AN INTERMODAL HUMANITARIAN LOGISTICS MODEL BASED ON MARITIME TRANSPORTATION FOR RELIEF ITEM DISTRIBUTION IN İSTANBUL

DİLSU BİNNAZ ÖZKAPICI

JANUARY 2015

To my father…

AN INTERMODAL HUMANITARIAN LOGISTICS MODEL BASED ON MARITIME TRANSPORTATION FOR RELIEF ITEM DISTRIBUTION IN İSTANBUL

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DİLSU BİNNAZ ÖZKAPICI**

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Title of the Thesis: **An Intermodal Humanitarian Logistics Model Based On Maritime Transportation for Relief Item Distribution in İstanbul.**

Submitted by **Dilsu Binnaz ÖZKAPICI**

Approval of the Graduate School of Natural and Applied Sciences, Çankaya University.

Prof. Dr. Taner ALTUNOK
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Fetih YILDIRIM
Head of Department

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.

Assist. Prof. Dr. M. Alp ERTEM
Supervisor

Assist. Prof. Dr. Haluk AYGÜNEŞ
Co-supervisor

Examination Date: 20.01.2015
Examining Committee Members

Assoc. Prof. Dr. Serhan DURAN

Assist. Prof. Dr. Mustafa Alp ERTEM

Assist. Prof. Dr. Haluk AYGÜNEŞ

Assist. Prof. Dr. Gonca YILDIRIM

Assoc. Prof. Dr. Hadi Hakan MARAŞ

STATEMENT OF NON-PLAGIARISM PAGE

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name	:	Dilsu Binnaz, ÖZKAPICI
Signature	:	
Date	:	20.01.2015

ABSTRACT

AN INTERMODAL HUMANITARIAN LOGISTICS MODEL BASED ON MARITIME TRANSPORTATION FOR RELIEF ITEM DISTRIBUTION IN İSTANBUL

ÖZKAPICI, Dilsu Binnaz
M.Sc., Department of Industrial Engineering
Supervisor: Assist. Prof. Dr. Mustafa Alp ERTEM
Co-Supervisor: Assist. Prof. Dr. Haluk AYGÜNEŞ

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İstanbul is the most populated city and economic capital of Turkey and it is highly prone to earthquakes. In case of an earthquake, relief items will be supplied from national and international sources. Previous studies have not considered Bosporus strait which divides the city in two sides and the opportunities of maritime transportation for relief item distribution in İstanbul. In this study, an intermodal relief item distribution model for İstanbul involving sea and land transportation with vulnerabilities is proposed to alleviate the suffering of people in case of an earthquake. The proposed mathematical model utilizes efficiently seaports of İstanbul and maritime transportation, and it allows relief item transportation between the European and Anatolian sides. Sea-basing concept is also used for providing supply to the demand areas. Nationally - and internationally- supplied relief items are transported from the supply points (i.e., Port of Haydarpaşa, Port of Ambarlı, and a container ship located at the Sea of Marmara) to the demand areas (i.e., to the districts of İstanbul) directly by utilizing highways. Alternatively, relief items are transported firstly by maritime transportation to the seaports of İstanbul, and then, from the seaports to the districts by highways. Different scenarios based on the available amounts at the supply points are run, and the results are examined in terms of three performance measures: (1) average transportation time per unit relief item, (2) maritime transportation percentage, and (3) the number of ships used to transport relief items. Furthermore, an analysis on supply distribution proportions for the European and Anatolian sides is conducted and a comparison is done with an alternative relief distribution model which utilizes only land transportation. It is seen that benefiting from maritime transportation and sea-basing provides flexibility for humanitarian logistics activities, and the model proposed leads to an effective and reliable disaster relief system for İstanbul.

Keywords: Humanitarian Logistics, Disaster Relief, Intermodal Transportation, Maritime Transportation, Seaports, Sea-Basing.

ÖZ

İSTANBUL'DA YARDIM MALZEMESİ DAĞITIMI İÇİN DENİZYOLU ULAŞIMINA DAYALI İNTERMODAL BİR İNSANİ YARDIM LOJİSTİĞİ MODELİ

ÖZKAPICI, Dilsu Binnaz
Yüksek Lisans, Endüstri Mühendisliği Anabilim Dalı
Tez Yöneticisi: Yrd. Doç. Dr. Mustafa Alp ERTEM
Ortak Tez Yöneticisi: Yrd. Doç. Dr. Haluk AYGÜNEŞ

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İstanbul Türkiye'nin ekonomi başkenti ve en kalabalık şehri olup, deprem riski yüksektir. Bir deprem durumunda uluslararası ve ulusal kaynaklardan yardım malzemeleri tedarik edilecektir. Daha önceki çalışmalar, yardım malzemelerinin dağıtımı için, şehri ikiye bölen Boğaz'ı ve İstanbul'da deniz yolu ulaşımının avantajlarını göz önüne almamıştır. Bu çalışmada, İstanbul için, bir deprem durumunda insanların zararlarını azaltmak amacıyla deniz ve karayolu ulaşımını içeren ve bu yolların hasar görebilirlik olasılıklarını da göz önünde bulunduran intermodal bir yardım malzemesi dağıtım modeli geliştirilmiştir. Önerilen matematiksel model denizyolu ulaşımından ve İstanbul'un limanlarından etkin bir biçimde yararlanmakta ve Avrupa ve Anadolu yakaları arasında yardım malzemesi ulaşımına izin vermektedir. Talep noktalarına yardım malzemesi sağlamak için denizde-üs kavramı da kullanılmaktadır. Yerel ve uluslararası kaynaklardan tedarik edilen yardım malzemeleri, ana tedarik noktalarından (Haydarpaşa Limanı, Ambarlı Limanı ve Marmara Denizi'ne yerleştirilmiş bir konteyner gemisinden) doğrudan karayoluyla talep noktalarına (İstanbul'un ilçelerine) taşınmaktadır. Alternatif olarak, yardım malzemeleri denizyoluyla İstanbul'un limanlarına ve daha sonrasında karayoluyla limanlardan ilçelere taşınmaktadır. Tedarik noktalarında mevcut yardım malzemesi miktarına göre değişen çeşitli senaryolar çalıştırılmıştır ve sonuçlar üç performans ölçümü açısından incelenmiştir: (1) bir adet yardım malzemesini taşımak için gerekli ortalama süre, (2) intermodal taşıma yüzdesi ve (3) kullanılan gemi sayısı. Ayrıca, Avrupa ve Anadolu yakaları için tedarik dağılımı oranları üzerine bir analiz ve yalnızca karayolu ulaşımından yararlanan alternatif bir yardım malzemesi dağıtım modeliyle karşılaştırma yapılmıştır. Denizyolu ulaşımı ve denizde-üs kavramlarından yararlanılmasının insani yardım faaliyetlerinde esneklik sağladığı ve önerilen modelin İstanbul için etkili ve güvenilir bir afet yardımı sistemi oluşturduğu görülmüştür.

Anahtar Kelimeler: İnsani Yardım Lojistiği, Afet Yardımı, İntermodal Taşımacılık, Denizyoluyla Taşımacılık, Limanlar, Denizde-Üs.

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LIST OF ABBREVIATIONS

IFRC	International Federation of Red Cross and Red Crescent Societies
EM-DAT	Emergency Events Database
JICA	Japan International Cooperation Agency
IMM	İstanbul Metropolitan Municipality
DEMP	Turkish Disaster and Emergency Management Presidency
MFA	Ministry of Foreign Affairs of Turkey
TRC	Turkish Red Crescent
EADRCC	Euro-Atlantic Disaster Response Coordination Centre
ECHO-MIC	European Civil Protection Mechanism Monitoring and Information Centre
UN-OCHA	United Nations Office for the Coordination of Humanitarian Affairs
TCDD	Turkish State Railways
İDO	İstanbul Deniz Otobüsleri

CHAPTER 1

INTRODUCTION

Each year thousands of people are killed and millions of people are affected by natural and man-made disasters. Pre- and post-disaster activities are very important for saving lives of thousands of people and for providing relief to the affected people. The focus of this study is developing a mathematical model delivering relief items to people in need during the post-disaster activities in İstanbul, the most populated city and economic capital of Turkey and which is under high earthquake risk.

International Federation of Red Cross and Red Crescent Societies (IFRC) defines disaster as "a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community's or society's ability to cope using its own resources" [1]. According to Emergency Events Database (EM-DAT) a disaster is "a situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance" [2]. EM-DAT states that a disaster enters the database only if the following conditions hold:

- Ten (10) or more people reported killed.
- Hundred (100) or more people reported affected.
- Declaration of a state of emergency.
- Call for international assistance. [3]

Disasters are classified as natural or man-made and sudden-onset or slow-onset by Van Wassenhove as shown in Table 1 [4]. As it can be seen from Table 1, instantly man-made disasters are technological disasters, etc. Natural disasters such as famine and man-made disasters such as political crisis which develop in time fall into the category of slow-onset disasters.

Table 1 Disaster Classifications.

	Natural	Man-made
Sudden-onset	Earthquake Hurricane Tornadoes	Terrorist Attack Coup d'Etat Chemical Leak
Slow-onset	Famine Drought Poverty	Political Crisis Refugee Crisis

Delivering assistance to the victims of emergencies is a vital and very challenging work. At this point, humanitarian logistics concept comes to the fore. Fritz Institute, a nonprofit humanitarian assistance organization, defines humanitarian logistics as "Humanitarian Logistics refers to the processes and systems involved in mobilizing people, resources, skills and knowledge to help vulnerable people affected by natural disasters and complex emergencies" [5]. In recent years, after disasters which ended up in tragic losses, a great emphasis has been placed on disaster relief studies both in practice and academics.

Turkey is a country prone to natural disasters, especially earthquakes, being located on the Alpine-Himalayan seismic belt, one of the major seismic belts. As it can be seen from Table 2 taken from EM-DAT website, the most destructive natural disasters in terms of number of people killed, number of people affected and financial harm happened in Turkey between 1900 and 2014 are earthquakes [6].

Table 2 Natural Disasters in Turkey Between 1900 and 2014.

Disaster	# of Events	Killed	Total Affected	Damage (000US$)
Earthquake (seismic activity)	76	89,236	6,924,005	24,685,400
Epidemic				
Bacterial Infectious Diseases	1	11	150	-
Parasitic Infectious Diseases	2	-	1,000,000	-
Viral Infectious Diseases	5	602	104,705	-
Extreme temperature				
Cold wave	3	69	-	-
Extreme winter conditions	2	17	8,150	-
Heat wave	2	14	300	1,000
Flood				
Unspecified	11	897	372,617	65,000
Flash flood	10	243	1,341,382	1,892,000
General flood	18	202	64,521	238,500
Mass movement dry				
Avalanche	1	261	1,069	-
Mass movement wet				
Avalanche	2	146	6	-
Landslide	10	293	13,481	26,000
Storm				
Unspecified	4	49	3	-
Local storm	5	51	13,636	2,200
Wildfire				
Forest fire	5	15	1,150	-

17 August 1999 Earthquake of magnitude 7.4 hit the Marmara Region, which is the most industrialized region of Turkey, causing 17,479 people to be killed, 43,953 people to be injured and thousands of buildings to be damaged. In the city of İstanbul also a major loss of life and property occurred by 1999 Earthquake; 981 people were killed, 7,204 people were injured, 3,073 domiciles and 532 working places were badly damaged, and thousands of others had moderate damage [7].

After the 1999 Earthquake, many studies searching for ways to prevent İstanbul from the same destructive effects in case of another earthquake, which is highly probable, have been done by academics (Parsons et al. [8], Özdamar et al.[9] , Görmez et al. [10], Salman and Gül [11]) and also by governmental institutions (JICA [12]).

Likewise, this thesis aspires after contributing to the efforts of establishing an earthquake-resilient İstanbul.

İstanbul bestrides the Bosporus, the waterway which connects the Sea of Marmara and the Black Sea. It is a two-sided, transcontinental city; on the right of the Bosporus (on Asia) lies the Anatolian Side and on the left of the Bosporus (on Europe) lies the European side. Thanks to this geographical location, waterway transport plays an important role to provide the access between the two sides of the city. Therefore, there are many seaports located on both sides of the Bosporus and maritime transportation between these ports is a daily routine. The idea and motivation behind this study originated from taking advantage of this special geography and converting daily routine of transporting people to transporting relief items in case of a disaster, particularly an earthquake.

In the final report of the study of preparing a disaster prevention/ mitigation basic plan in İstanbul by Japan International Cooperation Agency (JICA) and Istanbul Metropolitan Municipality (IMM) [12], advantages of İstanbul for having many seaports are explained. In this report also, it is stated that as well as maritime transportation plays a very important role for movement of people and goods in daily life in İstanbul, it is necessary to take advantage of maritime transportation in case of a disaster. It is emphasized that using seaway and highway together effectively for transportation of people and relief items and also debris would certainly do a major positive effect on humanitarian relief efforts. It is pronounced that:

> "… an alliance between road and marine traffic is important for relief of concentrated road traffic, better transportation of relief supplies, and the transportation of disaster waste. From this point of view, it is necessary to develop harbor facilities, which can be responsible for transportation of goods, and roads leading to the harbors, based on a well-planned schedule. Harbor facilities, which are bases for marine traffic, are also effective as disaster prevention centers" [12].

Several benefits of utilizing seaway for relief item transportation are;

- Massive amounts of relief materials can be transported at a time
- When compared to highways, risk of collapse is very small for seaways. Therefore, even maritime transportation is considered much slower than land transportation, in case of disasters this situation can

be considered as reversed. Because, in case of a disaster there is much more risk of destruction or blockage etc. for highways, and speed of the land vehicles is lower than the daily routines.

- Using maritime transportation is safer in case of disasters again for the reason of being much less vulnerable to the effects of disasters. Therefore, maritime transportation is more reliable when compared to land transportation in times of emergencies.
- Utilizing sea transportation is much cheaper than land transportation because of economies of scale.

In this study, intermodal transportation is utilized for distribution of relief items arriving from national and international sources (i.e. international non-governmental organizations and foreign governments) and seaports are used with the purpose of transhipment of relief materials transported by seaway to highway. Intermodal transportation can be defined as: “the transportation of a person or a load from its origin to its destination by a sequence of at least two transportation modes, the transfer from one mode to the next being performed at an intermodal terminal” [13]. The transportation modes used in this study are maritime transportation and land transportation.

In case of another earthquake in İstanbul of a destructive magnitude similar to the one of 1999, a severe number of disaster victims is expected due to high population. Therefore, a call for international humanitarian assistance is likely to be realized. The coordination of international humanitarian assistance is a challenging work. An analysis for Turkey on coordination of humanitarian relief support activities provided by international actors was conducted by Özkapıcı et al. In their study, it is presented that Turkey called for international humanitarian assistance after the 7.2 magnitude earthquake hit the eastern province Van of the country on 23 October, 2011. The main institutions in Turkey that were involved in the coordination of international humanitarian relief support activities were Turkish Disaster and Emergency Management Presidency (DEMP), Ministry of Foreign Affairs of Turkey (MFA) and Turkish Red Crescent (TRC). DEMP was the authorized institution to accept humanitarian aid offers coming from foreign countries. MFA was the responsible institution for communication between foreign countries and DEMP.

