesis is a strong basis for planning general emergency response plan. On the other hand, a better version of this model could also be deployed by realizing the assumptions on model. Nevertheless, our efforts on efficient response planning is a key component for the planning part.

In addition to involvement of our study on preparedness part in disaster management system, inclusive mathematical model which has exact representations of emergency situation also reflects the actions should be taken in response phase. In such a disaster circumstance, optimized and detailed action plans could be executed by task managers. Those detailed transfer plan enlightens emergency staff to have optimized transfer of aid materials.

Assignment table displays what quantity should be transferred from each ERUs to each neighborhood. Blank cells stand for no transfer. Quantities assumed as fractional number just because the quantity represents the amount of aid materials. For instance, ERU7 is responsible for transmitting 204.7 SU emergency materials to Neighbor 3 whereas ERU21 is assigned for sending 143.6 SU aid supply. As aforementioned above, model solution report displays the transfer amount in detail and strong candidate for to be considered in response phase of disaster management system.

On the other hand, our system yields sensitivity analysis which also guides policy makers to implement maximum efficient solution. In brief, sensitivity analysis summarizes whether how much benefit generated or lost according to modification of time limit parameters. For instance, what would be the total cost of objective function if model builders increase the time limit of layer 1 to 15 minutes or what would be the cost of selecting another solution? Our study brings such analysis structure to decision makers. Having sensitivity analysis also meets our model with mitigation phase of disaster

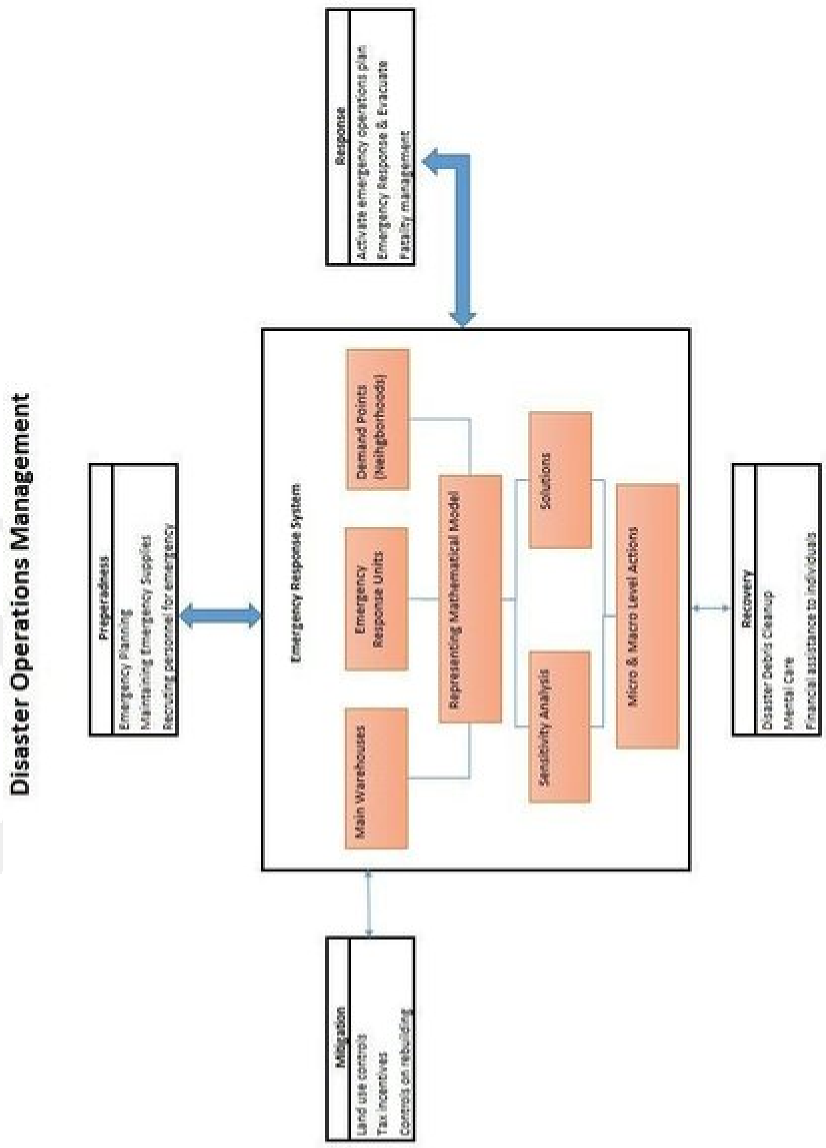

Figure 3.1: Disaster operations management and ERS relation.

management system which is a phase to revive to demolished structure of cities with development plans, tax incentives and land use controls to prevent irregular urbanization.

In conclusion, our proposed emergency model is a tailored and modified emergency assignment model for Istanbul which have the traits of preparedness, response and mitigation phase. As Tufekci and Wallace specified that an efficient disaster response plan should include all of the phases, our model is a strong candidate to be implemented on Istanbul domain [9]. Our suggested emergency response system has also the traits of recovery phase even its not linked strongly as other phases. To support this idea, some can conclude that the emergency officer in the field would easily use solution roadmap to learn which neighborhoods are affected much and need assistance urgent. In that way, he could shape his recovery actions which are debris cleaning, micro-finance supply and others in more efficient way.

To sum up, we propose first two-tier optimization model which employs the flow from main warehouses to neighborhoods. We meet the demand of each neighborhood. Model lets neighborhoods to be relief center so that relief centers are located close to neighborhoods. We also employ time constraints for each delivery to satisfy each neighborhood under time limit while minimizing overall cost.

Chapter 4

Proposed Emergency Response System

In this chapter, we present the details of Turkey's emergency response plan (TEMS) and our proposed emergency system (ERS) which complies with TEMS. We also include how TEMS and ERS match by their sub-parts.

4.1 Turkey Emergency Response Plan (TEMS)

Almost all countries compose their own plan to respond an emergency situation in most efficient way to eliminate effects of catastrophic events. Turkey has also compiled a comprehensive response plan for all emergency types which is extensively connected to public institutions. TEMS formed under vertical and horizontal integration to serve objective in coordination. TEMS is a sub-plan of Turkey Emergency Management Strategy (TAYSB) prepared by Disaster Emergency Coordination Presidency (AFAD) [42]. Risk mitigation, Emergency Response Plan, Emergency Recovery Plan are the essential parts of TAYSB. Operations service, logistics and maintenance service, information and planning services, finance and administrative services and monitoring services are expected to feed TEMS plan in action. These services are strongly connected to overall plan of response and formed according to way they function. Figure below explains how the overall plan of emergency has formed and how they linked to sub-phases.

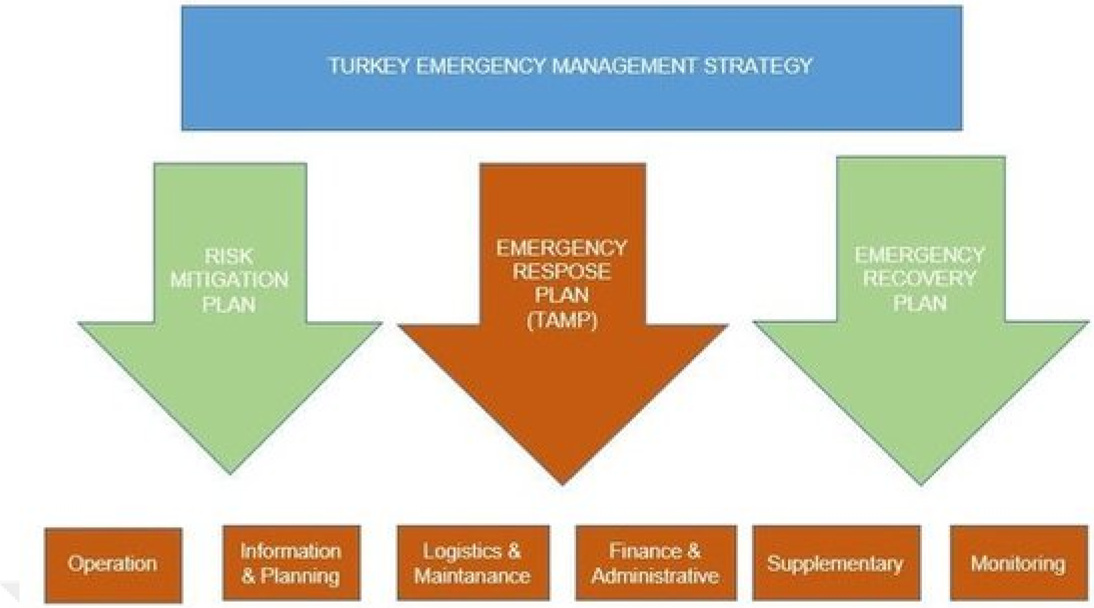

Figure 4.1: TEMS plan [42].

Operation service takes responsibility to act firstly in emergency situation to execute response plan. Healing of communication services, transportation infrastructure, social security and traffic stream, rescue efforts, first-aid activities, refugee locating are the principal responsibilities of Operation Service division. The scenes of frequently seen rescue operations on digital media is a duty of this service team.

Information and planning division aims to collect relevant documents about disaster outcomes in terms of portion of affected buildings, urgency classification of survivors and related statistics. Registration of information to public systems including necessary data and assessment of geographic data is also task of this division on disaster situation.

Logistics and Planning team's main objectives are transmitting relief materials to demand points, warehouse management, technical support to all divisions, resource management and international collaboration on disaster relief operations if needed. The results of our study would be great support to this team to guide them to optimum distribution of materials.

Finance and administrative team leads the duties of purchasing and renting of urgent materials, management of financial stream related to disaster elements, accounting and budgeting.

Supplementary division consists of dealing with legal issues, providing and retrieving information to media. Sustaining relief operations with safety over implementation plan is considered in this team.

Monitoring division holds responsibility for supplying coordination of these subdivisions so as to be operated in highest efficiency. This team involves the managers of AFAD presidency and strictly linked to management while sharing information to international collaborators and having coordination if necessary. Division also responsible for monitoring operation phases in detail to intervene and direct at critical points.

FIGURE 4.2: A snapshot from AFAD main warehouse.

4.2 Interaction of Proposed Emergency System and TEMS

Our proposed emergency system is strongly connected with the elements of TEMS. Suggested system's objective is extensively aligned with the objective of TEMS in order to serve efficiently. Our strongest development is that divisions of TEMS have mutual relations with the branches of proposed system in a level. Information and planning service have strong ties with the efforts of building a mathematical model. Proposed mathematical model needs certain information types including potential warehouse locations and numbers, coordination of demand points and estimated quantity of material request. In order to make a model that fully represents the disaster situation with all factors of reality, the model builders have to compile necessary information which the information and planning team compiles data including post disaster statistics.

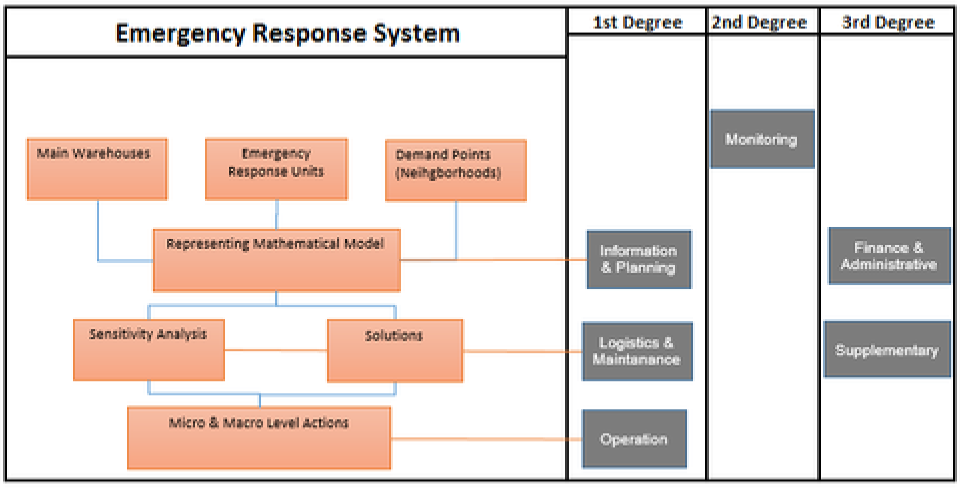

FIGURE 4.3: TEMS-ERS interaction.

Logistics and maintenance branch takes responsibility of warehouse locating and management in order to make sure that optimum transfer of aid materials supplied to survivors. In this context, solutions presented by suggested emergency response system should be implemented by the logistics team to reach top efficiency which is the most agile distribution plan among the solutions. Apart from micro level actions proposed by ERS that is highly aligned with Operation branch of TEMS, provided solutions pay attention to locating the warehouses and deciding the number of local and main deposits to have optimality. Sensitivity analysis also paves the way for optimality decision makers in both long and short term while providing cues to micro level action takers by deciding ERUs' optimum supply diameter. From that context, one can conclude that the included sensitivity analysis is tightly connected with the logistics and operation branches.

Finance and administrative branch plans long and midterm optimum budget planning. Financial planning would also be employed in linear programming models by simply integrating cost criteria which we did not include in our research. Nevertheless, the answer of optimum distribution of materials and efficient locating emergency elements on relief chain is also solution for minimum cost based design. Because of this weak tie, we located finance division in third degree.

Supplementary division holds the task of dealing with third party involvers such as media, legal issues and security of elements. Because of common service to same objective, we included this division in third degree.

Chapter 5

Methodology

Thereafter mentioning related literature review and proposed emergency system, this chapter has been designed to illustrate preferred methodology in aforementioned problem domain. In problem statement, we have outlined a specific problem on Istanbul emergency in detail in which we included the borders of problem domain stating which circumstances we address and the assumptions made on problem. The methods of retrieving relevant data, including coordinates and exact distance estimation, and reliability of data are also involved in problem statement section.

As linear programming requires predefined structure of the model, we present the in-depth details of our model to recognize indices, objective function, constraints, parameters and variables. While commenting on model, expressions of modeling language has been switched according to GAMS software form and linear programming form.

FIGURE 5.1: Material flow to survivors.

As shown in the figure above, problem domain consists of 2 layers of transfers in which the ultimate goal is to satisfy each demand below pre-specified time limits. Layer 1 named as

TABLE 5.1: Notations of Model

Notation	***Definition***
Sets	
I	Set of main warehouse candidates
J	Set of emergency response unit candidates
K	Set of demand points

Parameters	
Dem_k	Demand of neighborhood k
$Superu_k$	Supply capacity of ERU candidate j
$Supmain_i$	Supply capacity of main warehouse candidate i
$Dist1_{ij}$	Distance between main warehouse i to ERU candidate j
$Dist2_{jk}$	Distance between ERU j to demand point k
$Act1_{ij}$	Availability of transfer from main warehouse i to ERU j
$Act2_{jk}$	Availability of transfer from ERU j to demand k
$ERUnum$	Upper limit on the total number of ERUs
$Mainnum$	Upper limit on the total number of main warehouses

Decision Variables	
Rec_k	Received amount of demand point k from ERU j
P_{ij}	Sent amount to ERU j from main warehouse i
$Obj2$	Value of model 2 objective
$Obj3$	Value of model 3 objective
A_i	Utilization of main warehouse i
B_j	Utilization of ERU j
MTR_{ij}	Transfer status from main warehouse i to ERU j
LTR_{jk}	Transfer status from ERU j to demand point k

the transfer from main warehouses to ERU centers while layer 2 stands for transfer from ERUs to neighborhoods. In order to involve multiple perspectives on problem domain, we developed three different models to analyze and compare the differences and enlighten our final decision. On the other hand, all three models remain almost identical except objective functions and a few constraints of theirs.

