PREPOSITIONING OF RELIEF ITEMS IN HUMANITARIAN LOGISTICS CONSIDERING LATERAL TRANSSHIPMENT OPPORTUNITIES

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ABSTRACT

PREPOSITIONING OF RELIEF ITEMS IN HUMANITARIAN LOGISTICS CONSIDERING LATERAL TRANSSHIPMENT OPPORTUNITIES

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Prepositioning of relief items has been studied in humanitarian logistics by several researchers. Lateral transshipment applications are observed in commercial supply chains, but have not been included into the humanitarian relief chains. The main objective of this thesis is to include lateral transshipment opportunities into humanitarian relief chains and examine the effect of different parameters with the aim of minimizing the average response time to serve the people in need.

In this study, location of humanitarian relief facilities, number of opened humanitarian relief facilities, quantity of relief items to hold at those facilities, quantity of lateral transshipment between opened facilities are determined by using mathematical programming models. Vulnerability of the roads and heterogeneous capacitated facilities are considered. Firstly, a direct shipment model is developed where lateral transshipment made between relief facilities is not allowed. Then, a lateral transshipment model is developed where lateral transshipment between relief facilities is allowed for relief item distribution. Direct shipment and lateral transshipment models are compared using a possible earthquake scenario generated for İstanbul with respect to the average distance travelled per relief item in two models. It is seen that allowing lateral transshipment provides faster response time to reach the affected. In lateral transshipment model, transportation on highways is studied for Anatolian and European sides as separately. By allowing lateral transshipment on seaway between Anatolian and European sides, maritime lateral transshipment model is developed. Lateral transshipment model is compared with maritime lateral transshipment model with respect to the value of average distance travelled per relief item. It is observed that opening 20 and more than 20 relief facilities give lower average distance travelled value per relief item for maritime lateral transshipment model compared to the lateral transshipment model based on land transportation.

Key Words: Humanitarian relief logistics, lateral transshipment, facility location, vulnerability

ÖZ

YANAL SEVKİYAT UYGULAMALARINI DEĞERLENDİREREK İNSANİ YARDIM MALZEMELERİNİN İNSANİ LOJİSTİK AĞLARINDA ÖN KONUMLANDIRMASI

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İnsani lojistik ağlarında yardım malzemelerinin ön konumlandırması birçok araştırmacı tarafından çalışılmıştır. Yanal sevkiyat uygulamaları ticari tedarik zincirlerinde gözlemlenmiştir; fakat insani yardım ağlarına dâhil edilmemiştir. Bu tez çalışmasının temel amacı yanal sevkiyat uygulamalarını insani yardım ağlarına dâhil etmek ve farklı parametrelerin etkilerini yardım malzemelerinin afetzedelere ulaşması için geçen sürenin en aza indirgenmesi amacı üzerinde incelemektir.

Bu çalışmada, insani yardım merkezlerinin yerlerine, en uygun insani yardım merkezi sayısına, bu merkezlerde tutulacak olan insani yardım malzemesinin miktarına, açılmış olan merkezler arasında yapılan yanal sevkiyat miktarına matematiksel modelleme yöntemi ile yolların hasar görebilirliği ve farklı kapasiteye sahip yardım merkezleri göz önünde bulundurularak karar verilmektedir. İlk olarak insani yardım merkezleri arasında yanal sevkiyata izin vermeyen direkt sevkiyat modeli geliştirilmiştir. Sonrasında yanal sevkiyat modeli geliştirilmiş ve bu model ile insani yardım malzemesi dağıtımında insani yardım merkezleri arasında yanal sevkiyata izin verilmiştir. Direkt sevkiyat ve yanal sevkiyat modelleri İstanbul’da yaşanabilecek olası bir deprem senaryosu üzerinde insani yardım malzemelerinin afetzedelere ulaşmak için kat ettiği ortalama mesafe değerleri baz alınarak karşılaştırılmıştır. İnsani yardım merkezleri arasında yanal sevkiyata izin vermenin afetzedelere daha hızlı ulaşmayı sağladığı görülmüştür. Yanal sevkiyat modelinde yanal sevkiyat Anadolu ve Avrupa yakasında ayrı ayrı karayoluyla gerçekleştirilecek şekilde çalışılmıştır. Anadolu ve Avrupa yakası arasında deniz yoluyla yanal sevkiyat uygulamasına izin verilerek deniz yoluyla yanal sevkiyat modeli geliştirilmiştir. Deniz yoluyla yanal sevkiyat modeli yanal sevkiyat modeli ile insani yardım malzemelerinin afetzedelere ulaşmak için kat ettiği ortalama mesafe değerlerine gore kıyaslanmıştır. Açılan insani yardım merkezi sayısının 20 ve daha fazla olmasının deniz yoluyla yanal sevkiyat modelinin karayolu üzerinden yanal sevkiyat gerçekleştiren yanal sevkiyat modeline kıyasla insani yardım malzemelerinin afetzedelere ulaşmak için kat ettiği ortalama mesafe değerlerini daha düşük verdiği gözlemlenmiştir.

Anahtar Kelimeler: İnsani yardım lojistiği, yanal sevkiyat, tesis konumlandırma, hasar görebilirlik.

To my wife, Ayşe

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LIST OF ABBREVIATIONS

JICA	Japan International Cooperation Agency
İDO	İstanbul Deniz Otobüsleri
LTSP	Lateral Transshipment between Supply Points
MLTSP	Maritime Lateral Transshipment between Supply Points
DT	Direct Shipment
RF	Relief Facility
CRED	Centre for Research on the Epidemiology of Disasters
IMM	İstanbul Metropolitan Municipality
NGO	Non-governmental Organization
CARE	Cooperative for Assistance and Relief

CHAPTER 1

INTRODUCTION

A disaster is defined as "an unforeseen and often sudden event that causes great damage, destruction and human suffering with at least ten people reported killed, 100 people reported affected, a declaration of a state of emergency, and a call for international assistance" [1]. Several floods, earthquakes, tsunamis following earthquakes, famines, or refugee crises were observed all over the world in the last two decades. From 2003 to 2012, an annual average of 106,654 people were reported dead, more than 216 million people were reported to be affected by disasters, and close to $157 billion worth of economic damage was reported [2]. These facts revealed the importance of disaster management in mitigating the negative effects of the disaster.

Humanitarian logistics, which plays a key role in every stage of disaster relief operations, is defined as "the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from point of origin to point of consumption for the purpose of meeting the end beneficiary's requirements" [3]. When a state of emergency is declared and aid is appealed, resources such as relief personnel, relief goods and equipment are mobilized to the disaster location. By its definition, mobilization of resources as well as its predecessor and successor operations in a relief chain [4] can be categorized as humanitarian logistics, which contributes to more than 80% of the total relief costs [5]. Although local government of the disaster location is the main authority responsible to alleviate the suffering of people [6], non-governmental organizations (NGOs) as well as other relief aid agencies offer their help to transport the right number of relief goods on time to the right place. NGOs and relief aid agencies spend about $20 billion annually to overcome those challenges [7].

The practice of allowing horizontal transportation within the same echelon is called lateral transshipment [8] and is mostly used for low demand, high value items where emergency orders are allowed [9], [10]. In order for lateral transshipments to be cost effective, inventory holding cost should be higher than the emergency transportation cost. The situation is pictured as follows for commercial logistics. A retailer normally replenishes its demand from the warehouse. Under some certain conditions (e.g. emergency), some retailers might have certain types of items, some might have other types on hand. In these models, as a cure to the burden of waiting for the next regular warehouse shipment or placing emergency orders with high cost to the warehouse, transshipments from other retailers with adequate inventory are proposed. So, retailers face two sources of demand (customers, other retailers) and two sources of supply (warehouse, other retailers) [8]. Inspired from the emergency nature of lateral transshipment decisions in commercial logistics, lateral transshipment in humanitarian logistics can be a viable alternative to alleviate the suffering of beneficiaries within the shortest time possible. Lateral transshipment in humanitarian logistics happens when aid distribution centers transfer relief items among themselves when they cannot satisfy the immediate need of beneficiaries from their own inventory. The scope of our study is to propose an integrated model for facility location and transportation decisions including lateral transshipment applications.

In Chapter 2, a literature review is presented. Firstly, the related studies in disaster management and emergency response are mentioned and then we focus on the studies in lateral transshipment applications in supply chain management. In Chapter 3, the problem is described in detail and assumptions are presented. In Chapter 4, the mathematical model formulations are explained. In Chapter 5, results of the experimental studies are provided. In Chapter 6, we conclude with our major findings and possible future research directions.

CHAPTER 2

LITERATURE REVIEW

Literature on disaster management is limited when compared to other classical problems of Operations Research. However, it has proliferated in recent years. We analyze the related literature in two sections. Firstly, in Section 2.1 we mention studies on the logistics problems faced in disaster management and emergency response operations. Secondly, in Section 2.2 we describe studies in the lateral transshipment applications in commercial supply chain management.

2.1 Disaster Management and Emergency Response

Mitigation, preparedness, response and recovery are considered as the four phases of disaster management [11]. In the mitigation phase, individuals are trained to deal with disaster situations and settlement planning decisions are taken. The preparedness phase focuses on preparing equipment and procedures for use when a disaster occurs to reduce its impact. In the response phase, activities related to fulfilling the basic humanitarian needs of the affected population are performed. Finally, in the recovery phase, reconstruction is performed to bring the affected area back to normal life.

In disaster management literature, authors usually study on specific regions that suffer from disasters. Japan International Cooperation Agency (JICA) [12] prepares a comprehensive earthquake preparedness plan for possible earthquake scenario generated for Istanbul. Social and physical condition of the city such as population of districts, potential damage estimations for each district, seismic analysis for the city, vulnerability of roads are investigated. In addition, emergency road network, crisis management centers are provided.

Günneç [13] proposes a facility location model for locating emergency response and distribution centers in İstanbul. Authors use a set of scenarios and a set of commodities with specified weights indicating their importance. In addition, a service level concept is employed by enforcing an upper bound on the service distance. As it is the case in many scenario-based approaches, the objective is the minimization of the expected total weighted distance over all scenarios and there is a set of constraints in each scenario. In this study, authors study with multiple demand points and facilities are uncapacitated.

Balcik and Beamon [14] propose a scenario-based model with service levels to determine the number and the location of distribution centers in a relief network. In addition to the locations of the facilities, they also determine the amount of each relief commodity stored at each facility. In their formulation, they consider a single demand point and a set of capacitated supplier locations where the suppliers need to neither have the same capacity, nor supply the same commodities. They differentiate between commodities by assigning a criticality weight to each commodity. Then, the objective is to maximize the total expected demand covered by the located facilities. Here, the weights are determined by the criticality of the commodity and the quality of the service. Scenarios are incorporated such that the model satisfies a set of constraints for each scenario and the expected value over all scenarios is considered in the objective function.

Apart from the studies on the facility location problem in disaster response, Barbarosoğlu and Arda [15] provide a two-stage stochastic programming framework for transportation planning for disaster response in İstanbul. In this study, they consider a stochastic demand. Moreover, the capacities of the arcs in the road network and the supply amounts are considered to be random. First stage decisions are made before the scenarios are realized, while the second stage decisions are made based on the realized scenario. Hence, the number of two stage models to be solved is equal to the number of scenarios.

Duran et al. [16] study inventory pre-positioning in humanitarian logistics. The system described in the study includes 12 potential warehouse locations determined by CARE International, 7 relief items to be distributed and 22 demand locations taken from United Nation's 22 sub-regions. They develop a mathematical model to obtain the configuration of the supply network that minimizes the average response time over all the demand distances and decide which warehouse to open and how to allocate the inventory among them. Demand instances are obtained from historical data. For the calculation of demand instances, authors calculate the time between two disaster occurrences by using start and end date of each disaster. Then the disaster data is grouped into instances which includes disasters occurred in two-week time periods. Each demand instance consists of demand quantities for different relief items at one or more demand points.

Özkapıcı [17] studies the problem of locating disaster response and relief facilities in the city of Istanbul considering Bosphorus strait. The author includes maritime transportation for relief item distribution in İstanbul. Two main ports and a container ship located on the Marmara Sea are considered as main supply facilities. From these supply facilities relief items can be transported directly to demand locations by land vehicles. In addition to land transportation, relief items are sent from supply facilities to sea ports by maritime transportation and then by using land vehicles items reaching sea ports are sent to demand locations. Afterwards, relief item distribution system developed by Özkapıcı [17] is compared with the relief item distribution system where only land transportation is used. The author concludes that including maritime transportation into the relief item distribution system provides a more flexible humanitarian logistics system for İstanbul.

2.2 Lateral Transshipment Applications in Commercial Supply Chains

In this section, studies on the lateral transshipment applications that are not necessarily related to disaster response, but have some common characteristics to our problem are presented. Some of these characteristics are the uncertainty in demand, existence of possible future states, and uncertainty in the number of facilities to be established. These characteristics are related to the uncertainty in the time and the effect of a disaster.

There are practices of lateral transshipment applications generally in commercial logistics in which low demand is observed, high value items are stored and emergency orders are allowed [9], [10]. In these models, instead of waiting for the next shipment from the warehouse, any retailer can satisfy its requirement from neighbor retailers. As a result, each retailer has to satisfy demand of both customers and neighbor retailers assigned to that retailer [8].

Lee [18] states that multi-echelon inventory systems are usually used to provide service support for products whose customers are distributed over an extensive geographical region. Continuous review monitoring of inventory and one-for-one replenishment policy is used in the system author dealt with. Also in that system emergency lateral transshipment times are substantially lower than the normal resupply times. The author shows that by using emergency lateral transshipment, high service level can be obtained with reducing the expected inventory level and expected cost of backorder while incurring extra transportation cost. Also the author states that with emergency lateral transshipments, less stock is needed at the bases, since inventory sharing is possible at the base level. Finally the author concludes that the problem of whether emergency lateral transshipment should be used or not depends on the magnitudes of the costs and the lead times of transshipments.

Axsäter [8], [19], [20] develops models in a similar environment as Lee [18] does. The author assumes Poisson demand distribution and bases are divided into a number of groups and emergency lateral transshipments are allowed with in a group but not between the groups. The author determines the portion of demand that would be met immediately, met by lateral transshipment or is backordered. The characteristic approach the author used is that the demand rate at the base depends on the inventory situation.

Wong [9] deals with the analysis of a multi-item, continuous review model of two-location inventory system for repairable spare parts used for expensive technical systems with high target availability levels. Lateral and emergency shipments occur in response to stock-outs. A continuous review base stock policy is assumed for the inventory control of spare parts. The objective of the study is to minimize the total costs for inventory holding, lateral transshipments and emergency shipments subject to a target level for the average waiting time per demanded part at each of the two locations. A solution procedure based on Lagrangian relaxation is developed to obtain both a lower bound and an upper bound on the optimal total cost.

Kutanoğlu and Mohajan [10] study an inventory sharing optimization problem and find a set of stocking levels at the local warehouses that meet all the time-based service level constraints at minimum total cost including inventory holding cost, transportation cost and penalty cost due to lost demand. In their study time-based service level is defined as the percentage of demand satisfied within a certain time window and it is defined as a system wide measure that includes all the warehouses and hence is a function of stock levels and customer demands of all warehouses. Time-based service level depends not only on item availability but also on distances between warehouses and customers. Authors use time based service levels as performance measure instead of fill rate due to fact that fill rate does not capture the time taken to satisfy the demand.

Reyes et al. [21] prove that lateral transshipment in a disaster relief system is more efficient using a simulation model based on system dynamics. Mulyono and Ishida [22] build a logistics and inventory model using probabilistic cellular automata for the enterprise inventory model and self-repair network model, which is applicable to humanitarian relief situations.

In the literature examined so far, lateral transshipment applications are not utilized in detail for humanitarian logistics. As explained above, lateral transshipment applications are used for commercial supply chains where highly valued items are stocked and low rate of demand is observed. It is also seen that lateral transshipment helps satisfying the emergency orders without waiting the replenishment of stocks of warehouses in commercial supply chains. In humanitarian logistics satisfying the requirement of the affected as soon as possible is crucial. Using lateral transhipment can help the affected to obtain relief items faster. Addressing the literature gap of lateral transshipment in humanitarian logistics has not been analysed thoroughly and observing the benefit of lateral transshipment applications for satisfying the emergency orders in commercial supply chains, the main objective of this study is to investigate whether lateral transshipment in humanitarian logistics decrease the average distance travelled per relief item when the vulnerability effect of roads between relief facility pairs and between relief facilities and demand locations are considered. While investigating the effect of lateral transshipment in humanitarian logistics, we study in an environment where capacity of each relief facility is different from each other.

CHAPTER 3

PROBLEM DEFINITION

In this chapter, a detailed discussion on the proposed relief item distribution system is presented in Section 3.1. Then, in Section 3.2, sources of the data used are described and finally, the assumptions are presented in Section 3.3.

3.1 System Description

The problem on hand requires determination of the locations for relief facilities. The locations of these facilities are selected from a potential set of available locations. While determining the locations of these facilities, demand regions are also considered and allocated to the selected facilities. A distribution system with two echelons is suggested. In the upper echelon relief facilities used for storing relief items are established. In the lower echelon demand locations are established. Each demand location is assigned to one relief facility and relief items are transported from relief facilities to demand locations assigned to that relief facility. We call this type of material shipment as direct shipment. Also lateral transshipment between relief facilities are possible in the case of out of stock situations. In such a case any relief facility can engage in lateral transshipment with possible neighbor relief facility. We call this type of material shipment as lateral transshipment. In this type of material shipment any relief facility can satisfy demand of any demand location assigned to it by using excess stock of neighbor relief facility. It is noted that in case of lateral transshipment, relief item is shipped from neighbor relief facility to relief facility which is out of stock and then it is sent to a demand location. The relief item is not shipped directly from neighbor relief facility to demand location assigned to any other relief facility which is out of stock. The main reason for this type of relief item flow is to ease of the management of relief item flow in the demand location. Each demand location takes all required relief item through just one relief facility. It helps authorities to organize the flow of relief items better in demand location to supply relief items to the affected. In Figure 3.1, the suggested distribution system of relief item flow is presented.

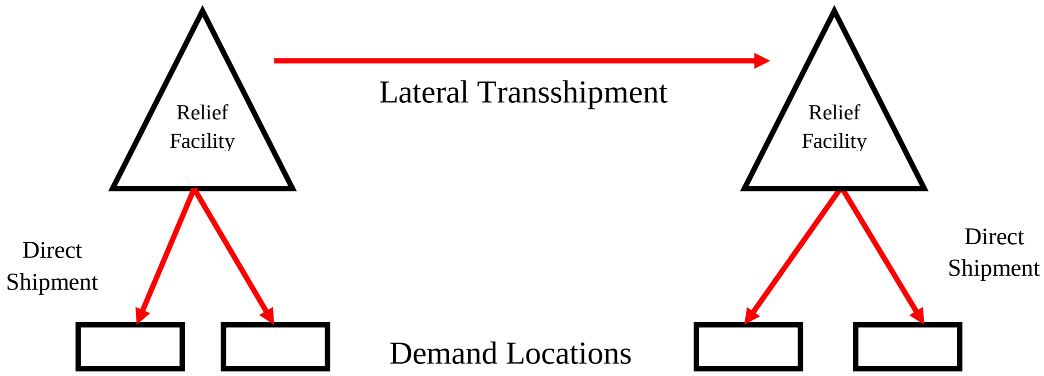

Figure 3.1: Relief Item Flow in the Distribution System

3.2 Sources of Data

Basic data we need is taken from JICA Report [12], and Özkapıcı [18]. How we update all of these data is explained below in detail. JICA report states four different earthquake scenarios for Istanbul. These scenarios are as follows:

- Scenario A: This scenario is suggested to be the most probable scenario. Its magnitude is estimated to be 7.5 on the Richter scale.
- Scenario B: The magnitude of this scenario is estimated to be 7.4 on the Richter scale.
- Scenario C: This is the worst case scenario. Its magnitude is estimated to be 7.7 on the Richter scale.
- Scenario D: The magnitude of this scenario is estimated to be 6.9 on the Richter scale.

In the JICA report, the effects of the earthquake in terms of the number of damaged buildings and the number of affected people are estimated for scenarios A and C only. In our analysis, we use the data for scenario A which is stated as the most probable scenario.

3.2.1 Demand Locations

In the JICA report damage estimation and refugee population are provided based on districts of İstanbul. As a result, districts of İstanbul are taken as demand locations. There are 39 districts in İstanbul. However, we do not consider Şile as a demand location due to the fact that the damage estimation is not provided in the JICA report. Adalar is also not considered due to having very low population density compared to other districts. As a result, we studied 37 demand locations. The map of districts of İstanbul is illustrated in Figure 3.2. For each district, district center point is obtained and represented with a single coordinate (N°; E°) calculated as the weighted average of the coordinates of its neighborhoods. The coordinates of the center points of districts are provided in Appendix A. In order to find the coordinate of a center point of district, coordinates and populations of its neighborhoods are obtained. The coordinate of each neighborhood is taken as the coordinate of the mukhtar office belonging to that neighborhood. Then, the coordinate of a district is calculated by taking the weighted average of coordinates of its neighborhoods, where the weights are populations of neighborhoods.

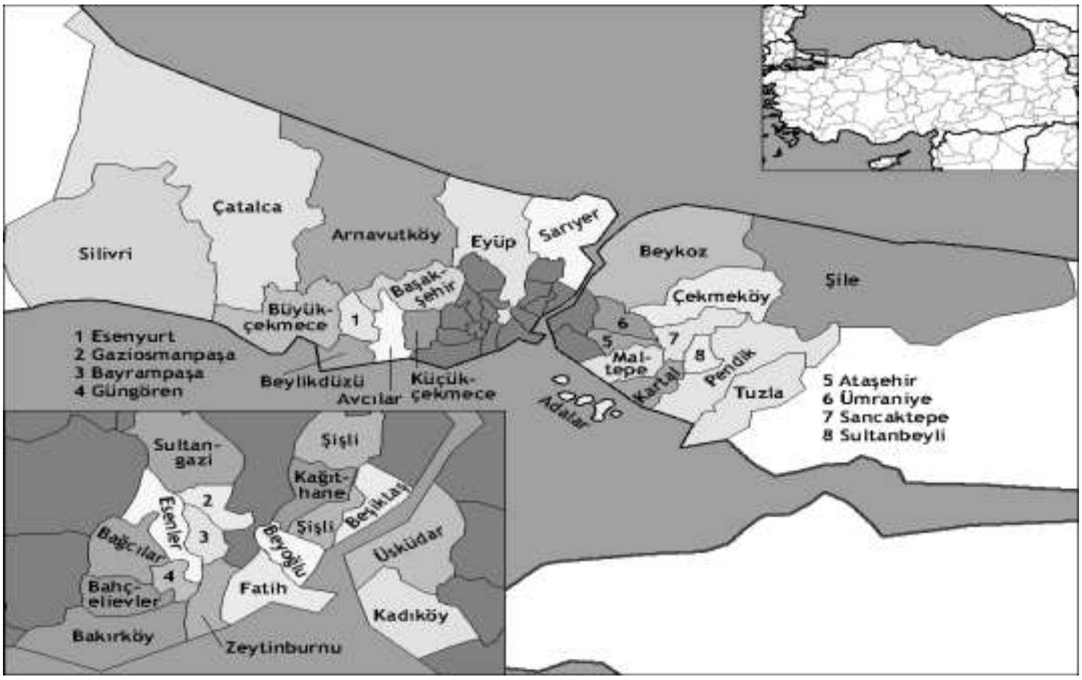

Figure3.2: Map of the Districts of İstanbul

3.2.2 Potential Relief Facility Locations

Similarly, there are 37 potential relief facility locations which are the same as demand locations. The capacities of potential facility locations are estimated from available public school buildings. As a result, the capacity of each relief facility is different from each other.

3.2.3 Demand

JICA report states the possible number of heavily, moderately and partly damaged buildings for each district. By using Formula 3.1, for each district the number of people living in one building is calculated.

$$A = \frac{population\ of\ district}{number\ of\ buildings\ in\ district} \qquad (3.1)$$

The data of population of districts in the above formulation are taken from the Turkish Statistical Institute [23] and shown in Appendix B.

The number of people affected from the earthquake in each district is calculated by using Formula 3.2.

$$Number\ of\ affected\ people =$$

$$= \quad A * 100\%\ of\ number\ of\ heavily\ damaged\ buildings + A * 50\%\ of\ number\ of\ moderately\ damaged\ buildings + A * 10\%\ of\ number\ of\ partly\ damaged\ buildings \qquad (3.2)$$

The number of relief items needed in each district is calculated by Formula 3.3. It is assumed that relief item is delivered to each family of four people. As a result, formulation includes a multiplication by 0.25.

$$Number\ of\ relief\ items\ required\ (demand_{2002}) =$$

$$= 0.25 * number\ of\ affected\ people\ in\ that\ district \qquad (3.3)$$

Actually the demand calculated above is according to the 2002 when 30 districts existed. However in 2008, IMM set 8 new districts and 1 district was abolished.

The demand data based on 2012 is obtained for the demand locations remain unchanged by Formula 3.4

$$Number\ of\ relief\ items\ required\ (demand_{2012}) =$$

$$= \frac{\text{Population of district in 2012}}{\text{population of district in 2002}} * demand_{2002} \qquad (3.4)$$

The demand data for demand locations from which some of neighborhoods are separated are calculated as follows. Firstly, the population of neighborhoods separated from that demand location is determined for 2002. Then by using Formula 3.5 the number of relief items required for separated neighborhoods are determined for 2002.

No. of relief items required for separated neighborhoods (separated demand$_{2002}$) =

$$= \frac{\text{Population of separated neighborhoods in 2002}}{\text{population of demand location in 2002}} * demand_{2002} \qquad (3.5)$$

The number of relief items required for demand location after related neighborhoods are separated is determined by Formula 3.6;

Number of relief items required at demand location after related neighborhoods are separated (after separation left demand$_{2002}$) = B

$$\text{B} \quad = 1 - (separated\ demand_{2002}) \qquad (3.6)$$

After related neighborhoods are separated from that demand location, the number of relief items required for that demand location is calculated for 2002. This data is updated by Formula 3.7 for 2012.

(after separation left demand$_{2012}$) =

$$= B* \frac{\text{population of demand location in 2012}}{\text{population of demand location in 2002 after related neighborhoods are seperated}} \ (3.7)$$

Finally, the demand data (the number of relief items required) of demand locations from which some of neighborhoods are separated is determined.

The demand data for new demand locations are calculated as follows. Firstly, each neighborhood separated from other demand locations and included in that new demand location is determined. The number of relief item required at each separated neighborhood is explained above. By summing up the number of relief item required at each neighborhood included to that new demand location, the number of relief items required at that new demand location is determined. By multiplying that value by the ratio of population value of 2012 to 2002, the demand data in 2012 for new demand locations is obtained. The number of relief items required at each demand location (district) is provided in Appendix B.