Assistance offers coming from foreign countries directly or via international organizations, such as Euro-Atlantic Disaster Response Coordination Centre (EADRCC), European Civil Protection Mechanism Monitoring and Information Centre (ECHO-MIC) and United Nations Office for the Coordination of Humanitarian Affairs (UN-OCHA) were transmitted to DEMP by MFA to get approval for acceptance. TRC was in direct contact with IFRC, and decisions on offers coming via IFRC were taken by TRC. Although the inclusion of different international agencies working on similar purposes increased the complexity of international humanitarian relief support coordination, relevant Turkish authorities successfully managed the coordination activities. General structure of coordination of humanitarian relief support activities provided by international actors is given in Figure 1 [14].

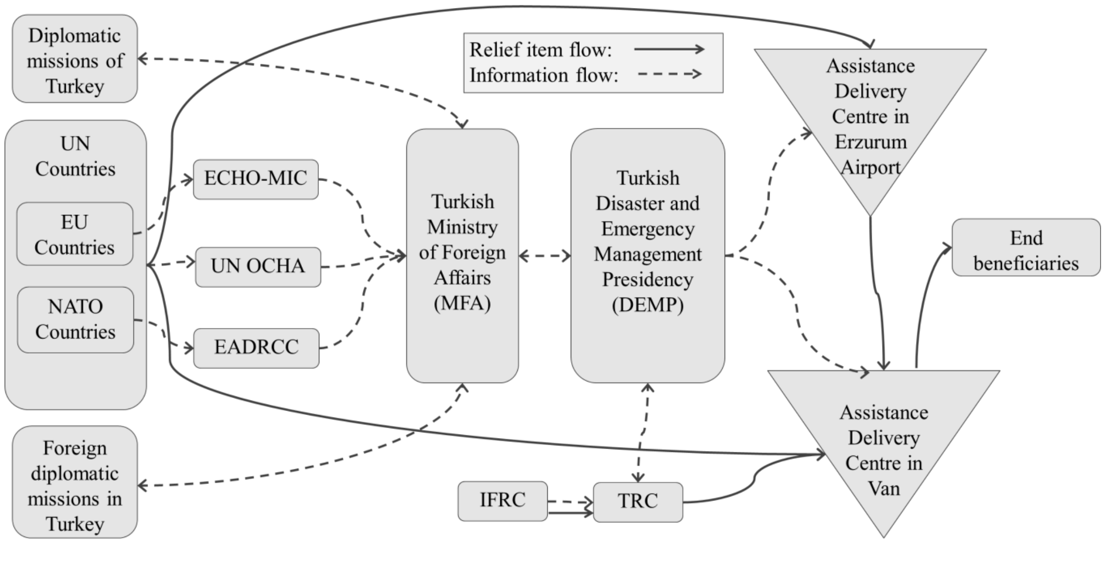

Figure 1 Coordination of humanitarian relief support provided by international actors.

The aim of this thesis is to propose a solution for transportation of relief items nationally and internationally supplied in case of an earthquake in İstanbul. For this purpose, an intermodal mathematical model is developed that takes advantage of ports and seaways of İstanbul and the Bosporus, which allows relief item transportation between the Anatolian and European sides and also considers vulnerability effect on travel times. Although there are relatively many studies on distribution of relief items in case of a disaster in İstanbul, to the best of the author's knowledge, there is no study which aims to take advantage of using maritime transportation in İstanbul. Main contribution of this study to the humanitarian logistics literature is that, it considers utilization of seaports and maritime transportation as well as land transportation for distribution of relief items. Another significant contribution is that, sea-basing concept is utilized for disaster relief activities in İstanbul by locating an international containership at the Sea of Marmara as one of the main sources of supply. Capacitated ships and land vehicles are used for relief item distribution. The objective of the mathematical model proposed is to minimize total transportation time of relief items to the demand areas. The effect of vulnerability on the roads and seaways after the disaster is reflected to the objective function; i.e., total transportation time of relief items.

The rest of the study is organized as follows: In Chapter 2, academic work related to the study is reviewed. In Chapter 3, characteristics of the problem on hand are defined. In Chapter 4, the mathematical model developed for the sea-based intermodal relief distribution network is introduced. In Chapter 5, experimental study is given. In Chapter 6, concluding remarks and suggestions on future research are pointed out.

CHAPTER 2

LITERATURE REVIEW

Van Wassenhove classifies disasters as natural or man-made and sudden-onset or slow-onset [4], while Duran et al. categorize disasters from three aspects: source, location and speed of onset, which is depicted in Figure 2 [15].

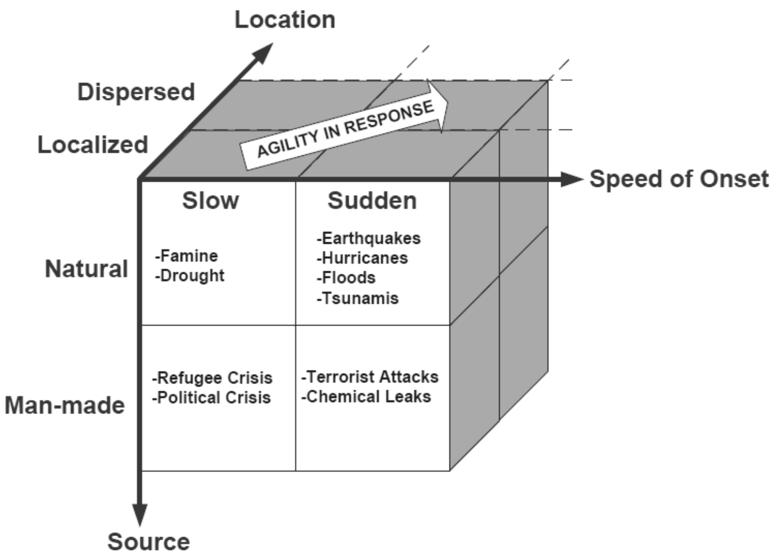

Figure 2 Classification of disasters.

As disasters of all kinds affect lives of millions of people continuously, response to disasters and disaster management is a vital issue for a better world. In Duran et al., disaster management is defined as “the whole of the operations aiming to prevent / reduce injuries, fatalities, and damage worth and to facilitate recovery from the onset of a disaster” [15]. Altay and Green refer to disaster management in terms of four phases which are mitigation, preparedness, response and recovery [16]; these phases are also referred in literature as “life cycle of a disaster”.

In disaster management literature, mitigation can be considered as the “prevention” phase and generally defined as any activities to prevent any future disasters and reducing hazardous effects of unavoidable disasters. Mitigation activities take place before and after a disaster. For instance, conducting earthquake drills in schools is a mitigation activity. Preparedness includes plans and preparations to handle an emergency. Relief item pre-positioning is an example of the preparedness activities. Preparedness activities occur before the emergency. Response to an emergency is implementing the plans prepared in the preparedness phase such as transportation of relief items to the people affected by the disaster. Response phase includes activities after the disaster. Finally, recovery phase activities are efforts to turn back to the normal or a better situation after the disaster. Debris removal can be considered as a recovery phase activity. Recovery activities are post-disaster actions. As indicated in Baird, the four phases of disaster management are considered as elements of a continuous process as depicted in Figure 3 [17].

Figure 3 Phases of disaster management.

Relief operations conducted in each phase of the disaster management is presented in Figure 4 [15]. As in Figure 4, planning the network for the delivery of relief items fall into the phase of preparedness while mobilizing relief items is a response phase activity. Therefore, this study focuses on preparedness and response phases of disaster management.

Figure 4 Operations in the phases of disaster management.

Humanitarian logistics constitutes a significant portion of efforts in disaster management [15]. The definition for humanitarian logistics given by Thomas and Mizushima is one of the most acknowledged definitions in humanitarian logistics world: Humanitarian logistics is;

> "The process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials as well as related information, from the point of origin to the point of consumption for the purpose of meeting the end beneficiary's requirements" [18].

In Van Wassenhove, the complex environment of humanitarian logistics which differentiates it from traditional (commercial) logistics concept is emphasized. Humanitarian logistics is more complex because it features continuously changing factors such as complicated operating conditions, delicate political environment in some cases, uncertainty in demand and supply, time pressure, high staff turnover, plenty number of different stakeholders, need for transparency, unsolicited donations, role of the media. However, again the main principle for traditional logistics remains the same for humanitarian logistics: "getting the right goods, at the right time, to the right place and to the right people" [4].

Although disasters and effort to help people in need because of disasters are as old as humanity, both practically and theoretically, research and studies on humanitarian logistics have been concentrated on in fairly recent years. Studies in humanitarian logistics field can be dated back to 1980s, intensifying gradually after 2000s. Altay & Green state that 109 articles were published between 1980 and 2004 on humanitarian logistics field, whilst more than 46% of these articles was published after 2000 [16]. Also, 2004 Indian Ocean Tsunami, which affected 2.5 million in 12 countries and killed 226.408 people [15], was a cornerstone for realizing the significance of logistics in humanitarian relief efforts, as indicated by Van Wassenhove: "… what the Indian Ocean Tsunami has done is to move logistics to centre stage" [4].

Haghani and Oh state that;

> "The basic underlying logistical problem for disaster relief management is to move a number of different commodities using a number of different modes of transportation, from a number of origins to one or more destinations over a transportation network in a timely manner effectively and efficiently" [19].

In this thesis, in accordance with the thesis subject, main focus of the literature survey is delivery of relief items to those in need, in other words, to the end beneficiaries. One of the first studies on disaster relief transportation was by Knott with a routing model developed in 1987, which was a single-commodity, single modal network flow problem with the objective of minimizing transportation cost [20].

Haghani and Oh present a multi-commodity, multi-modal network flow mixed integer programming model which aims to minimize total logistics cost. The authors emphasize that, their study differs from the previous ones in the sense that their model allows transportation mode change and proposes more detailed routing and scheduling [19]. Barbarasoğlu and Arda (2004) also develop a similar model but with considering uncertainty in different parameters of the model, such as demand and vulnerability of the arcs [21].

Özdamar et. al. propose a hybrid model and which combines multi-period, multi-commodity network flow problem and multi-period, multi-modal vehicle routing problem with the objective of minimizing amount of unsatisfied demand. Their study differentiate from the previous studies by its characteristics of being a hybrid of the two sub-problems [9]. In the article, although marine transportation is considered as a mode of transportation theoretically, in the application of the model it is not included.

Balçık et al. present a last mile distribution problem, in which, in the last step of relief item delivery, relief items are delivered from depots (local distribution centers) to the end beneficiaries by a mixed integer programming model, allocating relief items to the demand locations and deciding routing of the delivery vehicles. Their model aims to minimize maximum unsatisfied demand percentage. The authors emphasize that their study has different aspects from the previous studies on last mile distribution by taking into account that relief items can have different demand characteristics and interrelates vitality of the relief items with the vulnerability of the population [22].

Huang et al. investigate the impact of performance measures on last mile distribution problem decisions that are determining routing of the vehicles and determining number of relief items dispatched. In their study, the performance measures are efficiency in terms of costs, efficacy in terms of meeting the objective of delivering relief items in time and equity in terms of achieving that all end beneficiaries are delivered equal humanitarian relief. A specific last mile distribution problem model is developed in the article whose objective function is modified according to the three performance metrics. Hence, the generalized model is solved with three different objective functions to measure the effect of the three performance metrics. The authors conclude that there is a remarkable variation in the results when the problem is solved with the objectives taking into account efficacy, equity and efficiency [23]. The article is considered as a distinguished study as it combines performance measurement in humanitarian logistics and relief item distribution. In addition, the study can be considered as one of the studies which meet the lack of inclusion of ethical factors that was stated by Altay and Green such as equity in humanitarian logistics research [16]; as also pointed out by Galindo and Batta [24] for Balçık et al.

de la Torre et al. present a literature survey on disaster relief routing models in humanitarian logistics concept. In the article, relief distribution literature is reviewed and distribution models, which take into account relief item delivery by air, are considered as specialized type relief models [20]. It can be commented that relief item delivery by means of marine transportation, which would certainly be a specialized type model, was not studied before. The authors also state that in the models developed by Clark and Culkin, Tzeng et al. and Zhu et al. routes that individual vehicles follow are not tracked and decision variables are number of vehicles making deliveries and quantity of items delivered, which are also the decision variables in the model studied in this thesis. These types of models are described by de la Torre et al. as models with less operational detail and more strategic-level [20].

Although there are quite a few humanitarian logistics studies on intermodal transportation of relief materials, studies which take into account maritime transportation as part of the process are not frequent at all. Some of the relevant studies are analysed in the following paragraphs.

In Section 9.7 “Port and Harbours” of JICA-IMM Final Report [12], roles of ports in emergency management is explained. Firstly, it is stated that there are many small and large ports in İstanbul due to its geographical conditions and these ports, as well as they constitute an important part of people and goods traffic under normal conditions, in case of an disaster when land transportation is frozen, they should carry out vital roles such as storage and transportation of relief items and debris, providing shelter etc. It is emphasized that ports have many features which make them supreme emergency management centres as sea transportation is much less vulnerable to disasters such as earthquakes and large amounts of materials can be transported by ships.

In the report, the major idea of this thesis, which is building a network that includes cooperation of land and sea transportation by utilizing ports of İstanbul and connected roads, is also promoted strongly. The report emphasizes that there are large ports on both sides of the Bosporus as well on the coast of the Golden Horn Inlet and Marmara Sea and remarks that:

> “…it is thought that more effective disaster prevention measures can be achieved through cooperation among harbour facilities in times of emergency, as well as

> through the proper maintenance of the individual disaster prevention bases. The network formed by small and large harbour facilities in times of emergency makes it possible to implement properly organized relief activities. Such activities include the transportation of debris and restoration materials by large ships and that of miscellaneous goods by small ships, so that a comparatively smooth transportation of goods to urban districts can be secured even in an emergency" [12].

Also, Haydarpaşa Port and its surrounding areas are suggested as primary disaster management centres as they have facilities for handling of containers is connected to important roads. Figure 9.7.1 of the report illustrates the primary and secondary ports-roads network suggested by the study and it is shown in Figure A.1 in Appendix A.

Tatham and Kovacs introduce a possible application of the military "sea-basing concept" to humanitarian logistics in rapid-onset natural disasters which locates a "floating warehouse", a ship in which relief items are stocked, near the high probable risk area for disaster. The authors discuss advantages of sea-basing over transporting relief items with airfreight considering the 2005 Pakistan earthquake. The study explains that sea-basing concept is broadly used in military activities, mostly for providing logistic support to military personnel at the initial stage of intervention in a conflict, and is applicable to humanitarian logistics to provide relief items to the disaster area. In the study, the ship is located in Singapore for some certain reasons, such as the strategic location of that country in South East Asia, minimum piracy danger and it has extensive capacity to offer support services to the ships as it is an important harbour. The ship is equipped with relief materials and personnel, and is able to sail to a chosen point in 24 hours, so that the ship sails to the closest port to the disaster area to deliver relief items. In the study, comparison of utilizing sea-basing and airfreight in terms of cost and volume delivered is done by using 2005 Pakistan earthquake as a base case for several scenarios. It is concluded that, transporting the same volume of relief materials by utilizing sea-basing concept takes half the time required for transporting by airfreight and at nearly half of the cost of airfreight. Besides, advantages and disadvantages of applying sea-basing concept in humanitarian logistics are discussed in the study. Main advantages are pointed out as flexibility of choosing disembarkation location and time, eluding the possibility of failure of using single location as the main delivery/disembarkation point and also being environmentally much cleaner than airfreight. The disadvantages are: it is more convenient to use in large scale disasters as a massive volume of relief items are delivered, a large relief item stock is kept which most probably invites cost and other issues related with stock, and also some bureaucratic problems may arise as it is not a common concept in humanitarian activities [25]. This study is considered by the author of this thesis as an inspiring effort for utilizing maritime transportation in humanitarian logistics. As a matter of fact, in this thesis also sea-basing concept is utilized as a second scenario for delivery of relief items.