5.1 Model Formulation

A notation table including definitions explains the model concretely by sets, parameters and decision variables included in all models (Table 5.1).

5.2 Objective Functions

As we mentioned, in order to include three different perspectives, we built three models and run them separately. Model 1 tries to minimize total number of facilities (main warehouse and ERU centers) to lower cost, model 2's objective is to transfer of materials to demand points from closest ERUs to minimize delivery time while model 3 aims to the quick transfer of aid materials from main warehouses to ERUs. We assume that building and maintenance cost of main warehouse is 10 times bigger than ERU.

Model 1 - (Minimum Facility Cost Model): Minimize $10 * \sum_i A(i) + \sum_j B(j)$

Model 2 - (Urgent Delivery Model): Minimize $\sum_k \sum_k Rec_{jk} * Dist2_{jk}$

Model 3 - (Urgent Warehouse Transfer Model): Minimize $\sum_j \sum_i P_{ij} * Dist1_{ij}$

5.3 Parameters

5.3.1 Demand - Dem_k

Demand amount of each neighborhood is being represented by Dem_k parameter where demand of points based on the population of each neighborhood. Compilation of demand data is discovered in later sections.

5.3.2 ERU Capacity - $Superu_j$

Each ERU has been limited by its capacity, where warehouse areas, cookers, cleaners, technicians, transportation workers and all other emergency staff has been specified and limited to a certain level. In an emergency situation, a survivor is expected to have a group of relief materials such as blanket, tent, drinks and foods. So, we assume that this requirement package of each survivor is called as 1 Survivor Unit. By this fact, supply amount of each local facility has been restricted to 300.000 SU where model involves 960 ERU potential location each of which has same capacity.

5.3.3 Main Warehouse Capacity - $Supmain_i$

Main warehouses also have capacity limits. Regarding the demand of Istanbul and the actual main warehouses in Istanbul, we assign each capacity as 5.000.000 SU. Main warehouses will be chosen among 39 candidate points which are districts to serve ERU centers.

5.3.4 Main Storage-ERU Distance - $Dist1_{ij}$

This distance parameter represents the mutual distance between main warehouse candidate i to ERU candidate j. It is represented as time in minutes where the average velocity of 43 km/h. This velocity is determined by the ArcGIS sofware which generates the average travel time with traffic.

5.3.5 ERU - Demand Point Distance - $Dist2_{jk}$

Preliminary factor of our model is to supply materials as efficiently as possible by minimizing the total cost. This parameter is the dual distance of neighborhoods which constitutes a 960*960 matrix. So, distance between ERU_j to Dem_k is zero because of both representing the same neighborhood.

5.3.6 Assignment Parameter 1 - $Act1_{ij}$

Act1 parameter is the table value of 36*960 matrix which denotes the availability of transfer from main warehouse i to ERU center j aiming to deliver below certain minutes. Act parameters urges model to satisfy time constraints. It works for first layer of transportation.

5.3.7 Assignment Parameter 2 - $Act2_{jk}$

Act2 parameter is another table value of 960*960 matrix which urges the model to deliver goods to each neighborhood from ERU center below pre-specified time limit. This parameter pushes LTR variable to serve if allowed, or not to serve if not allowed. It works for second layer of transportation.

5.3.8 ERU number limit - *ERUnum*

This parameter puts limit on the number of ERU's set by mathematical model. For instance, if 120 ERU is available out of 960, ERUnum parameter equals to 120. As aforementioned, our objective is to serve survivors below the certain time limit while minimizing the deployment of both main and ERU warehouses. We run model for trials and we see that ERUnum is in interval between 50 and 124. So, we set ERUnum to plausible quantity of 140 in which the model yields far lower results that explains no limit actually functions on the result.

5.3.9 Main warehouse limit - *Mainnum*

Mainnum parameter represents the upper limit of main warehouse construction before the disaster. Basically, 5 main stores supposed to be chosen among 39 potential candidates. While we put a limit on the cost construction, result obtained from the model suggests the lower figures than the limit, which points to the fact that Mainnum is not constrained.

5.4 Decision Variables

In linear programming, decision variables are the crucial elements whose values are decided as a part of the solution. At the final form of the mathematical model, we have 8 variables to be determined by GAMS software.

5.4.1 Transfer amount of layer 2 - Rec_{jk}

This variable sits at the core of the model because the foremost priority of models is to supply materials to survivors, and this variable lets us check whether desired amount has been supplied or not. More basically, it represents the amount received from ERU j by demand point k (neighborhood). "Rec" is the abbreviation of "received".

5.4.2 Transfer amount of layer 1 - P_{ij}

As discussed earlier, ERUs are the intermediate clients which have an objective to supply materials to neighborhoods as soon as possible. Since they are not supposed to be production areas and are not responsible for manufacturing, the total amount of all ERUs received from main deposit centers should be equal to the amount transferred to demand points. In order to fully represent this circumstance in model, we insert P_{ij} variable which denotes the amount transferred to ERU j from main deposit center i. It should be considered that from no other sources, any emergency kit would be transferred to any ERU other than main deposit centers.

5.4.3 Main warehouse functioning - A_i

It is the first of binary state variables representing whether the main deposit center A_i is supposed to function at optimum solution. Among 39 candidate main warehouses, the solver determines the optimized selection of a few. Total number of A_i controlled by Mainnum parameter.

5.4.4 ERU center functioning - B_j

As well as diagnosing the functioning of main deposit centers, algorithm also yields the status information of ERUs to inform practitioner whether they are supposed to serve even a single demand point. We chose neighborhoods as the potential ERU centers and we have 960 ERU candidates in our model. Total number of B_j controlled by ERUnum parameter.

5.4.5 Objective Value of Second Model - *Obj2*

As mentioned in objective values section, we had three different models. In order to reach values according to objective value of model 2 while experimenting model 1, we insert Obj2 variable in our model. Obj2 value formula is at below;

$Obj2 = Rec_{jk} * Dist2_{jk}$

By this variable we gather data on the effectiveness of transportation at layer 2.

5.4.6 Objective Value of Third Model - *Obj3*

Another objective function has compiled from model 3 is as follows;

$Obj3 = P_{ij} * Dist1_{ij}$

By this variable we gather data on the effectiveness of transportation at layer 1 while minimizing subsequent objective.

5.4.7 Assignment variable of layer 1 - MTR_{ij}

The model's decision whether to assign main warehouse I to ERU center j by denoting MTR variable. This binary variable's limit has been specified by the Act1 parameter. MTR variable lets model builders to implement time constraint for layer 1.

5.4.8 Assignment variable of layer 2 - LTR_{jk}

Another binary variable of assignment, LTR represents the occurrence of transfer at layer 2. The reason why we incorporate LTR into the mathematical model is that it allows the builders of model to insert time constraints according to policymakers. By utilizing LTR and MTR variables we comfortably represent the four different time limits on which we commented in the sensitivity analysis section. According to the wish of model builders or implementers, one could insert this variable into objective function to pay more attention of transfer status as well.

5.5 Constraints

In order to fully represent bottlenecks and requirements of emergency situation of Istanbul, we have endorsed ten unique constraints in the model.

5.5.1 Constraint-1

This is the prominent constraint that has been endorsed in the mathematical model. The obligatory duty of the algorithm is to assure that each demand point is served by certain local facilities in which all sums to at least demand quantity.

$$Dem_k \leq \sum_j Rec_{jk} \qquad \forall k \in K(Demandsatisfaction)$$

Via constraint-1, all demands have been satisfied. Each neighborhood retrieves aid materials from single or multiple ERU centers.

5.5.2 Constraint-2

Another leading constraint of this mathematical model is to represent ERU capacity limits where each ERU is being served by specified limits by main stores and constructed at moderate size. Parameter $Superu_j$ denotes the limit of each ERU.

$$\sum_k Rec_{jk} \leq B_j * Superu_j \qquad \forall j \in J(Capacity\, limit)$$

By deploying constraint-2, model ensures that assigned quantity could not exceed the SU limit. Constraint also makes sure that if solution decides to open any ERU, than B_j binary situation variable of related facility will also be 1. Solution shows that group of ERUs capacity usage is 100%.

5.5.3 Constraint-3

Amount transferred to ERU centers from main warehouses should not exceed capacity of theirs. $A(i)$ binary variable denotes the functioning of main warehouse i. $Supmain_i$ is the capacity of main warehouse i.

$$\sum_j P_{ij} \leq A_i * Supmain_i \qquad \forall i \in I \qquad (Main\, warehouse\, capacity)$$

According to results, we see that the capacity usages are above 90% for each model and an evident on the importance on supply constraint.

5.5.4 Constraint-4

All of the potential ERU numbers cannot be available at emergency situation. Even we assume the highly durable construction of emergency buildings, phenomenal situation would harm the facility buildings directly or indirectly by blocking the roads, vehicles, infrastructure. Also, not all ERU candidates should be opened due to high cost.

$$\sum_{j} B_j \leq ERUnum \qquad (Number\,of\,ERU\,limit)$$

We assume that the maximum number of ERU centers should be 140 out of 960 candidates. In that way, each ERU expected to serve 7 neighborhoods minimum. Constraint uses the binary variable $B(j)$. Results implies that the model suggests lower than the 140 ERUnum which is not affecting the result.

5.5.5 Constraint-5

Among the 39 main warehouse candidates, we assume that maximum number of warehouse location, Mainnum, should be 5.

$$\sum_{i} A_i \leq Mainnum \qquad (Number\,of main\,stores\,)$$

Multiple runs on model show that the model's suggestion of main warehouse number is way lower from the Mainnum limit, which is clearly not affecting the idea of optimization while considering the cost case.

5.5.6 Constraint-6

Constraint 6 combines the supply capacity problem by parameter $Superu$ and the dual availability of any ERU center to neighborhood by LTR_{jk}. Another explanation is that each assigned transfer cannot exceed to ERU's capacity even if transfer has been activated and approved.

$$Rec_{jk} \leq Superu_j * LTR_{jk} \qquad \forall j,k \in J,K \qquad (ERU - neighborhood\,availability)$$

Activation of each ERU is being represented by binary variable LTR_{jk} which is highly dependent to time constraint parameter $Act2(j,k)$. Solution proves that there is no transfer from point j to k if it is not allowed by LTR variable.

5.5.7 Constraint-7

Another availability constraint urges P_{ij} parameter to consider the availability of transfer by MTR_{ij} variable.

$$P_{ij} \leq Supmain_i * MTR_{ij} \qquad \forall i,j \in I,J \qquad (Main - ERU\ availability)$$

Results shows that there is a concrete connection between the availability of transfer and the transfer status.

5.5.8 Constraint-8

This constraint stands for balance between main supply storage facilities and local service facilities. By the main taught of model framework, all of the first-aid materials that would be supplied to refugees by local facilities must sum up to amount of transfer served by main stores to local facilities. In this model, we call this equation as balance of retrieved and sent.

$$\sum_i P_{ij} = \sum_k R_{jk} \qquad \forall j \in J \qquad (Balance\ of\ retrieved\ and\ sent)$$

Idea of equating the amounts of two transportation layers, which are main stores to local stores and local stores to demand points in order, stands for representing assurance of accessing all materials that come out from main stores to demand points where zero stock kept at any local stores in final situation.

5.5.9 Constraint-9

Time limit of model is urged by constraint 9 and 10. Parameter $Act1(i,j)$ represents if the transfer time is below the specified time (9, 10, 12, 15 min). So, $MTR(i,j)$ is a decision variable and takes value according to solver.

$$MTR(i,j) \leq Act1(i,j) \qquad \forall i,j \in I,J \qquad (Time\ limit\ for\ layer\ 1)$$

With this constraint, we urge layer 1 , transfer between main warehouses to ERU centers, to assure that each transfer will be under the specified time and model includes the time constraint.

5.5.10 Constraint-10

Another time limit we endorse is limit for layer 2, the transfer between ERU centers to neighborhood. As in previous constraint, $LTR(j,k)$ is the decision variable which limits imposed by $Act2(j,k)$

$$LTR(j,k) \leq Act2(j,k) \qquad \forall j,k \in J,K \qquad (Time\ limit\ for\ layer\ 2)$$

According to solution report, we assure that each demand point will receive the aid material below the pre-specified time limit in model. We share all the constraints together at below.

$$\begin{aligned}
Dem_k \leq \sum_j Rec_{jk} \qquad & \forall k \in K \qquad (1)\\
\sum_k Rec_{jk} \leq B_j * Superu_j \qquad & \forall j \in J \qquad (2)\\
\sum_j P_{ij} \leq A_i * Supmain_i \qquad & \forall i \in I \qquad (3)\\
\sum_j B_j \leq ERUnum \qquad & (4)\\
\sum_i A_i \leq Mainnum \qquad & (5)\\
Rec_{jk} \leq Superu_j * LTR_{jk} \qquad & \forall j,k \in J,K \qquad (6)\\
P_{ij} \leq Supmain_i * MTR_{ij} \qquad & \forall i,j \in I,J \qquad (7)\\
\sum_i P_{ij} = \sum_k R_{jk} \qquad & \forall j \in J \qquad (8)\\
MTR(i,j) \leq Act1(i,j) \qquad & \forall i,j \in I,J \qquad (9)\\
LTR(j,k) \leq Act2(j,k) \qquad & \forall j,k \in J,K \qquad (10)
\end{aligned} \tag{5.1}$$

5.6 Experimental Application

After completion of mathematical model development by the parameters indicated above, we write GAMS code to represent this situation in programming environment and get the experimental results in GAMS software. Apart from completely true data representing the original problem, we create a sample database to test if our model is generating an expected solution. So, the distance parameters have been generated by the "RANDBETWEEN" function in Excel with the interval of 5 to 30 minutes. ERU and main warehouse parameters are also inserted as plausible values as well. We aim to minimize MFC model in our experiment. And the experimental application results in 4 minutes and 50 seconds with acceptable suggestions which shows the true structure of our mathematical and programming representation and allowed us to import real data.

Chapter 6

Application

In previous chapter, the proposed methodology has been discussed. In this chapter, we experimentally evaluate our approach on Istanbul's data. In addition to the model based solutions, in-depth sensitivity analysis is conducted to form uppermost effective allocation of resources including number of main warehouses, ERUs and their locations. Sensitivity analysis leads decision makers to analyze further current situation and apply recommended actions to improve the objective. Supplementary discussions on attained solution have included to guide policymakers towards powerful decisions via optimum mathematical solution.

6.1 Test Environment and Dataset

In this section we discuss our test environment on how we retrieve the emergency data, and the general structure of our database. Moreover, we also explain how optimization software imports the database, and the models we propose in details.

6.1.1 Test Environment

Our model was run on single computer. Basic specification of our PC includes Intel Core i7-3770S 3.10 GHZ processor, 8 GB DDR3 RAM, Windows 10 64-bit operating system with GAMS 23.5.2 x64 version.

6.1.2 Emergency Data of Istanbul

According to requirements of mathematical programming, we constructed a database. The database includes latitude-longitude coordinates of 39 Emergency Response Units and 960 neighborhoods, the expected demand of each neighborhood, average ERU capacity, distance between each neighborhood and each main storage, and the mutual distance of each neighborhoods.

Main warehouse coordinates have been chosen as the coordinates of district centers. This is because the required supply deposits are involved in each district and the settlements smaller than districts are not likely to have sufficiently large storage centers. Istanbul has 39 districts, each of which has related warehouses.

If one considers to select the most appropriate settlement unit to distribute emergency materials efficiently in Istanbul, neighborhoods would be the best choice. Thus, neighborhoods are selected as ERU candidates. When the time constraint and the capacity of emergency distribution staff are considered, neither completely leaving the materials in district centers is nor the delivering to each house is an efficient solution. To mitigate this concern, 960 neighborhoods have been selected as the last delivery point with the longitude and latitude coordinates of each obtained from Google Maps and Yandex Navigation [43, 44].