3.2.4 Allowed Maximum Distance Travelled of Relief Item

Travel time of relief item in the system is restricted to ensure that in a determined time interval the relief item reaches to the affected. Maximum travel time is restricted to 1 and 2 hours. Under the assumption that maximum velocity of vehicle in the city is 40 km, maximum distance of relief item is restricted to 40 and 80 km in the city. For each side of the city relief item has to be reached to refugees in maximum 1 or 2 hours due to the fact that shipping relief items to the affected as soon as possible is highly critical to save lives.

3.2.5 Vulnerability

Vulnerability of the roads between demand locations and relief facilities and between relief facility pairs are determined according to the road blockage probability of roads of 7 to 15 meters wide obtained from JICA report. Figure 3.3 points to roads with probability of road blockage of 0.5 and over, between 0.3 and 0.5, between 0.2 and 0.3, between 0.1 and 0.2, between 0.05 and 1 and between 0-0.05. Here, 1 indicates the highest risk of blockage and 0 indicates the lowest risk of blockage. For each colour, vulnerability coefficient is determined and shown in Table 3.1 for different vulnerability cases.

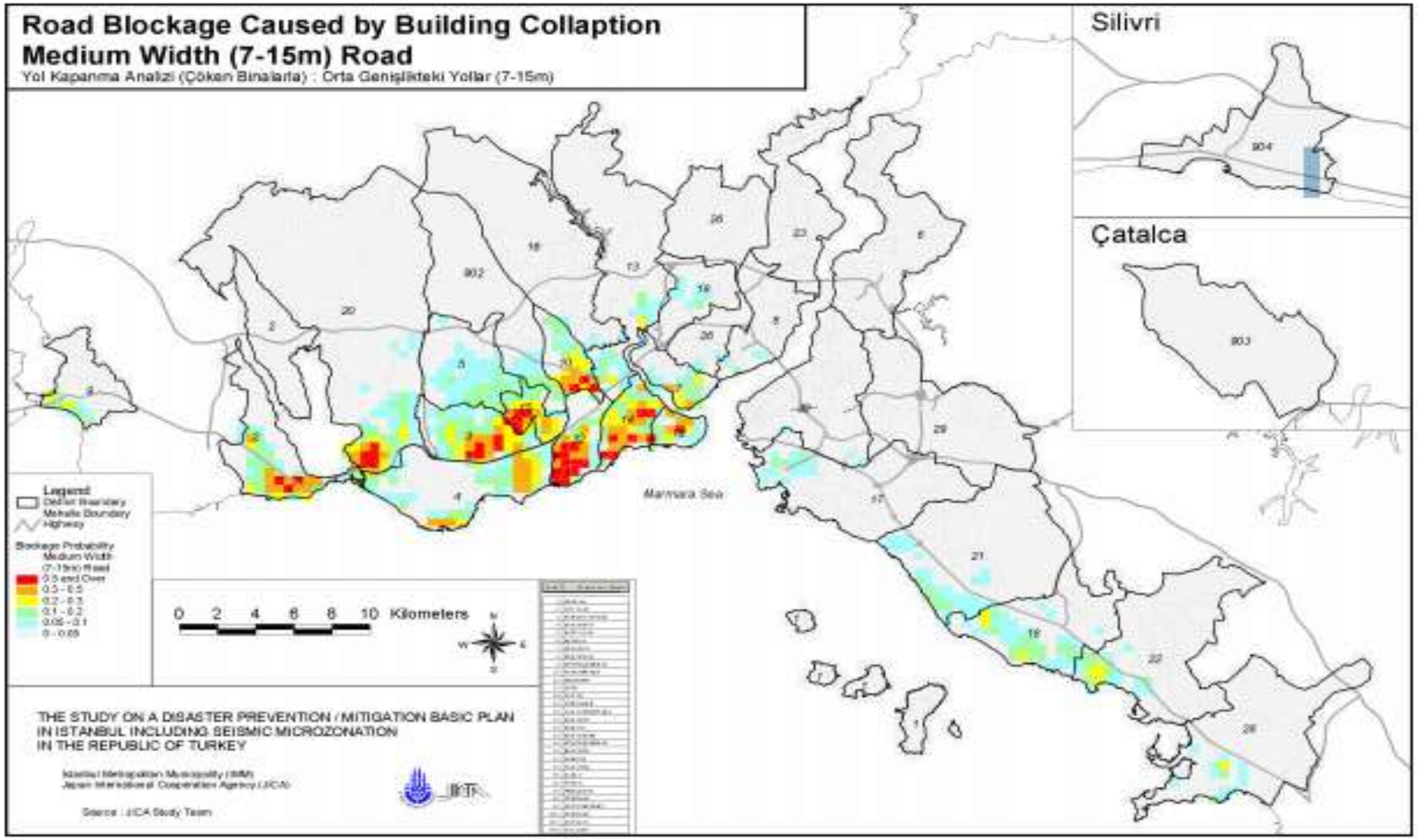

Figure 3.3: Road Blockage Caused by Building Collaption Medium Width (7-15m) Road (taken from JICA report [12])

Table 3.1: Vulnerability Coefficient of Each Colour for Different Vulnerability Cases

	Vulnerability Coefficient		
	Low Vulnerability	*Average Vulnerability*	*High Vulnerability*
Red	0.50	0.75	0.99
Orange	0.30	0.40	0.50
Yellow	0.20	0.25	0.30
Green	0.10	0.15	0.20
Blue	0.05	0.075	0.10
Grey	0	0.025	0.05

Vulnerability coefficients between demand locations and relief facilities and between each pair of relief facilities are provided in Appendix C.

To calculate the vulnerability coefficient of each path between the demand location and relief facility and between relief facility pairs, emergency road network proposed by the JICA report is used. In Figure 3.4 proposed emergency road network is shown. This proposed emergency network is put on the map of the road blockage caused by building collaption medium width road. The map shown in Figure 3.3 is divided into equal squares. Shortest path is determined on the emergency road network for each pair of district by using Google Maps. Then the numbers of red, orange, yellow, green, blue and grey squares are counted on that path. The vulnerability of that path is calculated by Formula 3.8.

Vulnerability of the path =

*= [(# of red squares * coefficient of red square) + (# of orange squares * coefficient of orange square) + (# of yellow squares * coefficient of yellow square) + (# of green squares * coefficient of green square) + (# of blue squares * coefficient of blue square) + (# of grey squares * coefficient of grey square)] / (# of total squares on the path)* (3.8)

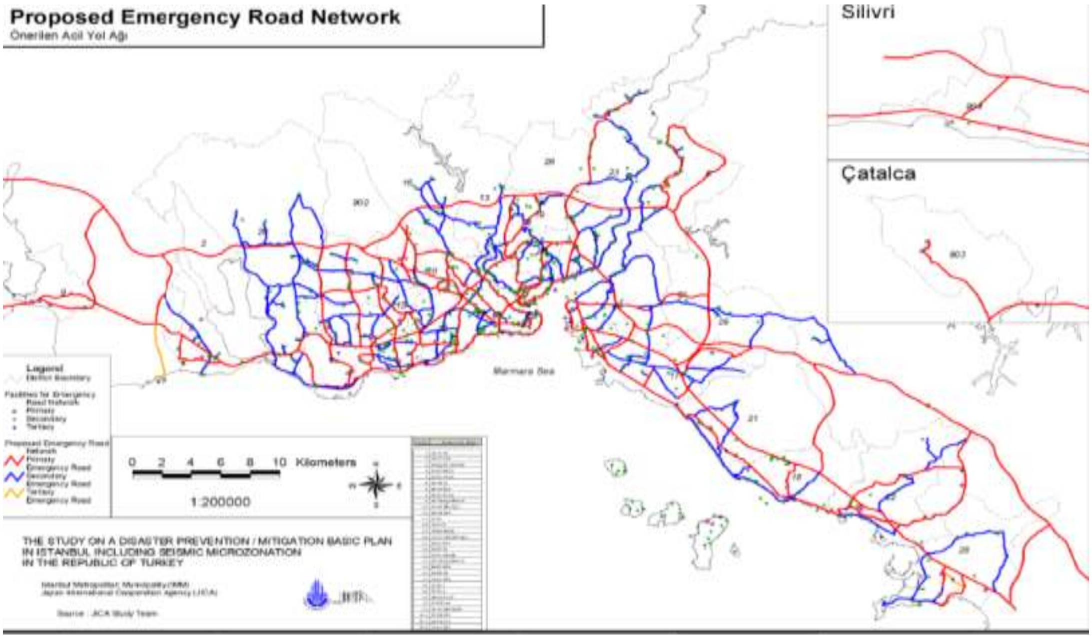

Figure 3.4: Emergency Road Network Proposed by JICA Report

3.2.6 Distance

Distances between relief facilities and demand locations and between relief facility pairs are obtained from Google Maps. The shortest distance between two points is selected from alternatives given by Google Maps. Appendix D presents the distance between relief facilities and the distance between relief facilities and demand locations.

3.2.7 Maximum Number of People That Can Be Served from a School Class

The number of classes in public schools in each district is used to determine the capacity of relief facilities. The number of classes in public schools in each district is shown in Appendix B. The capacity of each candidate relief facility is different from each other due to the fact that the number of classes in public schools in each district is different. Formula 3.9 is developed to find parameter A(P), maximum number of people can be served from a school class, considering maximum number of facilities that can be opened (P).

$$A(P) = \frac{\text{Total number of refugees in demand locations}}{\left\{\frac{\text{Total number of school classes available in districts}*0.9}{37}\right\} * P} \tag{3.9}$$

Since it is not known which relief facilities are opened, for each school class equal average number of people is calculated to be served in Formula 3.9. Total number of school classes available in districts is multiplied by 0.9 due to the assumption that 10% of the school classes are damaged during disaster.

For example, in the case of maximum number of facilities that can be opened is equal to 5, maximum number of people can be served from a school class is

$$A(\,5) = \frac{2027647}{\left\{\frac{61201*0.9}{37}\right\} * 5} = 272 \text{ people}$$

A(P) parameter increases with decreasing maximum number of facilities. The value of A(P) ranges between 681 to 36 when numbers of open relief facilities are equal to 2 and 37, respectively.

3.3 Assumptions

In the model development phase basic assumptions made are as follows:

1) There is no material shipment between Anatolian side and European side of İstanbul.
2) The geographical coordinates of mukhtar offices of neighborhoods are taken as the geographical coordinates of the neighborhoods.
3) For each relief facility, it is allowed to use only one neighbor relief facility for lateral transshipment.
4) From districts of İstanbul, shown in Figure 3.2, Adalar and Şile are excluded.

5) One standard "relief item package" is delivered to each family of four people. This package contains bottles of water and food cans.
6) Relief facilities are willing to release true information about their inventory position to other relief facilities.
7) School classes can only use 90% of their capacities due to damage probability.
8) The relief items are carried by trucks with an average speed of 40 km/h.
9) Capacity of land vehicles is ignored.
10) Single relief facility is assigned to each demand location.

For assumption (1), it is known that two bridges, Boğaziçi Bridge and Fatih Sultan Mehmet Bridge, connect Anatolian side to European side. In case of an earthquake bridges are very prone to damage. Therefore, we allow material flow within Anatolian and European side but not between them. For assumption (3) the basic reason of making such assumption is to help authorities to organize the flow of relief items better. Since damage estimation of Şile cannot be obtained and since population density of Adalar is very low compared to other districts, assumption (4) is used. Assumption (6) is required for lateral transshipment between different relief facilities, otherwise a central authority who knows the inventory position for all relief facilities is needed and relief facilities requesting items would appeal them from this central authority. Assumption (7) is used for the risk of damage of schools during an earthquake. Since after the earthquake the chaotic environment is expected to bring bad road conditions and unorganized urban behavior assumption (8) is set. Before the earthquake hits the region, it is assumed that sufficient number of trucks is prepared by assumption (9).

CHAPTER 4

MATHEMATICAL MODEL

In this chapter, the mathematical model is introduced to determine the location of relief facilities, amount of relief items that should be held at those relief facilities and the amount of lateral transshipment made between relief facilities. While determining these decision variables, number of relief facilities to open, vulnerability factor between each relief facility pairs and between relief facilities and demand locations, distance between relief facilities and between demand locations and relief facilities, number of school classes existing at each demand location, number of relief item required at each demand location and maximum distance traveled by the relief item are used as parameters in the model. The related notation of the MIP model is given below:

4.1 Model with Direct Shipment (DT)

Index Sets:

I set of possible relief facilities,

J set of demand locations.

Decision Variables:

$$y_i : \begin{cases} 1, & \text{if relief facility } i \text{ is opened,} \\ 0, & otherwise. \end{cases}$$

m_{ij} : $\begin{cases} 1, & \text{if demand location } j \text{ is assigned to relief facility } i, \\ 0, & otherwise. \end{cases}$

q_i : Quantity of relief item held at relief facility *i*,

x_{ij} : Quantity of relief item sent to demand point *j* from relief facility *i*.

Parameters:

W: A big number, taken as 1000000,

N : Quantity of relief items required by a beneficiary at demand point, (N=0.25, one relief item for family of four people)

P: Maximum number of relief facilities to open,

R: Maximum distance for a relief item to travel,

v_{ij} : Vulnerability factor between relief facility *i* and demand location *j*,

d_j : Number of people affected at demand location *j*,

c_i : Number of school classes available on relief facility *i*,

r_{ij} : Distance between relief facility *i* and demand location *j*.

DT Model:

$$\text{Minimize} \quad \frac{\sum_{i\in I}\sum_{j\in J}\left[x_{ij} * r_{ij} * \left(1 + v_{ij}\right)\right]}{\sum_{j\in J} (d_j * N)} \qquad (1)$$

subject to

$\sum_{i \in I} x_{ij} \geq d_j * N$ $\quad j \in J \quad (2)$

$r_{ij} * m_{ij} \leq R$ $\quad i \in I, j \in J \quad (3)$

$$\sum_{j \in J} x_{ij} \leq q_i \qquad i \in I \qquad (4)$$

$$\sum_{i \in I} y_i \leq P \qquad (5)$$

$$\sum_{i \in I} m_{ij} = 1 \qquad j \in J \qquad (6)$$

$$\sum_{j \in J} m_{ij} \leq W * y_i \qquad i \in I \qquad (7)$$

$$x_{ij} \leq W * m_{ij} \qquad i \in I, j \in J \qquad (8)$$

$$q_i \leq y_i * c_i * N * A(P) \qquad i \in I \qquad (9)$$

$$\sum_{i \in I} q_i \leq \left\{ \sum_{j \in J} d_j \right\} * N * 1.01 \qquad (10)$$

$$x_{ij}, q_i \geq 0 \qquad i \in I, j \in J \qquad (11)$$

$$y_i, m_{ij} \in \{0,1\} \qquad i \in I, j \in J \qquad (12)$$

The objective function (1) minimizes the average distance travelled per the relief item. Vulnerabilities of the routes affect the distances by inflating them. The formulation to calculate the vulnerability effect on distances is given below.

$$\text{Distance} = \text{Original distance} \times (1 + \text{Vulnerability}) \qquad (4.1)$$

As indicated in Formula (4.1), original distance of a route is inflated by the proportion of the vulnerability of that route.

Constraint (2) ensures that demand for relief items is met. With Constraint (3), relief items do not travel more than *R*, and the relief items sent do not exceed the respective inventory held at the relief facility *i* via Constraint (4). Via Constraint (5) at most *P* relief facilities can be opened. Constraints (6-8) makes sure that each demand location *i* is assigned to only one relief facility, a demand location can be assigned to a relief facility that is opened and relief items cannot be sent from a relief facility to a demand location unless that demand location is assigned to that relief facility. Constraint set (9) imposes a different upper bound on the maximum number of people can be served from each relief facility given maximum number of facility can be opened is *P*. Assuming that the total capacity of the facilities is 101% of total demand, Constraint (10) is added.

4.2 The Model with Direct Shipment and Lateral Transshipment between Supply Points (LTSP)

In this section the mathematical model with lateral transshipment between supply points is introduced. Relief facility visited for lateral transshipment is denoted as i' under the set *I*.

The following new parameters are added to the mathematical model:

$r_{i'j}$: the travel distance between relief facilities i' and demand location j,

$r_{i'i}$: the travel distance between relief facilities i' and relief facility i,

$v_{i'j}$: vulnerability factor between relief facilities i' and demand location j,

$v_{i'i}$: vulnerability factor between relief facilities i' and relief facility i.

The following new decision variables are added to the mathematical model:

$t_{ii'j}$: $\begin{cases} 1, & \text{if relief facilities } i \text{ and } i' \text{ engages in lateral transhipment for demand location } j, \\ 0, & otherwise. \end{cases}$

$\bar{x}_{ii'j}$: quantity of relief item sent to demand location j from relief facility i through relief facility i'.

$f_{ii'}$: $\begin{cases} 1, & \text{if relief facilities } i \text{ and } i' \text{ engages in lateral transshipment,} \\ 0, & otherwise. \end{cases}$

<u>LTSP Model</u>

$$\text{Min} \quad \frac{\sum_{i\in I}\sum_{j\in J}\left[x_{ij} * r_{ij} * \left(1 + v_{ij}\right)\right] + \sum_{i\in I}\sum_{i'\in I}\sum_{j\in J}\left[\bar{x}_{ii'j} * \left(r_{i'j} * \left(1 + v_{i'j}\right) + r_{ii'} * (1 + v_{ii'})\right)\right]}{\sum_{j\in J}\left(d_j * N\right)} \quad (13)$$

$subject\ to$ (3), (5), (6), (7), (8), (9), (10) and

$$\sum_{i\in I} x_{ij} + \sum_{i\in I}\sum_{i'\in I} \bar{x}_{ii'j} \geq d_j * N \qquad j\in J \qquad (14)$$

$$(r_{ii'} + r_{i'j}) * t_{ii'j} \leq R \qquad i \in I, i' \in I, j \epsilon J, i \neq i' \qquad (15)$$

$$\sum_{j \in J} x_{ij} + \sum_{j \in J} \sum_{i' \in I} \bar{x}_{ii'j} \leq q_i \qquad i \in I, i \neq i' \qquad (16)$$

$$\sum_{i \in I} f_{ii'} \leq 1 \qquad i' \in I, i \neq i' \qquad (17)$$

$$\bar{x}_{ii'j} \leq W * t_{ii'j} \qquad i \in I, i' \in I, j \in J, i \neq i' \qquad (18)$$

$$\sum_{j \in J} \sum_{i' \in I} t_{ii'j} \leq W * y_i \qquad i \in I, i \neq i' \qquad (19)$$

$$\sum_{j \in J} \sum_{i \in I} t_{ii'j} \leq W * y_{i'} \qquad i' \in I, i' \neq i \qquad (20)$$

$$\sum_{j \in J} t_{ii'j} \leq m_{i'j} \qquad i' \in I, j \in J, i \neq i \qquad (21)$$

$$\sum_{i \in I} t_{ii'j} \leq W * f_{ii'} \qquad i \in I, i' \in I, i \neq i \qquad (22)$$

$$x_{ij}, \bar{x}_{ii'j}, q_i \geq 0 \qquad i \in I, i' \in I, j \in J, i \neq i' \qquad (23)$$

$$y_i, m_{ij}, t_{ii'j} \in \{0,1\} \qquad i \in I, i' \in I, j \in J, i \neq i' \qquad (24)$$

The objective function (13) minimizes the average distance travelled per the relief item including the vulnerability affect. Constraint (14) ensures that demand of every demand location is satisfied either directly from relief facilities or through lateral transshipment. Constraints (3) and (15) limit the travel distance of relief items. Constraint (16) ensures that the capacity of a relief facility opened is sufficient to meet total demand assigned to that relief facility. Constraint (17) ensures that any relief facility can engage in lateral transshipment with at most one neighbor relief facility through a demand location. Constraint (18) ensures that relief item cannot be sent through a relief facility unless lateral transshipment is allowed. Constraints (19-20) allow only the open relief facility pairs to engage in lateral transshipment. Constraint (21) allows that lateral transshipment is made to neighbor relief facility to satisfy demand of demand location that assigned to that neighbor relief facility. Constraint (22) provides that lateral transshipment can be made for demand location j if related two relief facilities make lateral transshipment.

CHAPTER 5

EXPERIMENTAL STUDY APPLIED in İSTANBUL

In this chapter, the results obtained for the direct shipment model (DT) and lateral transshipment between supply points model (LTSP) described in the previous chapter are presented and discussed. Models are solved by GAMS 24.2 with Cplex 12.6 Solver. Firstly, solution of both models is presented for varying number of relief facilities (*P*), varying allowed maximum distance of relief item for travel (*R*) and varying vulnerability conditions of roads between relief facilities and between relief facilities and demand locations. Afterwards, by using maritime transportation it is allowed to transport relief items between Anatolian and European side for varying number of relief facilities (*P*), varying maximum allowed distance of relief item for travel (*R*) and varying vulnerability conditions of roads, again. Solution of this extension is compared with results of LTSP model.

The specifications of the computer environment that we use in solving the models and average solution times of each model in terms of seconds are presented in Table 5.1 and Table 5.2, respectively.

Table 5.1: Computer Environment

Computer Environment	
CPU	Intel Core i5-2410M 2.3 Ghz
Memory	4 GB
Operating System	Microsoft Windows 7 Ultimate
Optimization Suite	GAMS 24.2 with Cplex 12.6

Table 5.2: Average Solution Time of Models

VUL.	DT Model R=40	DT Model R=80	LTSP Model R=40	LTSP Model R=80	MLTSP Model R=40	MLTSP Model R=80
Low Vul.	2	2,5	115	521	-	-
High Vul.	2,5	3	176	724	19350	35756

The performance measures are average distance travelled per relief item and percentage of lateral transshipment between supply points. For maritime transportation case, percentage of maritime transshipment is also evaluated.

5.1 Performance Measures

5.1.1 Average Distance Travelled per Relief Item

Average distance travelled per relief item is the ratio of multiplication of total distance and amount of relief item travelled to the total demand.

5.1.2 Percentage of Lateral Transshipment between Supply Points

Lateral transshipment between supply points refers to the amount of shipment sent from a supply point to a neighbor supply point to provide the demand satisfaction of demand locations assigned to that neighbor supply point.

5.2 Results of DT and LTSP Models

DT and LTSP models are solved for varying number of relief facilities (P); 3, 5, 8, 10, 12, 15, 18, 20, 25, 30 where maximum allowed distance traveled of relief item (R) are equal to 40, 80 km and vulnerability factor of roads are taken as low, average and high, respectively. In Table 5.3, values of average distance travelled are shown for DT and LTSP models.

Table 5.3: Average Distance Travelled at DT and LTSP Models

Vulnerability Factor	No of Relief Facilities Opened	R = 40		R = 80	
		DT (in km)	LTSP (in km)	DT (in km)	LTSP (in km)
Low	P=3	11.72	11.47	10.23	10.16
Low	P=5	8.15	8.15	7.22	7.22
Low	P=8	5.77	5.44	5.47	5.34
Low	P=10	4.85	4.73	4.75	4.61
Low	P=12	4.25	4	3.98	3.95
Low	P=15	3.22	2.93	3.21	2.93
Low	P=18	4.42	2.4	4.42	2.4
Low	P=20	4.08	2.05	4.08	2.05
Low	P=25	infeasible	2.01	infeasible	2.01
Low	P=30	infeasible	3.35	infeasible	3.33
Average	P=3	12.2	11.91	10.66	10.59
Average	P=5	8.52	8.52	7.56	7.56
Average	P=8	6	5.65	5.68	5.55
Average	P=10	5.09	4.92	4.91	4.8
Average	P=12	4.4	4.18	4.12	4.12
Average	P=15	3.35	3.05	3.34	3.05
Average	P=18	4.58	2.48	4.59	2.48
Average	P=20	4.24	2.12	4.25	2.12
Average	P=25	infeasible	2.09	infeasible	2.09
Average	P=30	infeasible	3.47	infeasible	3.45
High	P=3	12.72	12.42	11.14	11.06
High	P=5	8.95	8.93	7.95	7.94
High	P=8	6.23	5.89	5.96	5.79
High	P=10	5.34	5.14	5.1	5.01
High	P=12	4.57	4.34	4.28	4.28
High	P=15	3.51	3.19	3.48	3.19
High	P=18	4.75	2.56	4.76	2.56
High	P=20	4.43	2.19	4.42	2.19
High	P=25	infeasible	2.18	infeasible	2.18
High	P=30	infeasible	3.59	infeasible	3.56

As seen on the Table 5.3 and Figure 5.1, the average distance travelled value per relief item in LTSP model is always equal or better than the average distance travelled value per relief item in DT model. The difference reaches the highest point when 21 relief facilities are opened, as seen on Figure 5.1 where average distance travelled is drawn for increasing number of relief facilities under high vulnerability factor when maximum allowed travel distance of relief item is equal to 40 km. Since maximum inventory level allowed at each relief facility decreases as number of open relief facilities increases, DT model becomes infeasible after 21 relief facilities are opened. At that point, amount of inventory hold at relief facilities can not satisfy the demand of demand locations assigned to those relief facilities in the DT model.

For the LTSP model, average distance travelled value decreases as number of open relief facilities increases. Until 15 relief facilities are opened, improvement in value of average distance travelled is high. After that point, although average distance travelled value continues to decrease; the amount of decrease is not as much as moving from 3 open relief facilities to 15 open relief facilities. Decrease in the average distance travelled value continues up to 23 relief facilities are opened. After 23 relief facilities are opened, average distance travelled value begins to increase in LTSP model.

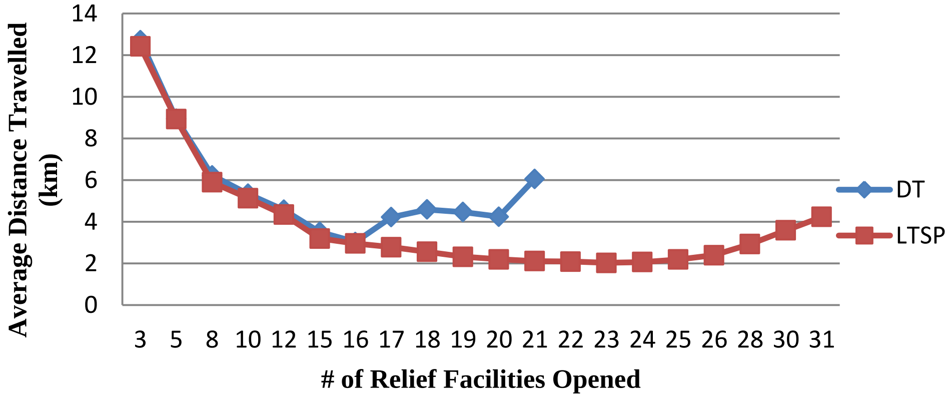

Figure 5.1: Average Distance Travelled for DT and LTSP Model under High Vulnerability when R=40 km

To analyze the effect of allowed maximum travel distance of relief item (R) on the average distance travelled value of LTSP model, Figure 5.2 is obtained where high vulnerability factor is used. As seen on Figure 5.2, until 15 relief facilities are opened, average distance travelled value of LTSP model is better when allowed maximum travel distance is equal to 80 km. After 15 relief facilities, it is seen that the effect of allowed maximum travel distance of relief item is lost and the average distance travelled value becomes the same for allowed maximum travel distance of relief item is equal to 40 and 80 km.