Bemley et al. takes into account utilizing maritime transportation for disaster relief activities. Main concern of the article is to secure port recovery after a natural disaster such as a hurricane by repairing aids to navigation (ATONs), such as lighted/unlighted buoys and beacons, to keep the waterways safe. The authors propose a two-stage stochastic facility location model with the aim of maximizing the number of ATONs repaired to make a port totally functioning [26].

In the master thesis of Wilberg and Olafsen, a simulation model in Microsoft Excel is developed with the aim of adapting distribution network of a commercial logistics company to a relief item distribution network for humanitarian aid which utilizes sources of the company, such as vessels and ports/terminals. Supply chain of IFRC is taken as an example, in which there are three regional logistics units (RLU) from which relief materials are transported by airfreight to disaster areas. The main challenge of this kind of humanitarian supply chains is defined as not knowing the demand and location of the next disaster, which brings about the effort to set up a temporary supply chain for each disaster to transport relief materials from RLUs to disaster points. The study proposes to change this last part of humanitarian supply chain. It suggests that instead of prepositioning relief items at RLUs, they will be stocked at vessels and terminals of the commercial logistics company, and in case of a disaster, the vessels will be unloaded at the closest port of the company to the disaster area, and from there, relief items will be delivered to demand points again by using the company's resources. Hence, airfreight transportation will be replaced by maritime transportation for the delivery of relief items and also humanitarian supply chain will be much more agile as "floating warehouse" concept is utilized, the lead times will be shorter and also the logistics costs will be reduced when compared to the airfreight transportation [27].

Studies of Tatham and Kovacs [25] and of Wilberg and Olafsen [27] share a similar view with this thesis basically, as maritime transportation constitutes an important part of the supply chain and also in this thesis a similar idea to sea-basing concept is utilized as one of the scenarios.

Table 3 Main Characteristics of the Studies Reviewed.

	Min Cost	Min Unsatisfied Demand	Min Total Response Time	Stochastic Data	Multi-Commodity	Multi-Modal	Maritime transportation
Knott 1987		x					
Haghani and Oh 1996	x		x		x	x	
Barbarasoglu and Arda 2004	x			x	x	x	
Özdamar et al. 2004		x		x	x	x	
Balçık et al. 2008	x	x			x	x	
Huang et al. 2010	x		x				
Tatham and Kovacs 2007	x		x			x	x
Bemley et al. 2013				x		x	x
Wilberg and Olafsen 2012	x		x			x	x
Our study			x			x	x

Table 3 summarizes main characteristics of the studies reviewed in this thesis. As it can be seen in Table 3, although multi-modal relief distribution models are common, only in a few recent studies maritime transportation is included. Our study comes to the fore by using maritime transportation and sea-basing concept for distribution of relief items.

CHAPTER 3

PROBLEM DEFINITION

In this chapter, firstly problem environment and transportation network are described, then assumptions made in this study are given, and finally, data gathering methods and data are presented.

3.1 Problem Environment and Transportation Network

The problem studied in this thesis finds its place in the relief item transportation part of humanitarian logistics. A multi-modal mathematical model which allows transportation of relief items via land and sea is set up, with the purpose of meeting the demand in the districts of İstanbul. The major difference of this study from the previous works on transportation of relief items is that it utilizes seaway transportation as a main component of humanitarian logistics activities.

As İstanbul is a two-sided city divided by the Bosporus strait, it has many seaports on each side and daily maritime transportation habit between these ports can be transformed to relief item transportation between the ports and between the two sides in case of a disaster. Therefore, seaports of İstanbul are analysed with the purpose of making effective use of maritime transportation as well as road transportation for delivering relief items in case of an earthquake. Consequently, an intermodal distribution system which utilizes maritime and land transportation together is built using a mathematical model.

İstanbul has many seaports; however the most important two ports are Port of Haydarpaşa and Port of Ambarlı. Haydarpaşa is a Turkish State Railways (TCDD) port located in the Anatolian side of İstanbul, in the district of Kadıköy. It is one of the most important ports, not only of İstanbul, but also of Turkey. Haydarpaşa Port handles approximately 20% of the total containers handled in Turkey in TCDD port. Additionally, it was damaged slightly by 1999 Marmara Earthquake and port functions were not affected [12]. Port of Ambarlı is one of the biggest ports in Turkey and is located in the European side of İstanbul, in the district of Beylikdüzü. Ambarlı is a private investment port complex which is used jointly by seven terminals. Port of Haydarpaşa and Port of Ambarlı are considered as main supply points in our study as they are the most suitable ports in İstanbul to handle the amount of relief items coming from inland and abroad. They are referred as “main ports” throughout the thesis.

Application of sea-basing concept in humanitarian logistics was analysed conceptually. In this study also, sea-basing concept is utilized. A container ship is located on a certain point on the Sea of Marmara as a third supplier of relief items.

There are some reasons for the necessity of a third source. Firstly it would not be possible to utilize whole capacity of the ports of Haydarpaşa and Ambarlı. This can be due to the other activities continuing after the disaster. For example, before the earthquake, it is a high possibility that most of the capacities of the main ports would be utilized by commercial ships and many commercial activities would be going on. However, it is not very realistic to think these activities would be terminated and the main ports would be emptied as soon as the disaster strikes. The other main reason for the necessity of a third source is the main ports can be damaged because of the earthquake more than the assumed vulnerability foreseen and a significant portion of the capacity might not be serviceable.

The container ship is referred as the third source (3rd source) in the thesis. The main ports Haydarpaşa and Ambarlı and the container ship are named as “main sources” throughout the study.

The main waterway transport company in İstanbul is İstanbul Deniz Otobüsleri (İDO). In this thesis, İDO seaports of İstanbul are considered as transhipment points of relief items to the demand areas. There are 19 İDO seaports in İstanbul, 11 of which are on the Anatolian side: Harem, Kadıköy, Bostancı, Maltepe, Pendik, Kartal, Beykoz, Burgazada, Kınalıada, Heybeliada and Büyükada. Eight İDO seaports are on the European side which are Yenikapı, Bakırköy, Kabataş, İstinye, Sarıyer, Beşiktaş, Sirkeci and Avcılar.

The locations of İDO seaports are obtained from İDO website. Relative locations of the main sources and İDO seaports are illustrated in Figure 5 [28].

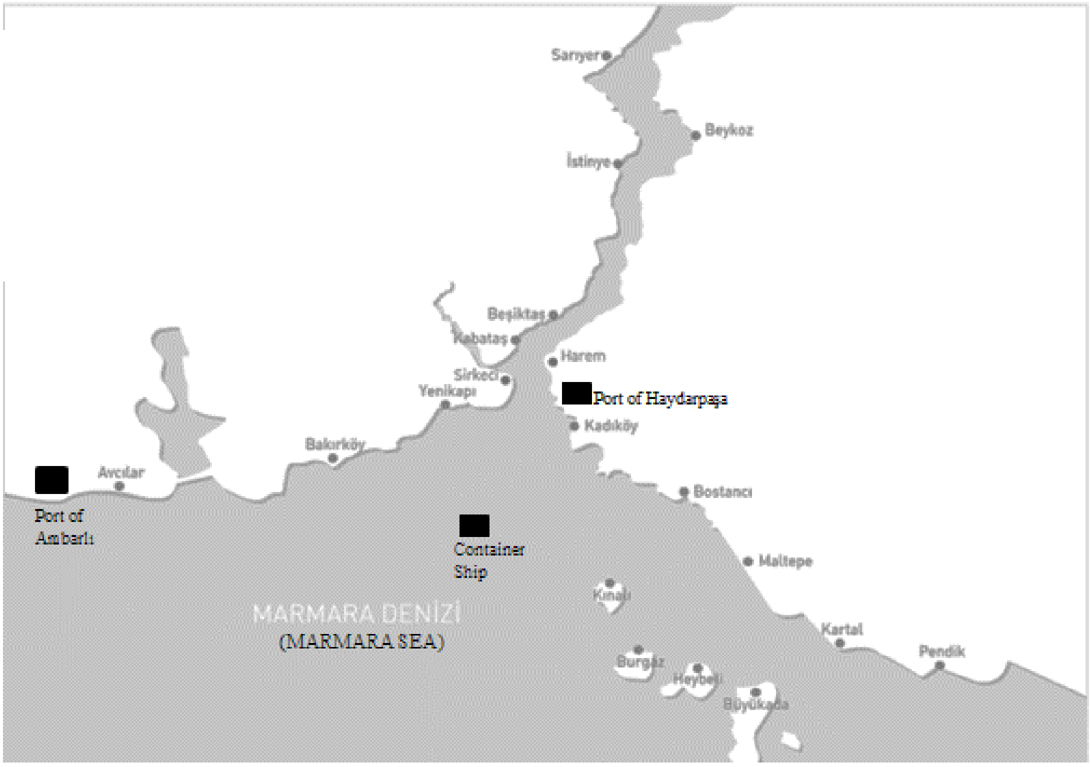

Figure 5 Locations of the main sources and İDO seaports.

The area that the container ship anchors is decided by taking into consideration distances to the İDO ports. To be able to place the ship at a point that is at a fair distance to both sides of İstanbul, on the map orthographic projection of the district centres, main ports and İDO ports are taken and the place of the ship is decided accordingly.

Demand areas are considered as districts of İstanbul. There are 39 districts of İstanbul, 14 on the Anatolian side and 25 on the European side. The map of the districts is illustrated in Figure 6 [29].

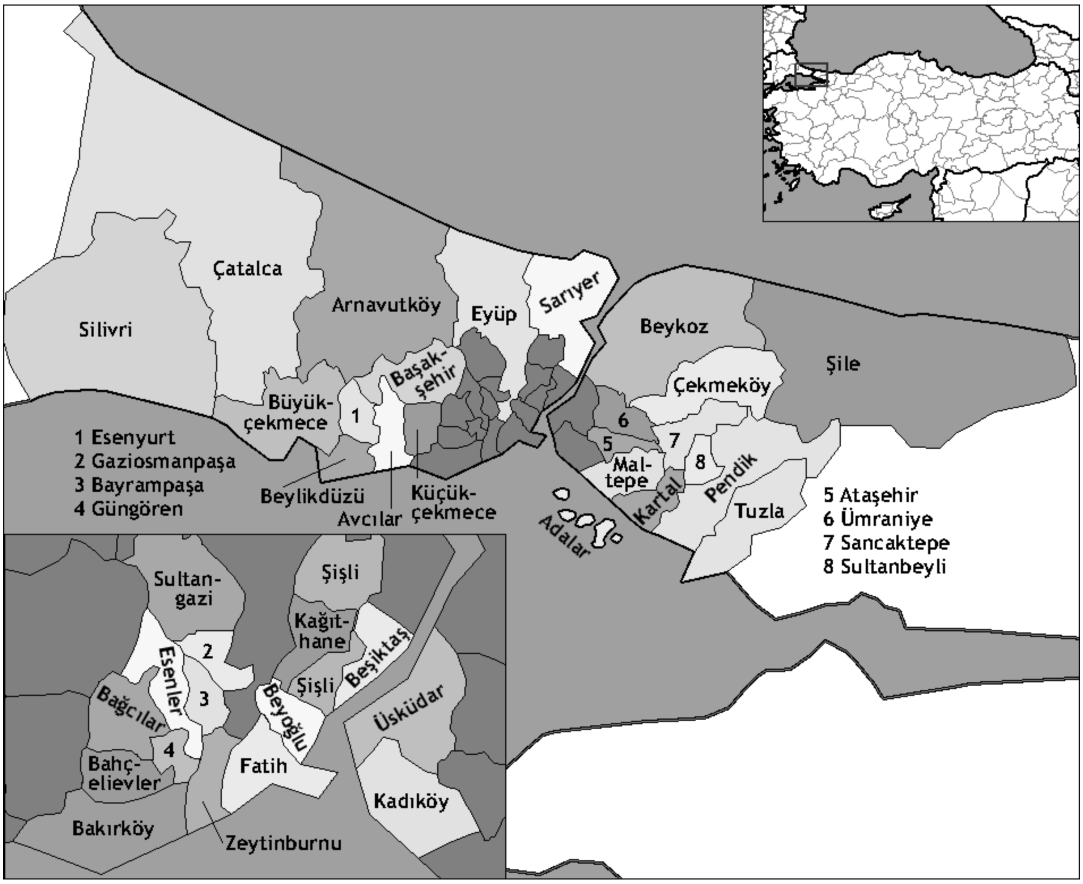

Figure 6 Map of the districts of İstanbul.

Relief item flow starts from the main sources. Humanitarian relief materials from sources abroad (international suppliers such as non-governmental relief organizations and foreign governments) and from sources within the country arrive at the main ports. From the main ports, relief materials can be delivered directly to the districts by land vehicles (i.e., via highways) or first to the İDO ports by ships (i.e., via seaway) and then from the İDO ports to the districts by land vehicles (i.e. via highways). From the container ship, relief items are sent to the İDO ports by maritime transportation, obviously, and from the İDO ports they are sent by land transportation to the districts. In our study, the main difference from traditional sea-basing concept is the containership does not sail to the İDO ports itself, as it is not possible for it to approach to the İDO ports and unload its freight for its size. The container ship's position is stable while smaller ships approach to it and are loaded with relief materials. After being loaded, smaller ships sail to the İDO ports to unload relief items. Figure 7 is a representative schema of the routes that relief materials can follow.