6.1.3 Assumptions on Model

Distance of two points has been calculated by Euclidian Distance principle. We take the coordinates of each neighborhood via Yandex Maps and Google Maps web frameworks [43, 44]. A list of neighborhoods has been compiled from the database portal of Turkish Statistics Institute (TUIK) where statistics of various segments are also included [45]. Portal serves users free of charge for most critical information in terms of statistics of Turkish citizens such as fertility rate, birth rate, life expectation and population of each neighborhood, district and city. Shared information of TUIK is a verified and top trusted source of information among related Turkish institutes. To sum up, according to TUIK database, Istanbul has 960 neighborhoods linked to 39 districts.

First priority is that the demand of each neighborhood is the foremost constraint that should be satisfied to have a feasible solution. It is not possible to estimate demands of survivors at the emergency case. Nevertheless, population gives an idea on average demand. For that reason, we assume the population as demand quantity regardless of disaster effect.

Distance between each neighborhood and each district has been calculated according to their coordinates. Instead of straight line estimation of distances, we calculated the differences by real path distance calculation as shown below.

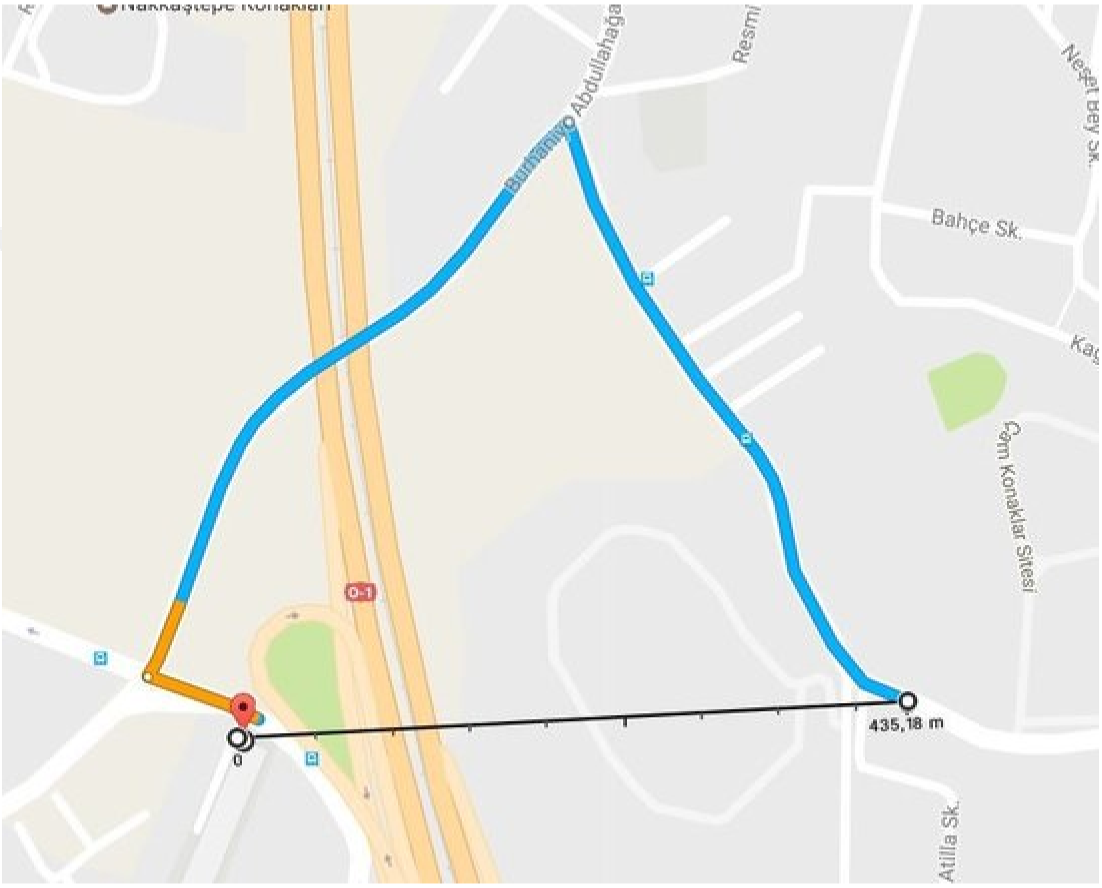

FIGURE 6.1: Straight line distance versus actual distance.

Figure 6.1 depicts the difference between straight line estimation versus actual distance calculation. Application of emergency model clearly requires the actual distance rather than straight line which is the sole information required on model.

6.1.4 Creating Database

The database of exact coordinates of demand points, local warehouse candidates and main deposit candidates has been created by using commonly preferred advanced sheet program Microsoft Excel 2013. We named our file as "Database.xlsx". Database file includes 7 sheets where each has been created for different parameters. Mutual path distance of 39 main warehouse candidates and 960 ERU candidate points constructed the matrix of 39 rows and 960 columns which has been inserted in Sheet 1. Two basement of fraction is accepted in sheet 1 and the table has been referred to Dist1(i,j) parameter in our model.

Mutual path distances of ERU centers are created in sheet 2. Table created of 960X960 matrix which includes 921.600 nonzero elements. This table has been referred to $Dist2_{j,k}$ parameter in model. Capacity parameter of each emergency response unit candidates has been set to 300.000 survivor unit (SU). Capacity of 300.000 has been calculated by the idea that in worst case, the total of 50 ERUs out of 960 candidates must be utilized in system to respond demands and has been saved in Sheet 3. The table includes 960 elements.

Sheet 4 stands for the demand quantity of each neighborhood in Istanbul. As clarified, each demand has been set according to population that is retrieved by the information supplied from related Internal Affairs Ministry of Turkey. The table created of 960 elements. Sheet 5 stands for the table of main warehouse capacities where each has been set to 3.000.000 SU by the idea that in worst case the minimum of 5 high-size warehouse must be in use. Table consists of 39 elements.

Lastly, sheet 6 and 7 stands for the LTR and MTR parameters where each denotes the time limits of layer 1 and layer 2. Sheet 6 includes 36*960 matrix table whereas sheet 7 has 960*960 matrix.

6.1.5 Reading the Database

After creating the database, next step is reading Excel data and passing it to parameters. GAMS software has a module to communicate with Excel sheets named as GDXXRW [46]. This module can read the separate cells in various sheets as multiple files. Module reads the each sheet of Excel file, transforms it to GDX file which is binary representation of values suitable for GAMS's data processing. Database.xlsx file has a size of 14.528 megabytes whereas equivalent Database.gdx file size is 9.393 megabytes that clearly shows the efficient data compression for GDX files. GDXXRW module has also capability to write Excel files in preferred format, but we did not utilize that functionality to create Excel file.

6.1.6 Solvers

There are 18 solvers included in GAMS software to solve MIP models and end-user can select specific solver, if desired. If nothing has been selected as a solver, CPLEX by IBM Company has been set as default solver for MIP. We let GAMS to choose its default to solve suggested problem, but CPLEX solver has returned with insufficient resource errors at initial trials. Then, we modify the solvers parameters. For instance, we edit the "workmem" memory parameter to "3072 MB" to expedite processes and "reslim" parameter to 100.000 seconds to generate result. Also, we set "nodefileind" parameter to "3" to compress nodefiles and relieve burden on memory. Then, we have the solutions for most of our experiments whereas a few of trials concluded in infeasibility.

Apart from CPLEX, we also try to get results for GLPK (GNU Linear Programming Kit), which aims to solve mixed integer programming and linear programing models [47]. GLPK resulted in infeasibility for our model with a run time of 30 minutes approximately. Further MIP solvers such as BDMLP, CBC, XA, are also applied to solve model, but none of resulted with feasible solution. OSL Solver also generated the feasible results with objective value of 44.488.419 which is 5% lower result then the solution generated by XPRESS solver.

XPRESS solver has been designed to solve huge and complex linear, mixed-integer, quadratic linear problems in an extraordinary time as CPLEX does. It has been originally created by Dash Optimization, then acquired by FICO in 2008 [48]. Superiority of XPRESS solver is that it has capability of solving MIP problems in a very short duration. In our complicated and high-size data based model, XPRESS resulted in a short time of 18 minutes. Because of superiority by objective values and computation time, we also chose XPRESS for further model computations.

6.1.7 Models

Optimum deploying of emergency facilities creates different aspects if researchers investigate it. One aspect is about creating a network which has minimum cost of construction and maintenance fund. The idea would be supported with the fact that AFAD 2016 budget plan has been approved by the parliament with more than 1 billion TRY. There was no certain information about the budget of Istanbul, but it is clear that how Istanbul would take a big slice from budget cake. Thus, in our model, we consider constructing main warehouses and ERUs to meet the demand. Our first model, Minimum Facility Cost model will investigate to meet survivors' demands with the time constraint of maximum delivery time by minimizing the total cost of facility maintenance and structure.

As well as keeping the cost at minimum level idea, one would support the aspect of meeting demands of citizens' as soon as possible from the ERUs regardless of total cost. This idea prioritize to enhance customer (survivor) satisfaction with the suggestion that states should not limit the amounts they allocate when theirs citizens' live are in question. Hence, in our Urgent Delivery Model, we aim to minimize the multiplication of amount transferred from each ERU to neighborhood by the distance between them while assuring a minimum delivery time.

Lastly, another aspect of optimum network design is the urgent material transfer from main warehouses to emergency response units. The buttressing idea behind the third model, Urgent transfer Model is that the transfer from main warehouses to ERU facilities is the first and most fragile layer of meeting the demands and need to be prioritized. That is, the transfer fails between these two layers, there is no possibility to serve neighborhoods by ERUs with no stocks. Urgent Warehouse transfer Model aims to meet the demand of each neighborhood below the maximum delivery time.

6.2 Minimum Facility Cost Model (MFC)

In addition to aiming to minimize delivery time from ERU to neighborhood by objective 1 and minimizing the delivery time fro main warehouse to ERU by objective 2, we have applied the minimum facility cost model to optimize the total cost of construction for both main warehouses and ERUs.

We had implemented the objective function for minimizing. Among 39 main warehouse candidates and 960 emergency response unit candidates, we had the results for optimized network results for the basics of model which provides the model builders with insight on parameters. For instance, we had solutions without enforcing a time limit for delivery and then compared the results.

The reason of supporting minimum number of warehouse idea is that supplying sufficient materials to survivors by constructing and maintaining of warehouses requires huge funds, and costs well beyond than the budget of the responsible institute. For this reason, policymakers related to sustainability of city welfare would consider to keep the bill as small as possible while supplying survivor demand as quick as possible.

Our mathematical problem includes 925.524 rows, 1.881.643 columns, and 7.486.201 nonzero elements in the matrix. Model was designed to have both integer and fractional values, called as mixed integer programming (MIP). After implementing related parameters for MFC model, we had the results in 7 minutes 58 seconds. Objective value for solution is 97.277.894. Average delivery time for ERU to neighborhood is 6.64 minutes whereas average delivery time for Main warehouse to ERU is 35 minutes. Objective function has been set as below;

$$min \sum 10 * A(i) + \sum B(j)$$

Solution suggests to build 3 main warehouses and 125 ERUs to meet demands by least cost of deploying warehouses. We had inserted the suggested ERUs and main warehouses to Google Maps at the below. Figure 6.2 shows main warehouse locations, while fig. 6.3 shows ERU locations.

FIGURE 6.2: Main warehouse suggestion to MFC model.

As it is seen on the maps above main facility suggestions are spread upon Istanbul territory. In Anatolian continent, there is single warehouse which is in Umraniye, whereas in

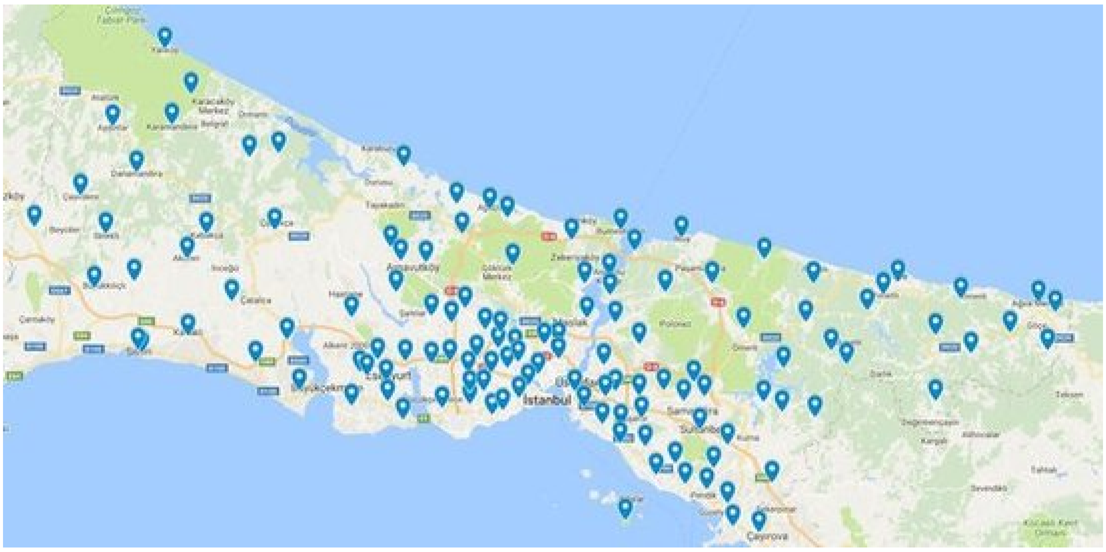

FIGURE 6.3: ERU suggestions to MFC model.

European continent, we have main warehouses in Sultangazi and Arnavutköy. Likewise, ERUs are spread equally on Istanbul to meet each demand in maximum 10 minutes as well as minimizing the total number of facilities.

6.2.1 Capacity Usage

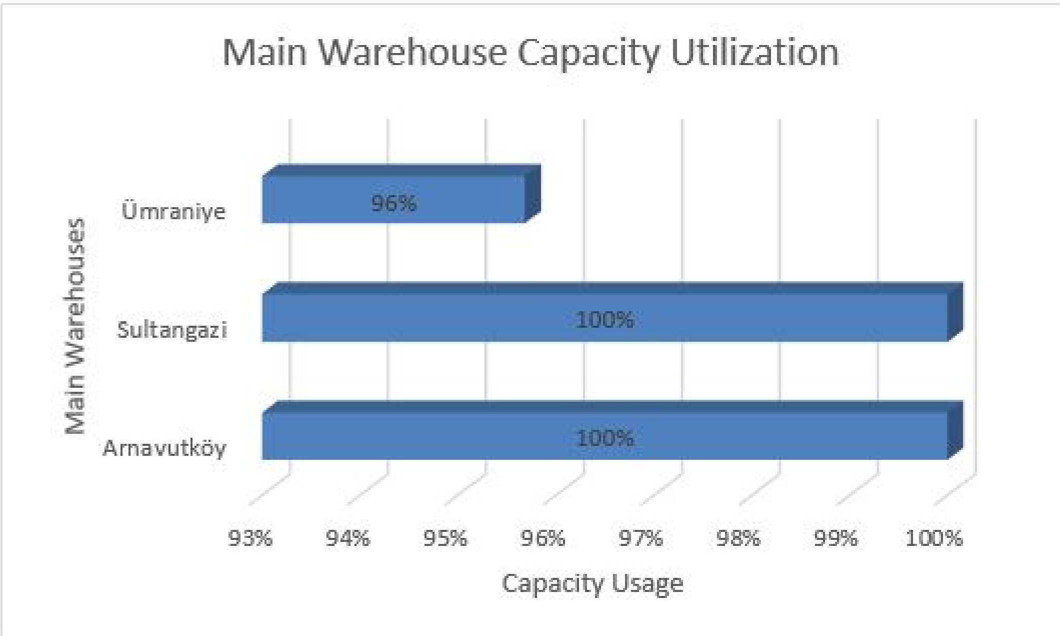

FIGURE 6.4: Capacity utilization of main warehouses (MFC).