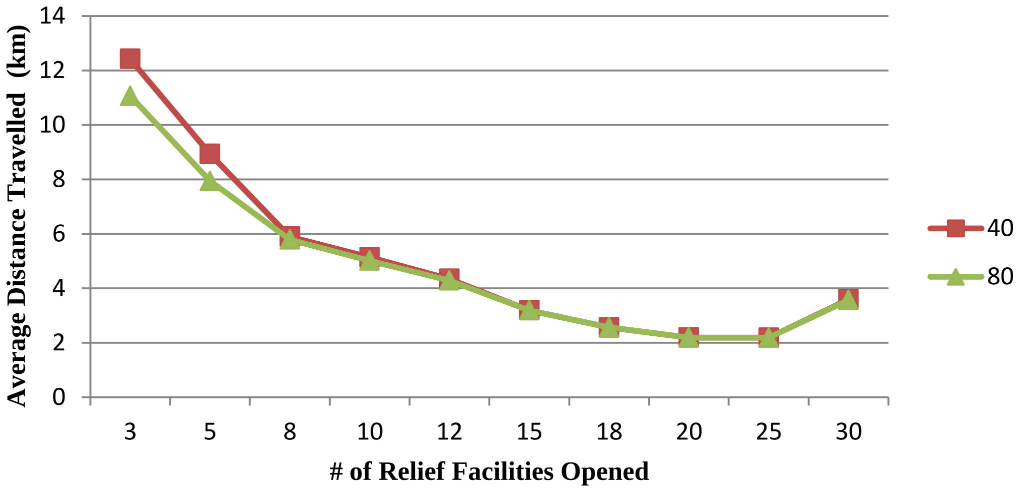

Figure 5.2: Average Distance Travelled for LTSP Model when R=40 and R=80 km under High Vulnerability

To analyze the effect of vulnerability factor on the average distance travelled value of LTSP model, Figure 5.3 is drawn for the case of allowed maximum distance travelled of relief item is equal to 40 km. As expected, at high vulnerability case LTSP model gives the highest average distance travelled value due to the fact that high vulnerability means that it is more difficult to make relief item transportation on roads. As a result, as vulnerability factor increases the average distance travelled value also increases.

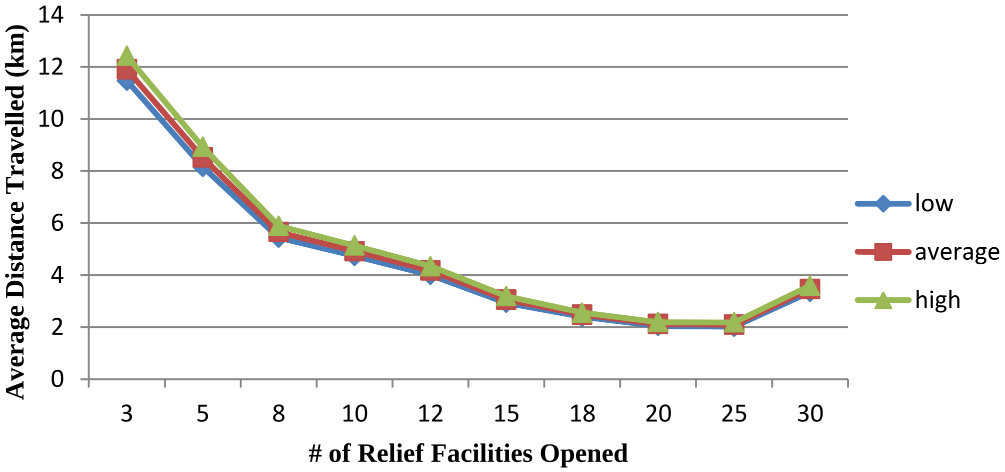

Figure 5.3: Average Distance Travelled for LTSP Model for Low, Average and High Vulnerability Factors when R=40 km

In Table 5.4 the percentage of lateral transshipment are presented for LTSP model for varying number of relief facilities (*P*); 3, 5, 8, 10, 12, 15, 18, 20, 25, 30 where allowed maximum travel distance of relief item (*R*) is equal to 40 and 80 km and vulnerability factor of roads are determined as low, average and high, respectively.

Table 5.4: The Percentage of Lateral Transshipment in LTSP Model

No. of Relief Facilities Opened	low vulnerability		average vulnerability		high vulnerability	
	R=40	R=80	R=40	R=80	R=40	R=80
P=3	0.10	0.10	0.10	0.10	0.10	0.10
P=5	0	0	0	0	0.08	0.08
P=8	0.60	0.48	0.60	0.48	0.60	0.48
P=10	0.25	0.65	0.25	0.65	0.25	0.65
P=12	2.39	1.92	0.47	0	0.47	0
P=15	1.30	1.30	1.30	1.30	1.30	1.30
P=18	3.05	3.05	1.14	1.14	1.14	1.14
P=20	2.74	2.74	2.65	2.65	2.65	2.65
P=25	9.57	9.57	9.74	9.74	9.74	9.74
P=30	20.56	19.92	20.56	19.79	18.99	20.12

For low, average and high vulnerability factors respectively, the percentage of lateral transshipment is drawn at Figure 5.4, 5.5 and 5.6 for allowed maximum travelled distance is equal to 40 km and 80 km as number of open relief facility increases.

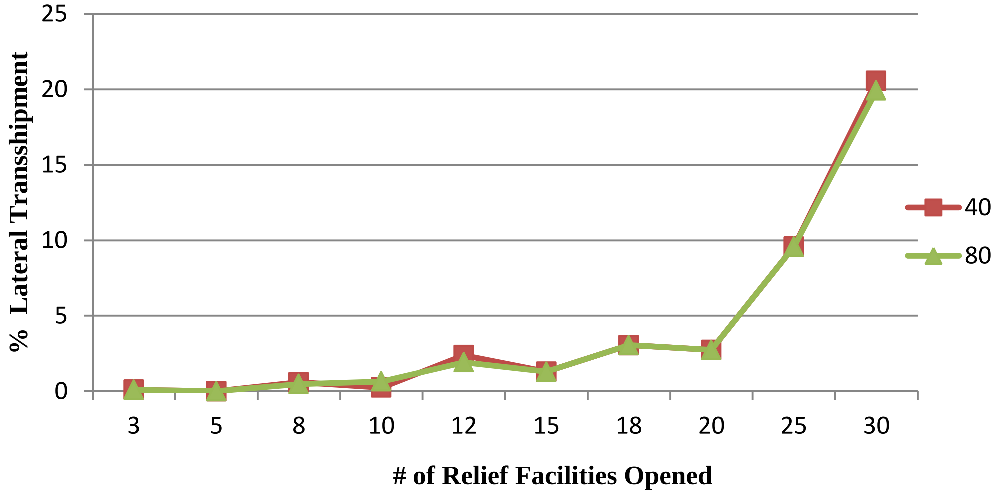

Figure 5.4: Percentage of Lateral Transshipment for LTSP Model for R=40 and R=80 km for Low Vulnerability Factor

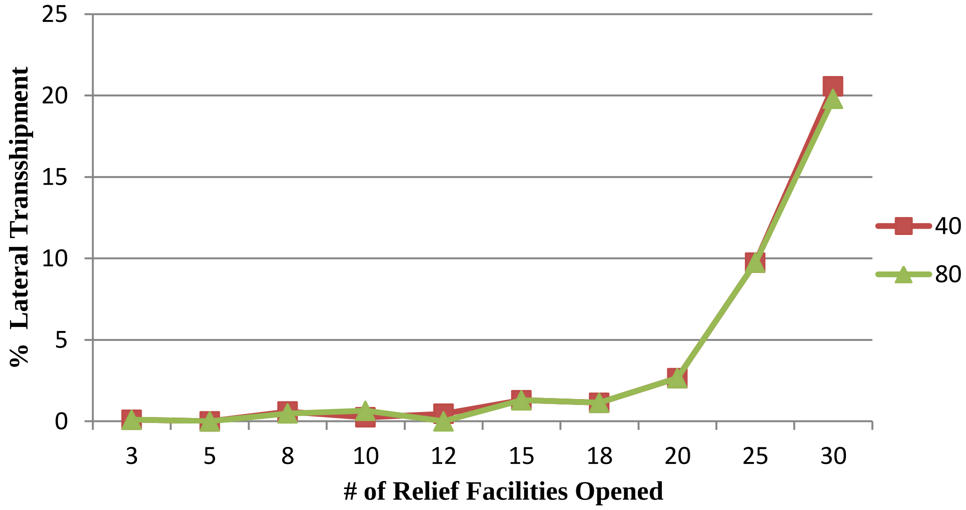

Figure 5.5: Percentage of Lateral Transshipment for LTSP Model for R=40 and R=80 km for Average Vulnerability Factor

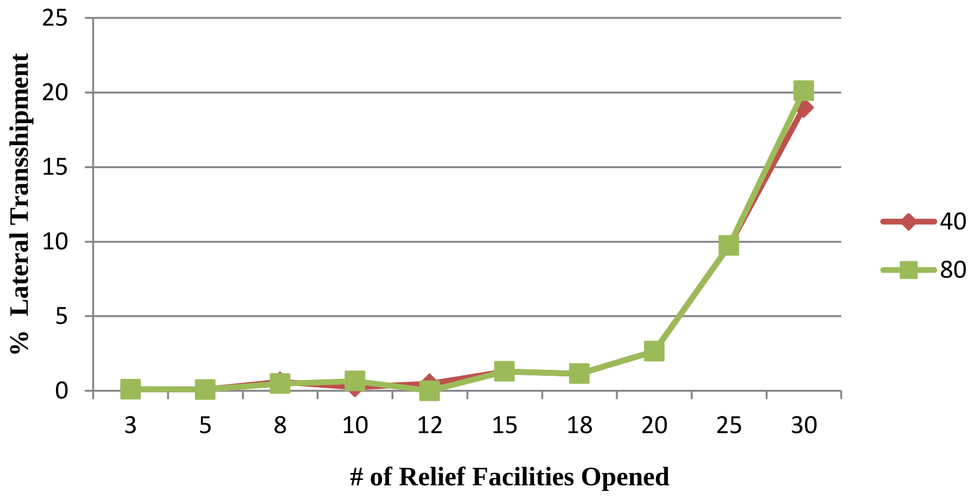

Figure 5.6: Percentage of Lateral Transshipment for LTSP Model for R=40 and R=80 km for High Vulnerability Factor

As seen in Figure 5.4, 5.5 and 5.6, again it can be concluded that after 15 relief facilities are opened, the parameter of allowed maximum travel distance of relief item begins to be ineffective. The percentage of lateral transshipment value becomes close to each other after 15 relief facilities are opened for allowed maximum travel distance of relief item is 40 km and 80 km.

From Figure 5.4, 5.5 and 5.6, it can be seen that the percentage of lateral transshipment begins to increase sharply after 20 relief facilities are opened. As a result, Figure 5.6 is redrawn for the case of high vulnerability factor and allowed maximum travel distance of relief item is equal to 40 km for number of open relief facilities is greater than 18 in Figure 5.7.

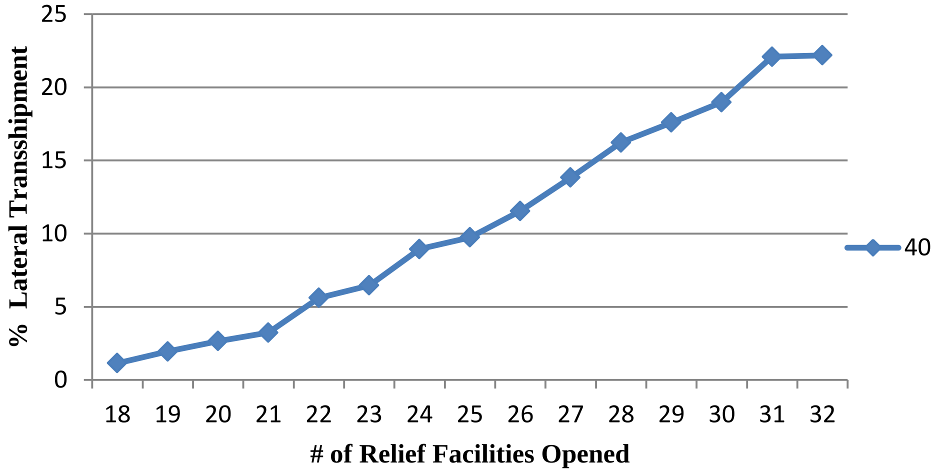

Figure 5.7: Percentage of Lateral Transshipment for LTSP Model for R=40 km for High Vulnerability Factor

As seen in Figure 5.7, there exists a smooth increase of the percentage of lateral transshipment. After 32 relief facilities are opened LTSP model begins to be infeasible due to not satisfying the requirement of 40 km maximum allowed travel distance of relief item and also due to having the constraint that relief item transportation between Anatolian and European side is not allowed.

As seen in Figure 5.4, 5.5 and 5.6, the percentage of lateral transshipment decreases and increases between numbers of open relief facilities are equal to 12 and 18. As vulnerability factor increases these transitions become smoother. Figure 5.8 also shows this result. To analyze the effect of vulnerability on the percentage of lateral transshipment, Figure 5.8 is drawn for allowed maximum travelled distance of relief item is equal to 40 km. From Figure 5.8, it can be concluded that LTSP model gives similar percentage values of lateral transshipment for low, average and high vulnerability factors except number of open relief facilities are equal to 12 and 18. It means that there is not a serious effect of vulnerability on the percentage of lateral transshipment in LTSP model except for low vulnerability factor used where 12 and 18 relief facilities are opened.

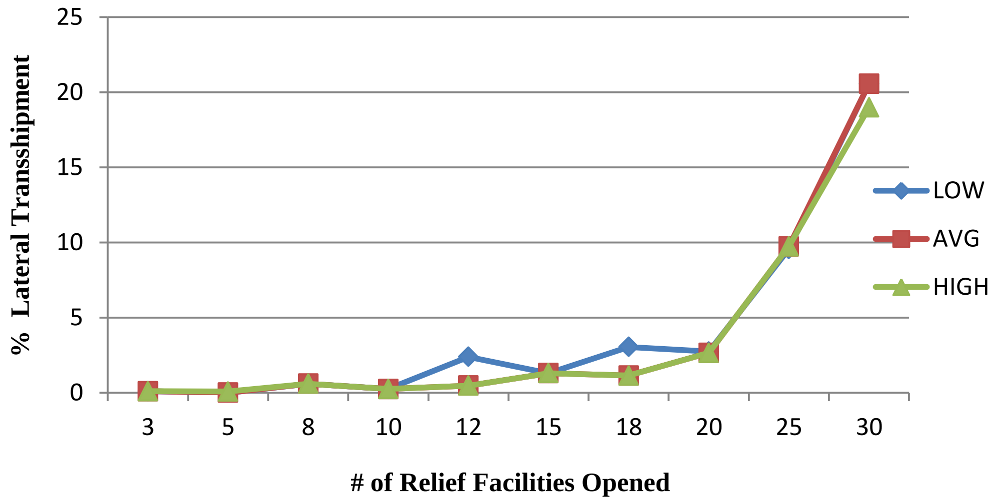

Figure 5.8: Percentage of Lateral Transshipment for LTSP Model for R=40 km for Low, Average and High Vulnerability Factors

To understand the decrease and increase in the percentage of lateral transshipment between number of open relief facilities is equal to 12 and 18, result of these cases are analyzed in detail by examining the location of relief facilities opened, assignment of demand locations to open relief facilities and also assignment of relief facilities engaged in lateral transshipment. Results show that model decides the location of open relief facilities by considering demand of the district and number of school classes existing in the district where relief facility is located in. The distance of relief facilities to each other is another factor to decide the location of relief facilities. Number of school classes existing in the district is one of the factors to decide the location of relief facility to open due to having capacity of holding excess inventory. Capacity of holding excess inventory encourages relief facilities to make lateral transshipment between each other. As a result, model can choose any district which is close to many relief facilities and whose number of class is bigger than the others to open a relief facility. Model can decide to select open relief facility location like this even the district where relief facility opened has not huge demand comparing to other districts where relief facility is not opened. This result explains the increase in the percentage of lateral transshipment.

When it is moved from the case where number of relief facility is equal to 12 to the case where number of relief facility is equal to 15 in low vulnerability case, the percentage of lateral transshipment decreases due to opening 3 more relief facilities and some of which corresponds to districts where high demand exists. This results in a decrease in the amount of lateral transshipment. That demand location can satisfy its own demand from relief facility located in that district and does not have any necessity to make lateral transshipment to satisfy its demand, anymore. These factors also affect the percentage of lateral transshipment by affecting the location of open relief facilities. Consequently, decrease and increase in the percentage of lateral transshipment between number of open relief facilities is equal to 12 and 18 is all about the assignment of demand locations to relief facilities and the selection of locations to open relief facilities. After number of open relief facilities is equal to 20, lateral transshipment always increases as number of open relief facilities increases due to the fact that amount of inventory held at each relief facility becomes insufficient to satisfy the demand of demand locations assigned to that relief facility. To satisfy the demand, relief facilities have to engage in lateral transshipment with neighbor relief facilities.

In Figure 5.9, LTSP model is modified according to the decision of opening relief facility. That model starts to open relief facility at location whose demand is the highest and continues to open relief facility at locations having higher demand.

From Figure 5.9 it can be concluded that if model started to open relief facility from the location having the highest demand, the percentage of lateral transshipment would always increase. However, this case is not optimal according to the objective value of minimizing the average distance travelled per relief item as seen Figure 5.10 due to the fact that model decides the location of open relief facilities by considering demand of district, number of school classes existing in district where relief facility located in and the distance of relief facilities to each other. In Figure 5.10 the modified LTSP model is compared with LTSP and DT models according to the average distance travelled value per relief item.

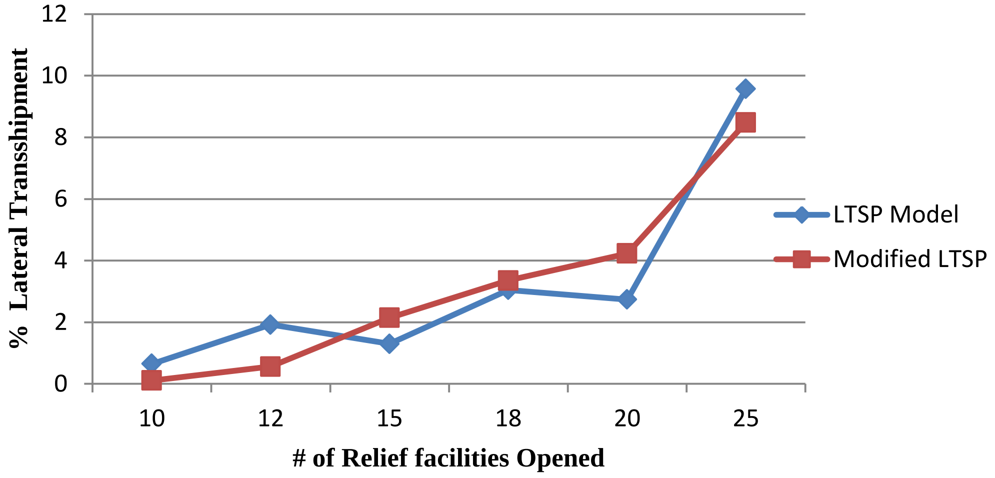

Figure 5.9: Percentage of Lateral Transshipment for LTSP Model and Modified LTSP Model for Low Vulnerability when R=40 km

In Figure 5.9, LTSP model is modified according to the decision of opening relief facility. That model starts to open relief facility at location whose demand is the highest and continues to open relief facility at locations having higher demand.

In Figure 5.10 the modified LTSP model is compared with LTSP and DT models according to the average distance travelled value per relief item.

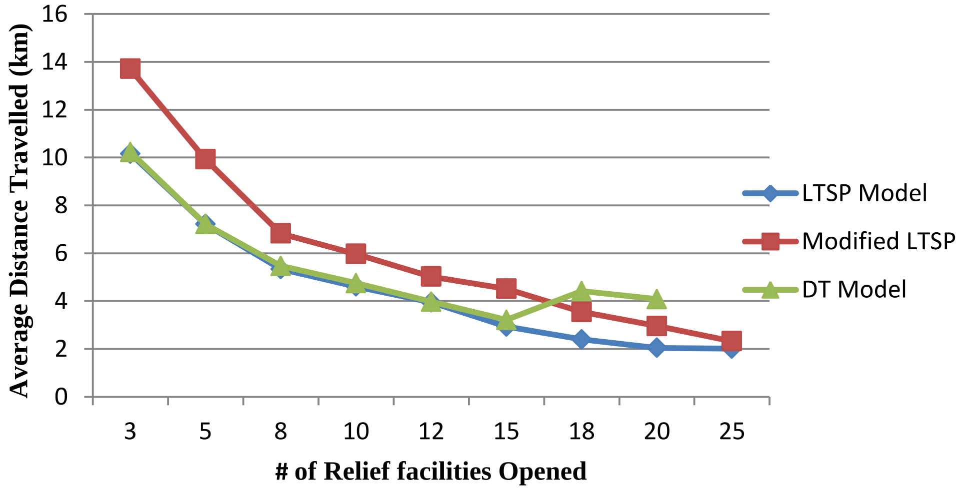

Figure 5.10: Average Distance Travelled for LTSP Model and Modified LTSP Model for Low Vulnerability when R=40 km

In Section 5.2, all results are obtained for the case in which different A(P) parameters are determined for each number of open relief facilities as explained in Formula 3.9 in Section 3.2.7. Although LTSP model gives the minimum average distance travelled per relief item value shown in Figure 5.1, it can not be surely said that opening 23 relief facilities is the optimal solution for LTSP model due to the fact that A(P) parameter changes for different number of open relief facility. As a result, for different constant values of A(P) parameter, Figure 5.11 and 5.12 are drawn for LTSP model, respectively.

In Figure 5.11 the average distance travelled per relief item is presented for different interval of A(P) parameter for different number of open relief facility for both LTSP and DT models.

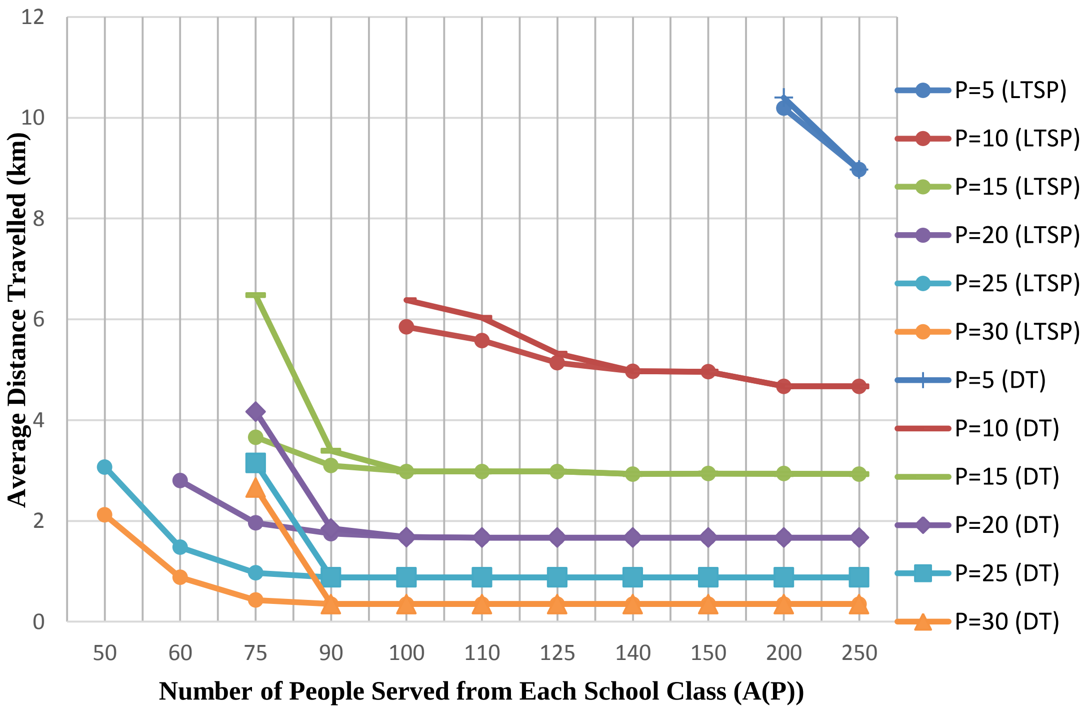

Figure 5.11: Average Distance Travelled in DT and LTSP Models for Different A(P) Parameter Intervals for High Vulnerability Case when R=40 km

As seen in Figure 5.11, for different A(P) parameter intervals, we have infeasible solutions for different number of open relief facilities. As A(P) increases, opening a few relief facilities can be possible. However, for low A(P) values, minimum certain number of open relief facility has to be satisfied for having feasible solutions. For instance, opening 5 relief facilities give feasible solutions when A(P) parameter is equal or greater than 200. For each different A(P) parameter intervals, it can be seen that the average distance travelled value decreases as number of open relief facility increases. Also in Figure 5.11, it is seen that for specific number of open relief facilities, the average distance travelled value is not affected after at certain value of A(P) parameter while it increases. For instance, when number of open relief facility is equal to 30, the average distance travelled is same after A(P) is equal to 90.

Finally, from Figure 5.11, it can be seen that LTSP model always gives equal or better average distance travelled values than DT model. In some cases where DT model is infeasible, LTSP model can give feasible solutions. After certain value of A(P), LSTP and DT models begin to give same value of average distance travelled for each specific number of open relief facility. For instance, in case where 25 relief facilities are opened, DT model is infeasible until A(P) is equal to 75. At this point LTSP gives lower value of average distance travelled per relief item than DT model. After A(P) is equal to 90, LTSP and DT begin to give same result when 25 open relief facility exist.

In Figure 5.12, the percentage of lateral transshipment is shown for different A(P) parameter intervals and for different number of open relief facility.