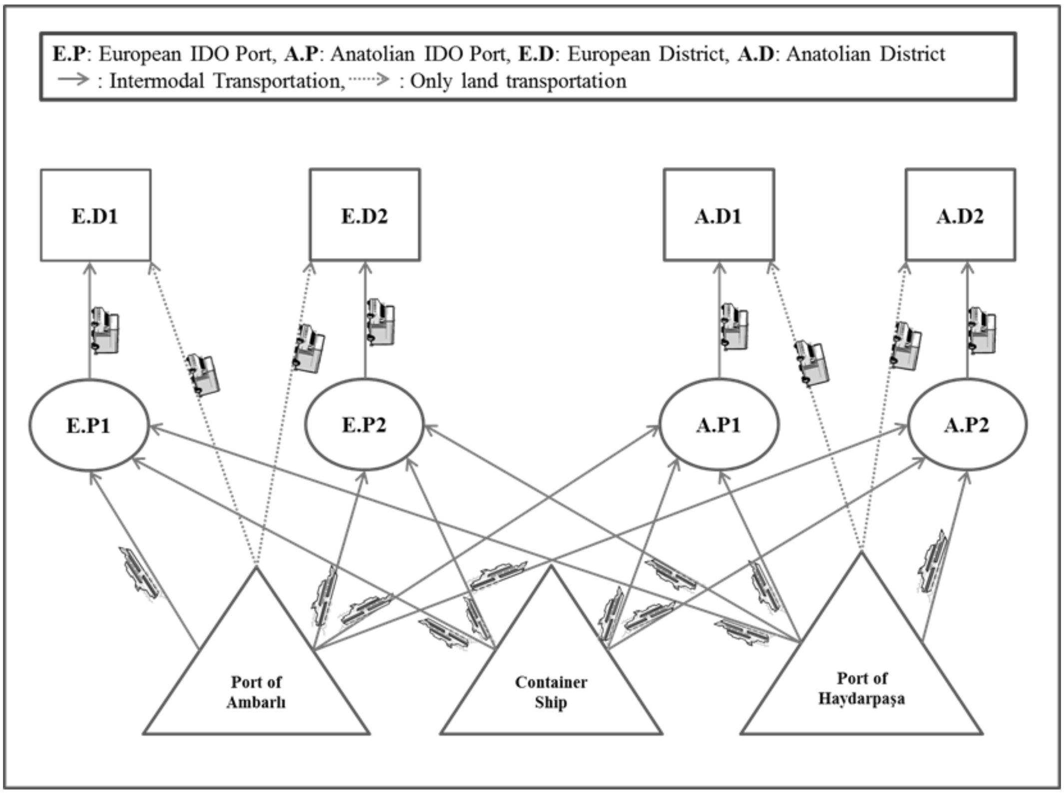

Figure 7 Illustration of intermodal relief item transportation network.

In the network illustrated in Figure 7, "E" describes "European side of İstanbul", while "A" holds for "Anatolian side of İstanbul". "D" represents "districts" and "P" represents "İDO ports". Continuous lines represent intermodal transportation and dotted lines represent direct flow from the main ports to the districts, i.e., only land transportation. As it can be seen from Figure 7, flow of relief items from the two main ports to the İDO ports on both sides is possible. In other words, Ambarlı can send relief items to the İDO ports on the European side and also to the İDO ports on the Anatolian side by ships while Haydarpaşa can send relief items to the İDO ports on the Anatolian side as well as to the İDO ports on the European side by ships. The container ship also can send relief items to the İDO ports on both sides. Therefore, it can be said that relief item transportation between the Anatolian and European sides of İstanbul is enabled by means of the main sources. Also, from the main ports direct transportation of relief items to the districts (of the same side by geographical constraints) by land vehicles is possible, (i.e., Ambarlı can send relief items via highways only to the districts on the European side and Haydarpaşa can send relief item via highways only to the districts on the Anatolian side). From the İDO ports on the European side relief items are sent to the districts on the European side and from the İDO ports on the Anatolian side relief items are sent to the districts on the Anatolian side, by land vehicles obviously. On the other hand, relief item flow between the main sources, between the İDO ports, and between the districts is not possible. Also, relief item flow is always one-way. No back-flow from the İDO ports to the main sources, or from the districts to the main ports or to the İDO ports is allowed. In addition, no relief item stock is allowed at the İDO ports. They are just used as transhipment points.

3.2 Assumptions

In this study, the following assumptions are made with the purpose of facilitating setting up a relief distribution model.

1) Main sources Port of Haydarpaşa, Port of Ambarlı and the container ship are considered as supply points; İDO seaports are considered as transhipment points and districts are considered as demand points.

2) Among the İDO seaports shown in Figure 5, the ports of Kınalı, Burgaz, Heybeli and Büyükada are excluded.

3) From the districts shown in Figure 6, Adalar is excluded.

4) The problem is a single-item type problem. One standard "relief item package" which weighs five kilograms is delivered to each family of four people. This package contains bottles of potable water and meals-ready-to-eat cans. From now on, "relief item package" is referred as "relief item".

5) Planning period is one-day (24 hours or 1440 minutes).

6) At transhipment points (İDO ports), because of space and time limit, relief item storage is not allowed.

7) Partial unloading of vehicles is allowed. In other words, a ship or a land vehicle does not have to unload its entire load at the İDO port or at the district.

8) A vehicle cannot visit more than one port or district after the point of origin.

9) A ship returns to the main source after visiting an İDO port, a land vehicle does not return to the main port or to the İDO port after visiting a district.

10) Transfer of relief items from the container ship to the smaller ships that travel to the İDO ports is done on the container ship.

11) Relief item flow is always one-way and from the main sources to the districts. No back-flow from the districts to the ports or from the İDO ports to the main sources is allowed.

12) Lateral transhipments between the main sources, between the districts and between the İDO ports are not allowed.

3.3 Data Gathering

In this section, data gathering methods for values of the components of the intermodal relief item distribution model (i.e. parameters) are explained, and relevant data are presented.

3.3.1 Demand

Demand is determined according to the population of the districts. Population data of the districts of İstanbul are obtained from Turkish Statistical Institute 2012 Address Based Population Registration System [30].

One relief item package is delivered for one family of four people. Accordingly, relief item demand for each district is determined by dividing the district’s population by four (fractions are rounded up). Demand figures for each district are illustrated in Tables B.1 and B.2 in Appendix B. Total demand is 3,424,000 units of relief items.

3.3.2 Supply to the main ports per day

Daily capacity and supply figures for the three main supply sources are decided by taking into account characteristics of post-disaster environment. Firstly, the main ports Haydarpaşa and Ambarlı might not be serviceable at full capacity because they can be damaged by the disaster more than estimated, or some part of the capacity may be utilized by daily commercial activities. Secondly, more supply than needed can create some problems. In Van Wassenhove (2006), it is stated that humanitarian supply chains are often jammed with "unsolicited donations" and the most needed resources such as personnel and transportation are utilized to carry those unsolicited goods. Excess supply of relief items can be considered as "unsolicited goods." These unsolicited goods cause bottlenecks in relief activities as they take up time and occupy capacity and staff to load, unload and sort etc. For example, when a disaster strikes, wide open areas that ports have can be used as places to provide temporary shelter for people in need, however excess supplies would narrow the serviceable area [4]. Also, as time is one of the most important factors in humanitarian relief operations, all unnecessary time-consuming activities should be avoided to the greatest extent possible. Therefore, a limited amount of the supply arriving from national and international sources can be accepted at the main ports due to capacity, time, and personnel etc., constraints.

For the reasons stated above, total supply from the three main sources is considered as low as possible. Taking into account total demand is 3,424,000 units of relief items and as it is assumed total demand is met, and also for the calculation convenience, the total supply from the three main sources is decided as 3,500,000 units of relief items in this study.

3.3.3 Vehicles

Transportation from the ports to the districts is provided with one type of truck which has the capacity of carrying 500 relief item packages and has an average speed of 50 km/h [11]. Sea transportation from the main sources to the İDO ports is provided with four types of ships which are characterized by their carrying capacity and speed. The vehicle types are described in Table 4.

Table 4 Vehicle Types.

Vehicles	Capacity (number of relief items)	Speed
Ship Type 1	6286	30.9 knot (~57 km/h)
Ship Type 2	6160	25 knot (~46 km/h)
Ship Type 3	5600	32 knot (~59 km/h)
Ship Type 4	6300	33.5 knot (~62 km/h)
Land vehicle	500	50 km/h

3.3.4 Vulnerability

Vulnerabilities [0.0-1.0 scale] of the roads between the main ports or İDO ports and the districts are determined according to the road blockage probability of roads of 7 to 15 meters wide according to JICA-IMM final report [12]. As indicated in Figure 8 [12], the red areas point to vulnerability of 0.5 and over, the brown areas between 0.3 and 0.5, the yellow areas between 0.2 and 0.3, the green areas between 0.1 and 0.2, the blue areas between 0.05 and 1 and the grey areas between 0-0.05. Here, 1 indicates the highest risk of blockage and 0 indicates the lowest risk of blockage.

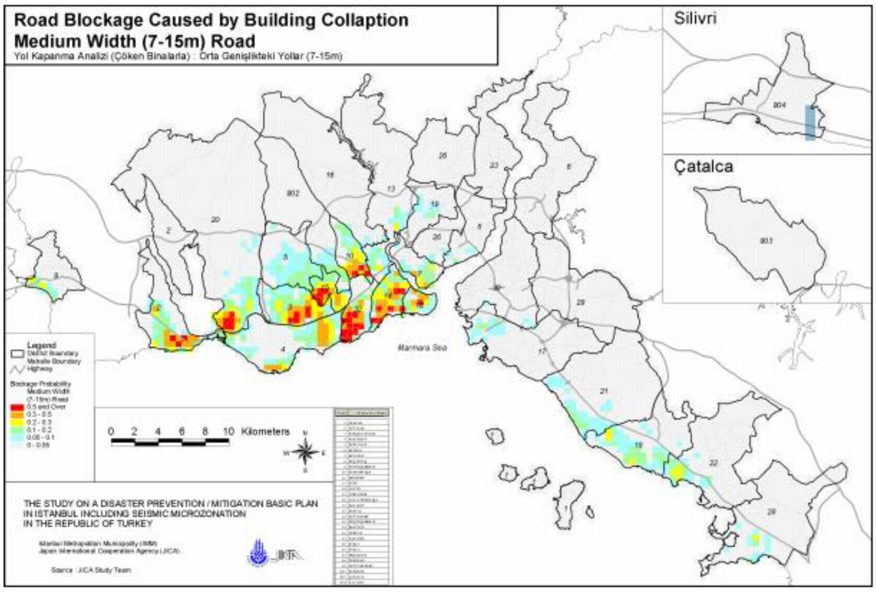

Figure 8 Road blockage caused by building collaption medium width (7-15m) road.

To calculate the vulnerability between the districts and the İDO ports or the main ports, a practical method is followed. Firstly, the vulnerability of each district is determined. The calculation of vulnerability of a district is done by calculating weighted mean of the coloured areas for each district. The vulnerabilities of the ports are considered as the same as the vulnerability of the district where the port is located. After vulnerability of each district is settled, the vulnerability of the highway between a district and a port is decided by calculating arithmetic mean of the vulnerabilities of the district and the port in question. The road vulnerabilities between the districts and the ports are presented in Appendix in Tables B.3 and B.4 in Appendix B. The vulnerabilities of the routes between the main sources and the İDO ports are set as 0.001. This is because there is no risk of collapse of any building on the seaway.

3.3.5 Travel time

Travel times from the main ports or the İDO port to the districts are obtained from Google Maps™. The shortest time between two points is selected from the alternatives given by Google Maps™. Tables B.5 and B.6 of Appendix B present travel times between the ports and the districts.

Travel times from the main sources to the İDO ports change according to the type of the ship used to carry relief items. The sea distances in miles between the main sources and the İDO ports are measured by using Google Earth. Then, the distances are divided by the speeds of ship types one, two, three and four to calculate the travel time. As it is assumed that the ships go to the İDO ports from the main sources and return from the İDO ports to the main sources to complete one tour, the travel times are considered as round-trip for ships, the time calculated is multiplied by two to find the round trip travel time. Also, ten minutes of loading/unloading time is added to the calculated travel times between the main sources and the İDO ports. Loading/unloading time is examined in Chapter 5. Table B.7 of Appendix B presents travel times between the main sources and the İDO ports. All travel times are considered in minutes.

Vulnerabilities of the routes affect the travel times. The formulation to calculate vulnerability effect on travel times is given below.

$$\text{Travel time} = \text{Original travel time} \times \frac{1}{1 - \text{Vulnerability}} \qquad (0)$$

As indicated in formulation (0), original travel time of a route is inflated by the proportion of the vulnerability of that route.

3.3.6 Maximum number of tours/trips of vehicles per day

In this study, it is considered that ships do “tours”, while land vehicles do “trips”. Because, the ships have to return to the point of origin, as the same ship is utilized for relief item distribution, while the land vehicles do not return to the point of origin, that means one land vehicle is only used for once. One “tour” of a ship can be considered as one “loop” of the vehicle between two points. The tour of a ship starts from one of the main sources and point of destination is one of the İDO ports. The ship is loaded with relief materials at the main source and is unloaded at the İDO port, and then it returns to the starting point. For land vehicles, the point of origin of the trip is either one of the main ports or one of the İDO ports, and point of destination is one of the districts. The land vehicle is loaded with relief materials at the port and is unloaded at the district; it does not return to the port. Maximum number of tours that a ship can make daily is calculated based on total travel time of the ship needed to make a tour. Total time interval value, which is one day or 1,440 minutes, is divided by total travel time of the ship to calculate the maximum number of tours that the ship can make in one day. The results are rounded down to the nearest integer values. Maximum numbers of tours that a type of ship can make from the main sources to İDO ports are demonstrated in Table B.8 in Appendix B. On the other hand, the maximum number of trips the land vehicles can do is not strictly limited; i.e., it is considered a very big number. The main reason for this assumption is that, the major focus in this study is on maritime transportation. As it is a subject much less frequently studied, and is considered as the main contribution of this study, it is more concentrated on. Counting the maximum number of tours that can be made by a ship would be helpful for performance measurement, calculating total cost and time incurred by maritime transportation, etc. Only one type of land vehicle is considered also for facilitation of modelling. A land vehicle has a capacity of carrying 500 relief items which is quite low when compared to carrying capacity of the ships used in this study. As the carrying capacity of the land vehicle is low, one land vehicle can make many trips. Hence, maximum number of trips that a land vehicle can make is considered a very big number.

3.3.7 Maximum daily transhipment capacity of İDO ports

Maximum daily transhipment capacity of İDO ports refers to the maximum amount of relief item materials that can arrive at an İDO port in one day, and is determined based on the carrying capacity of the ships and also maximum number of tours that ships can make in a day. To calculate the maximum daily transhipment capacity of an İDO port, the maximum number of tours that each ship type can make daily from the main sources to that İDO port is multiplied by the capacity of that ship type and the results are summed. Maximum daily transhipment of each İDO port is presented in Table B.9 in Appendix B.

CHAPTER 4

MATHEMATICAL MODEL

The problem defined in the previous chapter is formulated as an integer programming model to minimize the total transportation time to deliver relief items to the districts, while meeting all of the demand of the districts.

