FACILITY LOCATION AND ITEM PRE-POSITIONING FOR HUMANITARIAN RELIEF SYSTEMS UNDER UNCERTAIN DEMAND AND ROAD-FACILITY VULNERABILITIES

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

ECE ASLAN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
INDUSTRIAL ENGINEERING

AUGUST 2016

Approval of the thesis:

FACILITY LOCATION AND ITEM PRE-POSITIONING FOR HUMANITARIAN RELIEF SYSTEMS UNDER UNCERTAIN DEMAND AND ROAD-FACILITY VULNERABILITIES

submitted by **ECE ASLAN** in partial fulfillment of the requirements for the degree of **Master of Science in Industrial Engineering Department, Middle East Technical University** by,

Prof. Dr. Gülbin Dural Ünver
Dean, Graduate School of **Natural and Applied Sciences** _______________

Prof. Dr. Murat Köksalan
Head of Department, **Industrial Engineering** _______________

Assist. Prof. Dr. Melih Çelik
Supervisor, **Industrial Engineering Department, METU** _______________

Examining Committee Members:

Prof. Dr. Gülser Köksal
Industrial Engineering Department, METU _______________

Assist. Prof. Dr. Melih Çelik
Industrial Engineering Department, METU _______________

Assoc. Prof. Dr. İsmail Serdar Bakal
Industrial Engineering Department, METU _______________

Assoc. Prof. Dr. Zeynep Pelin Bayındır
Industrial Engineering Department, METU _______________

Assist. Prof. Dr. M. Alp Ertem
Industrial Engineering Department, Çankaya University _______________

Date: 24.08.2016

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

Name, Last name : ECE ASLAN

Signature :

ABSTRACT

FACILITY LOCATION AND ITEM PRE-POSITIONING FOR HUMANITARIAN RELIEF SYSTEMS UNDER UNCERTAIN DEMAND AND ROAD-FACILITY VULNERABILITIES

Aslan, Ece

M.S., Department of Industrial Engineering

Supervisor : Assist. Prof. Dr. Melih Çelik

August 2016, 225 pages

Disasters may have devastating effect on human life as well as economy, and Turkey is a disaster prone country, especially to earthquakes. This study aims to propose a multi-echelon humanitarian logistics network design by incorporation of demand uncertainty and road-facility vulnerabilities with an application to a possible earthquake scenario in Istanbul region of Turkey. In frame of the study, a two stage stochastic programming model is formulated. In the first stage, warehouse and distribution center locations as well as inventory pre-positioning decisions are made, whereas in the second stage, relief distribution decisions are made. The stochastic model considers different demand scenarios and also road and facility vulnerabilities are incorporated as discrete binary scenario sets into the baseline model. The model is executed under efficiency and equity based objective functions, to analyze the effect of different objective measures to model key performance measures. Sample average approximation heuristic method is utilized for the solution of the proposed mathematical model. A sensitivity analysis is conducted on the baseline model to see the effect of vulnerability as well as other parameters such as budget and facility capabilities on the results and model key performance measures.

Keywords: Humanitarian Logistics, Mixed Integer Programming, Warehouse Location Problems, Relief Item Pre-positioning, Vulnerability

ÖZ

BELİRSİZ TALEP VE YOL-TESİS KIRILGANLIĞI ALTINDA İNSANİ YARDIM SİSTEMLERİ İÇİN TESİS YERİ VE MALZEME KONUMLANDIRMA PLANLAMASI

Aslan, Ece

Yüksek Lisans, Endüstri Mühendisliği Bölümü

Tez Yöneticisi: Yrd. Doç. Dr. Melih Çelik

Ağustos 2016, 225 sayfa

Afetlerin insan hayatı ve yanı sıra ekonomi üzerinde yıkıcı etkileri olabilir ve Türkiye afetlere özellikle de depremlere eğilimli bir ülkedir. Bu çalışmanın amacı, belirsiz talep ve yol-tesis kırılganlığı altında çok kademeli insani lojistik ağı tasarlamak ve bu tasarımı özellikle İstanbul bölgesinde olabilecek muhtemel bir deprem felaketine uygulamaktır. Çalışma bünyesinde iki aşamalı olasılıksal programlama modeli oluşturulmuştur. İlk aşamada depoların ve dağıtım merkezlerinin konumlarının yanı sıra envanter miktarlarına karar verilirken, ikinci asamda acil yardım malzemesi dağıtım kararları verilmektedir. Temel olasılıksal model, farklı talep senaryolarını göz önünde bulundurur ve ayrıca yolların ve tesislerin hassasiyetleri ayrık ikili senaryo takımları halinde modele dahil edilmiştir. Model verimlilik ve eşitlik temelli farklı amaç fonksiyonlarıyla çözdürülerek farklı amaç fonksiyonlarının temel performans göstergelerine etkileri analiz edilmişti. Matematiksel modelin çözümünde örnek ortaklama yaklaştırımsal sezgisel yöntemi kullanılmıştır. Kırılganlığın yanı sıra bütçe ve tesis kapasitesinin temel performans göstergelerine etkilerini gözlemlemek için karşılaştırma modelleriyle duyarlılık analizi yapılmıştır.

Anahtar Kelimeler: İnsani Yardım Lojistiği, Karışık Tamsayı Programlama, Depo Konumlandırma Problemleri, İnsani Malzeme Konumlandırma, Kırılganlık

To my family

ACKNOWLEDGMENTS

I would like to express my sincere gratefulness to my advisor Assist. Prof. Dr. Melih Çelik for his guidance support, encouragements, insightful vision as well as understanding attitude.

Also, I am thankful to my parents and my sister for their support and encouragements.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF ABBREVIATIONS

EMDAT	International Disaster Database of Center for Research on the Epidemiology of Disasters
TEPAV	Turkish Economy Policy Research Foundation
JICA	Japan International Cooperation Agency
IMM	Istanbul Metropolitan Municipality
DOM	Disaster Operations Management
MIP	Mixed Integer Programming
CARE	Cooperative for Assistance and Relief Everywhere
GIS	Geographic Information System
OR	Operations Research
MS	Management Science

CHAPTER 1

INTRODUCTION AND MOTIVATION

The United Nations Office for Disaster Risk Reduction [1] defines a disaster as "a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources". According to The United Nations Office for Disaster Risk Reduction [1], "disasters are often described as a result of the combination of the exposure to a hazard, the conditions of vulnerability that are present, and insufficient capacity or measures to reduce or cope with the potential negative consequences and disaster impacts may include loss of life, injury, disease and other negative effects on human physical, mental and social well-being, together with damage to property, destruction of assets, loss of services, social and economic disruption and environmental degradation". Although most disasters are caused by nature, disasters may also have human origins [2].

According to the International Disaster Database of Center for Research on the Epidemiology of Disasters (EMDAT) [3], 11,285 disaster events have occurred in our planet since the year 2000 resulting in 1,416,660 deaths, 4,650,481 injured people, a total of 3,521,420,256 affected people (36,151,700 of whom have become homeless), and a total economic damage of 1,872,897,745,000 USD. Since disasters are mostly unpredictable in their nature and also have a massive scale of impact on humans, disaster management is critical to minimize the suffering and to prevent further damage. According to the Wisner and Adams [4], there are six main steps in disaster management, namely (i) vulnerability assessment, (ii) prevention and mitigation, (iii) emergency preparedness, (iv) planning, policy and capacity building, (v) emergency response, and finally (vi) rehabilitation, reconstruction and recovery stages. Among these steps of disaster management cycle emergency preparedness, planning, policy and capacity building and emergency response stages are closely related to humanitarian logistics activities.

Humanitarian logistics 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." according to Thomas and Mizushima [5] and humanitarian logistics activities make up around 80% of entire disaster relief efforts [6].

Humanitarian logistics is essential to provide rapid response to effected areas in a timely and cost efficient manner. Balcik and Beamon [7] explain that "there are fundamental differences between commercial supply chains and humanitarian relief chains in terms of their strategic goals, customer and demand characteristics, and environmental factors. The dominating characteristics that bring additional complexity and unique challenges to relief chain design and management … are: unpredictability of demand, in terms of timing, location, type, and size, suddenly-occurring demand in very large amounts and short lead times for a wide variety of supplies, high stakes associated with adequate and timely delivery, lack of resources (supply, people, technology, transportation capacity, and money".