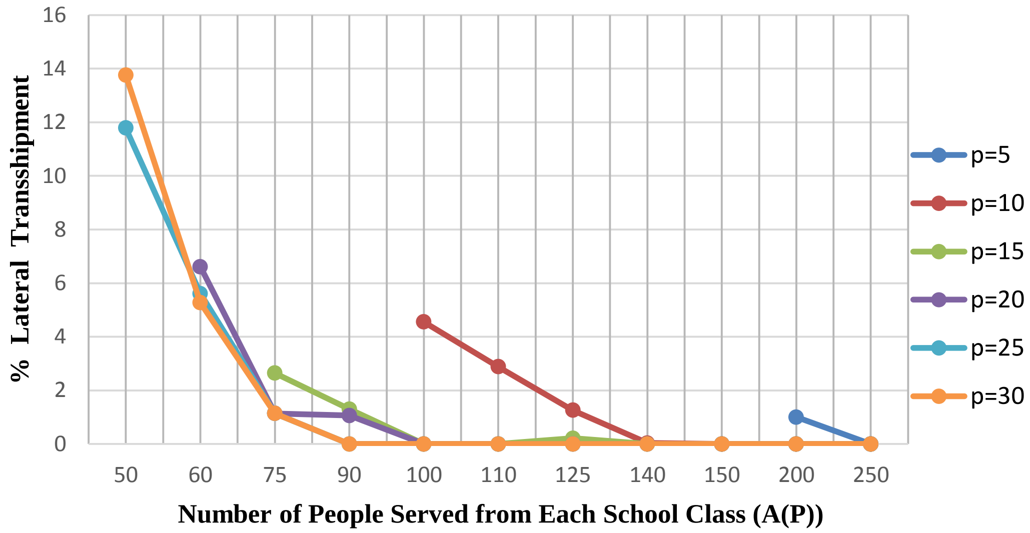

Figure 5.12: Percentage of Lateral Transshipment in LTSP Model for Different A(P) Parameter Intervals for High Vulnerability Case when R=40 km

Form Figure 5.12, it can be concluded that making lateral transshipment between relief facilities is meaningful after number of open relief facilities is higher than 20. For number of open relief facilities lower than 20, A(P) parameter is generally enough for satisfying demand of the affected without making lateral transshipment. For each A(P) parameter intervals, it can be seen that as number of open relief facility decreases, the percentage of lateral transshipment increases. Also it can be said that as A(P) parameter increases, the percentage of lateral transshipment decreases while number of open relief facility is constant.

5.3 Inclusion of Maritime Transportation into the LTSP Model

The model explained in Chapter 4 allows only land transportation in each side of the city (i.e., Anatolian and European sides). In the case of high vulnerability, sending relief items to demand locations using land vehicles is more difficult due to high risk of road blockages. İstanbul has many seaports on each side and daily maritime transportation is made between these ports. In case of a disaster, in addition to land transportation these ports can be used to transport relief items. This also allows relief item transportation between both sides of the city. As a result, in this section maritime transportation is included into the existing LTSP model. The obtained model is called as maritime lateral transportation between supply points model (MLTSP) and it is studied for the case where high vulnerability factors are used.

In Section 5.3.1 system description and data sources of MLTSP model are presented. In Section 5.3.2 assumptions made in MLTSP model are shown. In Section 5.3.3 mathematical model of MLTSP is presented. In Section 5.3.4 results of MLTSP model are shown. Finally, in Section 5.3.5 MLTSP model is compared with LTSP model according the performance measures defined in Section 5.1.

5.3.1 System Description and Data Sources of the MLTSP Model

In the model of MLTSP, transshipment between ports is also possible. As s result, two transshipment nodes are added to the existing nodes at this case. Figure 5.13 illustrates the flow of the relief item in the suggested distribution system.

In Figure 5.13, relief facility-1, shown as R/F-1 with triangle, sends relief item by land transportation to port-1, shown as P-1 with circle. Afterwards, relief item is sent to port-2, shown as P-2 with circle, from port-1 by maritime transportation. After relief item reaches at port-2, then it is sent to neighbor relief facility-2, shown as R/F-2 with triangle, by land transportation. Finally the required relief item is delivered to the affected waiting at demand location, shown as D/L with rectangular, by land transportation.

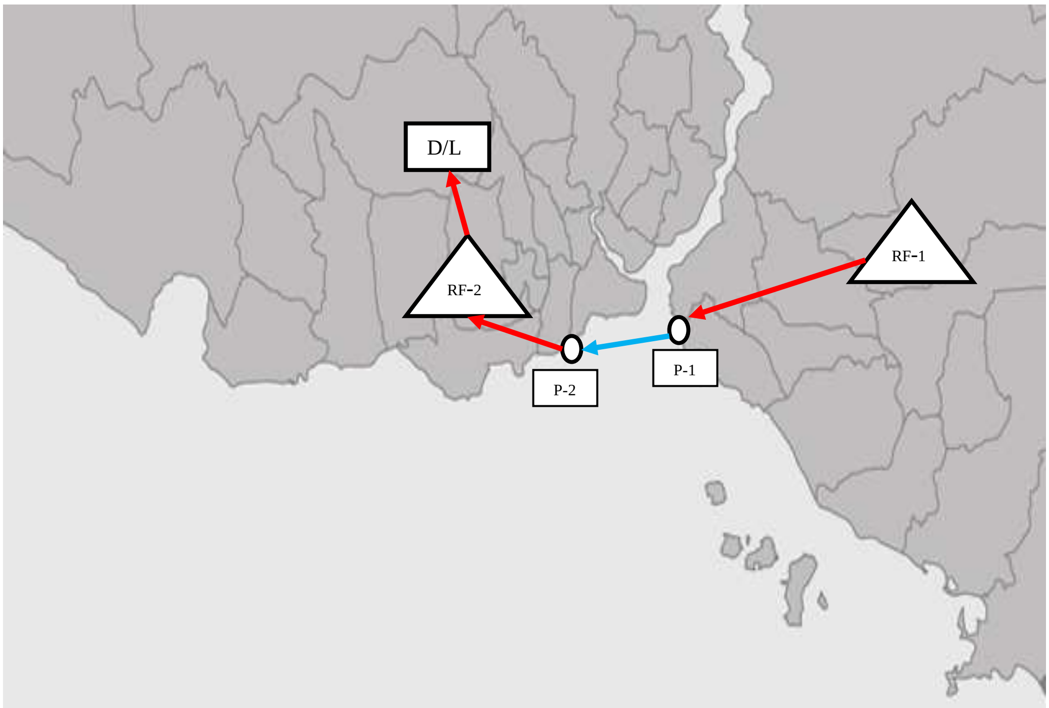

Figure 5.13: Relief Item Flow in the Distribution System Defined in MLTSP

5.3.1.1 Ports

Ports are new transshipment nodes of MLTSP model where maritime transportation is used. Port of Haydarpaşa and Port of Ambarlı are the most important two ports located in İstanbul. Haydarpaşa port is located in the Anatolian side of İstanbul, in the district of Kadıköy. Port of Ambarlı is located in the European side of İstanbul, in the district of Beylikdüzü.

İstanbul Deniz Otobüsleri (İDO) is the main company on seaway transportation. İDO ports in İstanbul are considered as transhipment points in MLTSP model. There are 19 İDO ports in İstanbul, 11 of which are on the Anatolian side: Harem, Kadıköy, Bostancı, Maltepe, Pendik, Kartal, Beykoz, Burgazada, Kınalıada, Heybeliada and Büyükada. Since last 4 ports are located in district of Adalar, they are not considered in MLTSP model. 8 İDO ports 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 ports are illustrated in Figure 5.14.

Figure 5.14: Locations of the Ports.

5.3.1.2 Distance

Distances between relief facilities and ports are calculated on Google Maps. The shortest distance between two points is selected on Google Maps. Distance between ports are calculated on Google Earth as sea miles and then converted to km. Distances between relief facilities and ports as well as distances between ports are presented in Appendix E and F, respectively.

5.3.1.3 Vulnerability

Vulnerability between relief facilities and ports is calculated in a similar manner of calculation of vulnerability between relief facilities and demand locations explained in Section 3.2. The vulnerability between relief facilities and ports are shown in Appendix G.

The vulnerability between ports is set as 0.001 due to the fact that there is no risk of blockage on the seaway resulting from building collapse.

5.3.1.4 Capacity of a Ship

Four types of ships are used for sea transportation in İstanbul. Each type of ship has different capacity and speed. In the model MLTSP, one type of ship is used and it is called as Average Ship. Capacity and speed of Average Ship is obtained by taking the average value of capacity and speed of those four ship types. Average Ship is defined in Table 5.5.

Table 5.5: Ship Types (taken from Özkapıcı [17])

Ship Types	Capacity (number of relief items)	Speed (km/h)
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)
Average Ship	*6100*	*30.4 knot (~56 km/h)*

5.3.1.5 Maximum Number of Ships Utilized

Maximum number of ships that can be utilized for relief item transportation is determined as 25, the number of İDO sea buses.

5.3.2 Assumptions of the MLTSP Model

In the MLTSP model various assumptions are made.

1) Ports are uncapacitated.
2) One type of ship is used and it is called Average Ship whose speed and capacity value is the average value of capacity and speed of four types of ship.
3) Ships are ready to make shipment of relief item at each port. There is no waiting time for ship coming to the port.
4) Loading/unloading time is ignored.
5) Ports located at the same side of İstanbul are not allowed to make relief item shipment between each other.

Assumptions (1), (2), (3), (4), and (5) are used due to the fact that the main objective is to examine the lateral behavior between two sides of city and the objective function value where relief item transportation is allowed between Anatolian and European side of İstanbul.

5.3.3 Mathematical Model of MLTSP

In this section the mathematical model with maritime lateral transshipment between supply points is introduced. Ports visited for lateral transshipment is denoted as $k \text{ and } k'$ under the set *K*.

The following new decision variables are added to the mathematical model:

$\bar{x}_{ikk'i'j}$: quantity of relief item sent to demand location j from relief facility i through ports *k* and *k'* and relief facility *i'*,

$z_{kk'}$: number of ships used between port *k* and port *k'* for shipment of relief item,

$$b_{ikk'i'j} : \begin{cases} 1, & \text{if relief facilities } i \text{ and } i' \text{ engages in lateral transhipment through ports } k \text{ and } k', \\ 0, & otherwise. \end{cases}$$

The following new parameters are added to the mathematical model:

v_{ik} : vulnerability factor between relief facility i and port *k*,

$v_{kk'}$: vulnerability factor between port *k* and port *k'*,

r_{ik} : distance between relief facility *i* and port *k*,

$r_{kk'}$: distance between port *k* and port *k'*,

cap : capacity of a ship.

<u>MLTSP Model</u>

Minimize

$$\frac{\sum_{i\in I}\sum_{j\in J}\left[x_{ij}*r_{ij}*(1+v_{ij})\right]+\sum_{i\in I}\sum_{j\in J}\sum_{i'\in I}\left[\bar{x}_{ii'j}*\left(r_{i'j}*\left(1+v_{i'j}\right)+r_{ii'}*(1+v_{ii'})\right)\right]+\sum_{i\in I}\sum_{k\in K}\sum_{k'\in K}\sum_{i'\in I}\sum_{j\in J}\left[\bar{x}_{ikk'i'j}*\left(r_{i'j}*\left(1+v_{i'j}\right)+r_{i'k'}*(1+v_{i'k'})+r_{kk'}*\left(1+v_{kk'}\right)+r_{ik}*(1+v_{ik})\right)\right]}{\sum_{j\in J}(d_j*N)} \quad (25)$$

$subject\ to$ (3), (5), (6), (7), (8), (9), (10), (15), (17), (18), (19), (20), (21)(19), (20), (21)and

$$\sum_{i\in I} x_{ij} + \sum_{i\in I}\sum_{i'\in I}\bar{x}_{ii'j} + \sum_{i\in I}\sum_{i'\in I}\sum_{k\in K}\sum_{k'\in K}\bar{x}_{ikk'i'j} \geq d_j * N \qquad j\in J \qquad (26)$$

$$((r_{ik}+r_{kk'}*(\frac{40}{56})+r_{k'i'}+r_{i'j})*b_{ikk'i'j} \leq R \qquad k\in K, k'\in K, i\in I, i'\in I, j\in J, i\neq i', k\neq k' \quad (27)$$

$$\sum_{j\in J} x_{ij} + \sum_{j\in J}\sum_{i'\in I}\bar{x}_{ii'j} + \sum_{j\in J}\sum_{i'\in I}\sum_{k\in K}\sum_{k'\in K}\bar{x}_{ikk'i'j} \leq q_i \qquad i\in I, i\neq i' \qquad (28)$$

$$\bar{x}_{ikk'i'j} \leq W * b_{ikk'i'j} \qquad k\in K, k'\in K, i\in I, i'\in I, j\in J, i\neq i', k\neq k' \qquad (29)$$

$$\sum_{j\in J}\sum_{i'\in I}\sum_{k\in K}\sum_{k'\in K} b_{ikk'i'j} \leq W * y_i \qquad i \in I, i \neq i' \qquad (30)$$

$$\sum_{j\in J}\sum_{i\in I}\sum_{k\in K}\sum_{k'\in K} b_{ikk'i'j} \leq W * y_{i'} \qquad i' \in I, i' \neq i \qquad (31)$$

$$z_{kk'} \leq \sum_{j\in J}\sum_{i\in I}\sum_{i'\in I} \bar{x}_{ikk'i'j} \qquad k \in K, k' \in K, k \neq k' \qquad (32)$$

$$\sum_{k\in K}\sum_{k'\in K} z_{kk'} \leq 25 \qquad (33)$$

$$\sum_{j\in J}\sum_{i\in I}\sum_{i'\in I} \bar{x}_{ikk'i'j} \leq cap * z_{kk'} \qquad k \in K, k' \in K, k \neq k' \qquad (34)$$

$$\sum_{k'\in K}\sum_{i\in I}\sum_{k\in K} b_{ikk'i'j} \leq m_{i'j} \qquad i' \in I, j \in J, i \neq i \qquad (35)$$

$$x_{ij}, \bar{x}_{ii'j}, q_i, \bar{x}_{ikk'i'j}, \geq 0 \qquad i \in I, i' \in I, j \in J, i \neq i' \qquad (36)$$

$$y_i, m_{ij}, t_{ii'j}, b_{ikk'i'j} \in \{0,1\} \qquad i \in I, i' \in I, j \in J, i \neq i' \qquad (37)$$

$$z_{kk'} \ integer \qquad k \in K, k' \in K, k \neq k' \qquad (38)$$

The objective function (25) minimizes the average distance travelled per the relief items with including vulnerability affect. Constraint (26) ensures that demand of every demand location is satisfied either directly from relief facilities or through lateral transshipment. Constraints (3), (15) and (27) limit the travel distance of relief item. In Constraint (27) the distance between ports is multiplied by the ratio of speed of land vehicle to speed of ship to convert the distance travelled by ship in a hour to distance travelled by land vehicle in a hour. Constraint (28) ensures that the capacity of a relief facility opened is sufficient to meet total demand assigned to that relief facility. Constraints (18) and (29) ensure that relief item cannot be sent through a relief facility unless lateral transshipment is allowed. Constraints (19-20) and (30-31) allow only the open relief facility pairs to engage in lateral transshipment. Constraints (21) and (35) allow lateral transshipment to be made to neighbor relief facility to satisfy demand of demand location that assigned to that neighbor relief facility. Constraint (32) is used in case there is no relief item shipment between ports, any ship cannot be utilized. Constraint (33) ensures that number of ship is limited. Constraint (34) ensures that shipment amount between ports cannot exceed the total capacity of ships used between that ports.

5.3.4. Results of the MLTSP Model

In Table 5.6 amount of lateral transshipment on highway, amount of lateral transshipment on seaway and average travelled distance are presented for MLTSP model for varying number of relief facilities (*P*); 5, 10, 15, 18, 20, 22, 25, 27, 30, 32, 35 and 37 where allowed maximum travel distance of relief item (*R*) is equal to 40 and 80 km.

Table 5.6: Results of the MLTSP Model

Max. Allowed Distance Travelled	No of Relief Facilities Opened	Average Distance Travelled	% Lateral Shipment Made on Seaway	% Lateral Shipment Made on Highway	% Total Lateral Shipment
R=40	P=5	8.926	0	0.08	0.08
R=40	P=10	5.135	0	0.25	0.25
R=40	P=15	3.191	0	1.30	1.30
R=40	P=18	2.557	0	1.14	1.14
R=40	P=20	2.171	0.30	2.10	2.41
R=40	P=22	2.084	1.32	4.55	5.87
R=40	P=25	2.146	1.01	7.65	8.65
R=40	P=27	2.529	2.34	9.24	11.58
R=40	P=30	3.182	5.13	12.28	17.40
R=40	P=32	3.530	4.73	14.65	19.38
R=40	P=35	4.408	7.39	13.05	20.43
R=40	P=37	5.242	10.40	12.15	22.54
R=80	P=5	8.926	0	0.08	0.08
R=80	P=10	5.135	0	0.25	0.25
R=80	P=15	3.191	0	1.30	1.30
R=80	P=18	2.557	0	1.14	1.14
R=80	P=20	2.171	0.30	2.10	2.41
R=80	P=22	2.084	1.32	4.55	5.87
R=80	P=25	2.146	1.01	7.65	8.65
R=80	P=27	2.529	2.34	9.24	11.58
R=80	P=30	3.182	5.13	12.28	17.40
R=80	P=32	3.522	4.86	14.05	18.91
R=80	P=35	4.428	7.39	13.11	20.50
R=80	P=37	5.232	10.91	13.11	24.03

In Figure 5.15, the average distance travelled value obtained from MLTSP model is shown as number of open relief facilities are increasing where allowed maximum distance travelled of relief item is equal to 40 km and 80 km.

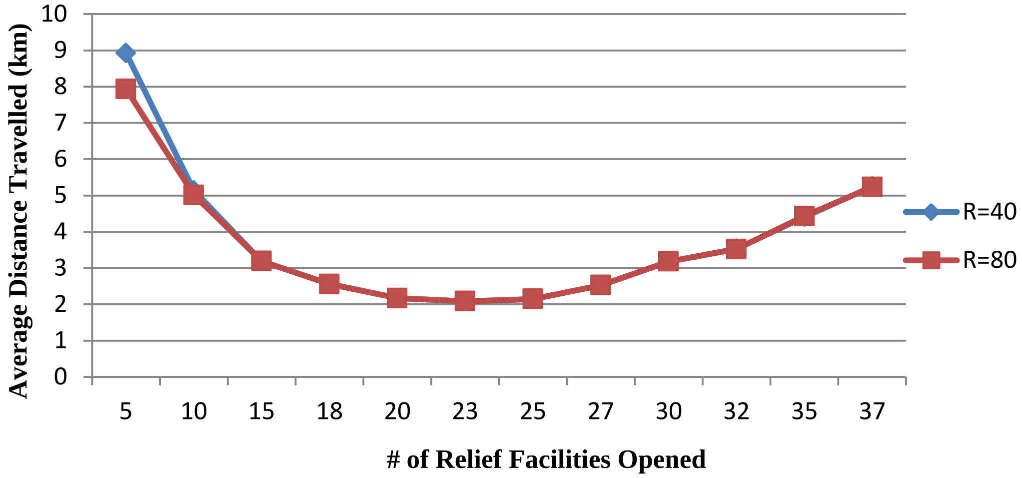

Figure 5.15: Average Distance Travelled for MLTSP Model when R=40 and R=80 km

As seen on Figure 5.15, the average distance travelled value continues to decrease until 23 relief facilities are opened. Afterwards, the average distance travelled value begins to increase. As a result, minimum average distance travelled value is obtained when 23 relief facilities are opened in MLTSP model.

Allowed maximum distance travelled of relief item does not affect the average distance travelled between 15 relief facilities 30 relief facilities are opened. After 30 relief facilities are opened, average distance travelled value becomes slightly smaller when allowed maximum distance travelled of relief item is equal to 80 km according to the average distance travelled value obtained when allowed distance travelled of relief item is equal to 40 km.

In Figure 5.16 and 5.17, the percentage of total lateral transshipment and the percentage of lateral transshipment on seaway are shown for increasing number of open relief facilities and allowed maximum distance travelled of relief item is equal to 40 km and 80 km, respectively.

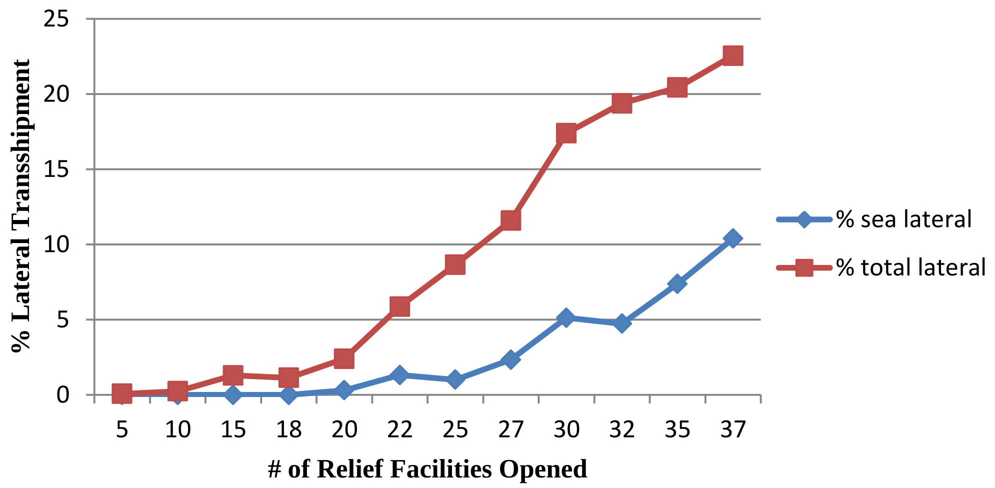

Figure 5.16: Percentage of Total Lateral Transshipment and Lateral Transshipment on Seaway in MLTSP Model for R=40 km

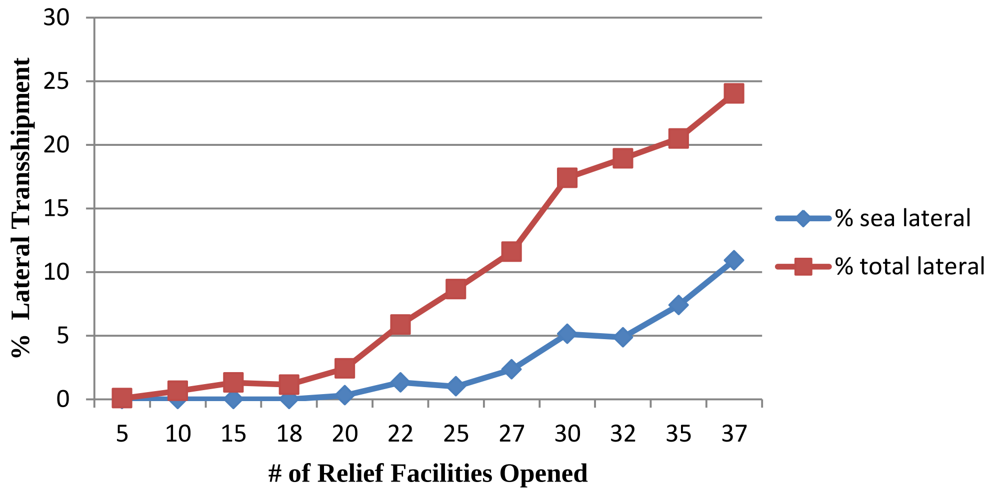

Figure 5.17: Percentage of Total Lateral Transshipment and Lateral Transshipment on Seaway in MLTSP Model for R=80 km

As seen on Figure 5.16 and 5.17, the percentage of total lateral transshipment shows a sharp increase after 18 relief facilities are opened and continues to increase. Lateral transshipment on seaway begins when 20 relief facilities are opened and generally shows an increase as number of open relief facilities increases. There is a slight decrease on lateral transshipment on seaway form number of open relief facilities are equal to 22 to number of open relief facilities are equal to 25 and from number of open relief facilities are equal to 30 to number of open relief facilities are equal to 32.

To understand the effect of allowed maximum distance travelled of relief item on the percentage of total lateral transshipment and lateral transshipment on seaway, Figure 5.18 and 5.19 are drawn.

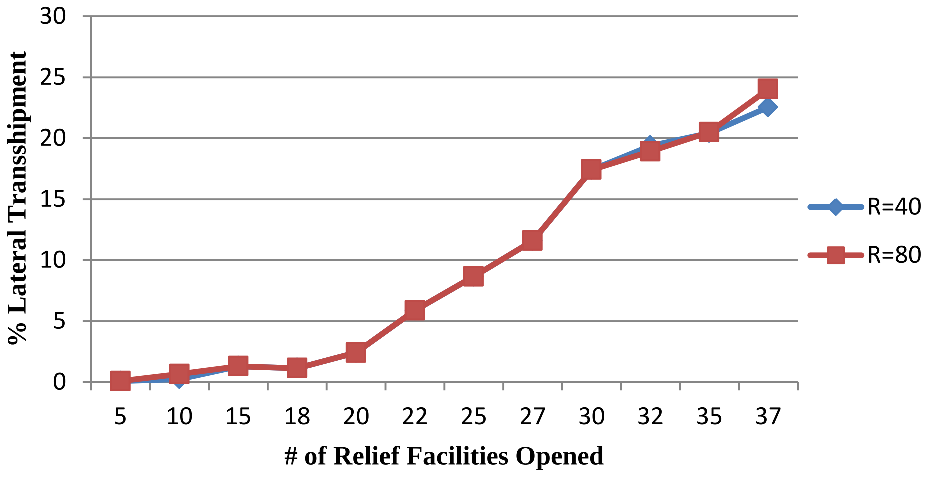

Figure 5.18: Percentage of Total Lateral Transshipment in MLTSP Model when R= 40 and R=80 km

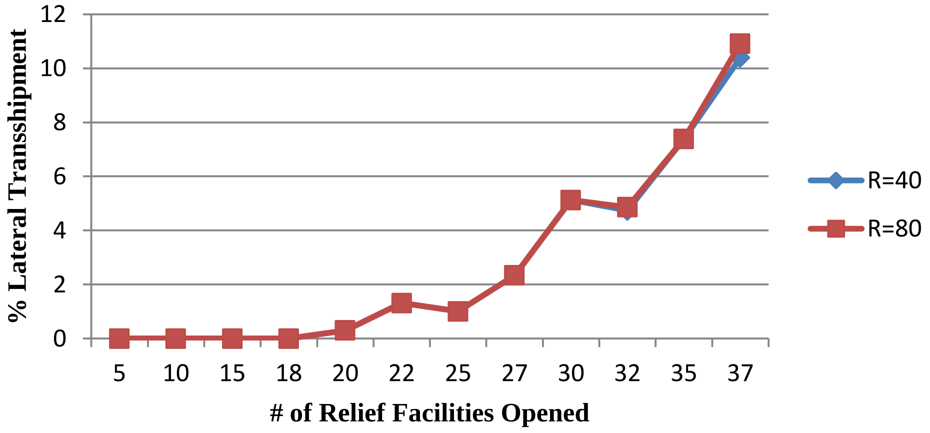

Figure 5.19: Percentage of Lateral Transshipment on Seaway in MLTSP Model when R= 40 and R=80 km

From Figure 5.18 and 5.19, moving from the allowed maximum distance travelled of relief item is equal to 40 km to the allowed maximum distance travelled of relief item is equal to 80 km, generally does not affect the MLTSP model with regard to the percentage of total lateral transshipment and the percentage of lateral transshipment on seaway. After 30 relief facilities are opened, the allowed maximum distance travelled of relief item begins to affect the percentage of lateral transshipments and this affect slightly increases as number of relief facilities increases.