The indices, parameters and variables of the integer model are presented below:

Indices:

i Index for main sources (i=1,2,…,I)

j Index for İDO ports (j=1,2,…,J)

k Index for districts (k=1,2,…,K)

f Index for ships (f= 1,2,….,F)

l Index for land vehicles (l=1,2,…,L)

Parameters:

s_i Supply of main source I

D_k Demand for district

c_j Maximum daily transhipment capacity of İDO port

$capb_f$ Capacity of ship f

$capb_l$ Capacity of land vehicle l

t_{ijf} Time to travel from main source i to İDO port j by ship f

t_{ikl} Time to travel from main source i to district k by land vehicle l

t_{jkl} Time to travel from İDO port j to district k by land vehicle l

v_{ijf} Vulnerability of the seaway between main source i and İDO port j (when travelled by ship f)*

v_{ikl} Vulnerability of the road between main source i and district k (when travelled by land vehicle l)*

v_{jkl} Vulnerability of the road between İDO port j and district k (when travelled by land vehicle l)*

* Ship type f and land vehicle type l are also included as index for convenience in modelling.

n_{ijf} Maximum number of tours per day ship type f can make from main source i to İDO port j

n_{ikl} Maximum number of trips per day land vehicle l can make from main source i to district k

n_{jkl} Maximum number of trips per day land vehicle l can make from İDO port j to district k

Decision variables:

x_{ijf} Number of relief items transported from main source i to İDO port j by ship f

x_{ikl} Number of relief items transported from main source i to district k by land vehicle l

x_{jkl} Number of relief items transported from İDO port j to district k by land vehicle l

b_{ijf} Number of tours of ship f makes from main source i to İDO port j

b_{ikl} Number of trips of land vehicle l makes from main source i to district k

b_{jkl} Number of trips of land vehicle l makes from İDO port j to district k

Integer Model:

Objective function

$$Minimize \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{f=1}^{F} x_{ijf} * t_{ijf} * \left(\frac{1}{1-v_{ijf}}\right) + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{l=1}^{L} x_{ikl} * t_{ikl} * \left(\frac{1}{1-v_{ikl}}\right) + \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L} x_{jkl} * t_{jkl} * \left(\frac{1}{1-v_{jkl}}\right) \quad (1)$$

Constraints

$$\sum_{i=1}^{I}\sum_{l=1}^{L} x_{ikl} + \sum_{j=1}^{J}\sum_{l=1}^{L} x_{jkl} \geq D_k , \qquad \forall k = 1, \dots, K \quad (2)$$

$$\sum_{j=1}^{J}\sum_{f=1}^{F} x_{ijf} + \sum_{k=1}^{K}\sum_{l=1}^{L} x_{ikl} \leq s_i , \qquad \forall i = 1, \dots, I \qquad (3)$$

$$\sum_{i=1}^{I}\sum_{f=1}^{F} x_{ijf} = \sum_{k=1}^{K}\sum_{l=1}^{L} x_{jkl} , \qquad \forall j = 1, \dots., J \qquad (4)$$

$$\sum_{i=1}^{I}\sum_{f=1}^{F} x_{ijf} \leq c_j , \qquad \forall j = 1, \dots, J \qquad (5)$$

$$b_{ijf} \leq n_{ijf}, \qquad \forall i = 1, \dots, I; \forall j = 1, \dots, J; \forall f = 1, \dots, F \qquad (6)$$

$$b_{ikl} \leq n_{ikl} , \qquad \forall i = 1, \dots, I;\ \forall k = 1, \dots, K; \forall l = 1, \dots, L \qquad (7)$$

$$b_{jkl} \leq n_{jkl} , \qquad \forall j = 1, \dots, J; \forall k = 1, \dots, K; \forall l = 1, \dots, L \qquad (8)$$

$$b_{ijf} *\ capb_f \geq x_{ijf}, \qquad \forall i = 1, \dots, I;\ \forall j = 1, \dots, J; \forall f = 1, \dots, F \qquad (9)$$

$$b_{ikl} *\ capb_l \geq x_{ikl}, \qquad \forall i = 1, \dots, I;\ \forall k = 1, \dots, K;\ \forall l = 1, \dots, L \qquad (10)$$

$$b_{jkl} *\ capb_l \geq x_{jkl}, \qquad \forall j = 1, \dots, J; \forall k = 1, \dots, K; \forall l = 1, \dots, L \qquad (11)$$

$$b_{ijf} \leq x_{ijf}, \qquad \forall i = 1, \dots, I; \forall j = 1, \dots, J; \forall f = 1, \dots, F \qquad (12)$$

$$b_{ikl} \leq x_{ikl}, \qquad \forall i = 1, \dots, I;\ \forall k = 1, \dots, K; \forall l = 1, \dots, L \qquad (13)$$

$$b_{jkl} \leq x_{jkl}, \qquad \forall j = 1, \dots, J;\ \forall k = 1, \dots, K; \forall l = 1, \dots, L \qquad (14)$$

$$x_{ijf}, x_{ikl}, x_{jkl},\ b_{ijf}, b_{ikl}, b_{jkl} \quad integer \qquad (15)$$

In the model above, the objective (1) is minimizing total transportation time of relief items. Effect of vulnerability on transportation time presented in formulation (0) is reflected to the objective function formulation. Constraint set (2) ensures that demand of each district is met. Constraint set (3) indicates that total number of relief items delivered from the main sources cannot exceed total daily supply of the main sources. Constraint set (4) guarantees that total number of relief items transported from an İDO port to the districts is equal to total number of relief items transported to that İDO port from the main sources, indicating that relief items are not stocked at İDO ports. Constraint set (5) presents that total number of relief items transported from the main sources to an İDO port cannot exceed maximum daily transhipment capacity of that İDO port. Constraint set (6) ensures that number of ship tours per day made from a main source to an İDO port cannot exceed the maximum number of ship tours that can be made daily from that main source to that İDO port by that ship type. Constraint set (7) and constraint set (8) indicate that number of land vehicle trips per day made from a main port or from an İDO port to a district cannot exceed the maximum number of land vehicle trips that can be made daily from that port to that district. Constraint set (9) present that a ship travelling from a main source to an İDO port does not have to leave its entire load to the İDO port, partial unloading of the ships is allowed. Likewise, constraint set (10) and constraint set (11) present that a land vehicle travelling from a main port or from an İDO port to a district does not have to leave its entire load to the district, partial unloading of the land vehicles is allowed. Constraint sets (12), (13) and (14) guarantee that if there are no relief items transported from a main source to an İDO port or from a port (main or İDO) to a district, then there will be no tours/trips between these points. Constraint set (15) imposes integrality restriction on decision variables.

CHAPTER 5

EXPERIMENTAL STUDY

In this chapter, the results obtained by the solution of the integer programming model described in the previous chapter by GAMS Distribution 22.6 are presented and discussed. Firstly, solutions obtained by different scenarios based on changing supply amounts from the main sources are discussed. Afterwards, a comparison is done with one of the cases in Görmez et al. [10] to analyse better effect of maritime transportation for relief item distribution in İstanbul.

The performance measures that are concentrated on in each scenario are average time spent to send one unit of relief item to the demand area, intermodal transportation ratio and number of ships used to transport relief items. To obtain these figures, objective function value and amount of relief items transported by maritime navigation and by land transportation are analysed. Also, loading and unloading time are decided and included in travel times.

5.1 Performance Measures

The performance measures analysed in this study are “average transportation time per unit of relief item”, “intermodal transportation percentage” and “total number of ships used”.

“Average transportation time per unit of relief item” refers to the average time spent for one unit of relief item to be sent from a main source to a district. It is calculated by dividing value of objective function, which is a function of travel time, by total demand. As all of time values are considered in minutes, average transportation time of one unit of relief item is also in minutes. Hence, the formulation to calculate "average transportation time per unit of relief item" is:

$$\text{Average transportation time per unit of relief item} = \frac{\text{Objective function value}}{\text{Total demand}} \quad (16)$$

"Intermodal transportation percentage" refers to percentage of amount of relief materials transported from a main source to a district by maritime transportation and land transportation relative to total amount of relief items transported. It is obtained by subtracting "total amount transported from main ports by highways" (i.e., the sum of amount of relief items transported from Port of Haydarpaşa to the Anatolian side districts by land transportation and amount of relief items transported from Port of Ambarlı to the European side districts by land transportation), from total demand and dividing the result by total demand. The found proportion is then converted to percentage. Hence, the formulation to calculate "intermodal transportation percentage" is;

$$\text{Intermodal transportation percentage} = 100\,\frac{(\text{Total demand} - \text{Total amount transported from main ports by highways})}{\text{Total demand}} \quad (17)$$

"Total number of ships used" refers to number of ships (types one, two, three and four) used to transport relief items from the main sources to the İDO ports. To obtain number of ships used for transportation, firstly values of the decision variable b_{ijf} (number of tours of ship f makes from main source i to İDO port j) are checked out. After that, each value of b_{ijf} is multiplied by the corresponding value of the parameter t_{ijf} (time to travel from main source i to İDO port j by ship f) to find out total time required to send relief items from main source i to İDO port j. Then, the result is checked to see if it is greater or smaller than 1,440 minutes (one day). If the total transportation time from the main source to the İDO port by a certain ship type is smaller than or equal to 1,440 minutes, this means only one ship of that kind is sufficient for the relief item transportation process. If it is greater than 1,440 minutes, this means that one day would not be sufficient to carry total amount of relief item sent from the main source to the İDO port by only one of the ship type, so two or more ships are used according to the total travelling time. The formulation for the number of ships is presented below.

$$\text{Total number of ships}\begin{cases} 1 \text{ if } b_{ijf} \text{ x } t_{ijf} \leq 1{,}440 \\ \dfrac{\text{Total travelling time}}{1{,}440} \quad \text{otherwise} \end{cases} \tag{18}$$

5.2 Loading/Unloading Time

Loading/unloading time is also an important factor affecting total time incurred to transport relief items from the point of origin to the point of destination. In this study, loading/unloading time refers to the total time needed to load relief materials from the main sources to the ships or to the land vehicles, and to unload them from the ships or land vehicles to the İDO ports and to the districts. Total loading and unloading time is taken as ten minutes. To decide on this figure, the mathematical model proposed is run by adding five, ten and 30 minutes to travel times from the main sources to the İDO ports. In parallel with changes in travel times, values of the parameters maximum number of tours that a ship can made and maximum daily transhipment capacities of İDO ports are calculated. The model is run for each data set distributing total daily supply of the main sources (3,500,000 units of relief items) almost equally between the main sources (i.e., at a proportion of 0.33 for ports of Haydarpaşa and Ambarlı and 0.34 for the container ship) which correspond to 1,155,000 units of relief items for ports of Haydarpaşa and Ambarlı, and 1,190,000 units of relief items for the container ship. Average transportation time per unit relief item and intermodal transportation percentage for each run are presented in Table 5.

Table 5 Comparison of Loading/Unloading Times.

Loading/Unloading Time	Intermodal Transportation Percentage	Average Transportation Time per Unit Relief Item
5 minutes	38%	37.1 minutes
10 minutes	37%	38.8 minutes
30 minutes	33%	45.8 minutes

As it can be seen in Table 5, intermodal transportation percentage decreases and average transportation time per unit relief item increases as loading/unloading time increases. Hence, the best solution is obtained when loading/unloading time is taken as five minutes. However, there is a slight difference between the results obtained with five minutes and ten minutes. Intermodal transportation difference is 1% and average transportation time per unit relief item difference is 1.7 minutes. These figures are considered quite tolerable when compared with 5% intermodal transportation percentage difference and 8.7 minutes average transportation time difference with the best case for the case of 30 minutes. Because similar results are achieved in the case of using ten minutes with the case of using five minutes, and because considering ten minutes as the loading/unloading time is more realistic than considering five minutes, ten minutes loading/unloading time is accepted.

5.3 Experiments Based on Alternative Supply Values for the Main Sources

The integer programming model is solved by GAMS Distribution 22.6 for alternative supply values for the three main sources. As it is indicated before, total supply of Port of Haydarpaşa, Port of Ambarlı and the container ship is 3,500,000 units of relief items. This total supply is divided between the three main sources at different proportions in each experiment. Ten experiments are run considering supply distribution at proportions of 0.33, 0.67 and 1.00 for the main sources as presented in Table 6, where proportion 1.00 indicates 3,500,000 units. “Experiment zero” in Table 6 and in the following tables refers to the scenario in which only land transportation is utilized for relief item delivery, i.e., the scenario built based on Görmez et al. [10], and it is analysed in section 5.4. The analyses up to section 5.4 are done based on experiments one to ten.

Table 6 Supply Proportions of the Main Sources.

Experiment No	Port of Haydarpaşa	Port of Ambarlı	Container Ship
0	0	0	0
1	0	0	1.00
2	0	1.00	0
3	1.00	0	0
4	0.33	0.33	0.34
5	0.33	0.67	0
6	0.33	0	0.67
7	0	0.33	0.67
8	0.67	0.33	0
9	0.67	0	0.33
10	0	0.67	0.33

Table 7, which is generated based on Table 6, presents supplies from the three main sources in terms of units of relief items. As it can be seen, total supply from Port of Haydarpaşa, Port of Ambarlı and the container ship is 3,500,000 units of relief items and it is divided between them according to the proportions indicated in Table 6.

Table 7 Supply Amounts of the Main Sources (Units).

Experiment No	Port of Haydarpaşa	Port of Ambarlı	Container Ship
0	0	0	0
1	0	0	3,500,000
2	0	3,500,000	0
3	3,500,000	0	0
4	1,155,000	1,155,000	1,190,000
5	1,155,000	2,345,000	0
6	1,155,000	0	2,345,000
7	0	1,155,000	2,345,000
8	2,345,000	1,155,000	0
9	2,345,000	0	1,155,000
10	0	2,345,000	1,155,000

Tables 8-11 illustrate the results of the experiments in terms of units of relief items transported. As it can be seen from Table 8, there is no relief item transportation from Port of Haydarpaşa to the İDO ports on the Anatolian side. The most number of relief items transported from Port of Haydarpaşa by maritime transportation is obtained in experiment three, where all supply is provided by itself.

Table 8 Number of Relief Items Transported by Maritime Transportation from Port of Haydarpaşa.

Experiment No	To Anatolian Side İDO Ports	To European Side İDO Ports
0	0	0
1	0	0
2	0	0
3	0	2,218,091
4	0	150,687
5	0	0
6	0	175,150
7	0	0
8	0	1,063,091
9	0	1,139,087
10	0	0

Table 9 shows the number of relief items transported from the Port of Ambarlı by maritime transportation. The most number of relief items transported from Port of

Ambarlı by maritime transportation is obtained in experiment two, where all supply is provided by itself.

Table 9 Number of Relief Items Transported by Maritime Transportation from Port of Ambarlı.

Experiment No	To European Side İDO Ports	To Anatolian Side İDO Ports
0	0	0
1	0	0
2	73,102	1,205,913
3	0	0
4	0	0
5	73,102	50,913
6	0	0
7	0	0
8	0	0
9	0	0
10	73,102	50,913

Table 8 and 9 indicate that the general direction of maritime transportation from the main ports is towards to the other side. As it can be seen in Table 8, all of the relief items transported by ships from the Port of Haydarpaşa go to the İDO ports on the European side while as indicated in Table 9 most of the relief items transported from the Port of Ambarlı go to the İDO ports on the Anatolian side.

Table 10 Number of Relief Items Transported from the Container Ship.

Experiment No	To Anatolian Side İDO Ports	To European Side İDO Ports	Total
0	0	0	0
1	1,205,913	2,218,091	3,424,004
2	0	0	0
3	0	0	0
4	201,600	912,404	1,114,004
5	0	0	0
6	226,063	2,043,211	2,269,274
7	1,205,913	1,063,091	2,269,004
8	0	0	0
9	0	1,079,004	1,079,004
10	1,155,000	0	1,155,000

Table 10 shows the amounts of relief items transported from the container ship to the İDO ports on both sides. Naturally, there are no relief items transported from the container ship at experiments two, three, five and eight when the supply of it is zero.

When supply from the container ship is available, it sends relief items predominantly to the European side districts.

Table 11 Number of Relief Items Transported by Highways from the Main Ports.