Turkish Republic Country Report on Disaster Management [8] states that due to its geography, topography and climate, Turkey has always been a disaster prone country. The major natural disasters that Turkey faces are earthquakes, landslides, floods, drought, rock falls, avalanches, as well as deforestation and soil erosions. Since early 20th century, around 87,000 people have died, approximately 300,000 people have been injured and around 700,000 houses are damaged as a result of natural disasters. Turkey is located on the Mediterranean part of the Alpine-Himalayan orogenic system, which is one of the most seismically active regions of the world. Three main plates surrender Turkey, namely African, Eurasian, Arabian, as well as two minor plates: Aegean and Anatolian. The main reasons of the earthquake disaster in Turkey are the relative motion between the Eurasian and Arabian plates as well as the westward motion of the Anatolian block under this compressional plate motion. Earthquakes are the main disasters in Turkey causing massive suffering and damage. Table 1.1 represents summary data on disasters caused by natural hazards in Turkey between the years 1980 and 2014 [9]. According to Istanbul Seismic Risk Mitigation and Emergency Preparedness Project, financed by The World Bank [9], 70% of the Turkey's population is living in seismically active areas, 66% of Turkey is located on active fault zones, and 75% of damaged buildings as well as 64% of total disaster losses in the last century are because of earthquakes. The Study on A Disaster Prevention / Mitigation Basic Plan in Istanbul Including Seismic Microzonation in the Republic of Turkey report prepared by Japan International Cooperation Agency (JICA) and Istanbul Metropolitan Municipality (IMM) [10] suggests that "a large scale fault line called North Anatolian Fault (NAF) is formed more than 1,000 km long from east to west in the northern territory of Turkey and historically, many strong earthquakes have occurred along this fault line". The North Anatolian Fault passes through the Marmara Sea [10] in a region, where Turkey's largest city as well as economic and industrial capital Istanbul is located, with a population around 14 million people [52] corresponding to around 18.5% of Turkey's population in addition to other major industrial cities. According to Turkish Economy Policy Research Foundation (TEPAV) [11], one sixth of Turkey's GDP is generated in Istanbul. Istanbul Seismic Risk Mitigation and Emergency Preparedness Project [9] estimates that the probability of occurrence of a large earthquake in next 30 years in Istanbul is greater than 62% and probability of occurrence of a large earthquake in next 10 years is greater than 20%. The study also estimates that after a probable 7.5 Richter scale earthquake in Istanbul; approximately 70,000 dead people, 120,000 heavily injured people, 400,000 lightly injured people, as well as a direct economic loss of approximately 50 billion USD are expected.

Table 1.1: Summary Data on Disasters Caused by Natural Hazards in Turkey between the Years 1980 and 2014 [9]

Type of Disaster	Frequency	Loss of Lives	Injuries	Affected	Homeless	Total Affected	Total Loss (,000$)
Earthquake (Seismic Activity)	38	21,193	63,684	4,880,751	1,027,490	5,971,925	24,534,800
Flood	32	593	214	1,678,270	97,036	1,775,520	2,195,500
Landslide	11	633	260	11,911	2,385	14,551	26,000
Storm	7	70	139	1,500		1,639	
Fire	5	15		500	650	1,150	
Low/High Temperature	7	100	450	8,000		8,450	1,000
Epidemic	3	35		380		380	
Industrial Accident	22	860	454	175		629	
Transportational Accident	91	2,244	1,348	56		1,404	
Unspecified	11	235	527			527	
Total	227	25,978	67,076	6,581,543	1,127,561	7,776,175	26,757,300

A possible earthquake disaster in Istanbul would have devastating impact on human life and Turkey's economy, and this importance is the main motivation of this study. Therefore, in this study, we propose a humanitarian logistics network for facility location planning and item pre-positioning with a specific application to a potential earthquake in the Istanbul region of Turkey.

This study specifically focuses on the preparation stage of the humanitarian logistics cycle to rapidly provide response in case of a potential earthquake disaster in Istanbul. In particular, we consider the decisions of locating humanitarian relief warehouses and distribution centers, as well as the pre-positioning of inventory in the warehouses in expectation of the disaster. Pre-positioning, which refers to locating relief facilities and stocking relief supply inventories in these facilities in the preparedness stage of disaster management, is crucial to deliver aid quickly in an uncertain environment. By means of pre-positioning, a more rapid and effective response can be provided in case of a disaster, and investments can also be better allocated.

Disasters not only threaten human life, but also the infrastructure of cities and towns. In case of an earthquake, in addition to the buildings, transportation network is also damaged most of the time. Therefore, facility and road network vulnerability should be taken into account to confront the risk of malfunctioning of resources and infrastructure in a study. By this way, pre-positioning decisions can be optimized to accommodate possible vulnerabilities.

Exact timing, magnitude, as well as location of a potential earthquake are almost impossible to know in advance. Since the effects of an earthquake are mainly determined by its magnitude and location, there is no precise information about the demand and supply of disaster relief, as well as the availability of resources, infrastructure, facilities, and roads before the earthquake actually strikes. Hence, the very nature of an earthquake disaster is stochastic, and therefore a stochastic modeling approach is required to optimize the network.

The main objective of decisions made at the preparedness stage of a disaster is to optimize success at the response stage and hence to minimize suffering. For this reason, the proposed study should incorporate possible future demand and vulnerability uncertainty to optimize first stage decisions. Therefore, a two stage stochastic mixed integer programming model is formed in this study to determine facility locations as well as to pre-position relief items to facilities to minimize demand weighted arrival time to aggregated demand points. Vulnerability of facilities and roads linking facilities to each other as well as facilities to demand points are projected into discrete binary scenario sets. Then, these discrete binary scenario sets are integrated into the mathematical model as parameters. Demand uncertainty under different magnitudes and epicenter of an earthquake are also reflected to scenario sets and integrated to model as parameters.

The main contribution of this thesis work arises from the incorporation of road and facility breakdowns into the inventory pre-positioning and relief distribution models. Unlike the limited number of studies in the inventory pre-positioning literature, where road vulnerability is included as a deterministic factor that increases the travel time on these roads, our study takes a scenario-based approach and considers cases where roads become impossible to traverse due to the effects of the disaster, which is a more realistic assumption given the nature of disasters such as earthquakes. The resulting large-scale two-stage stochastic programs are solved heuristically by means of sample average approximation, and a potential real-life disaster scenario is used as a case study to assess the impacts of various policy-based decisions, incorporating stochasticity of the problem parameters, and the sensitivity of the results to the values of these parameters.

The remainder of this thesis is organized as follows: A literature review on relevant humanitarian logistics studies is provided in Chapter 2. Following this, the problem definition, proposed mathematical models, and the proposed solution approach are presented in Chapter 3. Parameter settings as well as assumptions for a case study based on a potential earthquake disaster in the Istanbul region of Turkey are introduced in detail in Chapter 4. Preliminary experiments, computational results, sensitivity analysis, and a comparison of the main model with the benchmark models are presented in Chapter 5. The final chapter of this thesis comprises a general summary and remarks on the work, as well as future work suggestions in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

Disaster management is one of the areas in which operations research (OR) and management science (MS) studies are widely applicable. In the recent years, interest in disaster management studies has increased due to enhanced awareness of importance of developing decision making mechanisms to take required actions in a time- and cost-efficient way both for pre- and post-disaster stages, so that possible devastating impacts of disasters on human life, on environment, and on economy can be minimized. Altay and Green [12] show that research interests in mainstream OR/MS research journals for disaster management increased twice as much between 1980s and 1990s. There are 109 articles published related to disaster management between 1980 and 2004. While 12.8% of these articles are published in the 1980s, 40.4% of the articles are published in the 1990s, and the remaining 46.8% are published between 2000 and 2004. Another study by Galindo and Batta [13] analyses 155 disaster management studies in the field of OR/MS between the years 2005 and 2010. The study [13] concludes that the research gaps observed by Altay and Green [12] are not filled yet. The authors make some future work suggestions addressing to the gaps observed: "(i) improvement of the coordination among DOM actors; (ii) introduction of new technologies through more application studies; (iii) study of DOM problems as a whole by exploring well-studied as well as understudied areas that can benefit from OR/MS, using formal statistical analysis to establish realistic assumptions in DOM models that reflect the stochastic nature of DOM; (iv) in-depth exploration of methodologies such as Soft OR and interdisciplinary techniques that are suitable to DOM; and (v) measurement of the effectiveness of adopted strategies through the use of performance indicators." Among these gaps, our study focuses on the establishment of realistic assumptions reflecting the stochastic nature of the environment by incorporating the stochasticity of road and facility vulnerabilities into inventory pre-positioning and relief transportation models.

In this part of the thesis, studies related to facility and inventory pre-positioning as well as relief distribution activities in humanitarian logistics are reviewed in Section 2.1. Since our work is focused on pre-disaster stage pre-positioning decisions, majority of the reviewed papers are on pre-positioning. Nevertheless, additional papers related to relief distribution that we consider substantial are also included. Additionally, papers related to sample average approximation and its application to humanitarian logistics are reviewed in Section 2.2, since we have used this method in our solution process. Lastly, our contributions are introduced in section 2.2 of this chapter.