As indicated in Section 5.2 for LTSP model, it is also valid for MLTSP model that it can not be surely said that opening 23 relief facilities is the optimal solution due to the fact that A(P) parameter changes for different number of open relief facility. As a result, for different constant values of A(P) parameter, Figure 5.20 and 5.21 are drawn for MLTSP model, respectively.

In Figure 5.20 the average distance travelled per relief item is presented for different interval of A(P) parameter for different number of open relief facility.

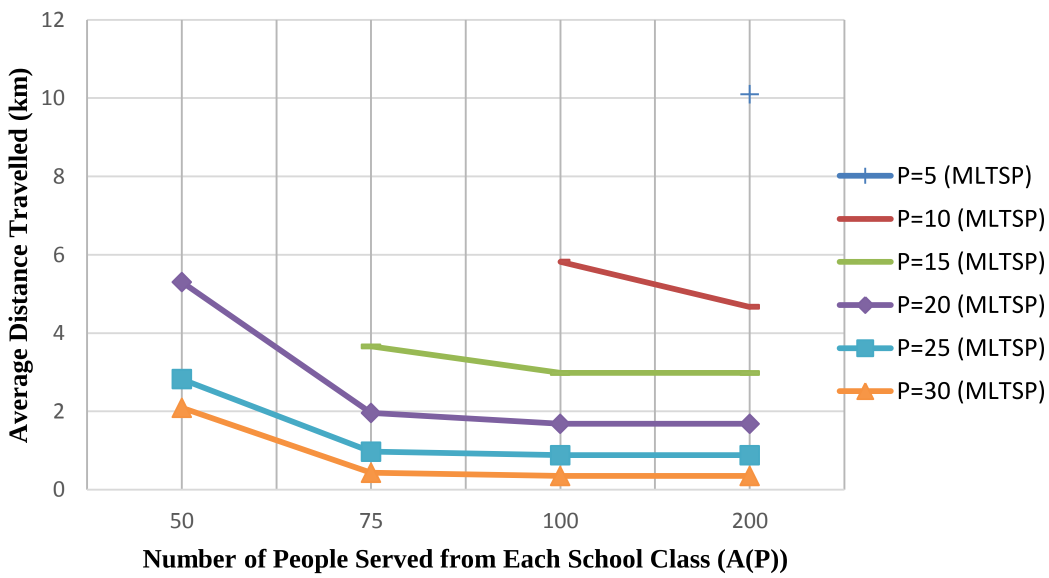

Figure 5.20: Average Distance Travelled in MLTSP Model for Different A(P) Parameter Intervals for High Vulnerability Case when R=40 km

As seen in Figure 5.20, for each different A(P) parameter intervals, it can be seen that the average distance travelled value decreases as number of open relief facility increases. Also in Figure 5.20, it is seen that for specific number of open relief facilities, the average distance travelled value is not affected after at certain value of A(P) parameter while it increases.

In Figure 5.21, the percentage of lateral transshipment is shown for different A(P) parameter intervals and for different number of open relief facility.

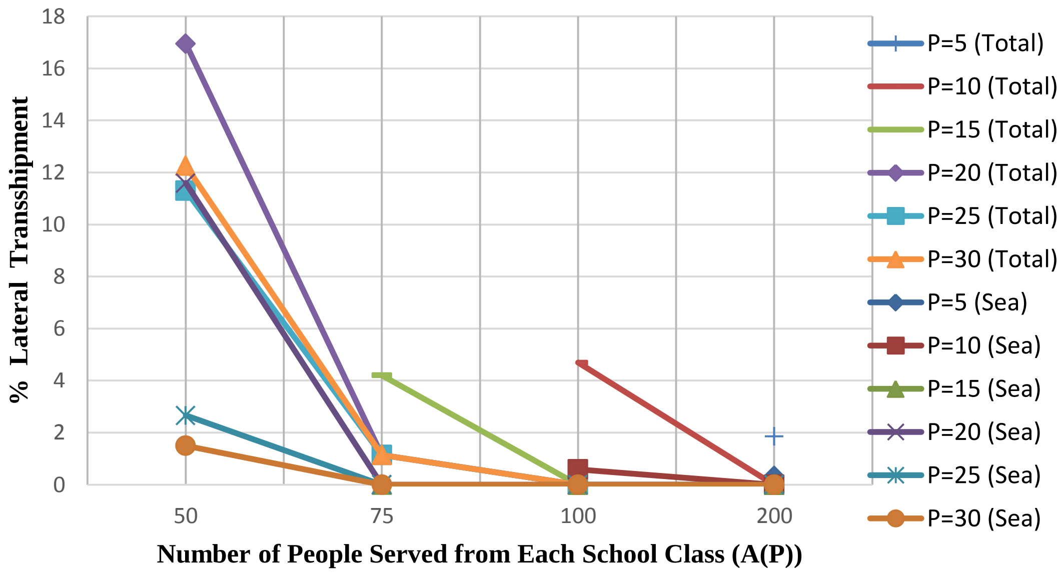

Figure 5.21: Percentage of Total and Sea Lateral Transshipment in MLTSP Model for Different A(P) Parameter Intervals for High Vulnerability Case when R=40 km

Form Figure 5.21, it can be seen that for each A(P) parameter intervals as number of open relief facility decreases, the percentage of total lateral transshipment increases. Also it can be said that as A(P) parameter increases, the percentage of lateral transshipment decreases while number of open relief facility is constant. Lateral transshipment made on seaway generally exists when A(P) is equal to 50 for number of open relief facility is equal and greater than 20. Also for these cases, it is seen that as number of open relief facility decreases, the percentage of lateral transshipment made on seaway increases. As a result, it can be concluded that making lateral transshipment on seaway is meaningful after number of open relief facilities is higher than 20 and A(P) parameter is equal to 50.

5.3.5 Comparison of MLTSP Model with LTSP Model

LTSP model is extended by including maritime transportation and MLTSP model is obtained. These two models are compared according to performance measures defined in Section 5.1.

Table 5.7 shows the average distance travelled value and the percentage of total lateral transshipment for LTSP and MLTSP models.

Table 5.7: Results of LTSP and MLTSP Models

Allowed Max. Distance Travelled	No. of Relief Facilities Opened	LTSP Model		MLTSP Model	
		Avg. Distance Travelled (km)	% Total Lateral Transshipment	Avg. Distance Travelled (km)	% Total Lateral Transshipment
R = 40	P=5	8.93	0.08	8.93	0.08
R = 40	P=10	5.14	0.25	5.14	0.25
R = 40	P=15	3.19	1.30	3.19	1.30
R = 40	P=18	2.56	1.14	2.56	1.14
R = 40	P=20	2.19	2.65	2.17	2.41
R = 40	P=22	2.09	5.61	2.08	5.87
R = 40	P=25	2.18	9.74	2.15	8.65
R = 40	P=27	2.67	13.83	2.53	11.58
R = 40	P=30	3.59	18.99	3.18	17.40
R = 40	P=32	4.27	22.18	3.53	19.38
R = 40	P=35	infeasible	infeasible	4.41	20.43
R = 40	P=37	infeasible	infeasible	5.24	22.54
R = 80	P=5	7.94	0.08	7.94	0.08
R = 80	P=10	5.01	0.65	5.01	0.65
R = 80	P=15	3.19	1.30	3.19	1.30
R = 80	P=18	2.56	1.14	2.56	1.14
R = 80	P=20	2.19	2.65	2.17	2.41
R = 80	P=22	2.09	5.61	2.08	5.87
R = 80	P=25	2.18	9.74	2.15	8.65
R = 80	P=27	2.67	12.21	2.53	11.58
R = 80	P=30	3.56	18.84	3.18	17.40
R = 80	P=32	4.28	22.66	3.52	18.91
R = 80	P=35	infeasible	infeasible	4.43	20.50
R = 80	P=37	infeasible	infeasible	5.23	24.03

Figures 5.22 and 5.23 are drawn to compare LTSP and MLTSP models with regard to average distance travelled for the allowed maximum distance travelled of relief item is equal to 40 and 80 km, respectively.

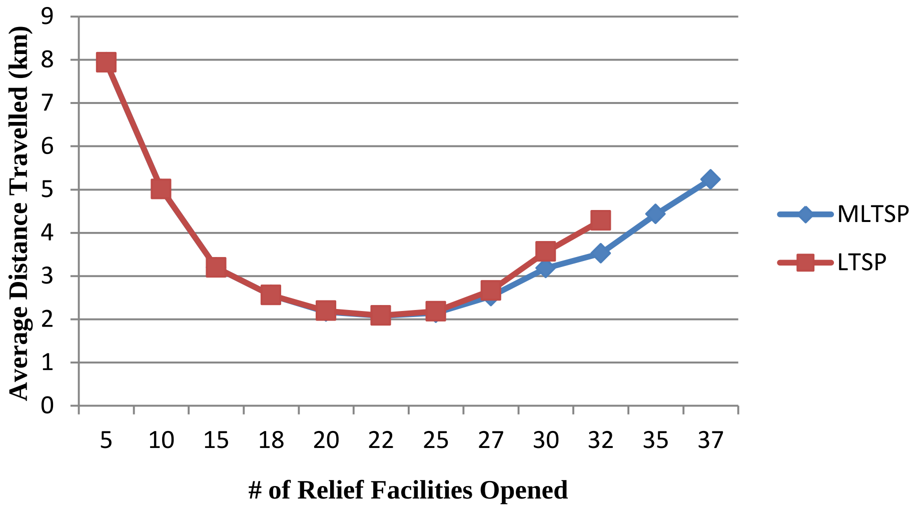

Figure 5.22: Average Distance Travelled in MLTSP and LTSP Models when R=40 km

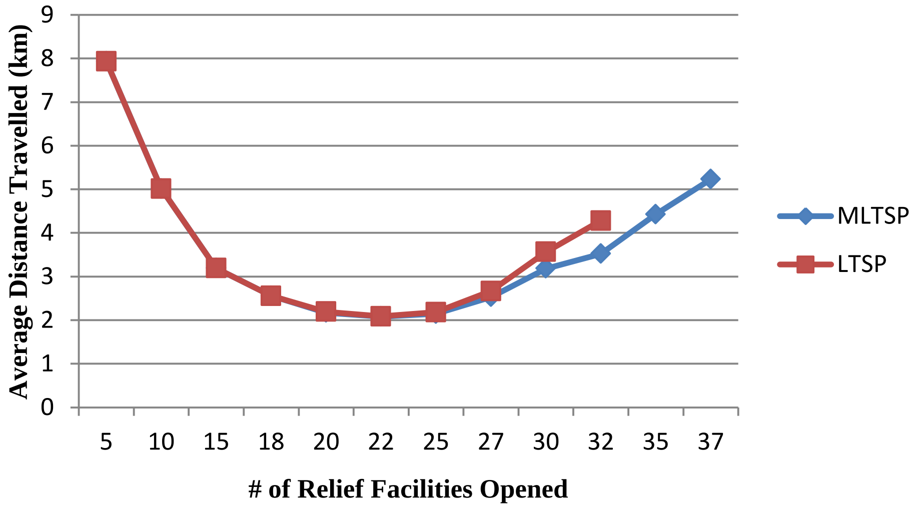

Figure 5.23: Average Distance Travelled in MLTSP and LTSP Models when R=80 km

As seen on Figure 5.22 and 5.23, MLTSP model begins to give better average distance travelled values according to LTSP model after 20 relief facilities are opened. At this point lateral transshipment on seaway also begins. LTSP model is infeasible after 35 relief facilities are opened due to not being able to satisfy demand with existing inventory and obligation of not taking relief item from a different side of the city. However, since MLTSP can make relief item transportation between Anatolian and European side, it is able to give better results after 35 relief facilities are opened. The difference between average distance travelled values obtained from MLTSP and LTSP models begins at 20 relief facilities are opened and continues to increase as number of open relief facilities increases on behalf of MLTSP Model.

Figure 5.24 and 5.25 show the percentage of total lateral transshipment in MLTSP and LTSP models as number of open relief facilities increases for the allowed maximum distance travelled of relief item is equal to 40 km and 80 km, respectively.

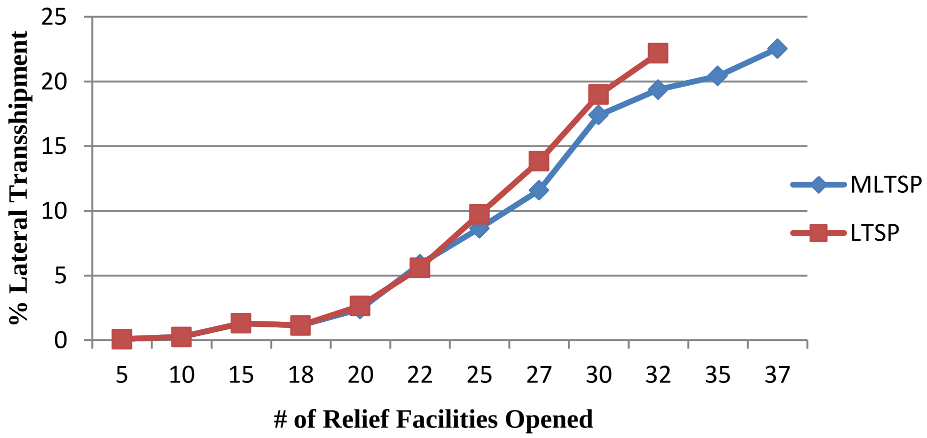

Figure 5.24: Percentage of Total Lateral Transshipment in MLTSP and LTSP Models when R= 40 km

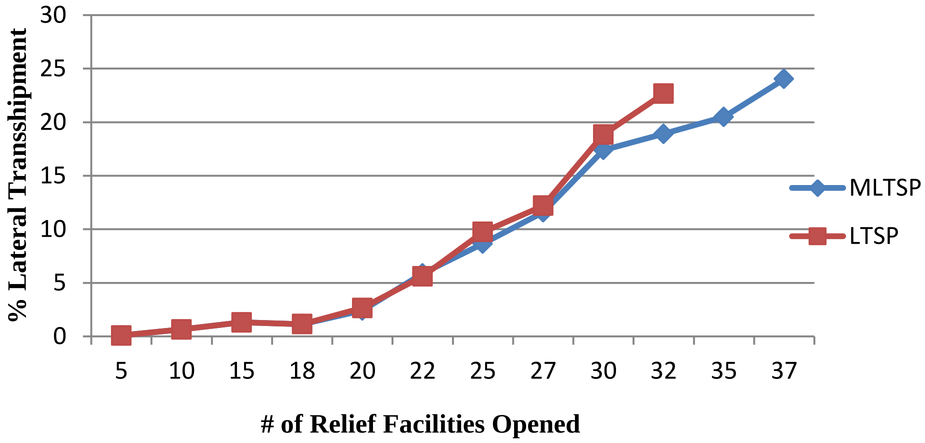

Figure 5.25: Percentage of Total Lateral Transshipment in MLTSP and LTSP Models when R= 80 km

As seen at Figure 5.24 and 5.25, after 20 relief facilities are opened, total lateral transshipment in LTSP is greater than total lateral transshipment in MLTSP. Before 20 relief facilities are opened, since there does not exist lateral transshipment on seaway, both models have same values of percentage of total lateral transshipment. Since lateral transshipment on seaway begins after 20 relief facilities are opened, the percentage of total lateral transshipment in MTLSP begins to differ from LTSP.

To understand the reason of having lower percentage of total lateral transshipment in MLTSP model, it can be stated that demand of districts located in European side has larger than the demand of districts located in Anatolian side. In addition to that, the number of classes of districts located in Anatolian side is greater than the number of classes of districts located in European side. That means districts located in Anatolian side can have more excess inventory to make lateral transshipment between relief facilities. Actually, results of MLTSP also confirm this explanation. All lateral transshipment on seaway is directed from relief facilities located in Anatolian side to relief facilities located in European side. In such a case, MLTSP model can satisfy demand of districts located in European side by making just one lateral transshipment on seaway through a neighbor relief facility located in European side. However, for the lateral transshipment case of LTSP, demands in European side has to be satisfied from another neighbor relief facility located in

European side. In such a case, any relief facility makes lateral transshipment with any other neighbor relief facility and after making lateral transshipment, the neighbor relief facility may have to make another lateral transshipment to satisfy demand assigned to it. That is, in LTSP model, any lateral transshipment may result in another lateral transshipment. As a result, the percentage of total lateral transshipment in LTSP is greater than the percentage of total lateral transshipment in MLTSP after lateral transshipment on seaway begins where 20 relief facilities are opened.

For certain A(P) parameter intervals LTSP and MLTSP models are also compared to each other. Figure 5.26 and Figure 5.27 shows the average distance travelled values and the percentage of total lateral transshipment values, respectively.

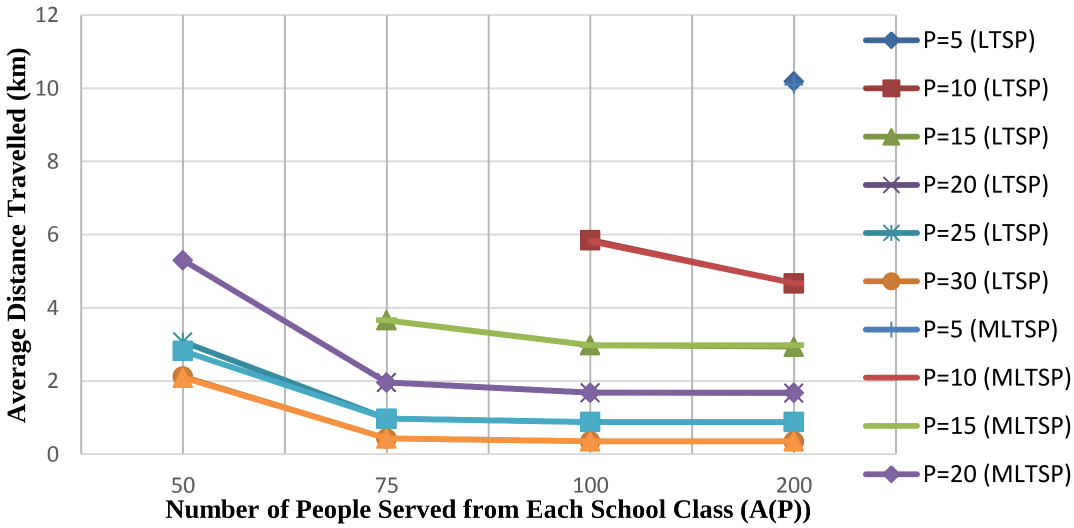

Figure 5.26: Average Distance Travelled in LTSP and MLTSP Models for Different A(P) Parameter Intervals for High Vulnerability Case when R=40 km

As seen on Figure 5.26, both LTSP and MLTSP models give same results as number of open relief facility and A(P) parameter increases. For cases where A(P) is equal to 50, the difference between two models reaches the highest point on behalf of MLTSP model in terms of having lower average distance travelled values. Also, in these cases lateral transshipment made on seaway exists in MLTSP model.

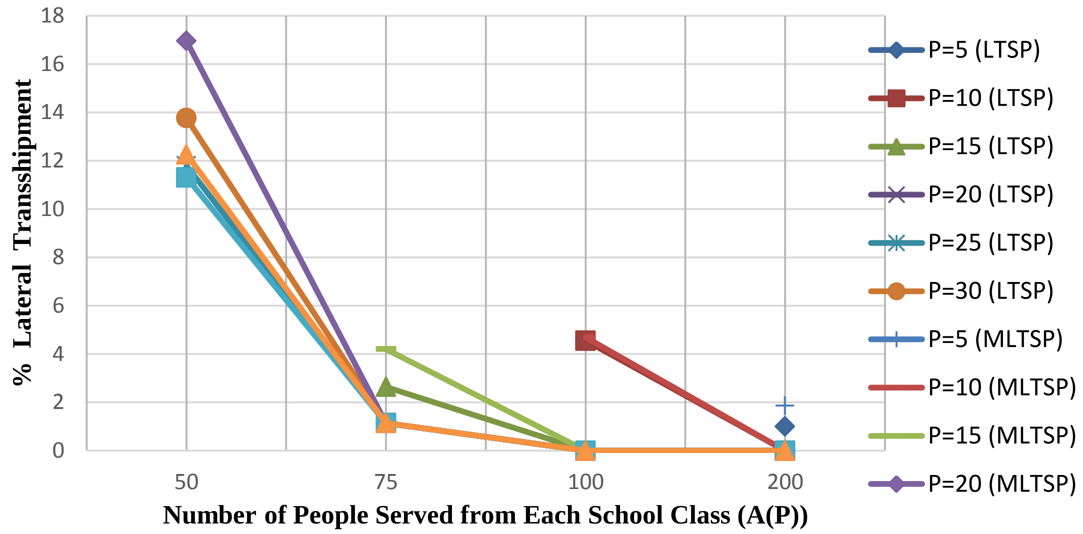

Figure 5.27: Percentage of Lateral Transshipment in LTSP and MLTSP Models for Different A(P) Parameter Intervals for High Vulnerability Case when R=40 km

From Figure 5.27, it can be seen that the percentage of lateral transshipment is higher in MLTSP model than LTSP model where A(P) parameter is equal to 50. For other cases, both models give similar results.

From Figure 5.26 and 5.27, it can be concluded that using seaway for relief item transportation is good alternative for lower value of A(P) parameter due to having lower capacity of relief facilities. As a result, making lateral transshipment on seaway provides faster response for satisfying the requirements of the affected for lower value of parameter A(P).

CHAPTER 6

CONCLUSION

In this study, lateral transshipment opportunities are included into the humanitarian relief logistics. All applications are studied on a possible earthquake scenario generated for İstanbul.

The main motivation of this study is the potential advantage of using lateral transshipment in such a humanitarian logistics system that each relief facility is allowed to hold different maximum amount of inventory level. Firstly, in such a system direct shipment model (DT) is developed where lateral transshipment between relief facilities are not allowed. After developing DT model, to examine the effect of lateral transshipment on the humanitarian logistics, LTSP model is developed in which lateral transshipment between relief facilities is allowed. According to the performance measure of average distance travelled per relief item, LTSP model gives always equal or better results than DT model. These results show that lateral transshipment between relief facilities in such a system that each relief facility has different inventory capacities provides faster response time to refugees. After comparing DT and LTSP models regarding to the average distance travelled per relief item, LTSP model is studied in detail to understand the effect of model parameters on the objective value. LTSP model is run for different allowed maximum distance travelled of relief item, number of relief facilities opened, varying vulnerability factors, and then changes in the average distance travelled value and the percentage of lateral transshipment value are examined. Results obtained from these runs show that;

- As vulnerability factor increases average distance travelled also increases.

- Until 15 relief facilities are opened, when allowed maximum distance travelled of relief item is equal to 80 km average distance travelled value is better than the average distance travelled value when allowed maximum distance travelled of relief item is equal to 40 km. After number of relief facilities opened is greater than 15 relief facilities, the effect of allowed maximum distance travelled is lost.

LTSP model is also evaluated for percentage value of lateral transshipment for different values of model parameters. It is seen that;

- As number of open relief facilities increases, the percentage of lateral transshipment generally increases. However, it is not valid for all cases. The reason of this is about the assignment of demand locations to relief facilities with varying capacities.
- Vulnerability and allowed maximum distance travelled of relief item does not affect the percentage of lateral transshipment substantially. However, it can be stated that as vulnerability factor decreases, the percentage of lateral transshipment increases. Lower vulnerability makes roads between relief facilities more secure and model may prefer to make lateral transshipment.

Although it seen that LTSP model gives minimum value of average distance travelled per relief item when 23 relief facilities are opened, it can not be surely said that this case is optimal for LTSP model. Since value of number of people served by each school class is changed as number of open relief facility changes, we have to examine the model for constant A(P) parameter to understand the effect of number of open relief facility. As a result, for certain different A(P) parameter intervals, the average distance travelled and the percentage of lateral transshipment are studied as number of open relief facility increases. From these, it can be said that making lateral transshipment is meaningful for cases where number of open relief facility is greater than 20. Also, it is seen that for specific number of open relief facility, the value of average distance travelled begins to be same after certain amount of parameter A(P). It shows that, certain amount of relief facility capacity is enough for specific number of open relief facility to minimize the value of the average distance travelled per relief item.

After analysing the LTSP model in detail and observing that LTSP model gives better results than DT model, MLTSP model is developed. Since using highway is more difficult and time consuming in high vulnerability case, MLTSP model is studied in the high vulnerability scenario to allow lateral transshipment between both sides of İstanbul on seaway. MTLSP model is studied for different value of model parameters and it is seen that;

- After 30 relief facilities are opened, for allowed maximum distance travelled is equal to 80 km average distance travelled value is slightly better than the average distance value when allowed maximum distance travelled of relief item is equal to 40 km. When number of open relief facilities is between 10 and 30, the allowed maximum distance travelled does not affect the value of average distance travelled.
- As number of open relief facilities increases, the percentage of lateral transshipment on seaway generally increases. However, it is not valid for all cases.

After analyzing the MLTSP model, it is compared with LTSP model to examine the effect of lateral transshipment on seaway between Anatolian and European sides of İstanbul. Since demand of districts located in European side is larger than the demand of districts located in Anatolian side and maximum level of inventory holding capacity of districts (number of school classes of districts) located in Anatolian side is greater than maximum level of inventory holding capacity of districts located in European side, all lateral transshipment on seaway directed from Anatolian side to European side. MLTSP model gives better average distance travelled values after 20 relief facilities are opened where the lateral transshipment on seaway begins. As a result, allowing sea transportation provides faster response time to refugees after 20 relief facilities are opened.

In this thesis study, lateral transshipment opportunities are included into the humanitarian logistics system and developed models are applied on a possible earthquake scenario generated for İstanbul. Also maritime transportation is evaluated for relief item transportation between relief facilities located different side of the city. Both LTSP and MLTSP models give better results than DT model and using lateral transshipment opportunities can help refugees to obtain relief items faster.

This thesis is studied for the most probable earthquake scenario stated by the JICA Report. By developing stochastic models, all of four scenarios can be studied together. Developed models (DT, LTSP, MLTSP) have assumptions like ignoring the capacity and number of land vehicles, ignoring loading/unloading time for LTSP model and assuming that each ship is ready for shipment at each port and ignoring loading/unloading time for MLTSP model. By relaxing these assumptions additional models can be studied. In addition to that, instead of using ships more than one at ports, one ship can be used and it is allowed to make tours between assigned ports.