Experiment No	From Haydarpaşa to Anatolian Side Districts	From Port of Ambarlı to European Side Districts	Total
0	0	0	0
1	0	0	0
2	0	2,144,989	2,144,989
3	1,205,913	0	1,205,913
4	1,004,313	1,155,400	2,159,713
5	1,155,000	2,144,989	3,299,989
6	979,850	0	979,850
7	0	1,155,000	1,155,000
8	1,205,913	1,155,000	2,360,913
9	1,205,913	0	1,205,913
10	0	2,144,989	2,144,989

Table 11 indicates amount of relief items transported directly from the main ports to the districts by land vehicles.

Table 12 Number of Ships Utilized.

Experiment No	Type 1	Type 2	Type 3	Type 4	Total
0	0	0	0	0	**0**
1	4	1	8	9	**22**
2	2	1	5	5	**13**
3	1	0	3	2	**6**
4	1	0	2	6	**9**
5	0	0	1	1	**2**
6	3	1	5	8	**17**
7	1	0	5	8	**14**
8	1	0	1	3	**5**
9	3	0	3	4	**10**
10	0	0	3	6	**9**
Total	**16**	**3**	**36**	**52**	

Table 12 presents the number of each type of ship used in different scenarios. The number of ships used is the maximum in experiment one where all supply is provided from the container ship. The number of ships used is at the minimum in experiment five where there is no supply from the container ship and two third of the total supply is obtained from the Port of Ambarlı. Another important result that Table 12 illustrates is that the most preferred ship type by the network is type four ship.

This is mainly because it is the ship in the fleet which is the fastest and which has the maximum carrying capacity. Therefore, by using type four ship, more relief items can be transported in less time.

Table 13 Average Transportation Time, Intermodal Transportation Percentage and Total Number of Ships Used.

Experiment No	Average Transportation Time per Unit Relief Item (min)	Intermodal Transportation Percentage	Total Number of Ships Used
0	22.75	0	0
1	72.7	100%	22
2	57.3	37%	13
3	40.7	65%	6
4	38.8	37%	9
5	32.2	4%	2
6	56.8	71%	17
7	54.7	66%	14
8	30.6	31%	5
9	45.4	65%	10
10	47.7	37%	9

Table 13 illustrates average transportation time per unit relief item, intermodal transportation percentage and total number of ships required in each scenario. To be able to analyse better the relationship between the three performance measures the graph in Figure 9 and 10 are drawn.

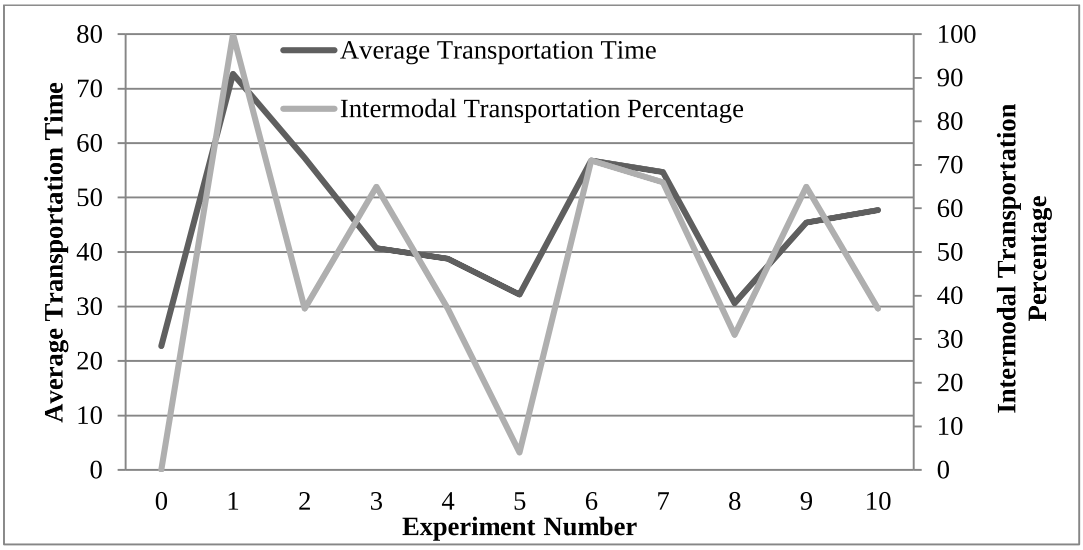

Figure 9 Average transportation time versus intermodal transportation percentage.

Figure 9 shows the relationship between average transportation time and intermodal transportation percentage. Generally, as average transportation time decreases intermodal transportation percentage also decreases and as it increases intermodal transportation percentage also increases. This may be because of when intermodal transportation is used, relief items are transported to the demand points in two steps, this can be considered as travel time-extending situation. This directly proportional pattern deviates in experiments three and ten. In experiment three, average transportation time decreases as intermodal transportation percentage increases while in experiment ten, average transportation time increases as intermodal transportation percentage decreases. Therefore, it can be said that although generally average transportation time and maritime transportation is directly proportionate, this situation can change depending on the vehicle type used, the district travelled, etc.

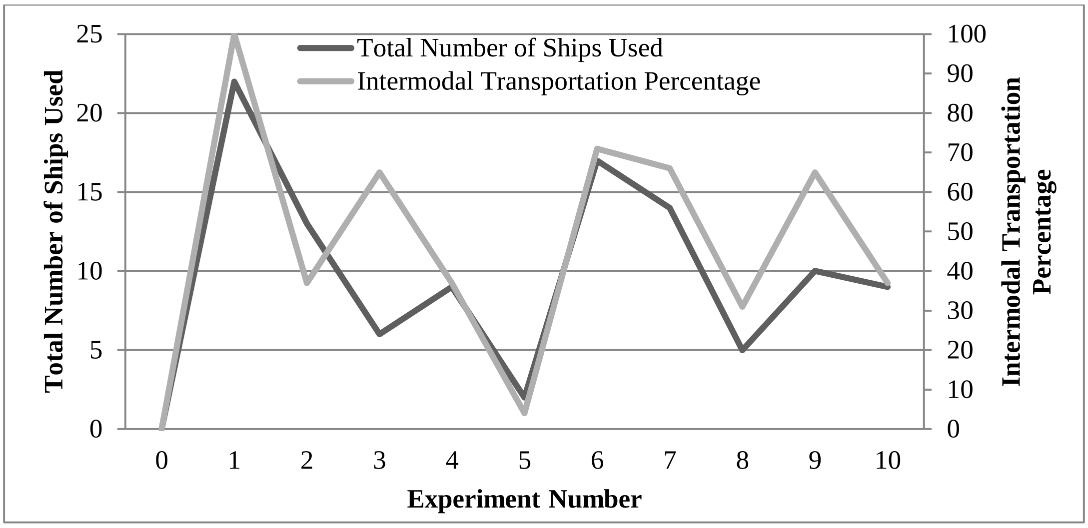

Figure 10 Total number of ships used versus intermodal transportation percentage.

Figure 10 depicts the relationship between total number of ships used and intermodal transportation percentage. As it can be seen, generally total number of ships used and intermodal transportation percentage follow the same pattern. Total number of ships used decreases as intermodal transportation percentage decreases and it increases as intermodal transportation percentage increases. This can be considered as a natural result since intermodal transportation percentage is directly proportional to utilization of maritime transportation, i.e., utilization of ships. However, it cannot be said definitely that total number of ships used is directly proportionate to intermodal transportation percentage; it is also related to the type of the ship used; i.e., if higher capacity ships are used more relief items are distributed with fewer ships, so total number of ships used decreases. The deviation from the general pattern comes forward in experiments three and four. In experiment three, total number of ships used decreases while intermodal transportation percentage increases. In experiment four, total number of ships used increases while intermodal transportation percentage decreases.

In our study, it would not be very accurate to refer to one of the scenarios as "best case" or "worst case". The experiments are designed taking into account possible scenarios and the results show the possible situation in each scenario. Hence, the decision maker is prepared to encounter different scenarios and can plan the necessary arrangements; such as the ship fleet for each scenario.

Table 14 indicates percentages of demand of the Anatolian side districts met by the main sources. To meet the demand of the Anatolian side districts, four alternatives are possible. Firstly, demand can be directly met by Port of Haydarpaşa via land transportation, relief materials are sent by land vehicles to the Anatolian side districts directly. The other alternatives are, relief materials can be sent to the Anatolian side districts by Port of Haydarpaşa, by Port of Ambarlı or by the container ship via the Anatolian side İDO ports; relief materials are sent to first to the Anatolian side İDO ports by maritime transportation and then from the ports to the Anatolian side districts. Average values of ten experiments for each alternative route are also given.

Table 14 Supply Percentages for the Anatolian Side Districts.

Experiment No	**From Haydarpaşa directly (%)**	**From Haydarpaşa via İDO ports (%)**	**From Ambarlı via İDO ports (%)**	**From 3rd Source via İDO ports (%)**
0	0	0	0	0
1	0	0	0	100
2	0	0	100	0
3	100	0	0	0
4	83	0	0	17
5	96	0	4	0
6	81	0	0	19
7	0	0	0	100
8	100	0	0	0
9	100	0	0	0
10	0	0	4	96
Average	**56**	**0**	**10.8**	**33.2**

Table 15 indicates percentages of demand of the European side districts met by the main sources. To meet the demand of the European side districts, four alternatives are possible. Firstly, demand can be directly met by Port of Ambarlı via land transportation, relief materials are sent by land vehicles to the European side districts directly. The other alternatives are, relief materials can be sent to the European side districts by Port of Ambarlı, by Port of Haydarpaşa or by the container ship via the European side İDO ports; relief materials are sent to first to the European side İDO ports by maritime transportation and then from the ports to the European side districts. Average values of ten experiments for each alternative route are also given.

Table 15 Supply Percentages for the European Side Districts.

Experiment No	From Ambarlı directly (%)	From Ambarlı via İDO ports (%)	From Haydarpaşa via İDO ports (%)	From 3rd Source via İDO ports (%)
0	0	0	0	0
1	0	0	0	100
2	97	3	0	0
3	0	0	100	0
4	52	0	7	41
5	97	3	0	0
6	0	0	8	92
7	52	0	0	48
8	52	0	48	0
9	0	0	51	49
10	97	3	0	33
Average	**44.7**	**0.9**	**21.4**	**33**

Figures 11 and 12 display the average supply distribution for the Anatolian side and the European side districts. They depict proportions of demand met by the main sources via intermodal transportation or directly via land transportation. The proportions are averages of the values obtained in ten experiments as indicated in Table 14 and Table 15.

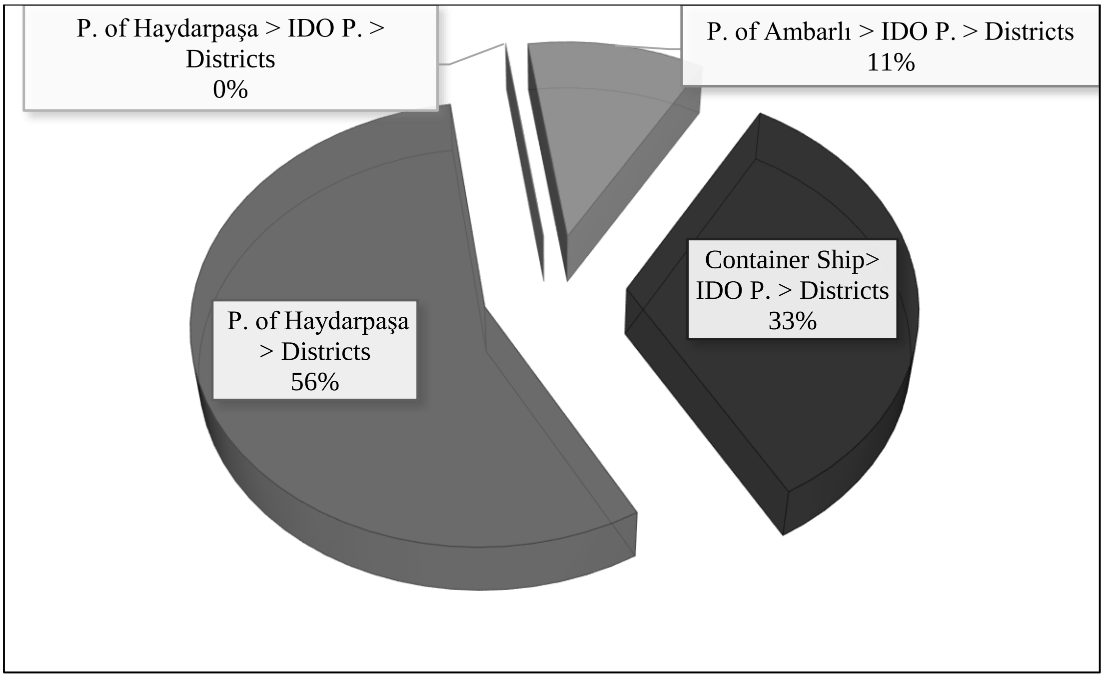

Figure 11 Supply distribution for the Anatolian side districts.

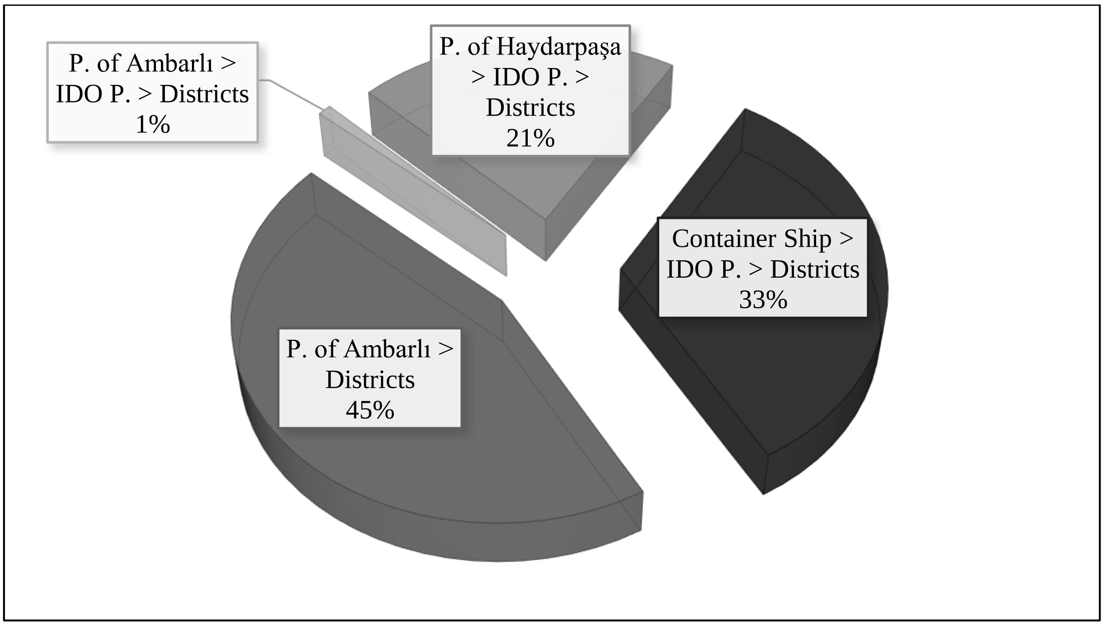

Figure 12 Supply distribution for the European side districts.