2.1. Literature Review on Inventory Pre-positioning and Relief Distribution in Humanitarian Logistics

Within the last decade, there has been an increased level of interest in the inventory pre-positioning problem in the humanitarian logistics literature. The studies mainly differ in terms of which additional decisions are included (e.g., facility location, relief distribution), the main objective(s), solution methods, and side constraints (e.g., minimum service levels, limits on number of facilities). In this part, we provide a review of the relevant literature on inventory pre-positioning and subsequent relief distribution. While this review is by no means comprehensive, we aim to present the studies that, to the best of our knowledge, are most relevant to this thesis work.

Balcik and Beamon [7] develop a mixed integer programming model for location planning of potential distribution centers and item pre-positioning. Different scenarios with known probability are used to capture the stochastic elements of the problem. Uncertainty of demand amounts, transportation costs, demand satisfaction times at the demand points, and candidate distribution center coverage of various relief items are considered. The model also includes lower and upper response time limits for different relief items. The model is solved under two different budget restrictions: (i) for pre-positioning of distribution centers and relief items in the pre-disaster stage, and (ii) for distribution of relief items in the post-disaster stage. The computational analysis is made by utilizing historical data of earthquakes on different global locations. In the study by Balcik and Beamon [7], vulnerabilities of roads connecting distribution centers to disaster locations or those of the distribution centers are not considered.

In the study by Duran et al. [14], a mixed integer programming model is developed with an initial upfront investment in terms of the number of warehouses and total inventory to allocate with the objective of minimizing average response time for the demand points. The study considers global demand for relief items in case of different type of disasters and a total of 233 separate demand instances are formed, each corresponding to different demand quantities. The MIP model optimizes the number and the location of warehouses, as well as the quantity and type of each item to pre-position in the warehouses.

Mete and Zabinsky [15] propose a two-stage stochastic mixed integer programming (MIP) model for the storage and distribution problem of medical supplies to disaster areas under a variety of possible disaster types and magnitudes. In the first stage of the model, which corresponds to preparedness stage, warehouse locations as well as inventory amounts at warehouses are determined, whereas the second stage of the model determines the amounts of medical supplies to be delivered to demand locations under different demand scenarios. The objective is to minimize total cost of warehouse opening, weighted arrival times, and penalty cost of unmet demand. A secondary MIP model is introduced to find optimal routing from warehouses to demand points based on optimal delivery amounts found in the second stage of the stochastic model. The transportation model considers different vehicle types and routes to minimize transportation time of assigned vehicles. A case study based on potential earthquake scenarios in Seattle is also presented.

Tzeng et al. [16] consider the overall design of a relief delivery system. There are three objectives in the proposed fuzzy multi-objective linear programming model: (i) minimization of total transfer and facility set up costs, (ii) minimization of total travel time, and (iii) maximization of minimum demand satisfaction. Three echelons, namely relief collection points, capacitated transfer depots, and relief demand points, are considered in the supply network. As opposed to permanent facilities, these temporary transfer depots that serve as distribution centers are also assumed to deliver to isolated areas via helicopters. The study divides the time into discrete periods and determines the optimal inventory levels and item quantities to transfer to demand points in each period. Demand for relief items at different locations are assumed to be deterministic, that is, different scenarios are not considered for different magnitudes and epicenter of disaster. A case study of model is illustrated based on The Taichung, Nantou City earthquake in September 1999.

Rawls and Turnquist [17] also consider a two-stage setting where facility locations, facility sizes and stock quantities for various type of commodities are determined before the disaster hits, whereas the second stage decisions involve distribution of available supplies to demand locations in response to different demand scenarios and network availability conditions. The objective function includes fixed facility opening and item acquisition costs for the first stage, as well as transportation costs, unsatisfied demand penalties, and holding cost of unused items for the second. A two-stage stochastic MIP model for emergency response pre-positioning strategy is proposed considering uncertainty in demand, transportation network availability, and destruction of some or all of the pre-positioned inventory. Due to the complexity of the model, a heuristic Lagrangian L-shaped method is developed for large instances. The proposed two-stage MIP model is applied to a case study of hurricane disasters in southeastern parts of USA.

Rawls and Turnquist [18] extend their previously proposed model in [18] and add new service quality constraints to ensure that the probability of meeting all demand is at least a certain specific percentage. They also impose maximal service distance constraints to ensure that demand for all commodities are supplied from facilities where the average shipment distance is less than a specific limit. In this version of the study, a reliable set of scenarios are defined and demand in these reliable sets are covered from facilities serving from the maximal service distance. Total of probabilities of the reliable scenarios is guaranteed to be greater than or equal to a specified level. By this way, percentage of demand served from facilities within maximal service distance is guaranteed to be greater than or equal to the specified service level (reliability percentage).

Rawls and Turnquist [19] further extend [18] with service quality constraints and include multiple time periods for planning short term urgent demands. This version of the study has same settings as in [18], except that parameters and decision variables related to forecasted demand and commodity delivery are added as a time index. The horizon is divided into four 12-hour periods. The emergency response policy developed in this study is that at least half of all demand should be in place by the 12^{th} hour after disaster and other half should be in place by the 24^{th} hour. The dynamic response model is tested on a case study of hurricane events that affect North Carolina.

Abounacer et al. [20] study a three-objective location-transportation problem for disaster response, which is quite similar to [16], except that it focuses on a location-transportation problem. While the location model determines the locations of distribution centers as well as the humanitarian aid quantities to stock to these distribution centers, the transportation model determines distribution of humanitarian aid from distribution centers to demand locations. The model is solved under three conflicting objectives: (i) minimization of total transportation time from distribution centers to demand locations, (ii) minimization of the number of first-aid agents required to operate the opened distribution centers, and (iii) minimization of total uncovered demand. Demand is assumed to be deterministic and known, while the state of the roads connecting distribution centers to demand locations is reflected in the travel time. An epsilon-constraint method is proposed to generate the exact pareto-front. It is also concluded that the solution time might be large for some instances and therefore a heuristic method is also proposed which resulted in a good approximation of pareto-front in relatively shorter computing time.

Wisetjindawat et al. [21] develop a hub location and routing optimization model for the preparedness stage of disaster relief operations. The study assumes that demand is deterministic. On the other hand, similar to the work in this thesis, failure of roads is considered as a stochastic parameter based on constant failure rate by intensity level. The study also considers the recovery of damaged roads and assigns a probability to each road for a possible recovery in 24 hours in which recovery rate is incorporated. Additionally, stochastic travel times as well as stochastic shortest paths are calculated under the road failure probabilities. These road failure probabilities as well as stochastic travel times and shortest paths are incorporated into item routing and location routing models. The multi-depot and multi-commodity routing model for item delivery minimizes total response time and decides sequence of delivery under maximum carrying capacity and maximum utilization of a truck constraints. The location routing model determines location of hubs to deliver items to secondary storage yards to minimize total response time under road network failure uncertainty. The model is solved as an uncapacitated single allocation problem using a genetic algorithm. The study is numerically illustrated with Tokai-Tonankai earthquake in Aichi Prefecture in Japan.

Bozkurt [22] proposes a warehouse and relief item pre-positioning model for various types of natural disasters on global scale. Emergency response scenarios are generated and integrated as parameters to the model which minimizes demand-weighted total arrival time. EMDAT database is used to obtain data on location and type of disasters occurred as well as number of affected people. The author considers possible set of warehouse locations provided by CARE International.

Gormez et al. [23] consider a two-tier distribution system with permanent and temporary facilities. Permanent facilities are to be built for relief supply pre-positioning and temporary facilities are public facilities that are to be used as relief distribution centers. In the study, affected population is assigned to temporary distribution centers (schools) and relief supply is transferred from permanent facilities to temporary facilities and hence to the affected population. Due to large scale nature of the problem, two separate models are solved. The first model determines the number of schools appointed as temporary distribution centers in each neighborhood as well as number of people assigned to that temporary distribution centers under the objective of total demand weighted distance. The second model, on the other hand, determines location of permanent facilities and assignment of temporary facilities-schools to permanent facilities under the objectives of minimization of average traveled distance and minimizing the number of permanent facilities. An epsilon constraint method is used for the solution of the proposed model. The authors make sensitivity with benchmark models having min-max distance objective, distance limits, backup requirements as well as capacitated facilities. The authors used data of JICA & IMM Report [10] for demand generation at districts of Istanbul.