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APPENDIX A

COORDINATES OF DISTRICTS

Table A.1: Coordinates of Center Point of Districts

	Districts	North°	East°	Side of District
1	Arnavutköy	41.193.645	28.731.335	Europe
2	Avcılar	41.000.478	28.716.310	Europe
3	Bağcılar	41.040.667	28.844.080	Europe
4	Bahçelievler	41.006.842	28.843.080	Europe
5	Bakırköy	40.979.960	28.849.001	Europe
6	Başakşehir	41.088.674	28.758.063	Europe
7	Bayrampaşa	41.050.186	28.901.553	Europe
8	Beşiktaş	41.063.548	29.018.029	Europe
9	Beylikdüzü	40.994.109	28.643.696	Europe
10	Beyoğlu	41.041.741	28.964.738	Europe
11	Büyükçekmece	41.023.188	28.568.587	Europe
12	Çatalca	41.172.033	28.439.429	Europe
13	Esenler	41.043.376	28.878.071	Europe
14	Esenyurt	41.033.118	28.658.954	Europe
15	Eyüp	41.081.415	28.928.268	Europe
16	Fatih	41.015.024	28.938.128	Europe
17	Gaziosmanpaşa	41.072.693	28.904.717	Europe
18	Güngören	41.018.545	28.875.030	Europe
19	Kağıthane	41.080.627	28.984.613	Europe
20	Küçükçekmece	41.020.645	28.788.865	Europe
21	Sarıyer	41.130.616	29.035.391	Europe
22	Silivri	41.079.912	28.181.687	Europe
23	Sultangazi	41.101.763	28.875.939	Europe
24	Şişli	41.058.648	28.987.405	Europe
25	Zeytinburnu	40.996.988	28.903.160	Europe
26	Ataşehir	40.985.994	29.120.069	Anatolia
27	Beykoz	41.109.148	29.096.209	Anatolia
28	Çekmeköy	41.034.680	29.156.567	Anatolia
29	Kadıköy	40.979.843	29.064.436	Anatolia
30	Kartal	40.906.304	29.197.212	Anatolia
31	Maltepe	40.939.733	29.134.729	Anatolia
32	Pendik	40.889.081	29.272.735	Anatolia
33	Sancaktepe	40.998.519	29.221.051	Anatolia
34	Sultanbeyli	40.963.320	29.274.729	Anatolia
35	Tuzla	40.847.181	29.328.286	Anatolia
36	Ümraniye	41.021.493	29.122.627	Anatolia
37	Üsküdar	41.027.337	29.055.645	Anatolia

APPENDIX B

PROPERTIES OF DISTRICTS

Table B.1: Population, Demand and no. of Classes in Each District

	Districts	Population (2012)	No.of Refugees	Demand of Relief Item	No.of Classes
1	Arnavutköy	213.531	15.566	3892	1187
2	Avcılar	407.240	99.689	24.923	1577
3	Bağcılar	752.250	104.169	26.043	2483
4	Bahçelievler	602.931	144.422	36.106	2195
5	Bakırköy	220.974	66.670	16.668	1649
6	Başakşehir	333.047	54.060	13.515	1566
7	Bayrampaşa	269.677	55.644	13.911	900
8	Beşiktaş	186.570	15.943	3986	1386
9	Beylikdüzü	489.978	97.132	24.283	1161
10	Beyoğlu	245.219	38.571	9643	1146
11	Büyükçekmece	211.000	41.829	10.458	1280
12	Çatalca	65.811	4011	1003	505
13	Esenler	461.621	57.427	14.357	1153
14	Esenyurt	624.733	123.846	30.962	1872
15	Eyüp	361.531	49.089	12.273	1422
16	Fatih	425.865	123.777	30.945	1476
17	Gaziosmanpaşa	495.006	37.931	9483	1944
18	Güngören	306.854	67.569	16.893	1058
19	Kağıthane	428.755	35.644	8911	1451
20	Küçükçekmece	740.090	125.455	31.364	2893
21	Sarıyer	335.598	11.557	2890	912
22	Silivri	155.923	14.027	3507	1040
23	Sultangazi	505.190	39.396	9849	1301
24	Şişli	274.420	20.078	5020	1680
25	Zeytinburnu	292.313	81.969	20.493	1459
26	Ataşehir	395.974	34.822	8706	1468
27	Beykoz	247.820	10.233	2559	941
28	Çekmeköy	207.476	11.744	2936	1215
29	Kadıköy	506.293	53.686	13.423	2841
30	Kartal	447.110	67.723	16.931	1844
31	Maltepe	471.059	58.839	14.710	2553
32	Pendik	646.375	87.495	21.874	3255
33	Sancaktepe	304.406	29.460	7365	1208
34	Sultanbeyli	309.347	43.504	10.876	1398
35	Tuzla	208.807	34.109	8528	1205
36	Ümraniye	660.124	37.365	9342	3333
37	Üsküdar	534.636	33.196	8299	3244

APPENDIX C

VULNERABILITY OF ROADS

Table C.1: Vulnerability Coefficient of Routes between Relief Facilities and between Relief Facilities and Demand Locations

From	To	Low Vuln.	Average Vuln.	High Vuln.
Arnavutköy	Arnavutköy	0	0	0
Arnavutköy	Avcılar	0.006	0.033	0.059
Arnavutköy	Bağcılar	0.005	0.030	0.055
Arnavutköy	Bahçelievler	0.045	0.082	0.119
Arnavutköy	Bakırköy	0.068	0.112	0.156
Arnavutköy	Başakşehir	0	0.025	0.050
Arnavutköy	Bayrampaşa	0.012	0.038	0.064
Arnavutköy	Beşiktaş	0.031	0.066	0.100
Arnavutköy	Beylikdüzü	0	0.025	0.050
Arnavutköy	Beyoğlu	0.003	0.028	0.053
Arnavutköy	Büyükçekmece	0.004	0.030	0.056
Arnavutköy	Çatalca	0	0.025	0.050
Arnavutköy	Esenler	0.004	0.029	0.054
Arnavutköy	Esenyurt	0	0.025	0.050
Arnavutköy	Eyüp	0.001	0.026	0.051
Arnavutköy	Fatih	0.052	0.093	0.134
Arnavutköy	Gaziosmanpaşa	0	0.025	0.050
Arnavutköy	Güngören	0.043	0.083	0.122
Arnavutköy	Kağıthane	0.002	0.027	0.052
Arnavutköy	Küçükçekmece	0.006	0.032	0.057
Arnavutköy	Sarıyer	0	0.025	0.050
Arnavutköy	Silivri	0	0.025	0.050
Arnavutköy	Sultangazi	0	0.025	0.050
Arnavutköy	Şişli	0.028	0.063	0.098
Arnavutköy	Zeytinburnu	0.039	0.076	0.113
Avcılar	Arnavutköy	0.006	0.033	0.059
Avcılar	Avcılar	0	0	0
Avcılar	Bağcılar	0.067	0.109	0.150
Avcılar	Bahçelievler	0.115	0.174	0.233
Avcılar	Bakırköy	0.092	0.140	0.188
Avcılar	Başakşehir	0.011	0.038	0.066
Avcılar	Bayrampaşa	0.113	0.169	0.224
Avcılar	Beşiktaş	0.064	0.103	0.143
Avcılar	Beylikdüzü	0.024	0.051	0.079
Avcılar	Beyoğlu	0.112	0.164	0.215
Avcılar	Büyükçekmece	0.022	0.051	0.080
Avcılar	Çatalca	0.014	0.041	0.069
Avcılar	Esenler	0.008	0.034	0.060
Avcılar	Esenyurt	0.027	0.058	0.088
Avcılar	Eyüp	0.087	0.132	0.176

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Avcılar	Fatih	0.105	0.155	0.206
Avcılar	Gaziosmanpaşa	0.095	0.142	0.188
Avcılar	Güngören	0.105	0.157	0.209
Avcılar	Kağıthane	0.076	0.119	0.162
Avcılar	Küçükçekmece	0.138	0.198	0.257
Avcılar	Sarıyer	0.058	0.097	0.135
Avcılar	Silivri	0.006	0.032	0.058
Avcılar	Sultangazi	0.006	0.033	0.059
Avcılar	Şişli	0.076	0.119	0.162
Avcılar	Zeytinburnu	0.113	0.167	0.221
Bağcılar	Arnavutköy	0.005	0.030	0.055
Bağcılar	Avcılar	0.067	0.109	0.150
Bağcılar	Bağcılar	0	0	0
Bağcılar	Bahçelievler	0.085	0.125	0.165
Bağcılar	Bakırköy	0.144	0.213	0.280
Bağcılar	Başakşehir	0.005	0.030	0.055
Bağcılar	Bayrampaşa	0.057	0.087	0.117
Bağcılar	Beşiktaş	0.061	0.104	0.146
Bağcılar	Beylikdüzü	0.053	0.090	0.127
Bağcılar	Beyoğlu	0.085	0.135	0.184
Bağcılar	Büyükçekmece	0.047	0.084	0.121
Bağcılar	Çatalca	0.003	0.028	0.053
Bağcılar	Esenler	0.036	0.061	0.086
Bağcılar	Esenyurt	0.003	0.028	0.053
Bağcılar	Eyüp	0.037	0.064	0.092
Bağcılar	Fatih	0.111	0.163	0.215
Bağcılar	Gaziosmanpaşa	0.025	0.051	0.078
Bağcılar	Güngören	0.190	0.280	0.368
Bağcılar	Kağıthane	0.065	0.108	0.151
Bağcılar	Küçükçekmece	0.050	0.080	0.111
Bağcılar	Sarıyer	0.005	0.030	0.055
Bağcılar	Silivri	0.002	0.027	0.052
Bağcılar	Sultangazi	0.016	0.042	0.068
Bağcılar	Şişli	0.072	0.119	0.164
Bağcılar	Zeytinburnu	0.200	0.281	0.361
Bahçelievler	Arnavutköy	0.045	0.082	0.119
Bahçelievler	Avcılar	0.115	0.174	0.233
Bahçelievler	Bağcılar	0.085	0.125	0.165
Bahçelievler	Bahçelievler	0	0	0
Bahçelievler	Bakırköy	0.208	0.296	0.382

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Bahçelievler	Başakşehir	0.030	0.062	0.094
Bahçelievler	Bayrampaşa	0.209	0.285	0.361
Bahçelievler	Beşiktaş	0.080	0.127	0.174
Bahçelievler	Beylikdüzü	0.089	0.139	0.188
Bahçelievler	Beyoğlu	0.190	0.278	0.365
Bahçelievler	Büyükçekmece	0.082	0.131	0.180
Bahçelievler	Çatalca	0.058	0.100	0.142
Bahçelievler	Esenler	0.087	0.127	0.167
Bahçelievler	Esenyurt	0.100	0.155	0.210
Bahçelievler	Eyüp	0.077	0.122	0.166
Bahçelievler	Fatih	0.115	0.165	0.215
Bahçelievler	Gaziosmanpaşa	0.110	0.164	0.216
Bahçelievler	Güngören	0.200	0.281	0.360
Bahçelievler	Kağıthane	0.100	0.154	0.206
Bahçelievler	Küçükçekmece	0.096	0.138	0.179
Bahçelievler	Sarıyer	0.046	0.083	0.120
Bahçelievler	Silivri	0.040	0.078	0.114
Bahçelievler	Sultangazi	0.052	0.086	0.121
Bahçelievler	Şişli	0.109	0.167	0.224
Bahçelievler	Zeytinburnu	0.294	0.403	0.511
Bakırköy	Arnavutköy	0.068	0.112	0.156
Bakırköy	Avcılar	0.092	0.140	0.188
Bakırköy	Bağcılar	0.144	0.213	0.280
Bakırköy	Bahçelievler	0.208	0.296	0.382
Bakırköy	Bakırköy	0	0	0
Bakırköy	Başakşehir	0.010	0.037	0.064
Bakırköy	Bayrampaşa	0.173	0.238	0.302
Bakırköy	Beşiktaş	0.056	0.098	0.139
Bakırköy	Beylikdüzü	0.072	0.114	0.156
Bakırköy	Beyoğlu	0.204	0.300	0.393
Bakırköy	Büyükçekmece	0.065	0.106	0.146
Bakırköy	Çatalca	0.047	0.084	0.120
Bakırköy	Esenler	0.179	0.246	0.311
Bakırköy	Esenyurt	0.077	0.120	0.164
Bakırköy	Eyüp	0.099	0.149	0.198
Bakırköy	Fatih	0.208	0.309	0.408
Bakırköy	Gaziosmanpaşa	0.122	0.178	0.233
Bakırköy	Güngören	0.263	0.369	0.473
Bakırköy	Kağıthane	0.068	0.112	0.156
Bakırköy	Küçükçekmece	0.063	0.095	0.128

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Bakırköy	Sarıyer	0.048	0.087	0.126
Bakırköy	Silivri	0.032	0.065	0.098
Bakırköy	Sultangazi	0.106	0.158	0.210
Bakırköy	Şişli	0.177	0.261	0.343
Bakırköy	Zeytinburnu	0.232	0.350	0.465
Başakşehir	Arnavutköy	0	0.025	0.050
Başakşehir	Avcılar	0.011	0.038	0.066
Başakşehir	Bağcılar	0.005	0.030	0.055
Başakşehir	Bahçelievler	0.030	0.062	0.094
Başakşehir	Bakırköy	0.010	0.037	0.064
Başakşehir	Başakşehir	0	0	0
Başakşehir	Bayrampaşa	0.024	0.052	0.081
Başakşehir	Beşiktaş	0.030	0.065	0.100
Başakşehir	Beylikdüzü	0	0.025	0.050
Başakşehir	Beyoğlu	0.034	0.071	0.107
Başakşehir	Büyükçekmece	0.004	0.029	0.055
Başakşehir	Çatalca	0	0.025	0.050
Başakşehir	Esenler	0.002	0.027	0.052
Başakşehir	Esenyurt	0	0.025	0.050
Başakşehir	Eyüp	0.001	0.026	0.051
Başakşehir	Fatih	0.054	0.096	0.138
Başakşehir	Gaziosmanpaşa	0	0.025	0.050
Başakşehir	Güngören	0.032	0.067	0.101
Başakşehir	Kağıthane	0.002	0.027	0.052
Başakşehir	Küçükçekmece	0.007	0.033	0.059
Başakşehir	Sarıyer	0	0.025	0.050
Başakşehir	Silivri	0	0.025	0.050
Başakşehir	Sultangazi	0	0.025	0.050
Başakşehir	Şişli	0.034	0.071	0.107
Başakşehir	Zeytinburnu	0.051	0.092	0.132
Bayrampaşa	Arnavutköy	0.012	0.038	0.064
Bayrampaşa	Avcılar	0.113	0.169	0.224
Bayrampaşa	Bağcılar	0.057	0.087	0.117
Bayrampaşa	Bahçelievler	0.209	0.285	0.361
Bayrampaşa	Bakırköy	0.173	0.238	0.302
Bayrampaşa	Başakşehir	0.024	0.052	0.081
Bayrampaşa	Bayrampaşa	0	0	0
Bayrampaşa	Beşiktaş	0.083	0.136	0.187
Bayrampaşa	Beylikdüzü	0.014	0.041	0.068
Bayrampaşa	Beyoğlu	0.103	0.162	0.219

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Bahçelievler	Başakşehir	0.030	0.062	0.094
Bahçelievler	Bayrampaşa	0.209	0.285	0.361
Bahçelievler	Beşiktaş	0.080	0.127	0.174
Bahçelievler	Beylikdüzü	0.089	0.139	0.188
Bahçelievler	Beyoğlu	0.190	0.278	0.365
Bahçelievler	Büyükçekmece	0.082	0.131	0.180
Bahçelievler	Çatalca	0.058	0.100	0.142
Bahçelievler	Esenler	0.087	0.127	0.167
Bahçelievler	Esenyurt	0.100	0.155	0.210
Bahçelievler	Eyüp	0.077	0.122	0.166
Bahçelievler	Fatih	0.115	0.165	0.215
Bahçelievler	Gaziosmanpaşa	0.110	0.164	0.216
Bahçelievler	Güngören	0.200	0.281	0.360
Bahçelievler	Kağıthane	0.100	0.154	0.206
Bahçelievler	Küçükçekmece	0.096	0.138	0.179
Bahçelievler	Sarıyer	0.046	0.083	0.120
Bahçelievler	Silivri	0.040	0.078	0.114
Bahçelievler	Sultangazi	0.052	0.086	0.121
Bahçelievler	Şişli	0.109	0.167	0.224
Bahçelievler	Zeytinburnu	0.294	0.403	0.511
Bakırköy	Arnavutköy	0.068	0.112	0.156
Bakırköy	Avcılar	0.092	0.140	0.188
Bakırköy	Bağcılar	0.144	0.213	0.280
Bakırköy	Bahçelievler	0.208	0.296	0.382
Bakırköy	Bakırköy	0	0	0
Bakırköy	Başakşehir	0.010	0.037	0.064
Bakırköy	Bayrampaşa	0.173	0.238	0.302
Bakırköy	Beşiktaş	0.056	0.098	0.139
Bakırköy	Beylikdüzü	0.072	0.114	0.156
Bakırköy	Beyoğlu	0.204	0.300	0.393
Bakırköy	Büyükçekmece	0.065	0.106	0.146
Bakırköy	Çatalca	0.047	0.084	0.120
Bakırköy	Esenler	0.179	0.246	0.311
Bakırköy	Esenyurt	0.077	0.120	0.164
Bakırköy	Eyüp	0.099	0.149	0.198
Bakırköy	Fatih	0.208	0.309	0.408
Bakırköy	Gaziosmanpaşa	0.122	0.178	0.233
Bakırköy	Güngören	0.263	0.369	0.473
Bakırköy	Kağıthane	0.068	0.112	0.156
Bakırköy	Küçükçekmece	0.063	0.095	0.128

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Bakırköy	Sarıyer	0.048	0.087	0.126
Bakırköy	Silivri	0.032	0.065	0.098
Bakırköy	Sultangazi	0.106	0.158	0.210
Bakırköy	Şişli	0.177	0.261	0.343
Bakırköy	Zeytinburnu	0.232	0.350	0.465
Başakşehir	Arnavutköy	0	0.025	0.050
Başakşehir	Avcılar	0.011	0.038	0.066
Başakşehir	Bağcılar	0.005	0.030	0.055
Başakşehir	Bahçelievler	0.030	0.062	0.094
Başakşehir	Bakırköy	0.010	0.037	0.064
Başakşehir	Başakşehir	0	0	0
Başakşehir	Bayrampaşa	0.024	0.052	0.081
Başakşehir	Beşiktaş	0.030	0.065	0.100
Başakşehir	Beylikdüzü	0	0.025	0.050
Başakşehir	Beyoğlu	0.034	0.071	0.107
Başakşehir	Büyükçekmece	0.004	0.029	0.055
Başakşehir	Çatalca	0	0.025	0.050
Başakşehir	Esenler	0.002	0.027	0.052
Başakşehir	Esenyurt	0	0.025	0.050
Başakşehir	Eyüp	0.001	0.026	0.051
Başakşehir	Fatih	0.054	0.096	0.138
Başakşehir	Gaziosmanpaşa	0	0.025	0.050
Başakşehir	Güngören	0.032	0.067	0.101
Başakşehir	Kağıthane	0.002	0.027	0.052
Başakşehir	Küçükçekmece	0.007	0.033	0.059
Başakşehir	Sarıyer	0	0.025	0.050
Başakşehir	Silivri	0	0.025	0.050
Başakşehir	Sultangazi	0	0.025	0.050
Başakşehir	Şişli	0.034	0.071	0.107
Başakşehir	Zeytinburnu	0.051	0.092	0.132
Bayrampaşa	Arnavutköy	0.012	0.038	0.064
Bayrampaşa	Avcılar	0.113	0.169	0.224
Bayrampaşa	Bağcılar	0.057	0.087	0.117
Bayrampaşa	Bahçelievler	0.209	0.285	0.361
Bayrampaşa	Bakırköy	0.173	0.238	0.302
Bayrampaşa	Başakşehir	0.024	0.052	0.081
Bayrampaşa	Bayrampaşa	0	0	0
Bayrampaşa	Beşiktaş	0.083	0.136	0.187
Bayrampaşa	Beylikdüzü	0.014	0.041	0.068
Bayrampaşa	Beyoğlu	0.103	0.162	0.219

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Beyoğlu	Fatih	0.115	0.160	0.205
Beyoğlu	Gaziosmanpaşa	0.020	0.048	0.075
Beyoğlu	Güngören	0.122	0.185	0.246
Beyoğlu	Kağıthane	0.007	0.032	0.057
Beyoğlu	Küçükçekmece	0.041	0.072	0.104
Beyoğlu	Sarıyer	0	0.025	0.050
Beyoğlu	Silivri	0.017	0.047	0.078
Beyoğlu	Sultangazi	0.001	0.026	0.051
Beyoğlu	Şişli	0.043	0.075	0.107
Beyoğlu	Zeytinburnu	0.200	0.297	0.391
Büyükçekmece	Arnavutköy	0.004	0.030	0.056
Büyükçekmece	Avcılar	0.022	0.051	0.080
Büyükçekmece	Bağcılar	0.047	0.084	0.121
Büyükçekmece	Bahçelievler	0.082	0.131	0.180
Büyükçekmece	Bakırköy	0.065	0.106	0.146
Büyükçekmece	Başakşehir	0.004	0.029	0.055
Büyükçekmece	Bayrampaşa	0.015	0.043	0.070
Büyükçekmece	Beşiktaş	0.057	0.095	0.133
Büyükçekmece	Beylikdüzü	0.013	0.042	0.070
Büyükçekmece	Beyoğlu	0.061	0.100	0.139
Büyükçekmece	Büyükçekmece	0	0	0
Büyükçekmece	Çatalca	0	0.025	0.050
Büyükçekmece	Esenler	0.004	0.030	0.056
Büyükçekmece	Esenyurt	0.011	0.039	0.067
Büyükçekmece	Eyüp	0.003	0.029	0.055
Büyükçekmece	Fatih	0.069	0.110	0.151
Büyükçekmece	Gaziosmanpaşa	0.003	0.029	0.054
Büyükçekmece	Güngören	0.091	0.141	0.191
Büyükçekmece	Kağıthane	0.056	0.095	0.133
Büyükçekmece	Küçükçekmece	0.084	0.133	0.182
Büyükçekmece	Sarıyer	0.002	0.028	0.053
Büyükçekmece	Silivri	0	0.025	0.050
Büyükçekmece	Sultangazi	0.003	0.029	0.054
Büyükçekmece	Şişli	0.058	0.097	0.135
Büyükçekmece	Zeytinburnu	0.080	0.126	0.171
Çatalca	Arnavutköy	0	0.025	0.005
Çatalca	Avcılar	0.014	0.041	0.069
Çatalca	Bağcılar	0.003	0.028	0.053
Çatalca	Bahçelievler	0.058	0.100	0.142
Çatalca	Bakırköy	0.047	0.084	0.120

Table C.1 (Continued)

Çatalca	Başakşehir	0	0.025	0.050
Çatalca	Bayrampaşa	0.010	0.037	0.063
Çatalca	Beşiktaş	0.018	0.049	0.079
Çatalca	Beylikdüzü	0.004	0.031	0.057
Çatalca	Beyoğlu	0.019	0.050	0.081
Çatalca	Büyükçekmece	0	0.025	0.050
Çatalca	Çatalca	0	0	0
Çatalca	Esenler	0.001	0.026	0.051
Çatalca	Esenyurt	0.005	0.031	0.057
Çatalca	Eyüp	0.001	0.026	0.051
Çatalca	Fatih	0.025	0.058	0.090
Çatalca	Gaziosmanpaşa	0	0.025	0.050
Çatalca	Güngören	0.020	0.052	0.083
Çatalca	Kağıthane	0.002	0.027	0.052
Çatalca	Küçükçekmece	0.045	0.082	0.120
Çatalca	Sarıyer	0	0.025	0.050
Çatalca	Silivri	0	0.025	0.050
Çatalca	Sultangazi	0	0.025	0.050
Çatalca	Şişli	0.017	0.047	0.078
Çatalca	Zeytinburnu	0.037	0.076	0.113
Esenler	Arnavutköy	0.004	0.029	0.054
Esenler	Avcılar	0.008	0.034	0.060
Esenler	Bağcılar	0.036	0.061	0.086
Esenler	Bahçelievler	0.087	0.127	0.167
Esenler	Bakırköy	0.179	0.246	0.311
Esenler	Başakşehir	0.002	0.027	0.052
Esenler	Bayrampaşa	0.200	0.280	0.359
Esenler	Beşiktaş	0.071	0.119	0.166
Esenler	Beylikdüzü	0.015	0.043	0.072
Esenler	Beyoğlu	0.089	0.143	0.196
Esenler	Büyükçekmece	0.004	0.030	0.056
Esenler	Çatalca	0.001	0.026	0.051
Esenler	Esenler	0	0	0
Esenler	Esenyurt	0.001	0.026	0.051
Esenler	Eyüp	0.038	0.066	0.094
Esenler	Fatih	0.146	0.211	0.274
Esenler	Gaziosmanpaşa	0.014	0.039	0.064
Esenler	Güngören	0.200	0.294	0.385
Esenler	Kağıthane	0.078	0.128	0.177
Esenler	Küçükçekmece	0.016	0.043	0.070

Table C.1 (Continued)

Esenler	Sarıyer	0.005	0.030	0.055
Esenler	Silivri	0.002	0.028	0.053
Esenler	Sultangazi	0.011	0.036	0.061
Esenler	Şişli	0.072	0.121	0.169
Esenler	Zeytinburnu	0.158	0.231	0.302
Esenyurt	Arnavutköy	0	0.025	0.050
Esenyurt	Avcılar	0.027	0.058	0.088
Esenyurt	Bağcılar	0.003	0.028	0.053
Esenyurt	Bahçelievler	0.100	0.155	0.210
Esenyurt	Bakırköy	0.077	0.120	0.164
Esenyurt	Başakşehir	0	0.025	0.050
Esenyurt	Bayrampaşa	0.016	0.044	0.071
Esenyurt	Beşiktaş	0.063	0.102	0.141
Esenyurt	Beylikdüzü	0	0.025	0.050
Esenyurt	Beyoğlu	0.067	0.108	0.148
Esenyurt	Büyükçekmece	0.011	0.039	0.067
Esenyurt	Çatalca	0.005	0.031	0.057
Esenyurt	Esenler	0.001	0.026	0.051
Esenyurt	Esenyurt	0	0	0
Esenyurt	Eyüp	0.001	0.026	0.051
Esenyurt	Fatih	0.076	0.119	0.162
Esenyurt	Gaziosmanpaşa	0	0.025	0.050
Esenyurt	Güngören	0.104	0.159	0.213
Esenyurt	Kağıthane	0.001	0.026	0.051
Esenyurt	Küçükçekmece	0.100	0.153	0.206
Esenyurt	Sarıyer	0	0.025	0.050
Esenyurt	Silivri	0.003	0.029	0,055
Esenyurt	Sultangazi	0	0.025	0.050
Esenyurt	Şişli	0.063	0.103	0.142
Esenyurt	Zeytinburnu	0.047	0.087	0.126
Eyüp	Arnavutköy	0.001	0.026	0.051
Eyüp	Avcılar	0.087	0.132	0.176
Eyüp	Bağcılar	0.037	0.064	0.092
Eyüp	Bahçelievler	0.077	0.122	0.166
Eyüp	Bakırköy	0.099	0.149	0.198
Eyüp	Başakşehir	0.001	0.026	0.051
Eyüp	Bayrampaşa	0.065	0.096	0.127
Eyüp	Beşiktaş	0.014	0.040	0.067
Eyüp	Beylikdüzü	0.001	0.026	0.051
Eyüp	Beyoğlu	0.033	0.065	0.096