As it can be seen from Figures 11 and 12, for the Anatolian side, more than half of the demand is met directly from Port of Haydarpaşa by highways while for the European side almost half of the demand is met directly from Port of Ambarlı via highways. When Tables 14 and 15 are analysed, it is observed that when there is supply from the main ports the relief item distribution to the districts is done directly from the main ports using only highways. For both sides exactly the same portion of the demand 33% is met by the third supply source which is the sea-based container ship. Also, when there is supply from the container ship, the network prefers to send relief items from the container ship instead of sending relief items from the opposite side. It is remarkable that in any case, supply distribution from the main ports to the İDO ports on the same side; i.e., from Port of Haydarpaşa to the Anatolian side İDO ports and from Port of Ambarlı to the European side İDO ports, is almost zero for both sides. Portion of the demand met by relief item transportation from the main port of opposite side is more for the European side than the Anatolian side. Besides, for the Anatolian side, supply from the container ship is preferred when there is supply both from the Port of Ambarlı and the container ship or supply from the Port of Haydarpaşa via highways is preferred when there is both supply from Port of Haydarpaşa and Port of Ambarlı. On the other hand, for the European side, when there is supply both from Port of Ambarlı and Port of Haydarpaşa, the demand is met almost half by Port of Ambarlı via highways and half by Port of Haydarpaşa. Additionally, when there is supply from both the container ship and Port of Haydarpaşa, again almost equal portions are met by the two supply points. Therefore, Port of Haydarpaşa, the opposite side, is an important supply source for the European side in some cases.

Consequently, for the Anatolian side, if there is supply, Port of Haydarpaşa is the most important supply source and direct transportation of relief items via highways from Haydarpaşa is preferred. In none of the scenarios, relief items are transported from Haydarpaşa to the Anatolian side İDO Ports and proportion of transportation of relief items from the opposite side, Port of Ambarlı is quite low. For the European side, proportion of transportation of relief items from Port of Ambarlı to the European side İDO ports is almost zero while direct transportation of relief items via highways from Ambarlı to the European side districts holds an important proportion. Proportion of transportation of relief items from the opposite side, Port of Haydarpaşa, to the European side is at important levels at some cases. When there is supply from the container ship, it is also an important supply source for both of the districts.

5.4 Effect and Analysis of Excluding Maritime Transportation

To be able to see the effect of including maritime transportation and utilizing sea-basing concept for relief item distribution in İstanbul, the proposed model is modified, so it only allows land transportation for relief distribution. As indicated before, this scenario is referred as “experiment 0” in previous tables of chapter 5. One of the cases presented in Görmez et al. is chosen for comparison. They present a disaster response facility location problem in İstanbul. A two-stage mathematical model is proposed to determine the locations of regional disaster response facilities among 40 potential locations identified by IMM. The model also utilizes existing public facilities as temporary local disaster response facilities [10]. Our study is compared with the results of the Görmez et al. model which considers capacitated facilities, the 3-facility case. This model and case is chosen for comparison because in the model presented in our study, the facilities are capacitated and there are three main sources of supply. Disaster response facility locations in Görmez et al. is depicted in Figure 13 [10].

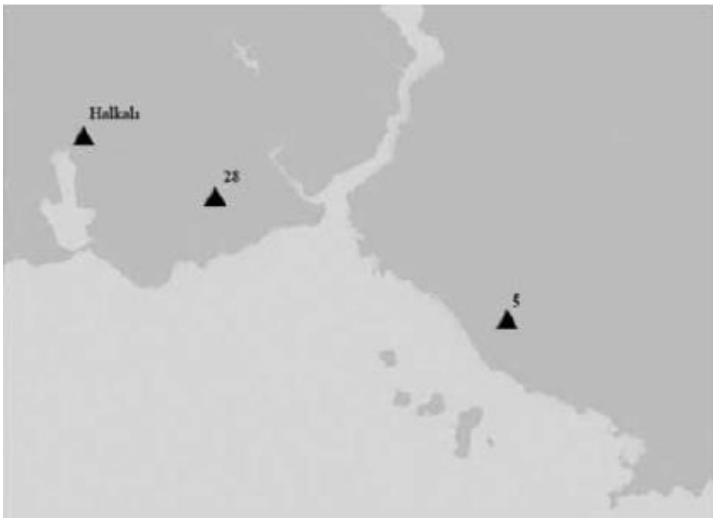

Figure 13 Disaster response facility locations.

To choose this case is logical also because it places two facilities on the European side while it places one facility on the Anatolian side, as the demand of the European side districts are more than two times of the demand of the Anatolian side districts.

The three facilities depicted in Figure 13 are considered as the main supply sources. Again, the districts of İstanbul are the demand points. Relief items are distributed directly to the districts by land vehicles. Relief item flow is always from the facilities to the districts, no back-flow is allowed. Relief item transportation between the facilities or between the districts is not permitted. Obviously, relief item transportation between European and Anatolian sides is not possible.

The mathematical model proposed in our study is modified for the 3-facility case of Görmez et al. [10]. Parameters, decision variables and constraints related to seaports, maritime and intermodal transportation and sea-basing are eliminated. So, the following mathematical model is set.

Indices:

i Index for disaster response facilities (i=1,2,…,I)

j Index for districts (j=1,2,…,J)

Parameters:

s_i Supply of disaster response facility i

D_j Demand for district j

t_{ij} Time to travel from disaster response facility i to district j

v_{ij} Vulnerability of the road between disaster response facility i and district j

Decision variables:

x_{ij} Number of relief items transported from disaster response facility i to district j

Integer Model:

Objective function

$$Minimize \sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij} * \ t_{ij} * \left(\frac{1}{1-v_{ij}}\right) \tag{19}$$

Constraints

$$\sum_{i=1}^{I} x_{ij} \geq D_j \ , \qquad \forall j = 1, \ldots ., J \tag{20}$$

$$\sum_{j=1}^{J} x_{ij} \ \leq s_i \ , \qquad \forall i = 1, \ldots, I \tag{21}$$

$$x_{ij} \quad integer \tag{22}$$

In the model above, the objective (19) is minimizing total transportation time of relief items. Again, vulnerability effect on travel times is taken into account. Constraint set (20) ensures that demand of each district is met. Constraint set (21) indicates that total number of relief items delivered from the warehouses cannot exceed total daily supply of the warehouses. Constraint set (22) imposes integrality restriction on decision variables.

The demand figures of the districts are the same as the demand figures of the original model presented, hence total demand is 3,424,000 units of relief items. Total supply is also considered as the same and it is 3,500,000 units of relief items. 65% of the total supply is allocated to the disaster response facilities on the European side where it is equally distributed between the two facilities and 35% is allocated to the disaster response facility on the Anatolian side. These allocation proportions are decided according to the demand (i.e., population) proportion between the two sides.

The model is solved by Gams Distribution 22.6. The only performance measure that can be figured out is average transportation time in this model, as the other two are related with intermodal transportation. It is seen from Figures 9 and 10, in experiment zero, the intermodal transportation percentage and total number of ships used is zero. The average transportation time is calculated as 22.75 minutes. It is seen that this value is lower than all the average transportation time results for the original model proposed presented in Table 13, where the least average transportation time value is measured as 30.6 minutes.

It can be said that utilizing only land transportation for relief item distribution is faster than utilizing intermodal transportation. On the other hand, if 10 minutes of loading/unloading time is excluded, average transportation time in some experiments for the intermodal transportation model would be shorter than the average transportation time (22.75 minutes) for the land transportation model. Moreover, we are considering round trips (i.e., tours) for ships, but one-way trips for land vehicles. Although, the main goal is to provide relief to the disaster area in the shortest time possible, utilization of maritime transportation has many advantages over using only land transportation. Firstly, in the three-facility case each facility is constrained to provide service to the side that it is placed. Neither the facility on the Anatolian side can send relief items to the European side, nor can the facilities on the European side send relief items to the Anatolian side. Therefore, in case of any harm to the facilities due to disaster effect such as collapse in some part of the building, there is no other source to replace the non-utilizable capacity of the facility. This situation is particularly probable for the sole facility on the Anatolian side. For instance, if the supply allocation had been done as 34% for the Anatolian side and 66% for the European side; the supply of the Anatolian side would not be sufficient to meet the demand of the Anatolian side districts and that would create infeasibility. On the other hand, if a very similar allocation is done for the model proposed in our paper, this situation does not create any infeasibility in the system. So as indicated in Table 6, in experiment 5 where average transportation time is 32.2 minutes, 33% of the total supply is allocated to the Port of Haydarpaşa (i.e., to the Anatolian side) while 67% is allocated to the Port of Ambarlı (i.e., to the European side). In this case, though 96% of the demand of the Anatolian side is met by the Port of Haydarpaşa, the remaining 4% is met by the opposite side, Port of Ambarlı and no insufficiency of supply for the Anatolian side districts is encountered. Secondly, sea-basing concept is utilized in our study. This contributes a lot to the flexibility of the relief item distribution system. Even though in an extreme case such as shut down of both of the ports of Haydarpaşa and Ambarlı (as in experiment one in Table 6), the container ship would be able to provide supply to the both sides via maritime transportation.

In conclusion, the system proposed in this study is more advantageous for İstanbul when compared to the classical system consisting of only relief distribution facilities placed on land, in terms of flexibility and reliability. Because in our system there are more alternatives to deliver relief to people in need, so it is more responsive to the emergencies.

CHAPTER 6

CONCLUSION

In this study, an intermodal humanitarian logistics model is proposed for distribution of relief items nationally and internationally supplied to people in need in case of an earthquake in İstanbul. The motivating idea behind this thesis is to benefit from the natural advantage of İstanbul by utilizing maritime transportation for relief items delivery. The model is based on maritime transportation and takes advantages of seaports and unique geography of the city. The main objective is to minimize transportation time of relief items. Vulnerability effect on transportation times is also taken into account. Besides, sea-basing concept is utilized in the model. Another important aspect is that the model allows relief item transportation between the Anatolian and European sides via Bosporus.

In the model, there are three main sources of supply which are Port of Haydarpaşa, Port of Ambarlı and a container ship which is located at the Sea of Marmara. The demand points are the district centres on both sides of İstanbul. İDO seaports are used as transhipment points. Supplies from inland and abroad arrive at the main sources and they are transhipped to the İDO ports by maritime transportation and then to the district centres by land transportation, or directly to the district centres by land transportation.

The mathematical model is run for different scenarios and the results are analysed with respect to three performance measures which are average transportation time per unit relief item, intermodal transportation percentage and number of ships used. The scenarios take into account different supply proportions for the three main sources of supply, one of which might be an international container ship.

Moreover, average supply distribution for the Anatolian side and the European side districts is examined. Although it is seen that direct transportation from Port of Ambarlı to the European side and from Port of Haydarpaşa to the Anatolian side via highways is the preferred way for distribution of relief items, a considerable proportion of relief items are transported between the two sides via utilization of maritime transportation and İDO ports. In addition, the container ship is an important supply source for both European and Anatolian sides.

Furthermore, to be able to understand better effect of including maritime transportation in relief item distribution system, an alternative mathematical model which utilizes only land transportation is constructed where three capacitated facilities of Görmez et al. [10] are the main supply sources. It is concluded that, although average time required for transportation of relief items in case of using only land transportation is shorter in some situations, intermodal transportation model is more reliable and flexible for İstanbul, because it allows transportation between the two sides.

All these analyses give a valuable insight to the relevant coordinator authorities for management and planning activities of facilities and resources for humanitarian logistics activities. For instance, in accordance with the results of different scenarios, DEMP can decide on the number and type of ships dedicated to humanitarian logistics activities and allocation of incoming supplies to the main ports Haydarpaşa and Ambarlı or the necessity of utilizing the container ship. In a similar manner, time management and scheduling of distribution activities may be achieved as expected values of average transportation time for different situations are known to the authorities.

Extensive utilization of maritime transportation and seaports for relief item distribution is the main contribution of this study to the humanitarian logistics literature. Our study establishes a base idea for benefiting from the special geography of İstanbul in case of an earthquake. The system proposed is open to future improvement. For instance, in our study, loading/unloading time is considered as ten minutes. A complete and detailed time study, which takes into account some other factors such as conjunction of the ships at the same port, can be done. These kind of considerations bring also some other aspects to the problem such as scheduling. By updating the mathematical model in accordance with this scheduling factor, a more comprehensive result can be achieved. Additionally, budget constraints can be included in the system. Also, consideration of including international airports to the relief item distribution network can be considered as a valuable development. Additionally, a more comprehensive vulnerability analysis may be conducted. Therefore, the effect of changing vulnerabilities of seaways and highways on relief item transportation patterns can be examined. Also, additional investigations for each district or for each port can be done. For instance, total number of land vehicles and ships can be fixed. With this constraint in mind, number of land vehicles allocated to the districts and number of ships allocated to the İDO ports for relief item transportation can be examined. This feature can be considered as another performance measure. Based on this analysis, optimal carrying capacities for vehicles may be decided, and a vehicle fleet dedicated to emergency relief activities may be organized.

After all, as the relief item delivery network developed in this study is based on seaports, earthquake-resistant features of the seaports should be improved. Also, port hinterlands should be organized and designed to allow efficient coordination with the seaports in case of emergencies; for example, roads connecting the seaports to the demand areas, in our case to the districts, should be kept in good conditions, infrastructure of surrounding area should also be maintained, and surrounding facilities and constructions should be improved for being resistant to earthquakes.

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APPENDICES A

PORTS FOR PRIMARY AND SECONDARY EMERGENCY ROADS

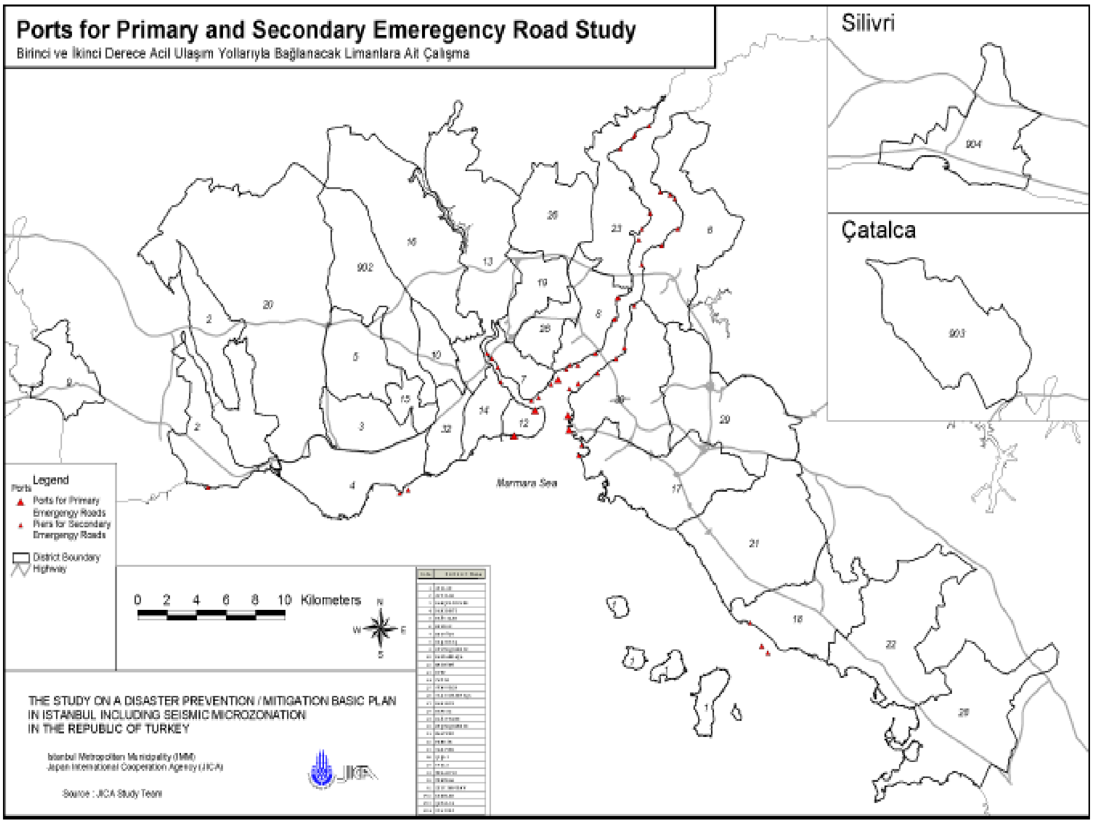

Figure A. 1 Ports for primary and secondary emergency roads [12].