The study by Renkli [24] develops a MIP model for warehouse location and item pre-positioning in these warehouses at the preparedness stage of a possible earthquake disaster in Istanbul region of Turkey. The proposed model minimizes the demand weighted distance/arrival time to demand locations. The model considers path vulnerability between warehouses and demand point and also guarantees that items are delivered to demand points within a specific time period with a certain reliability. Path vulnerability is expressed in terms of deterministic probabilistic fraction rather than stochastic discrete scenario sets. A probabilistic vulnerability constraint is formulated to meet the demand in every demand point for every relief item with a specific reliability.

Konu [25] develops a multi-commodity deterministic model considering transportation network and facility vulnerabilities for item and warehouse pre-positioning for the preparedness stage of a possible earthquake. The road network is categorized into three types of roads: primary, secondary, and tertiary roads. The proposed model determines location of warehouses, quantity of different types of items transferred from these warehouses to demand points, as well as types of roads to follow to send relief items. The objective is to minimize the demand weighted traveled distance. Three alternative models are developed: The first model does not consider road and facility vulnerabilities, the second model incorporates road vulnerabilities and the third model incorporates both vulnerabilities to the model. Road and facility vulnerabilities are expressed in terms of deterministic fractions and these parameters are multiplied by length of roads and the model objective is minimized over these combined vulnerability-distance multiplications. In contrast, in this thesis, we assume binary road and facility vulnerability, that is, roads and facilities either fully break down after the disaster, or they are fully operational. Furthermore, we assume that these vulnerabilities are stochastic. The author uses data from JICA & IMM Report [10] for demand, road vulnerability as well as warehouse vulnerability generation at districts of Istanbul.

Baskaya [26] proposes a deterministic mathematical model for relief facility locating and item-pre-positioning to these relief facilities considering road vulnerabilities and lateral shipments between relief facilities. Two models are developed, without and with lateral shipment. The model with direct shipment determines locations of relief facilities, assignment of demand locations to relief facilities, quantity of relief supply to pre-position to relief facilities as well as quantity of relief supply to send from relief facilities to demand location under the objective of minimizing average distance travelled by relief supply. The author assumes that road vulnerability affects travel time and hence inflated road lengths are incorporated into the model which are correlated to vulnerability. As vulnerability of a road increases its inflated road length also increases. This is in contrast to our work, where we assume binary and stochastic vulnerability. The setting of lateral shipment model is the same as direct shipment model except that supply delivery among relief facilities is assumed to be possible also the road vulnerability among relief facilities are incorporated into the model. The direct shipment and lateral shipment models are compared on a possible earthquake scenarios in Istanbul, Turkey. Data from the JICA & IMM Report [10] is used to generate demand, road length, and road vulnerability data.

Liberatore et al. [27] propose a network flow model for recovery of a damaged distribution network so that the distribution plan can be completed. In the proposed network, nodes represent the cities and towns and the edges correspond to roads, tunnels, bridges etc. A hierarchical model is developed to consider long term distribution horizon rather than a single objective. An uncapacitated commodity flow network with no restriction on the capacity of supply centers is developed. Furthermore, demand values of demand centers do not represent the exact need for commodities in the model, but rather characterize the size of the center. The hierarchical model assigns highest priority to maximizing total demand satisfied and delivery time, and network security and reliability are the other objectives. The model is solved under resource restrictions such as equipment and number of relief teams. The proposed study is illustrated with a case study applied to infrastructure recovery and distribution planning of the 2010 Haiti earthquake.

A comprehensive integrated logistics model is developed by Afshar and Haghani [28] for response operations of real time large scale disasters. A seven layer supply network, which is compatible with Federal Emergency Management Agency (FEMA)'s complex network, is proposed in the study. The mathematical model determines vehicle routing, pickup and delivery schedules, as well as optimal location of temporary facilities considering capacity constraints for facilities and transportation system by minimizing weighted unmet demand. The study does not consider demand uncertainty or vulnerability of facilities and transportation network. Several different type of vehicles with different capacities are assumed in the study. A numerical experiment is conducted with imaginary scenarios where a natural disaster such as a hurricane strikes the southern coast of the United States, two separate regions, one in Mississippi and one in Louisiana, are considered.

Liu and Guo [29] propose a multi-objective two-stage stochastic optimization model for a post-disaster humanitarian logistics network. In addition to developing relief supply delivery plan the authors also develop an evacuation plan for the critical population. The model is solved under two objectives: maximization of expected minimal fill rate where mismatch between demand and supply is penalized and also under the objective of minimizing expected total costs. Uncertainty in demand and affected critical population to be evacuated are reflected to possible pre-determined scenario sets. Deliveries from facilities to demand points are assumed to be made with different helicopter types, each having different capacity and costs. In the first stage of the model, decisions regarding facility locations, supply amounts to stock in these facilities as well as deployment of helicopters to facilities are made. In the second stage, decisions regarding transportation plan of affected population as well as supply items are made under each scenario. A lexicographic optimization approach is deployed for the solution of the model. The two-objective model is transformed into a sequence of single objective stochastic models. The first objective about demand fill rate is given priority hence considering the second objective of cost minimization not the best alternative but the sub-optimal solutions according to fill rate are chosen. Then, scenario-decomposition based heuristics are developed to solve the transformed models. A numerical case study is illustrated for disaster relief logistics of Great Wenchuan Earthquake.

Ozdamar and Demir [30] develop an efficient network flow model, as well as a hierarchical clustering and routing procedure for last-mile delivery transportation and pick-up evacuation plans considering a large scale disaster relief network. The model runs under the objective of minimizing total travel time of vehicles by obeying supply, hospital capacity, and vehicle capacity restrictions. The study assumes pre-known deterministic demand and also assumed that split delivery and pick-ups are possible due to vehicle capacities. A multi-level clustering algorithm is used to group demand nodes and create smaller demand clusters at each level of planning. First, demand nodes are divided into geographically dense clusters and then top-level routing problem is solved to determine warehouse locations, amount of relief supply to send each cluster center from warehouses, set of hospitals to accommodate injured people as well as number of people to be sent to each hospital from each cluster. At the next step, sub-cluster networks are formed and solution of a higher level network are integrated as parameters to lower level network. At the lower level network, optimal routing plan is determined. The algorithm uses divide and conquer approach and recursively divides demand node clusters into smaller clusters till the cluster size enables the optimal solution of the routing model. The authors re-run the algorithm 1,000 times to obtain best possible demand node partitioning in numerical experiment on hypothetical disaster relief networks and on a large scale earthquake scenario for Istanbul.

Ozdamar at al. [31] develop "an efficient optimization guided hierarchical clustering and routing procedure (OHOC)" and propose a system including set of instructions for rescue and evacuation operations carried out by helicopters at the post-disaster stage. The developed algorithm first solves the problem on the aggregated demand level by clustering demand nodes and finds the optimal allocation of warehouses and hospitals to demand nodes. After obtaining the aggregated solution, detailed sub-network routing problem is solved. In this stage solutions of the aggregated level problem are integrated as parameters to the routing algorithm. The developed algorithm is tested on a potential Istanbul earthquake and also on Katrina hurricane flooding disaster scenario.

Cui et al. [32] develop a multiple emergency flow routing model that minimizes evacuation-flow time cost, rescue-flow time cost, conflict cost, as well as lane reversal cost. The model is a non-convex mixed-integer non-linear programming model with bilinear, fractional and power components which is solved by branch and reduce optimization navigator. A numerical case study of the proposed model is applied to Nangang District, Harbin City, China with 27 intersections and 86 links.

Ahmadi et al. [33] develop two mathematical models, the first of which is a deterministic multi-depot location-routing model for real-life logistics network. The first model determines operational level decisions such as location of local depots from set of potential locations, quantity of supply to send to affected areas, routes of vehicles, and number of vehicles to assign local depots as well as time of delivery by minimizing total distribution time, penalty cost of unmet demand as and fixed local depot opening costs. The deterministic model is extended into a two-stage stochastic program to simulate possible earthquake scenarios for strategic level decisions at preparation stage. These strategic level decisions are location of main distribution centers considering probable road damage scenarios. The aggregated demand points in the stochastic model correspond to potential local depots later in response stage. In the stochastic model, travel time is also treated as random variables represented by different scenarios. Small instances of model solved with a commercial software and a variable neighborhood search algorithm is formed to solve the model with large instances. A case study is illustrated for a possible earthquake disaster in San Francisco based on GIS data of actual transportation network.