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Eyüp	Büyükçekmece	0.003	0.029	0.055
Eyüp	Çatalca	0.001	0.026	0.051
Eyüp	Esenler	0.038	0.066	0.094
Eyüp	Esenyurt	0.001	0.026	0.051
Eyüp	Eyüp	0	0	0
Eyüp	Fatih	0.048	0.080	0.113
Eyüp	Gaziosmanpaşa	0.017	0.044	0.071
Eyüp	Güngören	0.075	0.121	0.166
Eyüp	Kağıthane	0.036	0.061	0.086
Eyüp	Küçükçekmece	0.010	0.036	0.062
Eyüp	Sarıyer	0.007	0.032	0.057
Eyüp	Silivri	0.002	0.027	0.052
Eyüp	Sultangazi	0.011	0.037	0.063
Eyüp	Şişli	0.007	0.032	0.057
Eyüp	Zeytinburnu	0.081	0.131	0.180
Fatih	Arnavutköy	0.052	0.093	0.134
Fatih	Avcılar	0.105	0.155	0.206
Fatih	Bağcılar	0.111	0.163	0.215
Fatih	Bahçelievler	0.115	0.165	0.215
Fatih	Bakırköy	0.208	0.309	0.408
Fatih	Başakşehir	0.054	0.096	0.138
Fatih	Bayrampaşa	0.250	0.359	0.466
Fatih	Beşiktaş	0.033	0.065	0.098
Fatih	Beylikdüzü	0.074	0.116	0.158
Fatih	Beyoğlu	0.115	0.160	0.205
Fatih	Büyükçekmece	0.069	0.110	0.151
Fatih	Çatalca	0.025	0.058	0.090
Fatih	Esenler	0.146	0.211	0.274
Fatih	Esenyurt	0.076	0.119	0.162
Fatih	Eyüp	0.048	0.080	0.113
Fatih	Fatih	0	0	0
Fatih	Gaziosmanpaşa	0.110	0.165	0.219
Fatih	Güngören	0.176	0.251	0.325
Fatih	Kağıthane	0.039	0.072	0.106
Fatih	Küçükçekmece	0.070	0.109	0.147
Fatih	Sarıyer	0.039	0.072	0.106
Fatih	Silivri	0.039	0.073	0.108
Fatih	Sultangazi	0.073	0.118	0.163
Fatih	Şişli	0.097	0.138	0.180
Fatih	Zeytinburnu	0.200	0.285	0.369

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Gaziosmanpaşa	Arnavutköy	0	0.025	0.050
Gaziosmanpaşa	Avcılar	0.095	0.142	0.188
Gaziosmanpaşa	Bağcılar	0.025	0.051	0.078
Gaziosmanpaşa	Bahçelievler	0.110	0.164	0.216
Gaziosmanpaşa	Bakırköy	0.122	0.178	0.233
Gaziosmanpaşa	Başakşehir	0	0.025	0.050
Gaziosmanpaşa	Bayrampaşa	0.063	0.094	0.125
Gaziosmanpaşa	Beşiktaş	0.017	0.043	0.069
Gaziosmanpaşa	Beylikdüzü	0	0.025	0.050
Gaziosmanpaşa	Beyoğlu	0.020	0.048	0.075
Gaziosmanpaşa	Büyükçekmece	0.003	0.029	0.054
Gaziosmanpaşa	Çatalca	0	0.025	0.050
Gaziosmanpaşa	Esenler	0.014	0.039	0.064
Gaziosmanpaşa	Esenyurt	0	0.025	0.050
Gaziosmanpaşa	Eyüp	0.017	0.044	0.071
Gaziosmanpaşa	Fatih	0.110	0.165	0.219
Gaziosmanpaşa	Gaziosmanpaşa	0	0	0
Gaziosmanpaşa	Güngören	0.090	0.141	0.191
Gaziosmanpaşa	Kağıthane	0.022	0.049	0.075
Gaziosmanpaşa	Küçükçekmece	0.033	0.062	0.091
Gaziosmanpaşa	Sarıyer	0	0.025	0.050
Gaziosmanpaşa	Silivri	0.002	0.027	0.052
Gaziosmanpaşa	Sultangazi	0	0.025	0.050
Gaziosmanpaşa	Şişli	0.025	0.053	0.081
Gaziosmanpaşa	Zeytinburnu	0.094	0.146	0.197
Güngören	Arnavutköy	0.043	0.083	0.122
Güngören	Avcılar	0.105	0.157	0.209
Güngören	Bağcılar	0.190	0.280	0.368
Güngören	Bahçelievler	0.200	0.281	0.360
Güngören	Bakırköy	0.263	0.369	0.473
Güngören	Başakşehir	0.032	0.067	0.101
Güngören	Bayrampaşa	0.246	0.352	0.455
Güngören	Beşiktaş	0.079	0.130	0.180
Güngören	Beylikdüzü	0.100	0.153	0.206
Güngören	Beyoğlu	0.122	0.185	0.246
Güngören	Büyükçekmece	0.091	0.141	0.191
Güngören	Çatalca	0.020	0.052	0.083
Güngören	Esenler	0.200	0.294	0.385
Güngören	Esenyurt	0.104	0.159	0.213
Güngören	Eyüp	0.075	0.121	0.166

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Güngören	Fatih	0.176	0.251	0.325
Güngören	Gaziosmanpaşa	0.090	0.141	0.191
Güngören	Güngören	0	0	0
Güngören	Kağıthane	0.113	0.172	0.231
Güngören	Küçükçekmece	0.123	0.178	0.233
Güngören	Sarıyer	0.046	0.085	0.123
Güngören	Silivri	0.015	0.045	0.075
Güngören	Sultangazi	0.057	0.097	0.137
Güngören	Şişli	0.085	0.139	0.191
Güngören	Zeytinburnu	0.367	0.522	0.673
Kağıthane	Arnavutköy	0.002	0.027	0.052
Kağıthane	Avcılar	0.076	0.119	0.162
Kağıthane	Bağcılar	0.065	0.108	0.151
Kağıthane	Bahçelievler	0.100	0.154	0.206
Kağıthane	Bakırköy	0.068	0.112	0.156
Kağıthane	Başakşehir	0.002	0.027	0.052
Kağıthane	Bayrampaşa	0.053	0.084	0.116
Kağıthane	Beşiktaş	0.010	0.038	0.065
Kağıthane	Beylikdüzü	0.059	0.098	0.137
Kağıthane	Beyoğlu	0.007	0.032	0.057
Kağıthane	Büyükçekmece	0.056	0.095	0.133
Kağıthane	Çatalca	0.002	0.027	0.052
Kağıthane	Esenler	0.078	0.128	0.177
Kağıthane	Esenyurt	0.001	0.026	0.051
Kağıthane	Eyüp	0.036	0.061	0.086
Kağıthane	Fatih	0.039	0.072	0.106
Kağıthane	Gaziosmanpaşa	0.022	0.049	0.075
Kağıthane	Güngören	0.113	0.172	0.231
Kağıthane	Kağıthane	0	0	0
Kağıthane	Küçükçekmece	0.043	0.074	0.106
Kağıthane	Sarıyer	0.004	0.029	0.054
Kağıthane	Silivri	0	0.025	0.050
Kağıthane	Sultangazi	0.008	0.033	0.058
Kağıthane	Şişli	0.006	0.031	0.056
Kağıthane	Zeytinburnu	0.087	0.143	0.199
Küçükçekmece	Arnavutköy	0.006	0.032	0.057
Küçükçekmece	Avcılar	0.138	0.198	0.257
Küçükçekmece	Bağcılar	0.050	0.080	0.111
Küçükçekmece	Bahçelievler	0.096	0.138	0.179
Küçükçekmece	Bakırköy	0.063	0.095	0.128

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Küçükçekmece	Başakşehir	0.007	0.033	0.059
Küçükçekmece	Bayrampaşa	0.017	0.044	0.071
Küçükçekmece	Beşiktaş	0.036	0.067	0.098
Küçükçekmece	Beylikdüzü	0.095	0.147	0.198
Küçükçekmece	Beyoğlu	0.041	0.072	0.104
Küçükçekmece	Büyükçekmece	0.084	0.133	0.182
Küçükçekmece	Çatalca	0.045	0.082	0.120
Küçükçekmece	Esenler	0.016	0.043	0.070
Küçükçekmece	Esenyurt	0.100	0.153	0.206
Küçükçekmece	Eyüp	0.010	0.036	0.062
Küçükçekmece	Fatih	0.070	0.109	0.147
Küçükçekmece	Gaziosmanpaşa	0.033	0.062	0.091
Küçükçekmece	Güngören	0.123	0.178	0.233
Küçükçekmece	Kağıthane	0.043	0.074	0.106
Küçükçekmece	Küçükçekmece	0	0	0
Küçükçekmece	Sarıyer	0.007	0.033	0.058
Küçükçekmece	Silivri	0.041	0.078	0.114
Küçükçekmece	Sultangazi	0.011	0.038	0.064
Küçükçekmece	Şişli	0.038	0.069	0.100
Küçükçekmece	Zeytinburnu	0.098	0.152	0.204
Sarıyer	Arnavutköy	0	0.025	0.050
Sarıyer	Avcılar	0.058	0.097	0.135
Sarıyer	Bağcılar	0.005	0.030	0.055
Sarıyer	Bahçelievler	0.046	0.083	0.120
Sarıyer	Bakırköy	0.048	0.087	0.126
Sarıyer	Başakşehir	0	0.025	0.050
Sarıyer	Bayrampaşa	0.029	0.056	0.084
Sarıyer	Beşiktaş	0	0.025	0.050
Sarıyer	Beylikdüzü	0	0.025	0.050
Sarıyer	Beyoğlu	0	0.025	0.050
Sarıyer	Büyükçekmece	0.002	0.028	0.053
Sarıyer	Çatalca	0	0.025	0.050
Sarıyer	Esenler	0.005	0.030	0.055
Sarıyer	Esenyurt	0	0.025	0.050
Sarıyer	Eyüp	0.007	0.032	0.057
Sarıyer	Fatih	0.039	0.072	0.106
Sarıyer	Gaziosmanpaşa	0	0.025	0.050
Sarıyer	Güngören	0.046	0.085	0.123
Sarıyer	Kağıthane	0.004	0.029	0.054
Sarıyer	Küçükçekmece	0.007	0.033	0.058

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Sarıyer	Sarıyer	0	0	0
Sarıyer	Silivri	0	0.025	0.050
Sarıyer	Sultangazi	0	0.025	0.050
Sarıyer	Şişli	0	0.025	0.050
Sarıyer	Zeytinburnu	0.044	0.086	0.127
Silivri	Arnavutköy	0	0.025	0.050
Silivri	Avcılar	0.006	0.032	0.058
Silivri	Bağcılar	0.002	0.027	0.052
Silivri	Bahçelievler	0.040	0.078	0.114
Silivri	Bakırköy	0.032	0.065	0.098
Silivri	Başakşehir	0	0.025	0.050
Silivri	Bayrampaşa	0.008	0.034	0.060
Silivri	Beşiktaş	0.016	0.046	0.077
Silivri	Beylikdüzü	0.003	0.029	0.055
Silivri	Beyoğlu	0.017	0.047	0.078
Silivri	Büyükçekmece	0	0.025	0.050
Silivri	Çatalca	0	0.025	0.050
Silivri	Esenler	0.002	0.028	0.053
Silivri	Esenyurt	0.003	0.029	0.055
Silivri	Eyüp	0.002	0.027	0.052
Silivri	Fatih	0.039	0.073	0.108
Silivri	Gaziosmanpaşa	0.002	0.027	0.052
Silivri	Güngören	0.015	0.045	0.075
Silivri	Kağıthane	0	0.025	0.050
Silivri	Küçükçekmece	0.041	0.078	0.114
Silivri	Sarıyer	0	0.025	0.050
Silivri	Silivri	0	0	0
Silivri	Sultangazi	0.002	0.027	0.053
Silivri	Şişli	0.035	0.069	0.102
Silivri	Zeytinburnu	0.047	0.084	0.121
Sultangazi	Arnavutköy	0	0.025	0.050
Sultangazi	Avcılar	0.006	0.033	0.059
Sultangazi	Bağcılar	0.016	0.042	0.068
Sultangazi	Bahçelievler	0.052	0.086	0.121
Sultangazi	Bakırköy	0.106	0.158	0.210
Sultangazi	Başakşehir	0	0.025	0.050
Sultangazi	Bayrampaşa	0.033	0.062	0.090
Sultangazi	Beşiktaş	0.008	0.034	0.059
Sultangazi	Beylikdüzü	0	0.025	0.050
Sultangazi	Beyoğlu	0.001	0.026	0.051

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Sultangazi	Büyükçekmece	0.003	0.029	0.054
Sultangazi	Çatalca	0	0.025	0.050
Sultangazi	Esenler	0.011	0.036	0.061
Sultangazi	Esenyurt	0	0.025	0.050
Sultangazi	Eyüp	0.011	0.037	0.063
Sultangazi	Fatih	0.073	0.118	0.163
Sultangazi	Gaziosmanpaşa	0	0.025	0.050
Sultangazi	Güngören	0.057	0.097	0.137
Sultangazi	Kağıthane	0.008	0.033	0.058
Sultangazi	Küçükçekmece	0.011	0.038	0.064
Sultangazi	Sarıyer	0	0.025	0.050
Sultangazi	Silivri	0.002	0.027	0.053
Sultangazi	Sultangazi	0	0	0
Sultangazi	Şişli	0.001	0.026	0.051
Sultangazi	Zeytinburnu	0.100	0.155	0.210
Şişli	Arnavutköy	0.028	0.063	0.098
Şişli	Avcılar	0.076	0.119	0.162
Şişli	Bağcılar	0.072	0.119	0.164
Şişli	Bahçelievler	0.109	0.167	0.224
Şişli	Bakırköy	0.177	0.261	0.343
Şişli	Başakşehir	0.034	0.071	0.107
Şişli	Bayrampaşa	0.050	0.082	0.113
Şişli	Beşiktaş	0	0.025	0.050
Şişli	Beylikdüzü	0.061	0.100	0.140
Şişli	Beyoğlu	0.043	0.075	0.107
Şişli	Büyükçekmece	0.058	0.097	0.135
Şişli	Çatalca	0.017	0.047	0.078
Şişli	Esenler	0.072	0.121	0.169
Şişli	Esenyurt	0.063	0.103	0.142
Şişli	Eyüp	0.007	0.032	0.057
Şişli	Fatih	0.097	0.138	0.180
Şişli	Gaziosmanpaşa	0.025	0.053	0.081
Şişli	Güngören	0.085	0.139	0.191
Şişli	Kağıthane	0.006	0.031	0.056
Şişli	Küçükçekmece	0.038	0.069	0.100
Şişli	Sarıyer	0	0.025	0.050
Şişli	Silivri	0.035	0.069	0.102
Şişli	Sultangazi	0.001	0.026	0.051
Şişli	Şişli	0	0	0
Şişli	Zeytinburnu	0.075	0.129	0.182

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Zeytinburnu	Arnavutköy	0.039	0.076	0.113
Zeytinburnu	Avcılar	0.113	0.167	0.221
Zeytinburnu	Bağcılar	0.200	0.281	0.361
Zeytinburnu	Bahçelievler	0.294	0.403	0.511
Zeytinburnu	Bakırköy	0.232	0.350	0.465
Zeytinburnu	Başakşehir	0.051	0.092	0.132
Zeytinburnu	Bayrampaşa	0.204	0.291	0.377
Zeytinburnu	Beşiktaş	0.068	0.119	0.170
Zeytinburnu	Beylikdüzü	0.086	0.133	0.180
Zeytinburnu	Beyoğlu	0.200	0.297	0.391
Zeytinburnu	Büyükçekmece	0.080	0.126	0.171
Zeytinburnu	Çatalca	0.037	0.076	0.113
Zeytinburnu	Esenler	0.158	0.231	0.302
Zeytinburnu	Esenyurt	0.047	0.087	0.126
Zeytinburnu	Eyüp	0.081	0.131	0.180
Zeytinburnu	Fatih	0.200	0.285	0.369
Zeytinburnu	Gaziosmanpaşa	0.094	0.146	0.197
Zeytinburnu	Güngören	0.367	0.522	0.673
Zeytinburnu	Kağıthane	0.087	0.143	0.199
Zeytinburnu	Küçükçekmece	0.098	0.152	0.204
Zeytinburnu	Sarıyer	0.044	0.086	0.127
Zeytinburnu	Silivri	0.047	0.084	0.121
Zeytinburnu	Sultangazi	0.100	0.155	0.210
Zeytinburnu	Şişli	0.075	0.129	0.182
Zeytinburnu	Zeytinburnu	0	0	0
Ataşehir	Ataşehir	0	0	0
Ataşehir	Beykoz	0	0.025	0.050
Ataşehir	Çekmeköy	0	0.025	0.050
Ataşehir	Kadıköy	0	0.025	0.050
Ataşehir	Kartal	0.021	0.047	0.074
Ataşehir	Maltepe	0.004	0.029	0.054
Ataşehir	Pendik	0.008	0.033	0.058
Ataşehir	Sancaktepe	0	0.025	0.050
Ataşehir	Sultanbeyli	0	0.025	0.050
Ataşehir	Tuzla	0.016	0.043	0.070
Ataşehir	Ümraniye	0	0.025	0.050
Ataşehir	Üsküdar	0	0.025	0.050
Beykoz	Ataşehir	0	0.025	0.050
Beykoz	Beykoz	0	0	0
Beykoz	Çekmeköy	0	0.025	0.050

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Beykoz	Kadıköy	0	0.025	0.050
Beykoz	Kartal	0.006	0.032	0.057
Beykoz	Maltepe	0.001	0.026	0.051
Beykoz	Pendik	0.005	0.030	0.055
Beykoz	Sancaktepe	0	0.025	0.050
Beykoz	Sultanbeyli	0	0.025	0.050
Beykoz	Tuzla	0.010	0.036	0.062
Beykoz	Ümraniye	0	0.025	0.050
Beykoz	Üsküdar	0	0.025	0.050
Çekmeköy	Ataşehir	0	0.025	0.050
Çekmeköy	Beykoz	0	0.025	0.050
Çekmeköy	Çekmeköy	0	0	0
Çekmeköy	Kadıköy	0.002	0.027	0.052
Çekmeköy	Kartal	0.004	0.030	0.056
Çekmeköy	Maltepe	0	0.025	0.050
Çekmeköy	Pendik	0.004	0.029	0.054
Çekmeköy	Sancaktepe	0	0.025	0.050
Çekmeköy	Sultanbeyli	0	0.025	0.050
Çekmeköy	Tuzla	0.011	0.037	0.063
Çekmeköy	Ümraniye	0	0.025	0.050
Çekmeköy	Üsküdar	0	0.025	0.050
Kadıköy	Ataşehir	0	0.025	0.050
Kadıköy	Beykoz	0	0.025	0.050
Kadıköy	Çekmeköy	0.004	0.030	0.056
Kadıköy	Kadıköy	0	0	0
Kadıköy	Kartal	0.013	0.039	0.065
Kadıköy	Maltepe	0.011	0.036	0.061
Kadıköy	Pendik	0.007	0.032	0.057
Kadıköy	Sancaktepe	0	0.025	0.050
Kadıköy	Sultanbeyli	0	0.025	0.050
Kadıköy	Tuzla	0.014	0.041	0.067
Kadıköy	Ümraniye	0.004	0.029	0.054
Kadıköy	Üsküdar	0	0.025	0.050
Kartal	Ataşehir	0.021	0.047	0.074
Kartal	Beykoz	0.006	0.032	0.057
Kartal	Çekmeköy	0.002	0.027	0.052
Kartal	Kadıköy	0.013	0.039	0.065
Kartal	Kartal	0	0	0
Kartal	Maltepe	0.027	0.055	0.082
Kartal	Pendik	0.015	0.040	0.065

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Kartal	Sancaktepe	0.002	0.027	0.052
Kartal	Sultanbeyli	0.002	0.027	0.052
Kartal	Tuzla	0.020	0.047	0.074
Kartal	Ümraniye	0.009	0.034	0.059
Kartal	Üsküdar	0.007	0.032	0.057
Maltepe	Ataşehir	0.004	0.029	0.054
Maltepe	Beykoz	0.001	0.026	0.051
Maltepe	Çekmeköy	0	0.025	0.050
Maltepe	Kadıköy	0.011	0.036	0.061
Maltepe	Kartal	0.027	0.055	0.082
Maltepe	Maltepe	0	0	0
Maltepe	Pendik	0.010	0.035	0.060
Maltepe	Sancaktepe	0	0.025	0.050
Maltepe	Sultanbeyli	0.001	0.026	0.051
Maltepe	Tuzla	0.016	0.043	0.069
Maltepe	Ümraniye	0.002	0.027	0.052
Maltepe	Üsküdar	0.002	0.027	0.052
Pendik	Ataşehir	0.008	0.033	0.058
Pendik	Beykoz	0.005	0.030	0.055
Pendik	Çekmeköy	0.004	0.029	0.054
Pendik	Kadıköy	0.007	0.032	0.057
Pendik	Kartal	0.015	0.040	0.065
Pendik	Maltepe	0.010	0.035	0.060
Pendik	Pendik	0	0	0
Pendik	Sancaktepe	0	0.025	0.050
Pendik	Sultanbeyli	0	0.025	0.050
Pendik	Tuzla	0.011	0.038	0.064
Pendik	Ümraniye	0.003	0.028	0.053
Pendik	Üsküdar	0.004	0.029	0.054
Sancaktepe	Ataşehir	0	0.025	0.050
Sancaktepe	Beykoz	0	0.025	0.050
Sancaktepe	Çekmeköy	0	0.025	0.050
Sancaktepe	Kadıköy	0	0.025	0.050
Sancaktepe	Kartal	0.002	0.027	0.052
Sancaktepe	Maltepe	0	0.025	0.050
Sancaktepe	Pendik	0	0.025	0.050
Sancaktepe	Sancaktepe	0	0	0
Sancaktepe	Sultanbeyli	0	0.025	0.050
Sancaktepe	Tuzla	0.001	0.036	0.062
Sancaktepe	Ümraniye	0	0.025	0.050

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Sancaktepe	Üsküdar	0	0.025	0.050
Sultanbeyli	Ataşehir	0	0.025	0.050
Sultanbeyli	Beykoz	0	0.025	0.050
Sultanbeyli	Çekmeköy	0	0.025	0.050
Sultanbeyli	Kadıköy	0	0.025	0.050
Sultanbeyli	Kartal	0.002	0.027	0.052
Sultanbeyli	Maltepe	0.001	0.026	0.051
Sultanbeyli	Pendik	0	0.025	0.050
Sultanbeyli	Sancaktepe	0	0.025	0.050
Sultanbeyli	Sultanbeyli	0	0	0
Sultanbeyli	Tuzla	0.001	0.026	0.051
Sultanbeyli	Ümraniye	0	0.025	0.050
Sultanbeyli	Üsküdar	0	0.025	0.050
Tuzla	Ataşehir	0.016	0.043	0.070
Tuzla	Beykoz	0.010	0.036	0.062
Tuzla	Çekmeköy	0.011	0.037	0.063
Tuzla	Kadıköy	0.014	0.041	0.067
Tuzla	Kartal	0.020	0.047	0.074
Tuzla	Maltepe	0.016	0.043	0.069
Tuzla	Pendik	0.011	0.038	0.064
Tuzla	Sancaktepe	0.010	0.036	0.062
Tuzla	Sultanbeyli	0.001	0.026	0.051
Tuzla	Tuzla	0	0	0
Tuzla	Ümraniye	0.008	0.033	0.059
Tuzla	Üsküdar	0.009	0.035	0.060
Ümraniye	Ataşehir	0	0.025	0.050
Ümraniye	Beykoz	0	0.025	0.050
Ümraniye	Çekmeköy	0	0.025	0.050
Ümraniye	Kadıköy	0.004	0.029	0.054
Ümraniye	Kartal	0.007	0.032	0.057
Ümraniye	Maltepe	0.002	0.027	0.052
Ümraniye	Pendik	0.003	0.028	0.053
Ümraniye	Sancaktepe	0	0.025	0.050
Ümraniye	Sultanbeyli	0	0.025	0.050
Ümraniye	Tuzla	0.008	0.033	0.059
Ümraniye	Ümraniye	0	0	0
Ümraniye	Üsküdar	0	0.025	0.050
Üsküdar	Ataşehir	0	0.025	0.050
Üsküdar	Beykoz	0	0.025	0.050

Table C.1 (Continued)

From	To	Low Vuln.	Average Vuln.	High Vuln.
Üsküdar	Çekmeköy	0	0.025	0.050
Üsküdar	Kadıköy	0	0.025	0.050
Üsküdar	Kartal	0.007	0.032	0.057
Üsküdar	Maltepe	0.002	0.027	0.052
Üsküdar	Pendik	0.004	0.029	0.054
Üsküdar	Sancaktepe	0	0.025	0.050
Üsküdar	Sultanbeyli	0	0.025	0.050
Üsküdar	Tuzla	0.009	0.035	0.060
Üsküdar	Ümraniye	0	0.025	0.050
Üsküdar	Üsküdar	0	0	0

APPENDIX D

DISTANCE BETWEEN RELIEF FACILITIES AND BETWEEN RELIEF FACILITIES AND DEMAND LOCATIONS

Table D.1: Distance between Relief Facilities and between Relief Facilities and Demand Locations