APPENDICES B

DATA TABLES

Table B. 1 Demand of the Anatolian Side Districts (Units of Relief Items).

ANATOLIAN SIDE DISTRICTS	DEMAND
ŞİLE	3,315
BEYKOZ	55,091
ÇEKMEKÖY	47,073
ÜSKÜDAR	133,979
ÜMRANİYE	161,310
SANCAKTEPE	69,328
KADIKÖY	130,252
ATAŞEHİR	98,940
PENDİK	155,550
MALTEPE	115,239
SULTANBEYLİ	75,597
KARTAL	110,824
TUZLA	49,415

Table B. 2 Demand of the European Side Districts (Units of Relief Items).

EUROPEAN SIDE DISTRICTS	**DEMAND**
EYÜP	87,368
SARIYER	64,509
SULTANGAZİ	123,053
ŞİŞLİ	79,555
ÇATALCA	9,216
BAŞAKŞEHİR	77,774
GAZİOSMANPAŞA	122,065
KAĞITHANE	105,339
ESENLER	114,674
BEŞİKTAŞ	46,517
ARNAVUTKÖY	49,542
SİLİVRİ	34,466
ESENYURT	138,343
BAĞCILAR	187,256
BAYRAMPAŞA	67,444
BEYOĞLU	61,538
BÜYÜKÇEKMECE	50,270
AVCILAR	98,819
KÜÇÜKÇEKMECE	180,478
BAHÇELİEVLER	150,041
GÜNGÖREN	76,894
FATİH	107,215
BEYLİKDÜZÜ	57,279
BAKIRKÖY	55,334
ZEYTİNBURNU	73,102

Table B. 3 Vulnerabilities of the Routes Between the Ports and the Districts of the Anatolian Side.

		DISTRICTS												
		Şile	Beykoz	Çekmeköy	Üsküdar	Ümraniye	Sancaktepe	Kadıköy	Ataşehir	Pendik	Maltepe	Sultanbeyli	Kartal	Tuzla
PORTS	Haydarpaşa	0.05	0.05	0.05	0.05	0.05	0.05	0.055	0.05	0.06	0.055	0.05	0.075	0.055
	Beykoz	0.05	0.05	0.05	0.05	0.05	0.05	0.055	0.05	0.06	0.055	0.05	0.075	0.055
	Harem	0.05	0.05	0.05	0.05	0.05	0.05	0.055	0.05	0.06	0.055	0.05	0.075	0.055
	Kadıköy	0.055	0.055	0.055	0.055	0.055	0.055	0.06	0.055	0.065	0.06	0.055	0.08	0.06
	Bostancı	0.055	0.055	0.055	0.055	0.055	0.055	0.06	0.055	0.065	0.06	0.055	0.08	0.06
	Maltepe	0.055	0.055	0.055	0.055	0.055	0.055	0.06	0.055	0.065	0.06	0.055	0.08	0.06
	Kartal	0.075	0.075	0.075	0.075	0.075	0.075	0.08	0.075	0.085	0.08	0.075	0.1	0.08
	Pendik	0.06	0.06	0.06	0.06	0.06	0.06	0.065	0.06	0.07	0.065	0.06	0.085	0.065

Table B. 4 Vulnerabilities of the Routes Between the Ports and the Districts of the European Side.

		DISTRICTS													
		Eyüp	**Sarıyer**	**Sultangazi**	**Şişli**	**Çatalca**	**Başakşehir**	**Gaziosmanpaşa**	**Kağıthane**	**Esenler**	**Beşiktaş**	**Arnavutköy**	**Silivri**	**Esenyurt**	**Bağcılar**
PORTS	**Ambarlı**	0.13	0.125	0.125	0.125	0.125	0.125	0.125	0.13	0.13	0.13	0.125	0.125	0.2	0.15
	Sarıyer	0.055	0.05	0.05	0.05	0.05	0.05	0.05	0.055	0.055	0.055	0.05	0.05	0.125	0.075
	İstinye	0.055	0.05	0.05	0.05	0.05	0.05	0.05	0.055	0.055	0.055	0.05	0.05	0.125	0.075
	Beşiktaş	0.06	0.055	0.055	0.055	0.055	0.055	0.055	0.06	0.06	0.06	0.055	0.055	0.13	0.08
	Kabataş	0.1	0.095	0.095	0.095	0.095	0.095	0.095	0.1	0.1	0.1	0.095	0.095	0.17	0.12
	Yenikapı	0.23	0.225	0.225	0.225	0.225	0.225	0.225	0.23	0.23	0.23	0.225	0.225	0.3	0.25
	Bakırköy	0.1	0.095	0.095	0.095	0.095	0.095	0.095	0.1	0.1	0.1	0.095	0.095	0.17	0.12
	Avcılar	0.13	0.125	0.125	0.125	0.125	0.125	0.125	0.13	0.13	0.13	0.125	0.125	0.2	0.15

Table B. 4 (Continued) Vulnerabilities of the Routes Between the Ports and the Districts of the European Side.

		DISTRICTS										
		Bayrampaşa	**Beyoğlu**	**Büyükçekmece**	**Avcılar**	**Küçükçekmece**	**Bahçelievler**	**Güngören**	**Fatih**	**Beylikdüzü**	**Bakırköy**	**Zeytinburnu**
PORTS	**Ambarlı**	0.25	0.17	0.135	0.2	0.145	0.25	0.3	0.3	0.2	0.17	0.3
	Sarıyer	0.175	0.095	0.06	0.125	0.07	0.175	0.225	0.225	0.125	0.095	0.225
	İstinye	0.175	0.095	0.06	0.125	0.07	0.175	0.225	0.225	0.125	0.095	0.225
	Beşiktaş	0.18	0.1	0.065	0.13	0.075	0.18	0.23	0.23	0.13	0.1	0.23
	Kabataş	0.22	0.14	0.105	0.17	0.115	0.22	0.27	0.27	0.17	0.14	0.27
	Yenikapı	0.35	0.27	0.235	0.3	0.245	0.35	0.4	0.4	0.3	0.27	0.4
	Bakırköy	0.22	0.14	0.105	0.17	0.115	0.22	0.27	0.27	0.17	0.14	0.27
	Avcılar	0.25	0.17	0.135	0.2	0.145	0.25	0.3	0.3	0.2	0.17	0.3

Table B. 5 Travel Times Between the Ports and the Districts of the Anatolian Side (Minutes).

		DISTRICTS												
		Şile	**Beykoz**	**Çekmeköy**	**Üsküdar**	**Ümraniye**	**Sancaktepe**	**Kadıköy**	**Ataşehir**	**Pendik**	**Maltepe**	**Sultanbeyli**	**Kartal**	**Tuzla**
PORTS	**Haydarpaşa**	65	32	41	12	16	35	12	18	41	22	26	27	33
	Beykoz	71	16	42	29	23	42	28	30	49	38	37	41	45
	Harem	64	51	40	11	15	34	11	18	40	21	25	26	32
	Kadıköy	68	35	44	25	19	38	16	21	44	26	29	31	36
	Bostancı	65	32	41	18	18	36	13	17	42	17	27	21	34
	Maltepe	67	33	43	20	20	37	15	18	41	14	28	14	33
	Kartal	92	64	69	51	51	58	47	48	53	47	48	40	45
	Pendik	68	39	44	27	26	33	22	24	28	22	24	15	20

Table B. 6 Travel Times Between the Ports and the Districts of the European Side (Minutes).

		DISTRICTS													
		Eyüp	**Sarıyer**	**Sultangazi**	**Şişli**	**Çatalca**	**Başakşehir**	**Gaziosmanpaşa**	**Kağıthane**	**Esenler**	**Beşiktaş**	**Arnavutköy**	**Silivri**	**Esenyurt**	**Bağcılar**
PORTS	**Ambarlı**	29	45	29	41	31	27	29	38	26	40	49	40	15	24
	Sarıyer	25	3	28	22	54	35	27	25	30	25	52	63	44	33
	İstinye	24	18	28	21	54	35	27	25	29	23	51	63	43	33
	Beşiktaş	16	26	27	21	51	31	26	16	25	12	12	60	40	29
	Kabataş	15	28	26	23	50	30	25	16	24	14	14	59	39	28
	Yenikapı	15	39	25	33	47	27	23	24	20	25	53	56	36	25
	Bakırköy	16	41	27	35	47	27	25	26	23	27	55	56	35	22
	Avcılar	30	51	34	46	36	32	34	40	31	41	54	45	20	30

Table B. 6 (Continued) Travel Times Between the Ports and the Districts of the European Side (Minutes).

		DISTRICTS										
		Bayrampaşa	**Beyoğlu**	**Büyükçekmece**	**Avcılar**	**Küçükçekmece**	**Bahçelievler**	**Güngören**	**Fatih**	**Beylikdüzü**	**Bakırköy**	**Zeytinburnu**
PORTS	**Ambarlı**	29	36	21	18	25	27	31	33	19	27	38
	Sarıyer	27	26	53	52	37	36	34	31	51	38	39
	İstinye	26	26	53	52	37	36	34	31	51	37	38
	Beşiktaş	18	10	50	45	34	29	26	16	48	29	27
	Kabataş	17	9	49	44	33	28	25	14	47	28	25
	Yenikapı	14	14	46	41	30	25	21	9	44	20	17
	Bakırköy	16	20	40	33	24	17	13	16	39	10	7
	Avcılar	30	37	26	18	22	32	37	33	24	25	36

Table B. 7 Travel Times Between the Main Sources and the İDO Ports According to the Ship Types (Minutes).

		İDO PORTS													
SHIPS	**MAIN SOURCES**	**Beykoz**	**Harem**	**Kadıköy**	**Bostancı**	**Maltepe**	**Kartal**	**Pendik**	**Sarıyer**	**İstinye**	**Beşiktaş**	**Kabataş**	**Yenikapı**	**Bakırköy**	**Avcılar**
Type 1	**Haydarpaşa P.**	44	12	12	28	38	50	62	50	38	20	20	20	36	64
	Ambarlı P.	94	70	72	84	90	102	114	92	88	72	68	62	48	18
	Container Ship	84	52	48	48	48	54	64	90	78	60	56	48	46	62
Type 2	**Haydarpaşa P.**	52	14	12	32	44	60	74	58	44	22	22	22	42	76
	Ambarlı P.	112	84	86	102	110	124	138	112	106	86	82	74	54	20
	Container Ship	102	62	58	58	58	66	78	108	94	72	68	58	54	74
Type 3	**Haydarpaşa P.**	42	12	12	28	36	50	60	48	36	20	18	20	34	62
	Ambarlı P.	90	68	70	82	88	100	110	90	86	70	66	60	44	18
	Container Ship	82	50	48	46	46	54	62	86	76	58	56	48	44	60
Type 4	**Haydarpaşa P.**	42	12	12	26	36	48	58	46	36	20	18	20	34	60
	Ambarlı P.	86	66	68	78	84	96	106	86	82	68	64	58	44	18
	Container Ship	78	48	46	44	44	52	60	84	72	56	54	46	42	58

Table B. 8 Maximum Number of Tours A Ship Type Can Make Between the Main Sources and the İDO Ports.

		İDO PORTS													
SHIPS	**MAIN SOURCES**	**Beykoz**	**Harem**	**Kadıköy**	**Bostancı**	**Maltepe**	**Kartal**	**Pendik**	**Sarıyer**	**İstinye**	**Beşiktaş**	**Kabataş**	**Yenikapı**	**Bakırköy**	**Avcılar**
Type 1	**Haydarpaşa P.**	32	120	120	51	37	28	23	28	37	72	72	72	50	22
	Ambarlı P.	15	20	20	17	16	14	12	15	16	20	21	23	30	80
	Container Ship	17	27	30	30	30	26	22	16	18	24	25	30	31	23
Type 2	**Haydarpaşa P.**	27	102	120	45	32	24	19	24	32	65	65	65	34	18
	Ambarlı P.	12	17	16	14	13	11	10	12	13	16	17	19	26	72
	Container Ship	14	23	24	24	24	21	18	13	15	20	21	24	26	19
Type 3	**Haydarpaşa P.**	34	120	120	51	40	28	24	30	40	72	80	72	42	23
	Ambarlı P.	16	21	20	17	16	14	13	16	16	20	21	24	32	80
	Container Ship	17	28	30	31	31	26	23	16	18	24	25	30	32	24
Type 4	**Haydarpaşa P.**	34	120	120	55	40	30	24	31	40	72	80	72	42	24
	Ambarlı P.	16	21	21	18	17	15	13	16	17	21	22	24	32	80
	Container Ship	18	30	31	32	32	27	24	17	20	25	26	31	34	24

Table B. 9 Maximum Transshipment Capacity of İDO Ports (Units of Relief Items).

İDO PORTS	MAX. CAPACITY
Beykoz	1,532,384
Harem	3,948,182
Kadıköy	4,089,820
Bostancı	2,343,208
Maltepe	1,994,678
Kartal	1,606,808
Pendik	1,368,122
Sarıyer	1,423,114
İstinye	1,715,406
Beşiktaş	2,744,336
Kabataş	2,888,228
Yenikapı	2,956,730
Bakırköy	2,501,506
Avcılar	2,974,790

APPENDICES C

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: Özkapıcı, Dilsu Binnaz

Nationality: Turkish (TC)

Date and Place of Birth: 26 June 1988, Afyon

Marital Status: Single

Phone: +90 506 831 48 75

email: dilsu.ozkapici@gmail.com

EDUCATION

Degree	**Institution**	**Year of Graduation**
M.Sc.	Çankaya University/ Industrial Engineering	2015
B.Sc.	Çankaya University/ Industrial Engineering	2010
High School	Hacı Ömer Tarman Anatolian High School, Ankara	2006

WORK EXPERIENCE

Year	**Place**	**Enrollment**
2010-present	Ministry of Foreign Affairs	Third Secretary

FOREIGN LANGUAGES

Advanced English, Medium Spanish.