Salmeron and Apte [34] propose a two-stage stochastic optimization model for budget allocation in case of a disaster. A single budget is identified for both first and second stage activities. The authors divide affected population into three categories, critical population refers to people who are in need to be evacuated to relief locations by medical evacuation, stay-back population refers to people who can stay at where they are but need relief item supply from supply locations and transfer population needs to short term displacement to shelters. In the first stage, decisions regarding relief locations, supply locations, shelter locations, and ramp spaces as well as personnel assignment to relief locations are made. In the second stage, logistics decisions such as allocation of relief supply to stay-back population and transportation of the critical population to relief locations as well as transportation of transfer population to shelters are made. The model is solved under two objectives, the first objective is minimization of expected number of causalities from critical and stay-back populations and the second objective is minimization of expected unsatisfied demand of transfer population. Since the exact location and magnitude of a disaster cannot be pre-known second stage parameters as well as decision variables are represented as scenarios with pre-known probabilities. The study is tested for a possible hurricane disaster striking six different areas with different severities. Specific data for the test study is obtained from public sources.

Huang et al. [35] formulate performance metrics for relief routing focusing on efficiency, efficacy and equity. In the study, classical split delivery vehicle routing problem (SDVRP) is solved under efficiency, efficacy, equity based objectives. Efficiency based objective is about minimization of transportation cost, efficacy objective is about minimization of total demand-weighted arrival time and equity based objective is represented in terms of minimization of efficacy variation in different demand nodes. Variation is efficacy is also represented in three different forms: in terms of difference between maximum and minimum demand weighed arrival times of nodes, in terms of standard deviation of demand weighted arrival times and in terms of convex disutility function which minimizes disutility-weighted arrival time. The disutility based equity objective minimizes total disutility of unsatisfied demand over time and this objective prioritizes delivery to most urgent locations and then gradually satisfies demand at other demand nodes to achieve full coverage. The authors examine the effect of objective function in vehicle routing and supply distribution decisions. While routing decisions determine set of nodes that each vehicle visits as well as their visit sequence to nodes, supply distribution decisions determine amount of supply delivered at each visit. The proposed models having small instances are solved with a commercial software. However a metaheuristic is developed to solve the models with larger instances. Numerical examples are solved for small and large instances in the study. The results of models having different objectives are compared based on number of vehicles, route shape, node demand, differences in route structure, and similarities in route structure.

Barbarosoglu and Arda [36] develop a multi-commodity, multi-modal two-stage stochastic optimization model for the disaster transportation planning. The study incorporates transportation system vulnerability in terms of finite scenario samples for arc-route capacities, supply and demand. Both stages of the proposed model include response stage decisions. While the in the first stage early disaster phase decisions are made based on possible scenarios, in the second stage decisions are given based on actualized impact of earthquake. The model is solved under the objective of minimizing first stage transportation costs and second stage expected recourse costs with demand, supply, capacity and recourse constraints. The proposed model is validated by solving with real life data of 1999 Marmara Earthquake.

To the best of our knowledge, there are six studies considering application of their proposed model to a potential earthquake scenario in Istanbul. Table 2.1 summarizes characteristics of these studies.

Reviewing these studies we see that our study contributes in a way that both transportation network and facility vulnerabilities are incorporated in a stochastic scenario based approach rather than ignoring vulnerability or incorporating vulnerability as a deterministic factor. Additionally, uncertainty in demand based on the impact of earthquake is also integrated to our study in a stochastic scenario based manner.

Table 2.1: Studies with Application to a Potential Istanbul Earthquake

	Gormez et al. [23]	Renkli [24]	Konu [25]	Baskaya [26]	Ozdamar et al. [31]	Barbarosoglu and Arda [36]	Our Study
Model Type	Two-stage deterministic model	Deterministc MIP	Deterministc MIP	Deterministc MIP	Optimization guided hierarchical planning and clustering procedure	Two stage stochastic model	Two stage stochastic model
Demand	Deterministic	Deterministic	Deterministic	Deterministic	Deterministic	Stochastic	Stochastic
Road Vulnerability	No	Incorporated as deterministic chance constraint	Incorporated as deterministic coefficient to the objective function	Incorporated as deterministic coefficient to inflate travel times	No	Incpororated as finite scenario samples for arc-route capacities, supply and demand	Incopororated as stochastic binary scenaris sets
Facility Vulnerability	Incorporated as service level costraints based on vulnerability level	No	Incorporated as deterministic coefficient to the objective function	No	No	No	Incopororated as stochastic binary scenaris sets
Modes of Transportation	Single	Single	Single	Single	Single	Multiple	Multiple
Single/Multiple Period	Single	Single	Single	Single	Single	Single	Single
Single/Multiple Commodity	Single	Multiple	Multiple	Single	Single	Multiple	Single
Facility Locating/ Allocating	Yes	Yes	Yes	Yes	Yes	No	Yes
Relief Routing	Yes	Yes	Yes	Yes (including lateral shipment)	Yes	Yes	Yes
Evacuation/ Sheltering	Sheltering	No	No	No	Evacuation	No	No
Objective Function	minimize the average-weighted distance between casualty locations and closest facilities, and opening a small number of facilities	minimize total weighted distance	Minimize total demand weigted distance	Minimize the average distance travelled by the relief item	Minimize the total flight distance or time	Minimize first stage transportation cost and second stage exected recourse cost	Minimize total expected demand weigted arrival time
Solution Metedology	Direct solve with commercial software	Single run with CPLEX software	Direct solve with commercial software	Single run with CPLEX software	CPLEX commercial software	Single run with CPLEX software	Sample Average Approximation Heuristic (Solved with CPLEX software)

2.2. Literature Review on Sample Average Approximation

In this study, sample average approximation method is used as the solution method. Therefore, papers related to sample average approximation, especially application of this method to humanitarian logistics, are also reviewed. Studies by Kleywegt et al. [37] and Ahmed and Shapiro [38] constitute a basis for this method. Sample average approximation is a Monte-Carlo simulation based approach developed for discrete stochastic optimization problems. Kleywegt et al. [37] describe sample average approximation as "the basic idea of such methods is that a random sample is generated and the expected value function is approximated by the corresponding sample average function. The obtained sample average optimization problem is solved, and the procedure is repeated several times until a stopping criterion is satisfied."

Several authors apply this methodology to humanitarian logistics problems, which we review throughout the remainder of this section.

The study by Klibi et al. [39] proposes a two-stage stochastic optimization model for emergency supply network design over a multi-period planning horizon. In the first stage, decisions regarding distribution center locations, distribution center capacities as well as quantities of items to stock in these facilities are made under a pre-determined budget constraint. Possible disaster scenarios are generated through stochastic processes and Monte-Carlo procedure. In the second stage, decisions regarding item delivery to demand locations are made under different disaster scenarios. Both first and second stage models run under the objective of minimizing total procurement and transportation costs. The proposed model is solved using sample average approximation and the model is tested with a real world data obtained from North Carolina Emergency Management Division (NCEM).

Chang et al. [40] develop a two-stage programming model for the determination of a rescue distribution system for urban flood disasters. The study considers multi-group, multi-echelon, multi-level structure network structure with uncertain demand locations as well as demand amounts at these demand locations. The problem is solved in two stages, in the first stage possible disaster locations are classified and grouped according to level of risk of being attacked by flood by minimizing the expected shipping distance. The second stage location-allocation model determines the selected local rescue bases to be set up after disaster as well as the quantity of rescue equipment in the storehouses of all levels and delivery plan of these equipment to demand points. The second stage model minimizes current facility set up costs, average equipment procurement costs, expected transportation costs, supply shortage costs and demand shortage penalty costs. Sample average approximation method is used to solve the stochastic model with three rainfall scenarios.

Garrido et al. [41] propose a multi-period stochastic optimization model for the design of a flood emergency logistics system. The proposed model determines flow amount of different types of items from depots to demand locations by means of different types of vehicles in different time periods, inventory amounts to pre-position to depots in different time periods as well as flow of empty vehicles among affected zones. The proposed model is solved under the objective of transportation, inventory carrying and vehicle moving costs. Due to unpredictable stochastic nature of floods, a demand function is generated for each demand zone under each time period. Demand forecasting is performed via Monte Carlo simulation where demand follows a general correlation in time and space. The model is solved with sample average approximation method since the size and stochasticity of the problem makes the model difficult to solve due to its NP hard nature.

Salman and Yucel [42] consider a facility location and set coverage problem under random network damage for emergency relief systems. The study considers the vulnerability of paths constituting the network with dependency and hence failure of a path results in failure of nearby paths which are structurally more vulnerable. Demand is assumed to be deterministic and transportation network vulnerability is modeled through set of discrete scenarios, each scenarios having a pre-determined probability. The model determines facility locations, assignment of demand points to facilities under each scenario as well as weather a demand point will be covered or not under a specific scenario under the objective of maximizing expected demand coverage. In order to overcome computation difficulty due to large number of possible outcomes, a tabu search heuristic is developed to estimate objective function value of candidate solutions over a sample network scenarios by sample average approximation method.