Distance in km	Arnavutköy	Avcılar	Bağcılar	Bahçelievler	Bakırköy	Başakşehir	Bayrampaşa	Beşiktaş	Beylikdüzü	Beyoğlu	Büyükçekmece	Çatalca
Arnavutköy	0	36.6	24.9	29.1	38.2	19	25.5	39.7	33.4	36.6	34.2	38.1
Avcılar	38.5	0	21.6	21	18.4	22.5	26.4	33.1	10.3	29.2	14.7	35.9
Bağcılar	25	19.4	0	4.4	8.2	14.9	8.9	20.8	28.1	16.9	32.5	48.7
Bahçelievler	27.8	16.7	4.7	0	4.6	17.6	10.2	24.9	25.4	21	29.9	51.4
Bakırköy	37.3	16.6	8.3	4.7	0	21.7	11.8	23.7	25.3	17.1	29.8	51
Başakşehir	18.4	21	13.5	18.3	25.5	0	19.9	31.6	31.9	27.7	36.6	51.5
Bayrampaşa	24.4	25.4	9.6	14.3	13.5	19.7	0	14.9	33.9	9.9	38.6	53.5
Beşiktaş	34.2	32.6	20.7	20.9	20.6	30	13.6	0	41.3	8.3	45.8	63.8
Beylikdüzü	34	10.6	28.1	27.5	24.9	23.9	32.9	39.6	0	35.7	10.8	32.1
Beyoğlu	33.6	29.5	16.4	16.6	16.4	26.9	9.9	7.8	38.2	0	42.6	60.7
Büyükçekmece	36.3	17.9	34.3	38.7	32.3	30.2	40.1	47	11.2	43.1	0	21.3
Çatalca	36.6	38.7	47.6	52	58	43.4	53.3	64.3	32	60.4	21.5	0
Esenler	25.3	26.3	4	6.8	9.8	15.6	4.2	16.8	29.8	12.9	34.5	49.4
Esenyurt	29.9	7.5	24.2	24.9	25.2	20	29.2	40	6.6	36.1	10.1	31.3
Eyüp	22.7	30.9	15.6	19.1	18.9	21.6	7.1	13.4	35.8	8.4	40.5	55.4
Fatih	29.9	25	12.8	10.4	11.4	22.1	6.1	13.3	33.7	6.4	41	55.9
Gaziosmanpaşa	22.2	28.6	9.3	15	16.7	20.5	3.8	15.4	34.6	10.4	39.4	55.1
Güngören	28.9	18.3	5	3.8	6.2	18.6	6	20.3	27	13.1	31.5	52.4
Kağıthane	30.1	30.4	18.4	18.6	18.4	27.7	11.9	5.3	42	5.8	46.8	61.7
Küçükçekmece	27.5	12	8	7.2	11.4	12.1	16.1	29	20.7	25.1	25.2	46.4
Sarıyer	34.5	40	26.3	28.3	28	32.3	21.5	11	46.5	16.1	51.2	66.1
Silivri	73	58.5	73.5	77.9	72.8	69.3	79.2	87.6	51.8	83.7	42.1	33.2
Sultangazi	17.6	34.8	13.4	17.3	21.1	22.1	8	20.4	34.9	17.8	39.6	54.6
Şişli	34.9	30.5	18.6	18.7	18.5	27.9	12	4.2	39.2	4.1	43.6	61.7
Zeytinburnu	36	23.5	10.3	8.8	7.4	25.7	9.9	17	32.3	11.9	36.7	59.5

Table D.1 (Continued)

Distance (km)	Esenler	Esenyurt	Eyüp	Fatih	Gaziosmanpaşa	Güngören	Kağıthane	Küçükçekmece	Sarıyer	Silivri	Sultangazi	Şişli	Zeytinburnu
Arnavutköy	25.4	29.3	23.8	30.9	23.1	30	32.1	27.8	38.6	66.8	18.7	37.1	31.2
Avcılar	26.9	7.4	32.2	24.4	31.5	29	31.6	12.9	44.3	49.3	30.7	30.5	26.4
Bağcılar	5.4	24.9	13.4	12.1	11.1	4.9	19.3	7.1	26.5	67.1	12.9	18.2	10.9
Bahçelievler	7	23.2	20.2	11.8	15.2	4.3	23.4	7.1	32.3	64.5	16.7	22.3	8.1
Bakırköy	10.5	23.1	20.9	12.1	16.5	6.5	22.1	10.3	32	64.4	20	19	7.8
Başakşehir	16.1	27.7	21.8	22.8	21	19	28.7	12.1	33.9	69.9	20.2	29	23.3
Bayrampaşa	4.9	29.7	6.8	6.2	4	7.1	12.2	18.3	23.2	71.9	8.2	11.2	8.3
Beşiktaş	16	39.1	14.3	13.5	15.7	16.5	4.8	26.3	10.5	80.4	17.7	4.2	15.8
Beylikdüzü	29.3	6.8	35	30.9	34.2	27	38.1	19.4	47.1	45.4	33.4	37	33.7
Beyoğlu	11.7	36	8.3	6.2	10.7	12.2	6.1	23.1	16.5	77.2	17	4.1	11.4
Büyükçekmece	35.6	12.4	41.2	38.3	40.5	41.5	45.5	27.3	53.3	35.1	39.7	44.4	42.7
Çatalca	48.8	33.1	54.5	55.5	53.7	54.7	61.4	46.1	66.6	33.2	52.9	61.7	56
Esenler	0	25.6	10.7	8.1	6.7	3.9	15.3	14.2	24.2	67.8	10.1	14.2	7.6
Esenyurt	25.4	0	31.1	31.3	30.3	27.3	38	19.8	43.2	44.6	29.5	37.4	32.6
Eyüp	9	31.5	0	11.8	3.6	13.6	7	20.2	15.5	73.8	6.3	8.4	14.1
Fatih	8.1	31.5	11.1	0	9	6.6	11.8	20.7	21.6	72.7	13.1	8.6	5.5
Gaziosmanpaşa	6.4	30.4	3.1	9.4	0	11	10.9	19.8	16.9	73.5	4.4	10.9	12.3
Güngören	3.7	24.8	13.8	7.4	10.2	0	15.7	9.2	28.5	70.8	14.9	15	5.1
Kağıthane	13.7	37.8	6.6	11.2	10.4	14.3	0	24	11.3	80.1	13.1	3.1	13.5
Küçükçekmece	12.8	18.5	19.3	20.3	17.3	9.7	26.2	0	31.3	59.8	17.7	26.4	16.1
Sarıyer	23	42.2	14.6	20.9	16.7	23.9	10	33.7	0	84.5	18	11.8	23.2
Silivri	74.8	82.9	80.4	78.9	79.7	80.7	86	67.4	92.5	0	78.9	85	81.6
Sultangazi	10.9	30.7	6.3	16.4	5.2	15.5	13.2	17.7	19.8	77.2	0	19.4	16.7
Şişli	13.6	37	8.1	8.9	10.5	14.4	3.3	24.1	12.2	78.2	17.7	0	13.6
Zeytinburnu	9.3	30	14.2	6.7	12.5	5.5	15.4	15.5	25.3	77.9	17.1	13.8	0

Table D.1 (Continued)

Distance (km)	Ataşehir	Beykoz	Çekmeköy	Kadıköy	Kartal	Maltepe	Pendik	Sancaktepe	Sultanbeyli	Tuzla	Ümraniye	Üsküdar
Ataşehir	0	16.6	9.8	6.6	15	8.3	22.9	11.2	15.7	28.2	8.3	11.9
Beykoz	17.2	0	14.4	19.8	29.9	23.2	37.8	22.3	29.2	43.2	12.9	17
Çekmeköy	9.8	13.8	0	13.3	22.4	14.7	27.7	8	14.5	7.4	4.4	11
Kadıköy	5.9	19.5	12.2	0	17.2	9.2	25.1	19.4	20.9	30.5	8.6	8.1
Kartal	15.7	29.8	23.2	17.1	0	8.1	10.7	14.3	16.8	16	21.6	22.1
Maltepe	7.8	22	15.2	9.2	8.1	0	16	12.6	23.4	21.3	12.5	14.2
Pendik	22.5	37.8	27.3	23.9	10.4	14.9	0	17	11.2	9.4	29.6	28.9
Sancaktepe	11.6	21.6	9.1	19.8	14.8	12.5	16.4	0	6.9	25.5	12.2	18.8
Sultanbeyli	17.1	28.8	16.3	22.3	17.3	15.7	11.1	7.4	0	28.1	19.4	24.9
Tuzla	28	43.4	35.4	29.4	15.9	20.4	9.7	23.9	20.9	0	33.9	34.4
Ümraniye	5.5	12.7	4.1	8.9	23	13.6	30.9	12	17.3	36.3	0	6.3
Üsküdar	12.1	17.2	10.4	7	22.6	15.8	30.5	18.3	24.7	35.8	6.7	0

APPENDIX E

DISTANCE BETWEEN PORTS AND RELIEF FACILITIES

Table E.1: Distance between Ports and Relief Facilities

Distance (km)	Yenikapı	Bakırköy	Kabataş	İstinye	Sarıyer	Beşiktaş	Sirkeci	Avcılar	Ambarlı
Arnavutköy	32.7	39.7	37	38.5	42.9	39.6	36	37.3	40.1
Avcılar	26.2	18.5	30.5	41.3	45.7	34.3	29.4	3.8	10.4
Bağcılar	13.9	9.7	18.2	26.3	30.7	22	17.1	20	28.2
Bahçelievler	14.4	6.1	20	32.1	36.5	21.8	19	17.3	25.6
Bakırköy	11.5	3	17	31.8	36.3	18.9	16.1	17.2	25.5
Başakşehir	24.6	25.5	29	33.7	38.1	33	27.9	21.6	29.8
Bayrampaşa	8	15	11.1	21.1	27.5	16.3	10.1	26.1	34
Beşiktaş	13.3	22.2	6.3	9.6	14.8	3.7	9.5	33.2	41.5
Beylikdüzü	32.8	25	37	46.9	51.3	41	35.9	9.6	8
Beyoğlu	5.6	15.5	3.9	16.4	20.8	5.2	4.9	30.1	38.3
Büyükçekmece	40.1	32.3	44.4	53.2	57.6	48.4	43.3	17.9	16.8
Çatalca	57.3	58	61.6	66.4	70.8	65.6	60.6	42.7	37.6
Esenler	9.9	11.3	13.9	23.6	28.4	15.8	13	26.9	30
Esenyurt	33.1	25.3	37.4	43	47.4	41.4	36.3	9.9	9.6
Eyüp	12.8	20.4	11.4	17.1	21.5	11.6	12.6	32.8	35.9
Fatih	2.7	10.8	6.4	21.5	26	8.6	5.7	25.6	33.8
Gaziosmanpaşa	11.2	18.2	13	16.8	21.2	13.6	11.9	32.5	34.8
Güngören	9	7.7	13	25.3	32.7	14.9	12.1	18.9	27.2
Kağıthane	10.7	19.9	8.6	11.1	15.6	6.4	10	31	39.2
Küçükçekmece	22.1	16.3	26.4	31.2	35.6	30.4	25.3	12.6	20.9
Sarıyer	21.6	29.5	14.4	4.1	6.8	12.3	17.6	40.6	46.6
Silivri	80.5	74.2	84.7	92.3	96.8	88.8	83.7	58.4	57.4
Sultangazi	18.2	25.2	18.4	19.7	24.1	18.5	21.5	36.2	35.1
Şişli	8.3	18.2	4.6	12	16.4	4.1	7.6	31.1	39.3
Zeytinburnu	6	6.8	11.8	25.2	29.6	13.7	10.9	24.1	32.4

Table E.1 (Continued)

Distance (km)	Harem	Kadıköy	Bostancı	Maltepe	Pendik	Kartal	Beykoz	Haydarpaşa
Ataşehir	11.3	11	6	7.1	20.8	17.1	24.5	11.6
Beykoz	25.2	25.1	21.2	22.1	37	32	3.3	25
Çekmeköy	19.4	19	15.4	16.3	25.5	23.4	21	19.2
Kadıköy	8.2	5.7	5.1	6.6	21.9	16.9	27.4	8
Kartal	22.3	21.6	12.8	9.4	7	3.1	37.7	22.1
Maltepe	14.5	14.5	5.5	3.5	14	9.4	29.9	14.2
Pendik	29.2	30	20.8	18.2	8	11	45.7	28.9
Sancaktepe	25.2	26.1	17.3	14.6	17.9	15.8	29.5	25
Sultanbeyli	27.7	28.6	23.7	24.6	16.4	18.4	36.6	27.5
Tuzla	34.6	35.5	26.2	23.7	12.8	15.4	51.2	34.4
Ümraniye	12.9	13.8	13	14	30.1	25.1	20.6	12.7
Üsküdar	5.4	7.2	13.8	13.1	28.4	24.7	21.5	6.7

APPENDIX F

DISTANCE BETWEEN PORTS

Table F.1: Distance between Ports

Distance (km)	Yenikapı	Bakırköy	Kabataş	İstinye	Sarıyer	Beşiktaş	Sirkeci	Avcılar	Ambarlı
Harem	4.52	11.8	2.72	15.39	21.21	3.33	2.87	26.04	29.15
Kadıköy	5.37	12.02	5.15	15.8	21.62	5.82	4.96	26.45	29.56
Bostancı	12.98	18.17	14.02	24.76	31.52	15.24	12.93	31.52	35.34
Maltepe	14.37	19.84	14.87	25.63	32.45	16.23	14.48	33.4	38.54
Pendik	28.95	32.3	29.56	40.51	47.32	3.,01	28.36	45.08	49.69
Kartal	24.69	27.71	24.93	35.88	42.69	25.38	23.67	40.8	44.14
Beykoz	20.13	26.82	16.28	12.93	4.87	3.43	16.8	42.51	46.03
Haydarpaşa	4.95	12.09	4.26	13.17	18.76	4.82	3.32	25.6	29.54

APPENDIX G

VULNERABILITY OF ROADS BETWEEN RELIEF FACILITIES AND PORTS

Table G.1: Vulnerability Coefficient of Routes between Relief Facilities and Ports

From (Relief Facility)	To (Port)	High Vuln.		From (Relief Facility)	To (Port)	High Vuln.
Ataşehir	Harem	0.050		Kadıköy	Maltepe	0.061
Beykoz	Harem	0.050		Kartal	Maltepe	0.082
Çekmeköy	Harem	0.050		Maltepe	Maltepe	0
Kadıköy	Harem	0.050		Pendik	Maltepe	0.060
Kartal	Harem	0.057		Sancaktepe	Maltepe	0
Maltepe	Harem	0.052		Sultanbeyli	Maltepe	0.051
Pendik	Harem	0.054		Tuzla	Maltepe	0.069
Sancaktepe	Harem	0.050		Ümraniye	Maltepe	0.052
Sultanbeyli	Harem	0.050		Üsküdar	Maltepe	0
Tuzla	Harem	0.060		Ataşehir	Pendik	0.058
Ümraniye	Harem	0.050		Beykoz	Pendik	0.055
Üsküdar	Harem	0		Çekmeköy	Pendik	0.054
Ataşehir	Kadıköy	0.050		Kadıköy	Pendik	0.057
Beykoz	Kadıköy	0.050		Kartal	Pendik	0.065
Çekmeköy	Kadıköy	0.052		Maltepe	Pendik	0.060
Kadıköy	Kadıköy	0		Pendik	Pendik	0
Kartal	Kadıköy	0.065		Sancaktepe	Pendik	0.050
Maltepe	Kadıköy	0.061		Sultanbeyli	Pendik	0.050
Pendik	Kadıköy	0.057		Tuzla	Pendik	0.064
Sancaktepe	Kadıköy	0.050		Ümraniye	Pendik	0.053
Sultanbeyli	Kadıköy	0.050		Üsküdar	Pendik	0
Tuzla	Kadıköy	0.067		Ataşehir	Kartal	0.074
Ümraniye	Kadıköy	0.054		Beykoz	Kartal	0.057
Üsküdar	Kadıköy	0.050		Çekmeköy	Kartal	0.056
Ataşehir	Bostancı	0.050		Kadıköy	Kartal	0.065
Beykoz	Bostancı	0.050		Kartal	Kartal	0
Çekmeköy	Bostancı	0.052		Maltepe	Kartal	0.082
Kadıköy	Bostancı	0		Pendik	Kartal	0.065
Kartal	Bostancı	0.065		Sancaktepe	Kartal	0.052
Maltepe	Bostancı	0.061		Sultanbeyli	Kartal	0.052
Pendik	Bostancı	0.057		Tuzla	Kartal	0.074
Sancaktepe	Bostancı	0.050		Ümraniye	Kartal	0.057
Sultanbeyli	Bostancı	0.050		Üsküdar	Kartal	0.057
Tuzla	Bostancı	0.067		Ataşehir	Beykoz	0.050
Ümraniye	Bostancı	0.054		Beykoz	Beykoz	0
Üsküdar	Bostancı	0.050		Çekmeköy	Beykoz	0.050
Ataşehir	Maltepe	0.054		Kadıköy	Beykoz	0
Beykoz	Maltepe	0.051		Kartal	Beykoz	0.057
Çekmeköy	Maltepe	0.050		Maltepe	Beykoz	0.051

Table G.1 (Continued)

From (Relief Facility)	To (Port)	High Vuln.		From (Relief Facility)	To (Port)	High Vuln.
Pendik	Beykoz	0.055		Sultangazi	Yenikapı	0.163
Sancaktepe	Beykoz	0		Şişli	Yenikapı	0.180
Sultanbeyli	Beykoz	0.050		Zeytinburnu	Yenikapı	0.369
Tuzla	Beykoz	0.062		Arnavutköy	Bakırköy	0.156
Ümraniye	Beykoz	0.050		Avcılar	Bakırköy	0.188
Üsküdar	Beykoz	0.050		Bağcılar	Bakırköy	0.280
Ataşehir	Haydarpaşa	0.050		Bahçelievler	Bakırköy	0.382
Beykoz	Haydarpaşa	0.050		Bakırköy	Bakırköy	0
Çekmeköy	Haydarpaşa	0.052		Başakşehir	Bakırköy	0.064
Kadıköy	Haydarpaşa	0		Bayrampaşa	Bakırköy	0.302
Kartal	Haydarpaşa	0.065		Beşiktaş	Bakırköy	0.139
Maltepe	Haydarpaşa	0.061		Beylikdüzü	Bakırköy	0.156
Pendik	Haydarpaşa	0.057		Beyoğlu	Bakırköy	0.393
Sancaktepe	Haydarpaşa	0		Büyükçekmece	Bakırköy	0.146
Sultanbeyli	Haydarpaşa	0.050		Çatalca	Bakırköy	0.120
Tuzla	Haydarpaşa	0.067		Esenler	Bakırköy	0.311
Ümraniye	Haydarpaşa	0.054		Esenyurt	Bakırköy	0.164
Üsküdar	Haydarpaşa	0.050		Eyüp	Bakırköy	0.198
Arnavutköy	Yenikapı	0.134		Fatih	Bakırköy	0.408
Avcılar	Yenikapı	0.206		Gaziosmanpaşa	Bakırköy	0.233
Bağcılar	Yenikapı	0.215		Güngören	Bakırköy	0.473
Bahçelievler	Yenikapı	0.215		Kağıthane	Bakırköy	0.156
Bakırköy	Yenikapı	0.408		Küçükçekmece	Bakırköy	0.128
Başakşehir	Yenikapı	0.138		Sarıyer	Bakırköy	0.126
Bayrampaşa	Yenikapı	0.466		Silivri	Bakırköy	0.098
Beşiktaş	Yenikapı	0.098		Sultangazi	Bakırköy	0.210
Beylikdüzü	Yenikapı	0.158		Şişli	Bakırköy	0.343
Beyoğlu	Yenikapı	0.205		Zeytinburnu	Bakırköy	0.465
Büyükçekmece	Yenikapı	0.151		Arnavutköy	Kabataş	0.053
Çatalca	Yenikapı	0.090		Avcılar	Kabataş	0.215
Esenler	Yenikapı	0.274		Bağcılar	Kabataş	0.184
Esenyurt	Yenikapı	0.162		Bahçelievler	Kabataş	0.365
Eyüp	Yenikapı	0.113		Bakırköy	Kabataş	0.393
Fatih	Yenikapı	0		Başakşehir	Kabataş	0.107
Gaziosmanpaşa	Yenikapı	0.219		Bayrampaşa	Kabataş	0.219
Güngören	Yenikapı	0.325		Beşiktaş	Kabataş	0.050
Kağıthane	Yenikapı	0.106		Beylikdüzü	Kabataş	0.147
Küçükçekmece	Yenikapı	0.147		Beyoğlu	Kabataş	0
Sarıyer	Yenikapı	0.106		Büyükçekmece	Kabataş	0.139
Silivri	Yenikapı	0.108		Çatalca	Kabataş	0.081

Table G.1 (Continued)

From (Relief Facility)	To (Port)	High Vuln.		From (Relief Facility)	To (Port)	High Vuln.
Esenler	Kabataş	0.196		Bağcılar	Sarıyer	0.055
Esenyurt	Kabataş	0.148		Bahçelievler	Sarıyer	0.120
Eyüp	Kabataş	0.096		Bakırköy	Sarıyer	0.126
Fatih	Kabataş	0.205		Başakşehir	Sarıyer	0.050
Gaziosmanpaşa	Kabataş	0.075		Bayrampaşa	Sarıyer	0.084
Güngören	Kabataş	0.246		Beşiktaş	Sarıyer	0.050
Kağıthane	Kabataş	0.057		Beylikdüzü	Sarıyer	0.050
Küçükçekmece	Kabataş	0.104		Beyoğlu	Sarıyer	0.050
Sarıyer	Kabataş	0.050		Büyükçekmece	Sarıyer	0.053
Silivri	Kabataş	0.078		Çatalca	Sarıyer	0.050
Sultangazi	Kabataş	0.051		Esenler	Sarıyer	0.055
Şişli	Kabataş	0.107		Esenyurt	Sarıyer	0.050
Zeytinburnu	Kabataş	0.391		Eyüp	Sarıyer	0.057
Arnavutköy	İstinye	0.050		Fatih	Sarıyer	0.106
Avcılar	İstinye	0.135		Gaziosmanpaşa	Sarıyer	0.050
Bağcılar	İstinye	0.055		Güngören	Sarıyer	0.123
Bahçelievler	İstinye	0.120		Kağıthane	Sarıyer	0.054
Bakırköy	İstinye	0.126		Küçükçekmece	Sarıyer	0.058
Başakşehir	İstinye	0.050		Sarıyer	Sarıyer	0
Bayrampaşa	İstinye	0.084		Silivri	Sarıyer	0.050
Beşiktaş	İstinye	0.050		Sultangazi	Sarıyer	0.050
Beylikdüzü	İstinye	0.050		Şişli	Sarıyer	0.050
Beyoğlu	İstinye	0.050		Zeytinburnu	Sarıyer	0.127
Büyükçekmece	İstinye	0.053		Arnavutköy	Beşiktaş	0.100
Çatalca	İstinye	0.050		Avcılar	Beşiktaş	0.143
Esenler	İstinye	0.055		Bağcılar	Beşiktaş	0.146
Esenyurt	İstinye	0.050		Bahçelievler	Beşiktaş	0.174
Eyüp	İstinye	0.057		Bakırköy	Beşiktaş	0.139
Fatih	İstinye	0.106		Başakşehir	Beşiktaş	0.100
Gaziosmanpaşa	İstinye	0.050		Bayrampaşa	Beşiktaş	0.187
Güngören	İstinye	0.123		Beşiktaş	Beşiktaş	0
Kağıthane	İstinye	0.054		Beylikdüzü	Beşiktaş	0.137
Küçükçekmece	İstinye	0.058		Beyoğlu	Beşiktaş	0.050
Sarıyer	İstinye	0		Büyükçekmece	Beşiktaş	0.133
Silivri	İstinye	0.050		Çatalca	Beşiktaş	0.079
Sultangazi	İstinye	0.050		Esenler	Beşiktaş	0.166
Şişli	İstinye	0.050		Esenyurt	Beşiktaş	0.141
Zeytinburnu	İstinye	0.127		Eyüp	Beşiktaş	0.067
Arnavutköy	Sarıyer	0.050		Fatih	Beşiktaş	0.098
Avcılar	Sarıyer	0.135		Gaziosmanpaşa	Beşiktaş	0.069

Table G.1 (Continued)

From (Relief Facility)	To (Port)	High Vuln.		From (Relief Facility)	To (Port)	High Vuln.
Güngören	Beşiktaş	0.180		Bayrampaşa	Avcılar	0.224
Kağıthane	Beşiktaş	0.065		Beşiktaş	Avcılar	0.143
Küçükçekmece	Beşiktaş	0.098		Beylikdüzü	Avcılar	0.079
Sarıyer	Beşiktaş	0.050		Beyoğlu	Avcılar	0.215
Silivri	Beşiktaş	0.077		Büyükçekmece	Avcılar	0.080
Sultangazi	Beşiktaş	0.059		Çatalca	Avcılar	0.069
Şişli	Beşiktaş	0.050		Esenler	Avcılar	0.060
Zeytinburnu	Beşiktaş	0.170		Esenyurt	Avcılar	0.088
Arnavutköy	Sirkeci	0.134		Eyüp	Avcılar	0.176
Avcılar	Sirkeci	0.206		Fatih	Avcılar	0.206
Bağcılar	Sirkeci	0.215		Gaziosmanpaşa	Avcılar	0.188
Bahçelievler	Sirkeci	0.215		Güngören	Avcılar	0.209
Bakırköy	Sirkeci	0.408		Kağıthane	Avcılar	0.162
Başakşehir	Sirkeci	0.138		Küçükçekmece	Avcılar	0.257
Bayrampaşa	Sirkeci	0.466		Sarıyer	Avcılar	0.135
Beşiktaş	Sirkeci	0.098		Silivri	Avcılar	0.058
Beylikdüzü	Sirkeci	0.158		Sultangazi	Avcılar	0.059
Beyoğlu	Sirkeci	0.205		Şişli	Avcılar	0.162
Büyükçekmece	Sirkeci	0.151		Zeytinburnu	Avcılar	0.221
Çatalca	Sirkeci	0.090		Arnavutköy	Ambarlı	0.059
Esenler	Sirkeci	0.274		Avcılar	Ambarlı	0
Esenyurt	Sirkeci	0.162		Bağcılar	Ambarlı	0.150
Eyüp	Sirkeci	0.113		Bahçelievler	Ambarlı	0.233
Fatih	Sirkeci	0		Bakırköy	Ambarlı	0.188
Gaziosmanpaşa	Sirkeci	0.219		Başakşehir	Ambarlı	0.066
Güngören	Sirkeci	0.325		Bayrampaşa	Ambarlı	0.224
Kağıthane	Sirkeci	0.106		Beşiktaş	Ambarlı	0.143
Küçükçekmece	Sirkeci	0.147		Beylikdüzü	Ambarlı	0.079
Sarıyer	Sirkeci	0.106		Beyoğlu	Ambarlı	0.215
Silivri	Sirkeci	0.108		Büyükçekmece	Ambarlı	0.080
Sultangazi	Sirkeci	0.163		Çatalca	Ambarlı	0.069
Şişli	Sirkeci	0.180		Esenler	Ambarlı	0.060
Zeytinburnu	Sirkeci	0.369		Esenyurt	Ambarlı	0.088
Arnavutköy	Avcılar	0.059		Eyüp	Ambarlı	0.176
Avcılar	Avcılar	0		Fatih	Ambarlı	0.206
Bağcılar	Avcılar	0.150		Gaziosmanpaşa	Ambarlı	0.188
Bahçelievler	Avcılar	0.233		Güngören	Ambarlı	0.209
Bakırköy	Avcılar	0.188		Kağıthane	Ambarlı	0.162
Başakşehir	Avcılar	0.066		Küçükçekmece	Ambarlı	0.257

Table G.1 (Continued)

From (Relief Facility)	To (Port)	High Vuln.		From (Relief Facility)	To (Port)	High Vuln.
Sarıyer	Ambarlı	0.135		Şişli	Ambarlı	0.162
Silivri	Ambarlı	0.058		Zeytinburnu	Ambarlı	0.221
Sultangazi	Ambarlı	0.059				