In the figure above, we share the capacity utilization of main warehouses with ascending order. Sultangazi and Arnavutköy warehouses expected to use full capacity whereas

Ümraniye is going to use 96% of its capacity, which is a high rate as well. High utilization rate occurs by the objective of minimizing the number of main facilities. The least number of facility design brings the highest capacity usage rate.

As well as capacity usage of main warehouses, we provide the capacity usage of suggested ERUs in descending order with the total amount transferred to neighborhoods and the districts they belong to at appendix section. As it is seen on the table, capacity usage is more than a high utilization rate of 90% in 35 ERUs out of 125 ERUs.

Another surprising fact is 67 ERUs out of planned 130 ERUs are expected to utilize its capacity below 20% level. This fact arises from the constraint of meeting each demand in less than 10 minutes.

6.2.2 MFC Model without Time Limit

We also run the MFC model without time limit constraint by the objective of minimizing total number of facility construction to enforce constructions at minimum level possible. Again, we inherited each parameter from the previous model without the constraint below;

$$Ltr(j,k) \leq Act(j,k)$$

Act is a table parameter of binary variable which shows if there is possibly any transfer between any ERU and a neighborhood below 10 minutes. Hence, we omit this constraint.

We had the results of suggested 49 ERU construction with capacity utilization of 100% each. Unconstrained time model also suggests to build 3 main warehouses as the model with time limit does and the locations of those warehouses are in Beyoğlu, Şişli and Sultanbeyli. Sultanbeyli and Beyoğlu warehouses are expected to utilize its full capacity, Şişli would use a high utilization capacity of 94%. Service rate of each ERU center is 99.76% which clearly shows that planned ERUs are going to be responsible almost completely for other neighborhoods.

According to MFC model without time limit, official institutions will cover 10% of all neighborhoods below 10 minutes, %70 of all neighborhoods below 50 minutes and will

Table 6.1: Demand completion rate of MFC model without limit

Model without Time Limit		
Minutes	**transfer**	**Percentage**
10	55	10%
30	338	39%
50	656	70%
70	794	84%
90	873	92%
110	941	100%

Table 6.2: Demand completion rate of MFC model with limit

Model with Time Limit		
Minutes	**transfer**	**Percentage**
1	5	12,4%
3	88	20,4%
5	247	35,7%
7	457	56%
9	742	83,6%
10	912	100%

supply all under 110 minutes. Besides, according to the model, the maximum delivery time is 140 minutes by the ERU Center in Şile Hacılı district to Belgrat neighborhood in Çatalca neighborhood with an amount of 149 SU. Average delivery time from ERU to a neighborhood is 36.41 minutes. Average delivery time from main warehouses to ERU centers is 199.25 minutes.

In model with time limit, we cover 56% of all demands less than 7 minutes and cover all below 10 minutes as committed in the time constraint.

6.3 Urgent Delivery Model

Another aspect of optimum design for emergency case is delivering the goods to survivors from facilities as soon as possible regardless of total cost incurred under this emergency situation. One could easily put forward the idea that keeping surviving probability of each citizen should be the foremost priority of state officials. For this reason, we develop the Urgent Deliver Model (UD) and edit the objective function to minimize the distance in the second layer while keeping the constraints same. Model also assures to deliver to each survivor at maximum time of 10 minutes.

$$min \sum_{j,k} Rec(j,k) * Dist2(j,k)$$

We npw present the results we obtained from the mathematical program with the objective of minimizing the distance of ERU to demand point multiplied by received amount as shown in the equation above. We have candidate points for main deposit centers, and emergency response units. Our intention is to find an optimized distribution network to guide policymakers in the field that denotes which storage center should be located at what location. Model solver makes sure that it selects the warehouses and emergency units where no other improved pairings that satisfy the constraints could be devised.

GAMS took 2 hours and 2 minutes to create results in total. According to solution, the objective value is 40.860.147. Average delivery time for all the neighborhoods is 2.79 minutes. ERUs are expected to be located in each neighborhood. Thus, service rate of our optimized solution is %85 which means that the vast majority of transfer will take place to neighborhoods other than the ones that ERUs are located. In other words, the rest of whole demand, %15, is going to be meet at its center that is not going to contribute delivery time.

Optimized solution suggests the construction of 127 ERUs in neighborhoods and 3 main warehouse centers in various districts. Maximum amount that could be sent is named as the capacity of each ERU and was determined as 300.000 SU. In sum, 16 ERU uses its full capacity whereas total capacity usage is 38%. Suggested ERU centers are expected to be located in 36 different districts out of 39 total districts.

We inserted our optimized solutions to Google Maps with its coordinates by blue points for ERUs and by red points for main warehouses. We here present the screenshots of the customized maps with our suggested main warehouses and ERU points afterwards.

Suggested main warehouses are located in 3 districts named as Tuzla, Ümraniye and Kağıthane. Ümraniye and Tuzla warehouses are expected to be in Asia side, whereas warehouse in Kağıthane are to be in Europe side.

Our model has provided solutions with ERU centers included in the appendix section B. We here provide the maps of neighborhoods and the suggested centers to compare with the population distribution.

Figure 6.5: Main warehouse suggestion to UD model.

Figure 6.6: Positions of neighborhoods.

As it's seen on the figures, suggested ERU points and the amount of transfer are intensified at the ERUs located on the European side with the Esenyurt, Küçükçekmece, Bağcılar, Bahçelievler, Kağıthane whereas in Asian Side, Pendik, Üsküdar, Ümraniye and Sultanbeyli are the districts with intense amount of transfer. As expected, the solver pays attention the total population of neighborhoods rather than the number of them in single district.

Minimum delivery time of materials for survivors is 0 minutes as expected. It occurs from the idea of locating 127 ERU to center of 127 neighborhoods. As declared before,

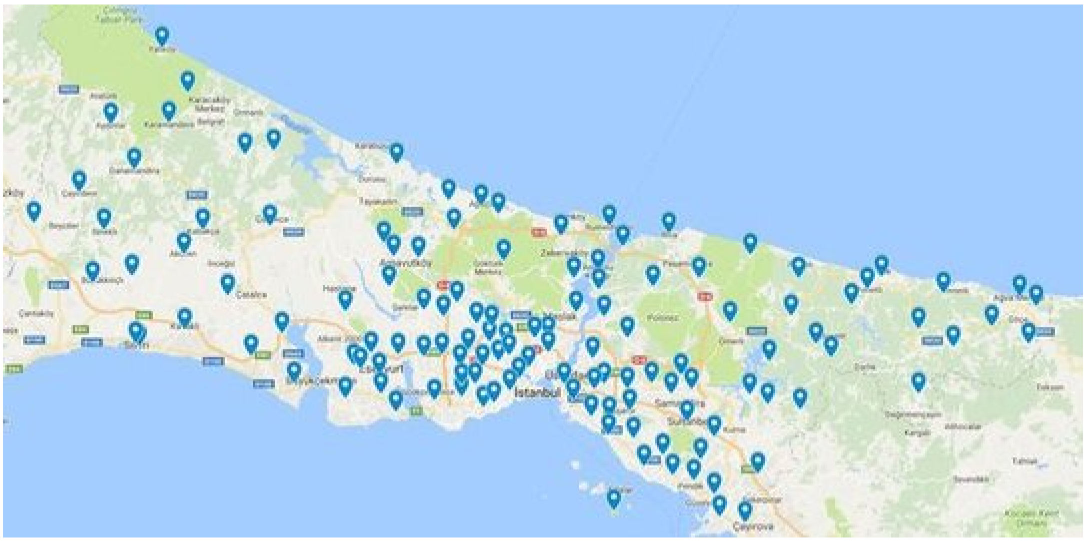

FIGURE 6.7: ERU suggestion to UD model.

we assume that the demand of each neighborhood has been cumulated at the centers which is the assumption of ERU point construction that causes no time to deliver.

We included our proposed 127 ERU Centers with their districts in table B.1 with the amount should be transferred in appendix B.

6.3.1 Capacity Usage

Each main store expected to have 5.000.000 SU capacity. In the figure 6.7 below, we present the capacity utilization of suggested main warehouses with their names.

In descending order, top capacity utilization rate belongs to Ümraniye and Kağıthane warehouses with full usage. Overall usage rate is 98% which denotes the high capacity usage.

TABLE 6.3: Demand completion rate of UD model with limit

Model with Time Limit		
Minutes	**Transfer**	**Percentage**
1	10	59%
3	322	82%
5	597	91%
7	739	96%
9	849	100%
10	849	100%

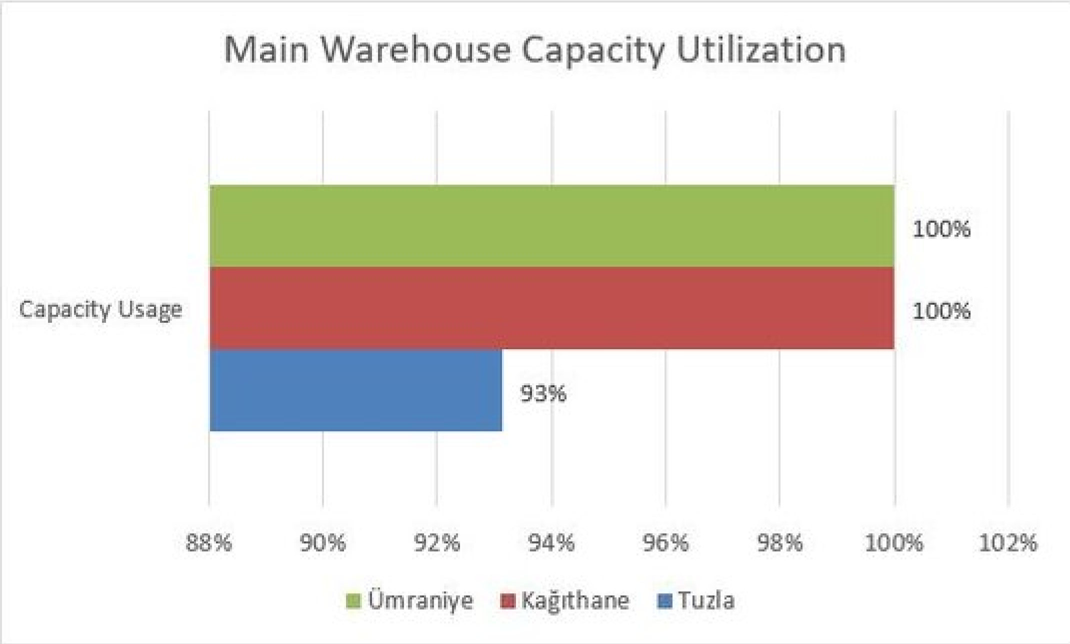

FIGURE 6.8: Capacity usage of main warehouses (UD).

TABLE 6.4: Demand completion rate of UD model without limit

Model without Time Limit		
Minutes	**Transfer**	**Percentage**
10	503	59%
30	698	82%
50	772	91%
70	816	96%
90	837	99%
All	848	100%

6.3.2 UD Model without Time Constraint

Apart from the model with 10 minutes time constraint, we also developed a model without any time restriction to evaluate its results.

As shown in table 6.4, official institutions will cover 59% of all neighborhoods below 10 minutes, %82 of whole below 30 minutes and will supply each under 106 minutes and also according to model, maximum delivery time is 106 minutes by the ERU Center in Pendik Yenişehir to Kadem neighborhood in Şile neighborhood with an amount of 479 SU. Average delivery time for ERU to neighborhood is 4.33 minutes. Average delivery time for main warehouses to ERU centers is 27 minutes.

6.4 Urgent Warehouse Transfer Model (UW)

In this model, our objective is to locate main warehouses and emergency response units as close as possible to decrease delivery time to ERU units. UW model has the objective function different from UD model, so the formula below has been accepted as an objective function.

$$min \sum P_{ij} * Dist1(i, j)$$

Constraints of UW model are also the same as UD model's constraints except time layer constraints. UW model optimizes layer 1, so time limit constraint is enforced for layer 1 rather than layer 2. According to the results, our objective value for 5 main warehouses is 24.926.839 per the above function. Average delivery time from main warehouses to ERU supplies is 1.7 minutes. Solution suggests to build warehouses to Bağcılar, Esenyurt, Beyoğlu, Fatih, Şişli district centers. As well as main storage centers, model also suggests the optimized network of ERUs with their locations and numbers. Even we set the upper limit of ERUs to 100, model results in 52 ERU construction.

Capacity utilization rate for ERUs is 99%. Because there is no objective to minimize any amount and time for ERU-demand transfers, ERU centers are suggested to be opened as amount of need. Next, we placed the points retrieved from GAMS model solution on Google Maps, where 5 main storage centers are shown with red icons and 49 ERUs with blue icons.

As seen in the figure below, solver selects the main storage centers closer to neighborhoods to meet demands of ERUs as fast as possible, while locating a bunch of ERUs to marginal points to cover their demands in 10 minutes.

6.4.1 Capacity Usage

Each main store is set to have 5.000.000 SU capacity. In the table below, we present the capacity utilization of suggested main warehouses with their names.

In descending order, top capacity utilization rate belongs to Silivri warehouse with 98% usage. Esenyurt warehouse is expected to use 92%, Zeytinburnu uses 60% capacity, Şişli

FIGURE 6.9: Main warehouse suggestion to UW model.

FIGURE 6.10: ERU suggestion to UW model.

uses 38% of capacity and Kadıköy warehouse has the least capacity usage rate of 4%. Overall usage rate is 59%. Given the distribution of population, the capacity utilization rate is proportional to population density distribution.

6.4.2 UW Model without Time Constraint

Apart from the UW model with 10 minutes time constraint, we also developed a model without any time restriction to evaluate its results.

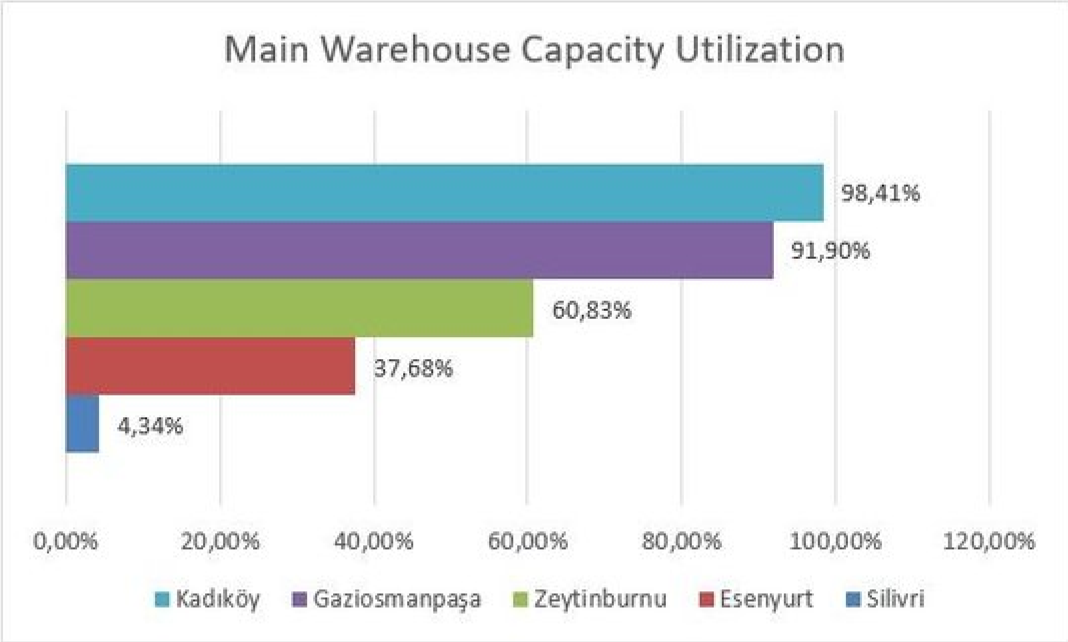

FIGURE 6.11: Capacity usage of main warehouses (UW).