Barahona et al. [43] develop an agile inventory and transportation models for disaster response as well as a simulation framework to evaluate these optimization models. The inventory model determines inventory amounts to be shipped through each link in each time step under the objective of maximizing coverage across stock nodes. The transportation model determines the optimal vehicle routing in a multi-stage distribution network with resource and delivery constraints under the objective of maximizing demand fulfillment in delivery locations with fairness. The simulation framework includes wide range of disaster scenarios as well as stressors to capture uncertainty in demand and location of disaster. A robust set based on sampled scenarios are generated and the solution is carried out using the sample average approximation method, since full problem size is too large to solve optimally for stochastic model.

Garrido [44] present different mathematical models for defense planning under different cases of unknown terrorist attacks with probabilities. The proposed models optimizes resource allocation to different targets and space locations under different objective functions. Four different models are formulated for human and material resource allocation under different cases and their solutions are provided to help decision makers make rational decisions to optimize investment decisions as well as to optimize risks of terrorist attacks. Due to the complexity of proposed mathematical models (all are NP-hard) sample average approximation method is utilized to solve the models. The models are not run under real life data and due to complexity of proposed models it is not possible to present most desired outcome of the models.

Rodríguez-Espíndola and Gaytán [45] introduce a method which combines raster geographic information system (GIS) with an optimization model for disaster preparedness to achieve efficient and effective flood management. The GIS provides information about flood situation and road failures in the first stage and enables decision makers to discard floodable facilities. GIS is used to analyze several flood scenarios as well as demand of rescue equipment. Then optimization model uses the outcomes of the GIS and provides an optimal solution in the second stage. This multi-commodity model determines the shelter and distribution center locations, assignment of affected population to shelters, pre-positioning of relief items to distribution center as well as routing of items to achieve effective delivery to shelters. A two-objective model is solved using sample average approximation under a weighted-sum method as well as the epsilon-constraint method.

2.3. Contributions of This Thesis

Studies on humanitarian logistics vary in their model settings, methodologies and assumptions greatly. Since it is almost impossible to estimate exact location as well as magnitude of a disaster developing advanced decision support mechanisms is crucial to make rational investment decisions to able to provide immediate response. Our study proposes a two-stage stochastic MIP optimization model for preparedness decisions of emergency relief system. The main difference of our study is that we consider vulnerabilities of facilities and transportation network simultaneously in case of a possible disaster. The possible outcomes of a disaster are reflected into discrete binary scenario sets to capture facility and transportation network vulnerability. When the nature of large-scale disasters is considered, the main effects on the road and facility networks are the generation of debris, collapsing of bridges, and breakdowns of roads or facilities. In general, such effects render these roads or facilities to be either completely unusable, or may leave them to operate at their full or near-full capacity. Hence, by using a binary approach to the modeling of vulnerability, we aim to provide a more realistic way to handle these effects. Usage of discrete binary scenario sets to simulate vulnerability is also a new approach to stochastic modeling.

CHAPTER 3

PROBLEM DEFINITION AND MATHEMATICAL MODELS

In this study, stochastic integer programming models are utilized to design a multi-echelon humanitarian logistics network involving facility location, item pre-positioning, and relief distribution with a specific application to a potential earthquake in the Istanbul region of Turkey.

The humanitarian logistics network that is proposed in this study is comprised of three echelons, which are warehouses, distribution centers, and aggregated demand points. The proposed network is presented in Figure 3.1. The network design problem considered in this study encompasses the preparedness and response stages for humanitarian logistics management. In the first stage (the pre-disaster period), warehouse and distribution center locations as well as relief item amounts that are to be pre-positioned in the warehouses are determined. No relief item is pre-positioned in the distribution centers in this stage. In the second stage (the post-disaster period), relief item allocations and routing decisions from (i) warehouses to distribution centers and (ii) from distribution centers to demand points are made. In this stage, it is also possible to outsource relief items to distribution centers to be delivered to demand points. Deliveries from warehouses to distribution centers are made through direct paths that connect the warehouses to the distribution centers using trucks. On the other hand, deliveries from distribution centers to demand points are assumed to be made through pre-determined routes. Here, delivery trucks start the route from distribution centers and follow a pre-determined route comprising a number of demand points. Additionally, when supply does not met demand for a demand point, a helicopter or cargo airplane delivery may be made from a distant location from a separate stock point that is further away from the demand points. For simplicity we will refer to airfreight as helicopter delivery in the remaining parts of this study.

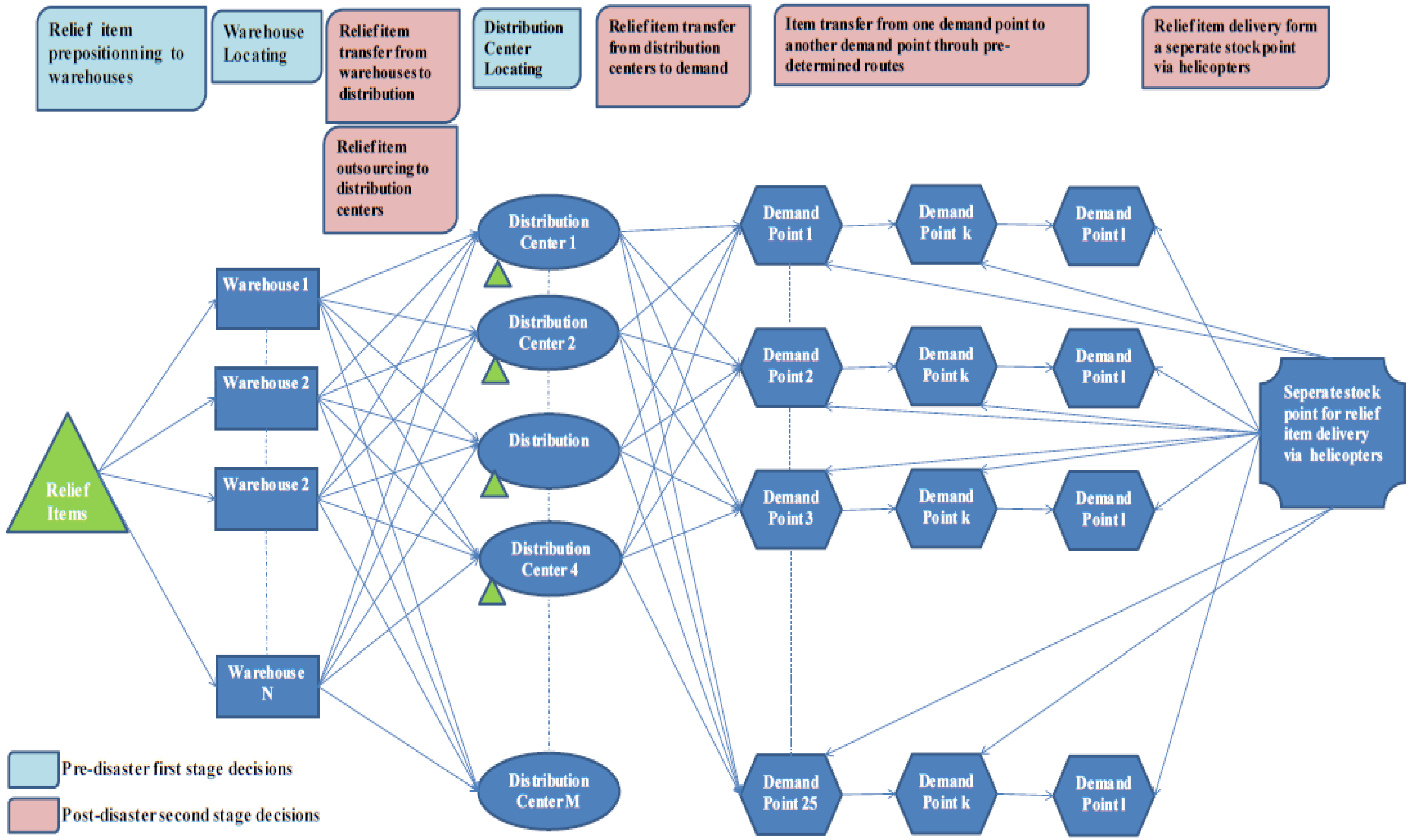

Figure 3.1: The Proposed Humanitarian Logistics Network

The exact epicenter and magnitude of an earthquake are almost impossible to know in advance. Due to the uncertain nature of earthquakes, potential damage on relief facilities as well as on humanitarian logistics network cannot be estimated precisely. For this reason, in making the facility location, pre-positioning and relief transportation decisions, vulnerabilities of facilities as well as logistics network are incorporated into the mathematical model in a stochastic manner. For our purposes, vulnerability refers to the probability that a road becomes impossible to traverse or a facility becomes unusable after the disaster. Vulnerability is incorporated into a two-stage stochastic model by means of discrete scenario sets. In the first stage of the mathematical model, scenario-independent warehouse and distribution center location and item pre-positioning decisions are made, whereas in the second stage, scenario-dependent item allocation decision are made. Additionally, the model assumes uncertain demand, and therefore disaster-dependent demand is projected into scenarios to capture demand difference under different magnitudes and epicenters of the disaster. These decisions are made under pre-determined first and second stage budget restrictions.

In the proposed humanitarian logistics network, if a direct path connecting a warehouse and a distribution center becomes impossible to traverse after the disaster, then delivery is not possible from that specific warehouse to that specific distribution center. In addition, since deliveries from distribution centers to demand points are assumed to be made through pre-determined routes, if a road segment is blocked at some point of these routes, the demand point(s) sequenced after this blocked road segment in the route cannot receive the delivery even if the remaining segments are not blocked. For example, in case there is a route visiting demand points A - B - C in sequence, if the road segment A - B is not traversable, then both demand point B and C cannot receive the delivery even if road segment B - C is functioning. It is also assumed that road damage cannot be repaired in a short time period to be utilized during the disaster; therefore, if a road is blocked, it cannot be re-opened and cannot be used for delivery.

Facility vulnerability is incorporated into this study in the following way: If a facility (warehouse or distribution center) becomes unusable after the disaster, no deliveries can be made starting from that facility. Although this does not prevent any shipments to pass through that node. When a facility is operational after the disaster, we assume that its full capacity is available.

Our models find optimal decisions under the objectives of minimizing total expected demand weighted arrival time and minimizing maximum expected demand weighted arrival time under pre-determined first and second stage budget constraints. Minimization of total expected demand weighted arrival time is an efficiency-based objective and both delivery amounts as well as arrival time to demand points are covered in this objective. In case of a disaster, response time is critical to prevent further suffering and while considering response time demand amounts should also be considered to meet the demand as much as possible with the available resources. The other objective is minimizing maximum expected demand weighted arrival time, which is an equity-based objective, and also captures both response time as well as demand amounts. However, this equity based objective only minimizes the maximum rather than the total expected demand weighted arrival time. Having these two different objectives enable us to compare the results under efficiency- and equity-based objectives.

3.1. Mathematical Models

As mentioned before, road and facility vulnerabilities refer to the probability that a road segment is not traversable and a facility becomes unusable, respectively. The corresponding problem of pre-disaster facility location and item pre-positioning and post-disaster relief transportation can be modeled as a two-stage stochastic program. Road vulnerability is integrated into the stochastic programs as discrete binary parameters. For every road between districts, random scenario sets are generated. In these scenario sets, road condition takes value of 1 or 0. If the road condition is 1, then the road is not blocked and can be used for item transportation under that specific scenario. Similarly, if the road condition is 0, then the road is blocked and cannot be used under that specific scenario for item transportation.

Facility vulnerability is also integrated into the stochastic mathematical model as discrete binary parameters. For every facility (warehouses and distribution centers), random scenario sets are generated. In these scenario sets the facility condition takes value of 1 or 0. If the facility condition is 1, then the facility is not damaged and can be used for item pre-positioning and transportation under that specific scenario. If facility condition is 0, then facility is damaged and cannot be used under that scenario.

In what follows, we describe two alternative models based on two different objectives.

Model 1.1. Efficiency-Based Baseline Model

Model 1.1 is formed as a stochastic model. Accordingly, road and facility vulnerabilities as well as demand amounts are projected into scenario sets, which are integrated into the mathematical model. This model assumes that delivery from warehouses to distribution center is possible only with trucks and delivery from distribution centers to demand points is possible either with trucks and helicopters. Helicopter delivery is possible when supply does not meet demand for a demand point, and is assumed to be made from a distant location with a separate stock with a 100 km distance to each demand point. It is also possible to outsource relief items to distribution centers from local suppliers rather than transferring them from warehouses to be further delivered to demand points. The objective function minimizes expected total demand weighted arrival time to demand points with truck and helicopter deliveries over different scenarios.

The sets, parameters, and decision variables for Model 1.1 are as follows:

Sets

I : set of potential permanent warehouses

J : set of potential temporary distribution centers

D : set of aggregated demand points

R : set of truck routes

S : set of scenarios

First Stage Parameters

B_1 : budget for first stage investments which comprises costs of permanent warehouse and temporary distribution center opening and item pre-positioning in the warehouses (TL)

f_i : fixed cost of opening and operating a permanent warehouse i (TL)

c_i : capacity for permanent warehouse i (m^3)

p : procurement cost for the relief item-tent (TL)

In : Inventory keeping cost for the relief item at the permanent warehouse and temporary distribution center (TL)

fd_j : fixed cost of opening and operating a distribution center j (TL)

cd_j : capacity for distribution center j (m^3)

Second Stage Parameters

B_2 : budget for second stage investments which comprises costs of item distribution from warehouses to distribution centers and from distribution centers to demand points via trucks, cost of item outsourcing to distribution centers and item distribution to demand points via helicopters from a separate stock keeping point (TL)

w_{ds} : demand for relief item-tent at aggregated demand point d under scenario s (units)

Mk : a large number

vt : volume of relief item (m^3)

ca_{rd} : arrival time on road r to demand point d (hour)

cah : arrival time with helicopter (or cargo airplane) to demand points (hour)

cau : arrival time penalty for unsatisfied demand (hour)

vtr : interior volume of a truck (m^3)

bl : liters of fuel consumed per kilometer of a truck delivery

pb : price of fuel per liter (TL)

vh : interior volume of a helicopter (or cargo airplane) (m^3)

hd : service distance of helicopter (or cargo airplane) to demand points (km)

kl : liters of fuel (kerosene) consumed per helicopter (or cargo airplane) delivery

kp : price of fuel per liter (TL)

pr_s : probability of scenario s occurring

bd_{ijr} : distance between warehouse i and distribution center j on route r with truck (km)

gd_{jdr} : marginal distance between distribution center *j* and demand point *d* on route *r* with truck (km)

pw_{is} : 1 if permanent warehouse *i* is in operating condition after disaster under scenario *s*,0 otherwise

dc_{js} : 1 if distribution center *j* is in operating condition after disaster under scenario *s*,0 otherwise

b_{ijrs} : 1 if route *r* that connects warehouse i and distribution center *j* to each other is in operating condition under scenario *s*,0 otherwise

g_{jdrs} : 1 if route *r* that includes distribution center *j* and demand point *d* is in operating condition under scenario *s*,0 otherwise

Decision Variables

Binary Variables

x_i : 1 if potential permanent warehouse *i* is opened,0 otherwise

m_j : 1 if potential distribution center *j* is opened,0 otherwise

u_{rs} : 1 if route *r* is used under scenario *s*,0 otherwise

Continuous Variables

y_i : units of relief item pre-positioned at permanent warehouse *i*

v_{ijrs} : units of relief item sent on road *r* under scenario *s* from warehouse *i* to distribution center *j*

st_{jdrs} : units of relief item sent on route *r* under scenario *s* from distribution center *j* to demand point *d*

q_{js} : units of relief item outsourced to distribution center *j* under scenario *s*

pn_{ds} : units of relief item directly sent with helicopter to demand point *d* from a distant location with a separate stock under scenario *s*

ud_{ds} : unsatisfied demand under scenario *s* (units) for demand point *d*

The resulting mathematical model is as follows:

$$\min \sum_{s\in S} (pr_s) * [\sum_{j\in J} \sum_{d\in D} \sum_{r\in R} (st_{jdrs} * ca_{rd}) + \sum_{d\in D} (pn_{ds} * cah)$$

$$+ \sum_{d\in D} (ud_{ds} * cau)] \quad (1)$$

subject to

$$\sum_{i\in I} (f_i * x_i) + \sum_{i\in I} ((p + In) * y_i) + \sum_{j\in J} (fd_j * m_j) \leq B_1 \quad (2)$$

$$y_i * vt \leq c_i \quad \forall i \in I \quad (3)$$

$$\sum_{j\in J} (q_{js} * p) + \sum_{j\in J} (q_{js} * In) + \sum_{i\in I} \sum_{j\in J} \sum_{r\in R} (v_{ijrs} * In)$$