TABLE 6.5: Demand completion rate of UW model without limit

UW model without limit		
Minutes	**transfer**	**Percentage**
10	131	17%
30	532	55%
50	841	84%
70	930	93%
90	966	96%
110	991	98%

As shown in table 6.5, official institutions will cover 17% of all neighborhoods below 10 minutes, %55 of whole below 30 minutes, and will supply all under 150 minutes. Besides, the maximum delivery time is 147 minutes by the ERU Center in Esenyurt Şehitler neighborhood to Kadıköy neighborhood in Şile district with an amount of 161 SU. Average delivery time from ERU to a neighborhood is 26.14 minutes. Average delivery time from main warehouses to ERU centers is 1.7 minutes.

In comparison, UW model with time limit covers nearly half of demands less than 7 minutes and all below 10 minutes. Also, average delivery time from ERU to neighborhoods is 6.89 minutes and 9.29 minutes from main warehouses to ERUs.

TABLE 6.6: Demand completion rate of UW model with limit

UW model with limit		
Minutes	**transfer**	**Percentage**
1	4	13,7%
3	50	18,1%
5	171	29,6%
7	353	46,9%
9	681	78%
10	912	100%

6.5 Discussion of the Results

After conducting thorough analysis from three distinct models, we have the suggested locations for main warehouses and ERUs. The result table proves that there is no coherence among the suggestions for main warehouses.

MFC Model		
MAIN11	MAIN27	MAIN28
Beykoz	Maltepe	Pendik

UD Model		
MAIN24	MAIN36	MAIN37
Kağıthane	Tuzla	Ümraniye

UW Model				
MAIN32	MAIN18	MAIN39	MAIN21	MAIN23
Silivri	Esenyurt	Zeytinbur	Gaziosma	Kadıköy

FIGURE 6.12: Main warehouse suggestions of all models.

Similarly, suggested ERU centers are not identical except 27 ERUs. Hence, it is not possible to suggest a combination out of these solution. For this reason, we developed a hybrid model which involves three perspectives in a way. UD and UW models' objective is to deliver materials at minimum time. On the other hand, MFC model's objective is to minimize the construction cost. Hence, there are two approaches to combine these three models. Firstly, select UD or UW model and insert the other time constraint. However, in this way, we cannot minimize the cost and it would lead to inefficient capacity usage. The second idea is selecting MFC model and inserting time constraints of both layers. In this way, we can assure that layer 1 and layer 2 transfer will not take beyond the certain limits and we will have the most efficient capacity usage by minimizing objective 1.

For this reason, we performed sensitivity analysis to analyze the trade-offs between choices for minimizing the total warehouses while assuring the time constraints of both layers.

We see that the model is infeasible if the max time for layer 2 is set as 8 minutes. Thus, the minimum upper bound for the maximum time in layer 2 is 9 minutes. Additionally,

Table 6.7: Time based sensitivity analysis

		Layer 2 (max)			
		9 min	*10 min*	*12 min*	*15 min*
Layer 1 (max)	*75 min*	173 (4-133)	155 (4-115)	132 (3-102)	117 (3-87)
	90 min	166 (3-136)	151 (3-121)	130 (3-100)	116 (3-86)
	105 min	165 (3-135)	145 (3-115)	130 (3-100)	116 (3-86)
	120 min	164 (3-134)	148 (3-118)	136 (3-106)	117 (3-86)

the minimum upper bound for the maximum time in layer 1 cannot be applied around 70 minutes, so we set the start point as 75 minutes to get feasible results.

Table 6.7 shows the model 1 objective value for binary experiments to understand the affecting layer. First value inside the brackets denotes the number of main warehouses and second value represents number of ERUs. As it is seen on the comparison matrix, if we push the model to supply all less than certain minutes, we need to build more warehouses. Considering the emergency case of Istanbul, we see that there are slight differences in layer 1 time constraint dimension which leads to a few more or less warehouse construction. We aim to deliver to layer 1 at maximum of 75 minutes.

On the other hand, decreasing the maximum delivery time for layer 2 leads to much more ERU construction compared to layer 1 improvements. Thus, we consider the trade-off between the total cost and the delivery time for survivors. Each incremental step on time limit will lead to average of 15 ERU construction. If inspected with the preference of 12 min, the model will provide a major decrease by one less main warehouse construction. On the other hand, the maximum of 15 minutes is the highest among the settings and considered as a long time for survivors. For that reason, we suggest policymakers to deliver to survivors in a maximum time of 12 minutes while supplying at maximum of 75 minutes from main warehouses to ERUs. This suggestion will lead to construction of 3 main warehouses and 102 ERU construction.

Tables 6.8 and 6.9 show the completion rate of demands below the specified minutes for layer 1 and layer 2. For layer 1, 59% of demand is met below 50 minutes and all of met below 75 minutes. For layer 2, 59% of demand is met below 9 minutes and all are met below 12 minutes.

We now present suggested locations for the main warehouses and ERU centers in figures 6.12 and figure 6.13.

Table 6.8: Demand completion rate of Hybrid model layer 1 with limit

Layer 1		
Minutes	**transfer**	**Percentage**
10	4	4%
25	19	19%
50	60	59%
75	102	100%

Table 6.9: Demand completion rate of Hybrid model layer 2 with limit

Layer-2		
Minutes	**transfer**	**Percentage**
3	60	11%
6	225	28%
9	534	59%
12	944	100%

Figure 6.13: Suggested main warehouses.

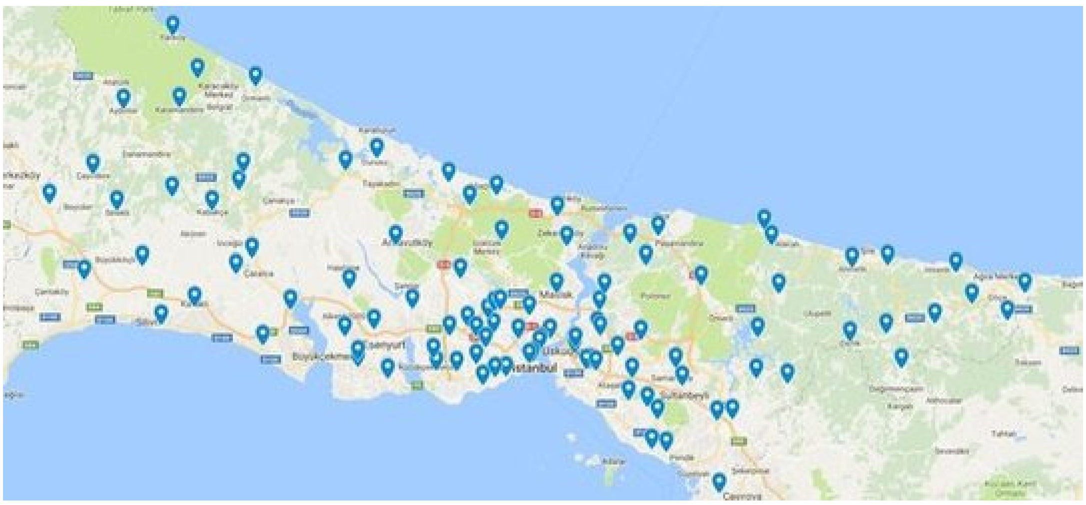

Figure 6.14: Suggested ERU centers.

Figure 6.14 denotes the capacity usage rate of each main warehouse, which clearly shows that the average usage rate is above 95%. Çatalca and Bayrampaşa are expected to utilize full capacity, while Şile remains 93% which is still a high rate.

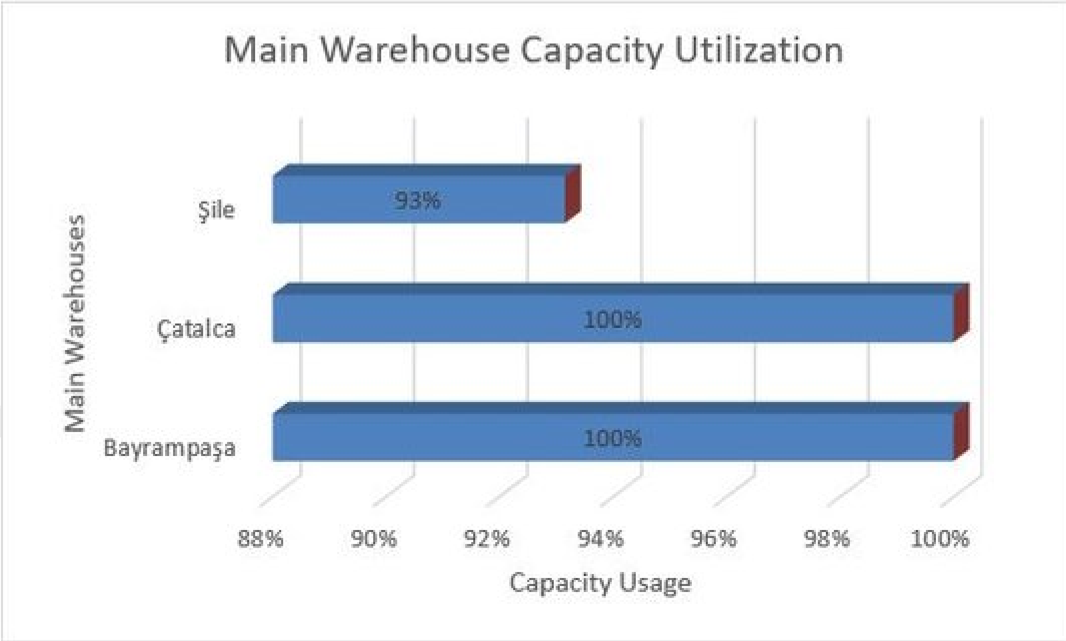

Figure 6.15: Main warehouse capacity utilization.

As noted earlier, 102 ERU construction is suggested. We present the location and capacity usage of each appendix D. The average capacity usage of ERUs is 48%, while 41 of 102 ERUs are expected to have a rate that is above 85%. On the other hand, 40 ERUs are expected to have a rate that is below 10%, which is the result of time constraints that is the model urges to locate ERUs at the marginal points to cover each demand below time limit. The maximum delivery time for layer 1 is 74.95 minutes with the transfer from Şile main warehouse to Küplüce ERU center in Üsküdar. Also, the maximum delivery time for layer 2 is 11.99 minutes with the transfer from ERU center in Küçükçekmece/Söğütlüçeşme to Bağcılar/Fatih neighborhood.

6.5.1 Comparison with the State of the Art

In order to compare results, we consider Gormez's [36] work which is about locating facilities in Istanbul. They divide their demands into two categories as low risk and high risk by utilizing vulnerability level. Time limit for high risk is 40 minutes whereas it is 87 minutes for low risk. They suggest to open 4 main facilities to serve 522 public facilities such as schools and hospitals. Their model yields an average of 12 minutes delivery. Our model meets each demand lower than 12 minutes and have an average delivery time of 7.9 minutes in layer 2. Our model also gives an average of 44.9 minutes while its upper limit is 75 minutes for each demand in layer 1. When considered as similar researches, our model's layer 2 is binding with their solution where both of them meets the final demands. They do not specify any information regarding delivery to neighborhoods from public facilities which they state as model 2.

Chapter 7

Conclusion and Future Work

In this thesis, we develop a state of art optimization model to propose emergency facilities in Istanbul. Through this model, policymakers would be able to decide on the location of main warehouses of the first layer and the local warehouses of the second layer to cover demand of each neighborhood. Adapters of the model can modify the parameters to have further analysis. As different from the past efforts applied on emergency situation in Istanbul, our study's advantage is to include the demand estimation of 960 neighborhoods of Istanbul with the official data provided by Internal Affairs.

Retrieving of population, capacity and location data for 960 neighborhoods and 39 districts of Istanbul was the prior step taken for this research. Secondly, we integrate those large data into our optimization environment with GAMS software. In the next step, we shape our GAMS model by defining the objective and constraints as well as certain parameters. For each of the three models developed, we revamp the objective function according to the purpose, while leaving the constraints the same. Subsequently, we select the most resource efficient solver, and then run the model and obtain the results.

The results from multiple executions of the model with various parameters have been compiled and provided insights for us. We analyze the three different models to review various approaches and compare the results. Direct combination of the three solutions would not lead to one coherent solution. For that reason, we modify model 1 and insert the objectives of other models as constraints. In order to assess the proposed model, we conduct sensitivity analysis by modifying time constraints of layer 1 and 2. Finally, we suggest policymakers to build minimum fund requiring solution while assuring each neighborhood and ERU center receiving supplies plausible time limits. More specifically, our model suggests the construction of 3 main warehouses and 102 ERUs in total.

Further research could be performed on the settings that our model considered as assumptions. One could improve our model by enhancing the population detail by each street, avenue and home with their coordinates. Our model assumes that demand of each neighborhood accumulates at the central points which may be reconsidered as part of future research.

Furthermore, cost analysis efforts could be more detailed to strengthen the truthfulness of the model for policymakers, even though we include and underline the cost approach in MFC model by assuming that cost of each main warehouse center is equal and ten times greater than ERU centers. Lastly, another point that should be considered is the availability of roads during a disaster. Even similar works done in Istanbul, there is no neighborhood level analysis that considers line usability.

Our suggestion is based on certain priorities which aim to minimize construction cost while satisfying time limits. On the other hand, policymakers would utilize our sensitivity analysis results by prioritizing the time limit for survivors or time limit for warehouses. Additionally, our suggestion considers 15 minutes time limit as the worse suggestion for survivors which also minimizes the total cost. The policymakers need to decide that 15 minutes or a lower time should be the upper limit for delivery and then decide on the final solution. In conclusion, our model is a general state representation that provides a solution map for policymakers according to their priorities.

Appendix A

Capacity Usage and Transactions of MFC Model

In our study, we had the results of capacity usage for each ERU center by the calculation of our linear program. In the table below, we share the details of capacity utilization of each ERU center of MFC model with time limit. Details include the district they belong to, the SU amount they are responsible, the neighborhood where they should located and the expected capacity usage of theirs.

Table A.1: ERU capacity usage of MFC model

Districts	**ERU Centers**	**Amount (SU)**	**Capacity Usage**
Ataşehir	Atatürk Mah.	300.000,00	100,00%
Ataşehir	Barbaros Mah.	300.000,00	100,00%
Ataşehir	Örnek Mah.	300.000,00	100,00%
Bahçelievler	Bahçelievler Mah.	300.000,00	100,00%
Bakırköy	Kartaltepe Mah.	300.000,00	100,00%
Başakşehir	Ziya Gökalp Mah.	300.000,00	100,00%
Beylikdüzü	Yakuplu Mah.	300.000,00	100,00%
Beyoğlu	Gümüşsuyu Mah.	300.000,00	100,00%
Esenler	Çifte Havuzlar Mah.	300.000,00	100,00%
Esenler	Namık Kemal Mah.	300.000,00	100,00%
Esenyurt	Saadetdere Mah.	300.000,00	100,00%
Eyüp	Alibeyköy Mah.	300.000,00	100,00%
Eyüp	Silahtarağa Mah.	300.000,00	100,00%
Fatih	Sümbül Efendi Mah.	300.000,00	100,00%
Gaziosmanpaşa	Kazım Karabekir Mah.	300.000,00	100,00%
Gaziosmanpaşa	Yenidoğan Mah.	300.000,00	100,00%
Güngören	Haznedar Mah.	300.000,00	100,00%
Güngören	Mareşal Çakmak Mah.	300.000,00	100,00%
Kadıköy	Koşuyolu Mah.	300.000,00	100,00%
Kağıthane	Talatpaşa Mah.	300.000,00	100,00%
Kartal	Yukarı Mah.	300.000,00	100,00%
Küçükçekmece	Cumhuriyet Mah.	300.000,00	100,00%
Küçükçekmece	Söğütlü Çeşme Mah.	300.000,00	100,00%
Küçükçekmece	Tevfikbey Mah.	300.000,00	100,00%
Maltepe	Çınar Mah.	300.000,00	100,00%
Maltepe	Fındıklı Mah.	300.000,00	100,00%
Pendik	Esenyalı Mah.	300.000,00	100,00%
Şişli	Esentepe Mah.	300.000,00	100,00%
Üsküdar	Ferah Mah.	300.000,00	100,00%
Zeytinburnu	Yeşiltepe Mah.	300.000,00	100,00%
Pendik	Ramazanoğlu Mah.	293.326,00	97,78%
Esenyurt	Turgut Özal Mah.	287.848,00	95,95%
Çekmeköy	Sultançiftliği Mah.	287.369,00	95,79%
Ataşehir	İnönü Mah.	284.510,00	94,84%
Şişli	Fulya Mah.	279.743,00	93,25%
Büyükçekmece	Fatih Mah.	234.662,00	78,22%
Sarıyer	Baltalimanı Mah.	230.751,00	76,92%
Esenyurt	Osmangazi Mah.	225.066,00	75,02%
Maltepe	Büyükbakkalköy Mah.	225.016,00	75,01%
Sultangazi	Eski Habipler Mah.	214.469,00	71,49%
Fatih	Balabanağa Mah.	212.386,00	70,80%
Tuzla	İstasyon Mah.	201.402,00	67,13%
Başakşehir	Bahçeşehir 1. Kısım Mah.	200.108,00	66,70%
Sancaktepe	Mevlana Mah.	196.745,00	65,58%
Sultanbeyli	Mehmet Akif Mah.	189.849,00	63,28%
Maltepe	Gülsuyu Mah.	183.978,00	61,33%
Sultanbeyli	Akşemsettin Mah.	167.884,00	55,96%
Küçükçekmece	Kanarya Mah.	163.873,00	54,62%
Beykoz	Rüzgarlıbahçe Mah.	163.254,00	54,42%

Table A.2: (Continued.) ERU capacity usage of MFC model

Districts	**ERU Centers**	**Amount (SU)**	**Capacity Usage**
Sarıyer	Çayırbaşı Mah.	155.538,00	51,85%
Başakşehir	Güvercintepe Mah.	146.379,00	48,79%
Beykoz	Baklacı Mah.	120.933,00	40,31%
Arnavutköy	Nenehatun Mah.	108.857,00	36,29%
Büyükçekmece	Murat Çesme Mah.	88.947,00	29,65%
Silivri	Alibey Mah.	84.343,00	28,11%
Beykoz	Merkez Mah.	71.394,00	23,80%
Esenyurt	Balıkyolu Mah.	70.267,00	23,42%
Arnavutköy	Arnavutköy Merkez Mah.	58.446,00	19,48%
Başakşehir	Kayabaşı Mah.	50.914,00	16,97%
Eyüp	Mithatpaşa Mah.	48.601,00	16,20%
Arnavutköy	Ömerli Mah.	44.645,00	14,88%
Çatalca	Muratbey Merkez Mah.	39.357,00	13,12%
Silivri	Sancaktepe Mah.	34.507,00	11,50%
Tuzla	Anadolu Mah.	34.335,00	11,45%
Sarıyer	Uskumruköy Mah.	32.833,00	10,94%
Silivri	Ortaköy Mah.	22.256,00	7,42%
Arnavutköy	Karlıbayır Mah.	22.216,00	7,41%
Çatalca	Aydınlar Mah.	18.279,00	6,09%
Arnavutköy	Durusu Mah.	16.215,00	5,41%
Şile	Hacı Kasım Mah.	12.023,00	4,01%
Büyükçekmece	Kumburgaz Mah.	11.409,00	3,80%
Çatalca	Kestanelik Mah.	9.187,00	3,06%
Çekmeköy	Sırapınar Mah.	8.309,00	2,77%
Silivri	Kadıköy Mah.	7.288,00	2,43%
Beykoz	Mahmutşevketpaşa Mah.	7.090,00	2,36%
Sarıyer	Rumelifeneri Mah.	6.419,00	2,14%
Silivri	Çayırdere Mah.	4.684,00	1,56%
Beykoz	Bozhane Mah.	4.451,00	1,48%
Çatalca	İhsaniye Mah.	4.449,00	1,48%
Arnavutköy	Balaban Mah.	4.108,00	1,37%
Çatalca	Karacaköy Merkez Mah.	3.969,00	1,32%
Çatalca	Gökçeali Mah.	3.609,00	1,20%
Arnavutköy	Boyalık Mah.	3.583,00	1,19%
Silivri	Büyük Kılıçlı Mah.	3.488,00	1,16%

Table A.3: (Continued.) ERU capacity usage of MFC model

Districts	**ERU Centers**	**Amount (SU)**	**Capacity Usage**
Silivri	Büyük Çavuşlu Mah.	3.350,00	1,12%
Şile	Göçe Mah.	3.299,00	1,10%
Çatalca	Başak Mah.	3.130,00	1,04%
Silivri	Çeltik Mah.	2.953,00	0,98%
Beykoz	Alibahadır Mah.	2.837,00	0,95%
Beykoz	Anadolufeneri Mah.	2.262,00	0,75%
Şile	Korucu Mah.	2.253,00	0,75%
Beykoz	Anadolu Kavağı Mah.	2.100,00	0,70%
Silivri	Kurfallı Mah.	2.087,00	0,70%
Çatalca	Yaylacık Mah.	2.028,00	0,68%
Şile	Çayırbaşı Mah.	1.816,00	0,61%
Çatalca	Örencik Mah.	1.768,00	0,59%
Şile	Çengilli Mah.	1.663,00	0,55%
Şile	İmrendere Mah.	1.638,00	0,55%
Şile	Alacalı Mah.	1.516,00	0,51%
Silivri	Bekirli Mah.	1.514,00	0,50%
Çatalca	Yalıköy Mah.	1.493,00	0,50%
Şile	Kurna Mah.	1.226,00	0,41%
Şile	Karacaköy Mah.	1.192,00	0,40%
Eyüp	Akpınar Mah.	1.187,00	0,40%
Pendik	Göçbeyli Mah.	1.073,00	0,36%
Şile	Geredeli Mah.	930	0,31%
Eyüp	Ağaçlı Mah.	796	0,27%
Şile	Üvezli Mah.	788	0,26%
Eyüp	Odayeri Mah.	779	0,26%
Şile	Bıçkıdere Mah.	717	0,24%
Şile	Sortullu Mah.	643	0,21%
Arnavutköy	Hacımaşlı Mah.	555	0,19%
Çatalca	Karamandere Mah.	548	0,18%
Silivri	Büyük Sinekli Mah.	494	0,16%
Pendik	Kurtdoğmuş Mah.	451	0,15%
Şile	Oruçoğlu Mah.	446	0,15%
Şile	Teke Mah.	435	0,15%
Şile	Göksu Mah.	431	0,14%
Pendik	Ballıca Mah.	425	0,14%
Şile	Çataklı Mah.	414	0,14%
Şile	Kurfallı Mah.	243	0,08%
Şile	Çelebi Mah.	161	0,05%
Eyüp	Çiftalan Mah.	152	0,05%
Şile	Esenceli Mah.	73	0,02%

Appendix B

Capacity Usage and Transactions of UD Model

In our study, we had the results of capacity usage for each ERU center by the calculation of our linear program. In the table below, we share the details of capacity utilization of each ERU center of UD model with time limit. Details include the district they belong to, the SU amount they are responsible, the neighborhood where they should located and the expected capacity usage of theirs.

Table B.1: ERU capacity usage of UD model

District	ERU Center	Amount	Capacity Usage
Bağcılar	100. Yıl Mah.	300.000,00	100,00%
Bağcılar	Yenimahalle Mah.	300.000,00	100,00%
Bahçelievler	Hürriyet Mah.	300.000,00	100,00%
Bahçelievler	Kocasinan Merkez Mah.	300.000,00	100,00%
Bakırköy	Kartaltepe Mah.	300.000,00	100,00%
Bayrampaşa	Muratpaşa Mah.	300.000,00	100,00%
Beyoğlu	Kaptanpaşa Mah.	300.000,00	100,00%
Esenler	Menderes Mah.	300.000,00	100,00%
Gaziosmanpaşa	Barbaros Hayrettinpaşa Mah.	300.000,00	100,00%
Güngören	Mareşal Çakmak Mah.	300.000,00	100,00%
Kağıthane	Çeliktepe Mah.	300.000,00	100,00%
Kağıthane	Merkez Mah.	300.000,00	100,00%
Küçükçekmece	Gültepe Mah.	300.000,00	100,00%
Küçükçekmece	Mehmet Akif Mah.	300.000,00	100,00%
Şişli	Fulya Mah.	300.000,00	100,00%
Zeytinburnu	Yeşiltepe Mah.	300.000,00	100,00%
Küçükçekmece	Atakent Mah.	294.230,00	98,08%
Esenyurt	Talatpaşa Mah.	290.826,00	96,94%
Üsküdar	Cumhuriyet Mah.	286.667,00	95,56%
Sultanbeyli	Hasanpaşa Mah.	284.904,00	94,97%
Beylikdüzü	Adnan Kahveci Mah.	284.742,00	94,91%
Ümraniye	Altınşehir Mah.	277.191,00	92,40%
Ümraniye	İstiklal Mah.	276.895,00	92,30%
Sultangazi	Uğur Mumcu Mah.	266.941,00	88,98%
Sultangazi	Yunus Emre Mah.	263.026,00	87,68%
Gaziosmanpaşa	Karlıtepe Mah.	260.237,00	86,75%
Maltepe	Zümrütevler Mah.	252.236,00	84,08%
Fatih	Seyyid Ömer Mah.	245.828,00	81,94%
Pendik	Fevzi Çakmak Mah.	245.157,00	81,72%
Çekmeköy	Mehmet Akif Mah.	238.845,00	79,62%
Esenyurt	Turgut Özal Mah.	234.245,00	78,08%
Kartal	Atalar Mah.	228.513,00	76,17%
Ataşehir	İçerenköy Mah.	227.909,00	75,97%
Kadıköy	Erenköy Mah.	225.496,00	75,17%
Fatih	Atikali Mah.	222.722,00	74,24%
Esenyurt	Balıkyolu Mah.	222.136,00	74,05%
Pendik	Yeşilbağlar Mah.	221.071,00	73,69%
Eyüp	Yeşilpınar Mah.	213.577,00	71,19%
Üsküdar	Valide-İ Atik Mah.	211.638,00	70,55%
Kadıköy	Hasanpaşa Mah.	206.422,00	68,81%
Üsküdar	Bahçelievler Mah.	206.057,00	68,69%
Avcılar	Merkez Mah.	195.626,00	65,21%
Pendik	Fatih Mah.	191.659,00	63,89%
Ataşehir	Kayışdağı Mah.	182.092,00	60,70%

Table B.2: (Continued.) ERU capacity usage of UD model

District	ERU Center	Amount	Capacity Usage
Sarıyer	İstinye Mah.	179.107,00	59,70%
Esenyurt	İstiklal Mah.	177.005,00	59,00%
Sultanbeyli	Akşemsettin Mah.	176.430,00	58,81%
Maltepe	Küçükyalı Merkez Mah.	170.519,00	56,84%
Sancaktepe	Kemal Türkler Mah.	164.258,00	54,75%
Büyükçekmece	Murat Çesme Mah.	150.596,00	50,20%
Pendik	Sülüntepe Mah.	148.619,00	49,54%
Kartal	Gümüşpınar Mah.	142.804,00	47,60%
Beykoz	Çiğdem Mah.	131.235,00	43,75%
Esenyurt	Aşık Veysel Mah.	126.899,00	42,30%
Başakşehir	Başak Mah.	119.129,00	39,71%
Adalar	Maden Mah.	118.448,00	39,48%
Başakşehir	Kayabaşı Mah.	111.623,00	37,21%
Avcılar	Tahtakale Mah.	107.388,00	35,80%
Sarıyer	Büyükdere Mah.	92.846,00	30,95%
Tuzla	Yayla Mah.	88.212,00	29,40%
Sancaktepe	Mevlana Mah.	87.423,00	29,14%
Silivri	Alibey Mah.	84.343,00	28,11%
Arnavutköy	Taşoluk Mah.	70.913,00	23,64%
Çekmeköy	Ekşioğlu Mah.	67.871,00	22,62%
Tuzla	Şifa Mah.	49.302,00	16,43%
Beykoz	Ortaçeşme Mah.	48.666,00	16,22%
Eyüp	Mithatpaşa Mah.	48.601,00	16,20%
Arnavutköy	Ömerli Mah.	40.392,00	13,46%
Silivri	Sancaktepe Mah.	37.103,00	12,37%
Sultangazi	Eski Habipler Mah.	36.981,00	12,33%
Sarıyer	Uskumruköy Mah.	34.120,00	11,37%
Çatalca	Muratbey Merkez Mah.	30.434,00	10,14%
Tuzla	Orta Mah.	26.789,00	8,93%
Silivri	Hürriyet Mah.	26.205,00	8,74%
Beykoz	Çiftlik Mah.	24.609,00	8,20%
Çekmeköy	Aydınlar Mah.	18.340,00	6,11%
Büyükçekmece	Kamiloba Mah.	17.781,00	5,93%
Arnavutköy	Atatürk Mah.	15.004,00	5,00%
Şile	Çavuş Mah.	13.498,00	4,50%
Çatalca	Kestanelik Mah.	12.267,00	4,09%
Çekmeköy	Sırapınar Mah.	8.309,00	2,77%
Beykoz	Mahmutşevketpaşa Mah.	7.090,00	2,36%
Çatalca	Elbasan Mah.	5.890,00	1,96%
Çatalca	Kabakça Mah.	5.200,00	1,73%
Sarıyer	Rumelifeneri Mah.	5.132,00	1,71%
Silivri	Çayırdere Mah.	4.684,00	1,56%
Arnavutköy	Yeniköy Mah.	4.572,00	1,52%

Table B.3: (Continued.) ERU capacity usage of UD model

District	**ERU Center**	**Amount**	**Capacity Usage**
Beykoz	Bozhane Mah.	4.451,00	1,48%
Arnavutköy	Adnan Menderes Mah.	4.108,00	1,37%
Çatalca	Karacaköy Merkez Mah.	3.969,00	1,32%
Silivri	Büyük Çavuşlu Mah.	3.350,00	1,12%
Şile	Ağva Merkez Mah.	3.134,00	1,04%
Çatalca	Başak Mah.	3.130,00	1,04%
Silivri	Fener Mah.	3.098,00	1,03%
Beykoz	Riva Mah.	2.837,00	0,95%
Silivri	Seymen Mah.	2.834,00	0,94%
Şile	Ahmetli Mah.	2.628,00	0,88%
Beykoz	Poyrazköy Mah.	2.262,00	0,75%
Beykoz	Anadolu Kavağı Mah.	2.100,00	0,70%
Silivri	Danamandıra Mah.	1.967,00	0,66%
Çatalca	Örencik Mah.	1.768,00	0,59%
Şile	Akçakese Mah.	1.686,00	0,56%
Şile	Alacalı Mah.	1.516,00	0,51%
Silivri	Akören Mah.	1.514,00	0,50%
Çatalca	Yalıköy Mah.	1.493,00	0,50%
Şile	Yaylalı Mah.	1.343,00	0,45%
Şile	Kurna Mah.	1.226,00	0,41%
Eyüp	Akpınar Mah.	1.187,00	0,40%
Şile	Çengilli Mah.	1.174,00	0,39%
Pendik	Göçbeyli Mah.	1.073,00	0,36%
Eyüp	Işıklar Mah.	937	0,31%
Şile	Sortullu Mah.	844	0,28%
Eyüp	Ağaçlı Mah.	796	0,27%
Şile	Üvezli Mah.	788	0,26%
Şile	Geredeli Mah.	782	0,26%
Şile	Gökmaşlı Mah.	763	0,25%
Şile	Bıçkıdere Mah.	717	0,24%
Şile	Satmazlı Mah.	666	0,22%
Şile	Bucaklı Mah.	623	0,21%
Arnavutköy	Hacımaşlı Mah.	555	0,19%
Çatalca	Karamandere Mah.	548	0,18%
Silivri	Büyük Sinekli Mah.	494	0,16%
Pendik	Kurtdoğmuş Mah.	451	0,15%
Şile	Oruçoğlu Mah.	446	0,15%
Pendik	Ballıca Mah.	425	0,14%
Eyüp	Çiftalan Mah.	152	0,05%
Şile	Esenceli Mah.	73	0,02%

Appendix C

Capacity Usage and Transactions of UW Model

In our study, we had the results of capacity usage for each ERU center by the calculation of our linear program. In the table below, we share the details of capacity utilization of each ERU center of UW model with time limit. Details include the district they belong to, the SU amount they are responsible, the neighborhood where they should located and the expected capacity usage of theirs.

Table C.1: ERU capacity usage of UW model

District	Neighborhood	Amount	Capacity Usage
Ataşehir	Küçükbakkalköy Mah.	300.000,00	100,00%
Bahçelievler	Çobançeşme Mah.	300.000,00	100,00%
Bahçelievler	Şirinevler Mah.	300.000,00	100,00%
Bayrampaşa	Kartaltepe Mah.	300.000,00	100,00%
Bayrampaşa	Yıldırım Mah.	300.000,00	100,00%
Esenyurt	Battalgazi Mah.	300.000,00	100,00%
Esenyurt	Pınar Mah.	300.000,00	100,00%
Esenyurt	Şehitler Mah.	300.000,00	100,00%
Eyüp	Esentepe Mah.	300.000,00	100,00%
Fatih	Şehremini Mah.	300.000,00	100,00%
Gaziosmanpaşa	Bağlarbaşı Mah.	300.000,00	100,00%
Gaziosmanpaşa	Fevzi Çakmak Mah.	300.000,00	100,00%
Gaziosmanpaşa	Hürriyet Mah.	300.000,00	100,00%
Gaziosmanpaşa	Kazım Karabekir Mah.	300.000,00	100,00%
Gaziosmanpaşa	Yeni Mahalle Mah.	300.000,00	100,00%
Güngören	Tozkoparan Mah.	300.000,00	100,00%
Kadıköy	Erenköy Mah.	300.000,00	100,00%
Kadıköy	Feneryolu Mah.	300.000,00	100,00%
Kadıköy	Göztepe Mah.	300.000,00	100,00%
Kadıköy	Kozyatağı Mah.	300.000,00	100,00%
Kadıköy	Merdivenköy Mah.	300.000,00	100,00%
Kağıthane	Hamidiye Mah.	300.000,00	100,00%
Kartal	Orta Mah.	300.000,00	100,00%
Küçükçekmece	Atatürk Mah.	300.000,00	100,00%
Maltepe	Zümrütevler Mah.	300.000,00	100,00%
Pendik	Yeşilbağlar Mah.	300.000,00	100,00%
Sancaktepe	Fatih Mah.	300.000,00	100,00%
Sultanbeyli	Hasanpaşa Mah.	300.000,00	100,00%
Ümraniye	Atakent Mah.	300.000,00	100,00%
Ümraniye	Esenşehir Mah.	300.000,00	100,00%
Üsküdar	İcadiye Mah.	300.000,00	100,00%
Zeytinburnu	Beştelsiz Mah.	300.000,00	100,00%
Zeytinburnu	Merkezefendi Mah.	300.000,00	100,00%
Zeytinburnu	Seyitnizam Mah.	300.000,00	100,00%
Zeytinburnu	Telsiz Mah.	300.000,00	100,00%
Zeytinburnu	Veliefendi Mah.	300.000,00	100,00%
Esenyurt	İstiklal Mah.	282.028,00	94,01%
Güngören	Abdurrahman Nafiz Gürman Mah.	244.719,00	81,57%
Avcılar	Firuzköy Mah.	238.327,00	79,44%
Kağıthane	Yahya Kemal Mah.	231.522,00	77,17%
Esenler	Kemer Mah.	211.806,00	70,60%
Adalar	Kınalıada Mah.	186.029,00	62,01%
Tuzla	İstasyon Mah.	162.649,00	54,22%
Sarıyer	Cumhuriyet Mah.	158.050,00	52,68%

Table C.2: (Continued.) ERU capacity usage of UW model

District	Neighborhood	Amount	Capacity Usage
Sultanbeyli	Hamidiye Mah.	157.519,00	52,51%
Büyükçekmece	Murat Çesme Mah.	150.596,00	50,20%
Beykoz	Rüzgarlıbahçe Mah.	144.663,00	48,22%
Başakşehir	Ziya Gökalp Mah.	137.472,00	45,82%
Pendik	Kurtköy Mah.	115.223,00	38,41%
Sultangazi	Cumhuriyet Mah.	112.747,00	37,58%
Başakşehir	Kayabaşı Mah.	111.623,00	37,21%
Avcılar	Tahtakale Mah.	107.388,00	35,80%
Beylikdüzü	Barış Mah.	93.281,00	31,09%
Sancaktepe	Mevlana Mah.	88.301,00	29,43%
Silivri	Kavaklı Mah.	88.009,00	29,34%
Eyüp	Sakarya Mah.	59.688,00	19,90%
Tuzla	Anadolu Mah.	52.098,00	17,37%
Beykoz	Gümüşsuyu Mah.	49.553,00	16,52%
Beykoz	Yeni Mahalle Mah.	49.027,00	16,34%
Eyüp	Mithatpaşa Mah.	48.601,00	16,20%
Sarıyer	Zekeriyaköy Mah.	46.675,00	15,56%
Küçükçekmece	Cumhuriyet Mah.	46.036,00	15,35%
Silivri	Semizkumlar Mah.	42.692,00	14,23%
Beşiktaş	Kültür Mah.	41.363,00	13,79%
Fatih	Akşemsettin Mah.	40.032,00	13,34%
Büyükçekmece	Ahmediye Mah.	30.434,00	10,14%
Tuzla	Fatih Mah.	24.403,00	8,13%
Eyüp	Pirinççi Mah.	23.864,00	7,95%
Arnavutköy	Hadımköy Mah.	21.917,00	7,31%
Arnavutköy	Yeşilbayır Mah.	20.185,00	6,73%
Çatalca	Fatih Mah.	18.279,00	6,09%
Büyükçekmece	Celaliye Mah.	17.781,00	5,93%
Silivri	Balaban Mah.	15.918,00	5,31%
Çekmeköy	Reşadiye Mah.	15.518,00	5,17%
Şile	Kumbaba Mah.	15.143,00	5,05%
Beykoz	Baklacı Mah.	12.970,00	4,32%
Beyoğlu	Kaptanpaşa Mah.	10.753,00	3,58%
Arnavutköy	Yassıören Mah.	8.616,00	2,87%
Çatalca	Gökçeali Mah.	7.804,00	2,60%
Arnavutköy	Terkos Mah.	7.571,00	2,52%
Çekmeköy	Koçullu Mah.	6.220,00	2,07%
Arnavutköy	Fatih Mah.	5.233,00	1,74%
Sarıyer	Garipçe Mah.	5.132,00	1,71%

Table C.3: (Continued.) ERU capacity usage of UW model

District	**Neighborhood**	**Amount**	**Capacity Usage**
Çatalca	Kestanelik Mah.	4.992,00	1,66%
Beykoz	İshaklı Mah.	4.553,00	1,52%
Silivri	Fener Mah.	4.544,00	1,51%
Çatalca	Çakıl Mah.	4.371,00	1,46%
Sarıyer	Gümüşdere Mah.	4.362,00	1,45%
Arnavutköy	Balaban Mah.	4.108,00	1,37%
Çatalca	Karacaköy Merkez Mah.	3.969,00	1,32%
Silivri	Büyük Çavuşlu Mah.	3.350,00	1,12%
Silivri	Akören Mah.	3.175,00	1,06%
Çatalca	Başak Mah.	3.130,00	1,04%
Beykoz	Alibahadır Mah.	3.118,00	1,04%
Beykoz	Mahmutşevketpaşa Mah.	2.917,00	0,97%
Çatalca	İhsaniye Mah.	2.788,00	0,93%
Silivri	Beyciler Mah.	2.687,00	0,90%
Şile	Ağva Merkez Mah.	2.530,00	0,84%
Beykoz	Anadolufeneri Mah.	2.262,00	0,75%
Beykoz	Anadolu Kavağı Mah.	2.100,00	0,70%
Çatalca	Gümüşpınar Mah.	2.028,00	0,68%
Silivri	Çayırdere Mah.	1.997,00	0,67%
Şile	Çayırbaşı Mah.	1.816,00	0,61%
Şile	Sahilköy Mah.	1.664,00	0,55%
Silivri	Gazitepe Mah.	1.519,00	0,51%
Çatalca	Yalıköy Mah.	1.493,00	0,50%
Şile	Gökmaşlı Mah.	1.443,00	0,48%
Silivri	Çeltik Mah.	1.389,00	0,46%
Beykoz	Kılıçlı Mah.	1.241,00	0,41%

Table C.4: (Continued.) ERU capacity usage of UW model

District	**Neighborhood**	**Amount**	**Capacity Usage**
Eyüp	Akpınar Mah.	1.187,00	0,40%
Çatalca	Yazlık Mah.	1.145,00	0,38%
Pendik	Göçbeyli Mah.	1.073,00	0,36%
Silivri	Büyük Kılıçlı Mah.	1.031,00	0,34%
Eyüp	Işıklar Mah.	937	0,31%
Şile	Değirmençayırı Mah.	848	0,28%
Şile	Sortullu Mah.	844	0,28%
Şile	Karacaköy Mah.	828	0,28%
Eyüp	Ağaçlı Mah.	796	0,27%
Şile	Üvezli Mah.	788	0,26%
Şile	Geredeli Mah.	782	0,26%
Şile	Alacalı Mah.	779	0,26%
Şile	Bıçkıdere Mah.	717	0,24%
Çatalca	Ormanlı Mah.	623	0,21%
Şile	Karabeyli Mah.	577	0,19%
Arnavutköy	Hacımaşlı Mah.	555	0,19%
Çatalca	Karamandere Mah.	548	0,18%
Şile	Ovacık Mah.	546	0,18%
Silivri	Büyük Sinekli Mah.	494	0,16%
Şile	Korucu Mah.	465	0,16%
Şile	İmrendere Mah.	456	0,15%
Pendik	Kurtdoğmuş Mah.	451	0,15%
Şile	Darlık Mah.	446	0,15%
Pendik	Ballıca Mah.	425	0,14%
Şile	Ağaçdere Mah.	323	0,11%
Şile	Bucaklı Mah.	309	0,10%
Şile	Hasanlı Mah.	231	0,08%
Eyüp	Çiftalan Mah.	152	0,05%
Şile	Esenceli Mah.	73	0,02%

Appendix D

Capacity Usage and Transactions of Hybrid Model

In our study, we had the results of capacity usage for each ERU center by the calculation of our linear program. In the table below, we share the details of capacity utilization of each ERU center of Hybrid model with time limit. Details include the district they belong to, the SU amount they are responsible, the neighborhood where they should located and the expected capacity usage of theirs.

Table D.1: ERU capacity usage of Hybrid model

District	Neighborhood	Amount	Capacity Usage
Ataşehir	Esatpaşa Mah.	300.000,00	100,00%
Ataşehir	Fetih Mah.	300.000,00	100,00%
Ataşehir	Mustafa Kemal Mah.	300.000,00	100,00%
Ataşehir	Yeni Çamlıca Mah.	300.000,00	100,00%
Avcılar	Cihangir Mah.	300.000,00	100,00%
Bağcılar	100. Yıl Mah.	300.000,00	100,00%
Bağcılar	Mahmutbey Mah.	300.000,00	100,00%
Bahçelievler	Fevzi Çakmak Mah.	300.000,00	100,00%
Bakırköy	Yenimahalle Mah.	300.000,00	100,00%
Bayrampaşa	Kartaltepe Mah.	300.000,00	100,00%
Beykoz	Rüzgarlıbahçe Mah.	300.000,00	100,00%
Beyoğlu	Halıcıoğlu Mah.	300.000,00	100,00%
Beyoğlu	Pürtelaş Hasan Efendi Mah.	300.000,00	100,00%
Esenler	Birlik Mah.	300.000,00	100,00%
Esenler	Mimar Sinan Mah.	300.000,00	100,00%
Esenyurt	Barbaros Hayrettin Paşa Mah.	300.000,00	100,00%
Esenyurt	Esenkent Mah.	300.000,00	100,00%
Eyüp	Merkez Mah.	300.000,00	100,00%
Gaziosmanpaşa	Karayolları Mah.	300.000,00	100,00%
Gaziosmanpaşa	Mevlana Mah.	300.000,00	100,00%
Güngören	Haznedar Mah.	300.000,00	100,00%
Kartal	Çavuşoğlu Mah.	300.000,00	100,00%
Kartal	Uğur Mumcu Mah.	300.000,00	100,00%
Küçükçekmece	Kemalpaşa Mah.	300.000,00	100,00%
Küçükçekmece	Söğütlü Çeşme Mah.	300.000,00	100,00%
Maltepe	Büyükbakkalköy Mah.	300.000,00	100,00%
Pendik	Harmandere Mah.	300.000,00	100,00%
Sancaktepe	Merve Mah.	300.000,00	100,00%
Sarıyer	Maslak Mah.	300.000,00	100,00%
Sultangazi	Habibler Mah.	300.000,00	100,00%
Tuzla	İstasyon Mah.	300.000,00	100,00%
Ümraniye	Ihlamurkuyu Mah.	300.000,00	100,00%
Üsküdar	Küplüce Mah.	300.000,00	100,00%
Zeytinburnu	Gökalp Mah.	300.000,00	100,00%
Üsküdar	Burhaniye Mah.	298.508,00	99,50%
Sultanbeyli	Adil Mah.	295.284,00	98,43%
Fatih	Yedikule Mah.	280.532,00	93,51%
Fatih	Hocapaşa Mah.	273.057,00	91,02%
Ümraniye	HekimbaşıMah.	258.234,00	86,08%
Beylikdüzü	Büyükşehir Mah.	257.263,00	85,75%
Başakşehir	Güvercintepe Mah.	255.052,00	85,02%
Çekmeköy	Merkez Mah.	229.129,00	76,38%
Esenyurt	Cumhuriyet Mah.	228.221,00	76,07%
Beyoğlu	Ömer Avni Mah.	221.599,00	73,87%
Arnavutköy	Karlıbayır Mah.	187.823,00	62,61%
Fatih	Taya Hatun Mah.	176.469,00	58,82%
Pendik	Yeni Mah.	171.978,00	57,33%
Büyükçekmece	Çakmaklı Mah.	164.613,00	54,87%

Table D.2: (Continued.) ERU capacity usage of Hybrid model

District	Neighborhood	Amount	Capacity Usage
Beşiktaş	Cihannüma Mah.	145.009,00	48,34%
Ümraniye	Topağacı Mah.	119.186,00	39,73%
Silivri	Cumhuriyet Mah.	105.407,00	35,14%
Tuzla	Fatih Mah.	87.311,00	29,10%
Arnavutköy	Ömerli Mah.	86.472,00	28,82%
Sarıyer	Maden Mah.	76.869,00	25,62%
Büyükçekmece	Kumburgaz Mah.	72.631,00	24,21%
Eyüp	Mithatpaşa Mah.	57.609,00	19,20%
Maltepe	Başıbüyük Mah.	50.337,00	16,78%
Beykoz	Soğuksu Mah.	38.041,00	12,68%
Sarıyer	Uskumruköy Mah.	37.241,00	12,41%
Silivri	Sancaktepe Mah.	36.071,00	12,02%
Çatalca	Kaleiçi Mah.	34.801,00	11,60%
Büyükçekmece	Ahmediye Mah.	33.217,00	11,07%
Çatalca	Aydınlar Mah.	19.172,00	6,39%
Arnavutköy	Durusu Mah.	18.632,00	6,21%
Beykoz	Mahmutşevketpaşa Mah.	17.981,00	5,99%
Şile	Ahmetli Mah.	14.352,00	4,78%
Çekmeköy	Hüseyinli Mah.	13.370,00	4,46%
Çatalca	Kalfa Mah.	9.132,00	3,04%
Beykoz	Kaynarca Mah.	8.610,00	2,87%
Arnavutköy	Boyalık Mah.	7.915,00	2,64%
Çatalca	Elbasan Mah.	7.175,00	2,39%
Beykoz	Alibahadır Mah.	5.647,00	1,88%
Silivri	Çayırdere Mah.	4.684,00	1,56%
Silivri	Fener Mah.	4.403,00	1,47%
Silivri	Yolçatı Mah.	3.866,00	1,29%
Çatalca	Akalan Mah.	3.628,00	1,21%
Çatalca	Kabakça Mah.	3.533,00	1,18%
Şile	Çayırbaşı Mah.	3.378,00	1,13%
Silivri	Büyük Çavuşlu Mah.	3.350,00	1,12%
Silivri	Bekirli Mah.	3.181,00	1,06%
Çatalca	Ormanlı Mah.	3.133,00	1,04%
Şile	Gökmaşlı Mah.	2.736,00	0,91%
Şile	Doğancılı Mah.	2.294,00	0,76%
Eyüp	Odayeri Mah.	1.733,00	0,58%
Silivri	Büyük Sinekli Mah.	1.629,00	0,54%
Çatalca	Yalıköy Mah.	1.493,00	0,50%
Şile	Çengilli Mah.	1.480,00	0,49%

Table D.3: (Continued.) ERU capacity usage of Hybrid model

District	**Neighborhood**	**Amount**	**Capacity Usage**
Şile	Geredeli Mah.	1.462,00	0,49%
Çatalca	Karacaköy Merkez Mah.	1.459,00	0,49%
Şile	Bozgoca Mah.	1.435,00	0,48%
Şile	Üvezli Mah.	1.313,00	0,44%
Eyüp	Akpınar Mah.	1.187,00	0,40%
Pendik	Göçbeyli Mah.	1.073,00	0,36%
Şile	Sortullu Mah.	1.057,00	0,35%
Pendik	Ballıca Mah.	876	0,29%
Şile	Darlık Mah.	638	0,21%
Şile	Kadıköy Mah.	623	0,21%
Şile	Teke Mah.	618	0,21%
Çatalca	Karamandere Mah.	548	0,18%
Şile	Sahilköy Mah.	448	0,15%
Eyüp	Çiftalan Mah.	152	0,05%
Şile	Esenceli Mah.	73	0,02%

Bibliography

[1] Disaster Statistics - UNISDR. URL https://www.unisdr.org/we/inform/disaster-statistics.

[2] Yillara Gore Il Nufuslari -TUIK. URL www.tuik.gov.tr/PreIstatistikTablo.do?istab_id=1590.

[3] J.Hawksworth and A. Tiwari. Which are the Largest City Economies in the World and How Might this Change by 2025? *UK Economic Outlook November*, (November):15, 2009. URL http://pwc.blogs.com/files/global-city-gdp-rankings-2008-2025.pdf.

[4] F. Gezici and E. Kerimoglu. Culture, tourism and regeneration process in Istanbul. *International Journal of Culture, Tourism and Hospitality Research*, 4(3):252–265, aug 2010. ISSN 1750-6182. doi: 10.1108/17506181011067637. URL http://www.emeraldinsight.com/doi/10.1108/17506181011067637.

[5] Types of disasters - IFRC. URL http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/definition-of-hazard/.

[6] Technological Hazards | FEMA.gov. URL https://www.fema.gov/technological-hazards.

[7] Disaster Data Statistics - Professional Resources - PreventionWeb.net. URL http://www.preventionweb.net/english/professional/statistics/.

[8] Most significant natural disasters worldwide by death toll up to 2015 | Statistic. URL https://www.statista.com/statistics/268029/natural-disasters-by-death-toll-since-1980/.

[9] S. Tufekci and W. Wallace. The emerging area of emergency management and engineering. *IEEE Transactions on Engineering*, 1998.

[10] What is Supply Chain Management? - SCM | Supply Chain Resource Cooperative (SCRC) | North Carolina State University. URL https://scm.ncsu.edu/scm-articles/article/what-is-supply-chain-management.

[11] What is Operations Research? - School of Operations Research and Information Engineering - Cornell Engineering. URL http://www.orie.cornell.edu/about/whatis.cfm.

[12] A. Bozorgi-Amiri and M. Khorsi. A dynamic multi-objective location routing model for relief logistic planning under uncertainty on demand, travel time, and cost parameters. *The International Journal of Advanced Manufacturing Technology*, 2015. ISSN 0268-3768. doi: 10.1007/s00170-015-7923-3. URL http://link.springer.com/10.1007/s00170-015-7923-3.

[13] N. Kunz. A meta-analysis of humanitarian logistics research. *Journal of Humanitarian Logistics and Supply Chain Management*, 2(2):116–147, 2012. ISSN 2042-6747. doi: 10.1108/20426741211260723.

[14] X. Li, Z. Zhao, X. Zhu, and T. Wyatt. Covering models and optimization techniques for emergency response facility location and planning: a review. *Mathematical Methods of Operations Research*, 74(3):281–310, 2011. ISSN 1432-2994. doi: 10.1007/s00186-011-0363-4. URL http://link.springer.com/10.1007/s00186-011-0363-4.

[15] M. Caunhye, X. Nie, and S. Pokharel. Optimization models in emergency logistics: A literature review. *Socio-Economic Planning Sciences*, 46(1):4–13, 2012. ISSN 00380121. doi: 10.1016/j.seps.2011.04.004. URL http://dx.doi.org/10.1016/j.seps.2011.04.004.

[16] V. Wassenhove, N. Luk, M. Pedraza, and J. Alfonso. Using OR to adapt supply chain management best practices to humanitarian logistics. *International Transactions in Operational Research*, 19(1-2):307–322, 2012. ISSN 09696016. doi: 10.1111/j.1475-3995.2010.00792.x. URL http://doi.wiley.com/10.1111/j.1475-3995.2010.00792.x.

[17] A. Bozorgi-Amiri, M. Jabalameli, M. Alinaghian, and M. Heydari. A modified particle swarm optimization for disaster relief logistics under uncertain environment. *The International Journal of Advanced Manufacturing Technology*, 60

(1-4):357–371, 2012. ISSN 0268-3768. doi: 10.1007/s00170-011-3596-8. URL `http://link.springer.com/10.1007/s00170-011-3596-8`.

[18] L. Wang, J. Song, and L. Shi. Dynamic emergency logistics planning: models and heuristic algorithm. *Optimization Letters*, 9(8):1533–1552, 2015. ISSN 1862-4472. doi: 10.1007/s11590-015-0853-z. URL `http://link.springer.com/10.1007/s11590-015-0853-z`.

[19] L. Ozdamar, E. Ekinci, and B. Kucukyazici. Emergency Logistics Planning in Natural Disasters. *Annals of Operations Research*, 129(1-4):217–245, 2004. doi: 10.1023/B:ANOR.0000030690.27939.39. URL `http://link.springer.com/10.1023/B:ANOR.0000030690.27939.39`.

[20] J. Kim S. Jin, S. Jeong and K. Kim. A logistics model for the transport of disaster victims with various injuries and survival probabilities. *Annals of Operations Research*, pages 1–17, 2014. ISSN 0254-5330. doi: 10.1007/s10479-013-1515-0.

[21] L. Ozdamar. Planning helicopter logistics in disaster relief. *OR Spectrum*, 33(3): 655–672, 2011. ISSN 01716468. doi: 10.1007/s00291-011-0259-y.

[22] A. Ben-Tal, M. Byung, R. Supreet, and T. Yao. Robust optimization for emergency logistics planning: Risk mitigation in humanitarian relief supply chains. *Transportation Research Part B: Methodological*, 45(8):1177–1189, 2011. ISSN 01912615. doi: 10.1016/j.trb.2010.09.002. URL `http://linkinghub.elsevier.com/retrieve/pii/S0191261510001050`.

[23] B. Vitoriano, M. Teresa, G. Tirado, and J. Montero. A multi-criteria optimization model for humanitarian aid distribution. *Journal of Global Optimization*, 51(2): 189–208, 2011. ISSN 0925-5001, 1573-2916. doi: 10.1007/s10898-010-9603-z.

[24] F. Barzinpour and V. Esmaeili. A multi-objective relief chain location distribution model for urban disaster management. *The International Journal of Advanced Manufacturing Technology*, 70(5-8):1291–1302, 2014. doi: 10.1007/s00170-013-5379-x. URL `http://link.springer.com/10.1007/s00170-013-5379-x`.

[25] A. Bozorgi-Amiri, M. Jabalameli, and A. Mirzapour. A multi-objective robust stochastic programming model for disaster relief logistics under uncertainty. *OR Spectrum*, 35(4):905–933, 2013. ISSN 0171-6468. doi: 10.1007/s00291-011-0268-x. URL `http://link.springer.com/10.1007/s00291-011-0268-x`.

[26] J. Sheu. Dynamic relief-demand management for emergency logistics operations under large-scale disasters. *Transportation Research Part E: Logistics and Transportation ReviewSheu, J. B. (2010). Dynamic relief-demand management for emergency logistics operations under large-scale disasters. Transportation Research Part E: Logistics and Transportation Review. do*, 46(1):1–17, 2010. ISSN 13665545. doi: 10.1016/j.tre.2009.07.005. URL `http://dx.doi.org/10.1016/j.tre.2009.07.005`.

[27] Z. Hu. Multi-Objective Optimization Model for Emergency Logistics Distribution with Multiple Supply Points and Multiple Resource Categories. 2010.

[28] A. Doyen, N. Aras, and G. Barbarosoglu. A two-echelon stochastic facility location model for humanitarian relief logistics. *Optimization Letters*, 6(6):1123–1145, 2012. ISSN 1862-4472. doi: 10.1007/s11590-011-0421-0. URL `http://link.springer.com/10.1007/s11590-011-0421-0`.

[29] J. Sheu. An emergency logistics distribution approach for quick response to urgent relief demand in disasters. *Transportation Research Part E: Logistics and Transportation Review*, 43(6):687–709, 2007. ISSN 13665545. doi: 10.1016/j.tre.2006.04.004. URL `http://linkinghub.elsevier.com/retrieve/pii/S1366554507000191`.

[30] B. Adivar and A. Mert. International disaster relief planning with fuzzy credibility. *Fuzzy Optimization and Decision Making*, 9(4):413–433, 2010. ISSN 15684539. doi: 10.1007/s10700-010-9088-8.

[31] D. Ozkapici. Intermodal Humanitarian Logistics Model Based on Maritime Transportation in Istanbul Intermodal Humanitarian Logistics Model Based on Maritime Transportation in Istanbul Abstract. 90(4), 2016.

[32] S. Baskaya, M. Ertem, and S. Duran. Pre-positioning of relief items in humanitarian logistics considering lateral transhipment opportunities. *Socio-Economic Planning Sciences*, 2016. ISSN 00380121. doi: 10.1016/j.seps.2016.09.001. URL `http://dx.doi.org/10.1016/j.seps.2016.09.001`.

[33] F. Kilci, B. Kara, and B. Bozkaya. Locating temporary shelter areas after an earthquake: A case for Turkey. *European Journal of Operational Research*, 243(1):323–332, 2015. ISSN 03772217. doi: 10.1016/j.ejor.2014.11.035.

[34] C. Renkli and S. Duran. Pre-Positioning Disaster Response Facilities and Relief Items. *Human and Ecological Risk Assessment: An International Journal*, 21(5): 1169–1185, 2015. ISSN 1080-7039. doi: 10.1080/10807039.2014.957940. URL `http://www.tandfonline.com/doi/abs/10.1080/10807039.2014.957940`.

[35] F. Salman. Emergency facility location under random network damage: Insights from the Istanbul case. *Computers and Operations Research*, 62:266–281, 2014. doi: 10.1016/j.cor.2014.07.015. URL `http://linkinghub.elsevier.com/retrieve/pii/S0305054814001981{%}5Cnhttp://dx.doi.org/10.1016/j.cor.2014.07.015`.

[36] N. Gormez, M. Koksalan, and F. Salman. Locating disaster response facilities in {Istanbul}. *J Oper Res Soc*, 62(7):1239–1252, 2011. ISSN 0160-5682. doi: 10.1057/jors.2010.67. URL `http://www.palgrave-journals.com/jors/journal/v62/n7/abs/jors201067a.html`.

[37] Logistics Dictionary, . URL `http://dictionary.reference.com/browse/logistics`.

[38] What is logistics? – A collection of Logistics Definitions from LogisticsWorld, . URL `http://www.logisticsworld.com/logistics.htm`.

[39] A. Thomas and L. Kopczak. From logistics to supply chain management: the path forward in the humanitarian sector. *Fritz Institute*, 2005.

[40] A. Cozzolino. *Humanitarian Logistics: Cross-Sector Cooperation in Disaster Relief Management*. Springer Berlin Heidelberg, 2012. ISBN 9783642301858.

[41] N. Altay and G. Walter. OR/MS research in disaster operations management. *European Journal of Operational Research*, 175(1):475–493, 2006. ISSN 03772217. doi: 10.1016/j.ejor.2005.05.016.

[42] Turkiye Afet Mudahale Plani - Planlar - AFAD. URL `https://www.afad.gov.tr/tr/2419/Turkiye-Afet-Mudahale-Plani`.

[43] Yandex Haritalar. URL `https://yandex.com.tr/harita`.

[44] Google Haritalar. URL `https://www.google.com.tr/maps?source=tldsi&hl=tr`.

[45] Turkiye Istatistik Kurumu Web sayfasi. URL `http://www.tuik.gov.tr`.

[46] GDXXRW. URL http://www.gams.com/latest/docs/tools/gdxxrw/index.html.

[47] GLPK - GNU Project - Free Software Foundation (FSF). URL http://www.gnu.org/software/glpk/.

[48] FICO® Xpress Optimization Suite. URL http://www.fico.com/en/products/fico-xpress-optimization-suite{#}overview.