$$+ \sum_{i\in I} \sum_{j\in J} \sum_{r\in R} (bd_{ijr} * ((v_{ijrs} * vt)/vtr) * bl * pb)$$

$$+ \sum_{j\in J} \sum_{d\in D} \sum_{r\in R} (gd_{jdr} * ((st_{jdrs} * vt)/vtr) * bl * pb)$$

$$+\sum_{d\in D} (((pn_{ds} * vt)/vh) * kl * hd * kp) + \sum_{d\in D} (pn_{ds} * p) \leq B_2 \quad \forall s \in S \quad (4)$$

$$\sum_{i\in I} \sum_{r\in R} ((q_{js} + v_{ijrs}) * vt) \leq cd_j * m_j \quad \forall j \in J, \forall s \in S \quad (5)$$

$$\sum_{j\in J} \sum_{r\in R} (v_{ijrs}) \leq y_i * pw_{is} \quad \forall i \in I, \forall s \in S \quad (6)$$

$$v_{ijrs} \leq y_i * b_{ijrs} \quad \forall i \in I, \forall j \in J, \forall r \in R, \forall s \in S \quad (7)$$

$$q_{js} + \sum_{i\in I} \sum_{r\in R} (v_{ijrs}) \geq \sum_{d\in D} \sum_{r\in R} (st_{jdrs}) \text{ for } \forall j \in J, \forall s \in S \quad (8)$$

$$\sum_{j\in J} \sum_{r\in R} (st_{jdrs}) + pn_{ds} + ud_{ds} \geq wd_{ds} \quad \forall d \in D, \forall s \in S \quad (9)$$

$$\sum_{d\in D} (pn_{ds}) \leq 0.1 * \sum_{d\in D} (w_{ds}) \quad \forall s \in S \quad (10)$$

$$q_{js} \leq Mk * dc_{js} \quad \forall j \in J, \forall s \in S \quad (11)$$

$$v_{ijrs} \leq Mk * b_{ijrs} * pw_{is} * x_i \quad \forall\, i \in I\,, \forall\, j \in J\,, \forall\, r \in R\,, \forall\, s \in S \qquad (12)$$

$$st_{jdrs} \leq Mk * g_{jdrs} * dc_{js} * m_j \quad \forall\, j \in J\,, \forall\, d \in D\,, \forall\, r \in R\,, \forall\, s \in S \qquad (13)$$

$$v_{ijrs} \leq Mk * u_{rs} \quad \forall\, i \in I\,, \forall\, j \in J\,, \forall\, r \in R\,, \forall\, s \in S \qquad (14)$$

$$st_{jdrs} \leq Mk * u_{rs} \quad \forall\, j \in J\,, \forall\, d \in D\,, \forall\, r \in R\,, \forall\, s \in S \qquad (15)$$

$$x_i \in \{0,1\} \quad \forall\, i \in I \qquad (16)$$

$$m_j \in \{0,1\} \quad \forall\, j \in J \qquad (17)$$

$$u_{rs} \in \{0,1\} \quad \forall\, r \in R\,, \forall\, s \in S \qquad (18)$$

$$y_i \geq 0 \; \forall\, i \in I \qquad (19)$$

$$v_{ijrs} \geq 0 \quad \forall\, i \in I\,, \forall\, j \in J\,, \forall\, r \in R\,, \forall\, s \in S \qquad (20)$$

$$st_{jdrs} \geq 0 \quad \forall\, j \in J\,, \forall\, d \in D\,, \forall\, r \in R\,, \forall\, s \in S \qquad (21)$$

$$q_{js} \geq 0 \quad \forall\, j \in J\,, \forall\, s \in S \qquad (22)$$

$$pn_{ds} \geq 0 \quad \forall\, d \in D\,, \forall\, s \in S \qquad (23)$$

$$ud_{ds} \geq 0 \quad \forall\, d \in D\,, \forall\, s \in S \qquad (24)$$

Objective function (1) minimizes total expected demand weighted arrival time for truck and helicopter deliveries to demand points as well as total expected penalized weighted arrival time of unsatisfied demand over all different scenarios.

In the first part of the equation, delivery amount to each demand point from each distribution center on each truck route under each scenario is multiplied by arrival time to each demand point on each truck route and also by probability of each scenario occurrence. This multiplication is then summed for every distribution center, demand point, truck route and scenario. Hence, the first part gives total expected demand weighted arrival time with truck delivery over all scenarios.

In the second part of the objective function, delivery amount to each demand point via helicopter under each scenario is multiplied by the arrival time to demand points via helicopter and also by the probability of each scenario becoming true. In the study it is assumed that helicopter delivers relief item-tent to demand points from a 100 km distant location with a separate stock apart from the stock of distribution centers. Average speed of helicopter is assumed as 300 km/hour and hence delivery and arrival time to each demand point is assumed as 0.333 hours (20 minutes) via helicopter. This multiplication is summed overall demand points and scenarios. This part gives total expected demand weighted arrival time via helicopter over all scenarios.

In the third part of the objective function, unsatisfied demand amount for each demand point under each scenario is multiplied by the arrival time penalty for unsatisfied demand and also by probability of each scenario coming true. It was assumed that in case delivery of relief items cannot be made to demand points right after the disaster, unsatisfied demand is met 1,000 hours (41.66 days) later with donations. A high value constant of 1,000 is used in the objective function to penalize unsatisfied demand, since the objective function is minimizes demand weighted arrival time. The multiplication is summed for all demand points and for all scenarios. Hence this part gives total expected demand weighted unsatisfied demand.

Constraints (2), which are the first stage budget constraints, restrict first stage costs. The first part gives total warehouse opening and operating costs, the second part gives the item procurement and inventory keeping costs for item pre-positioned to warehouses, and the third part gives total distribution center opening and operating costs.

Constraints (3) restrict units of item stored at each warehouse in terms of volume (m^3).

Constraints (4), which are the second stage budget constraints, include the following costs: The first and second parts give procurement and inventory keeping costs for items outsourced at distribution centers respectively. The third part calculates inventory keeping costs for items sent to distribution centers from the warehouses, whereas the fourth part gives transportation costs for items transferred from warehouses to distribution centers. The fifth part yields the transportation costs for item transferred from distribution centers to demand points via trucks, the sixth part gives transportation costs via helicopters from a distant location with a separate stock to demand points, and the last part gives item procurement cost for item urgently outsourced for delivery to demand points from a distant location with a separate stock.

Here, in calculating the transportation costs via trucks, total amount transferred in terms of volume (m^3) is divided by 79, which is the interior volume (m^3) of jumbo trucks [46]; hence yielding the number of trucks. This amount is multiplied by 0.35, which is the average liters of benzene consumed by jumbo trucks per km [47], and then with 4.3, which is the average price (TL) per liter of fuel [48]. Finally, this cost per km is multiplied by the distance traveled (km).

Similarly, while calculating the transportation costs via helicopters, total amount transferred in terms of volume (m^3) is divided by 120, which is the interior volume of helicopter [49], hence number of helicopters required is found. This amount is multiplied by 5, which is the approximate liters of kerosene consumed by helicopter per km [50], and then with 2.8, which is average price (TL) per liter of kerosene [51]. Finally, this cost per km is multiplied by the distance traveled (km).

Constraints (5) restrict units of item stored at each distribution center under each scenario in terms of volume (m^3). This constraint accumulates volumes of item outsourced to distribution centers as well as item transferred from warehouses to distribution centers. These constraints also prevent item accumulation to distribution center if that potential distribution center is not opened.

Constraints (6) ensure that units of item transferred from each warehouse to all distribution centers though all routes is less than or equal to units of item pre-positioned at this warehouse under each scenario. In addition under each scenario no item is sent from a warehouse to a distribution center if that warehouse is not operating under that scenario.

Constraints (7) ensure that units of item transferred from each warehouse to each distribution center though each route is less than or equal to units of item pre-positioned at this warehouse under each scenario. Furthermore, under any scenario, no item is sent from a warehouse to a distribution center through a specific route if this specific route does not connect the warehouse and distribution center to each other.

Constraints (8) guarantee that for each distribution center and under each scenario, total amount of item sent from warehouses plus total amount of item outsourced to that distribution center is greater than or equal to units of items send from that distribution center to all demand points on all routes.

Constraints (9) ensure that amount of item sent from all distribution centers to a demand point through all routes and units of item delivered with helicopter to that demand point plus unsatisfied demand for that demand point is guaranteed to be greater than or equal to demand at that demand point under each scenario.

Constraints (10) ensure that total units of item delivered to all demand points is less than or equal to 10% of total consolidated demand of all demand points under all scenarios.

Constraints (11) guarantee that no item is outsourced to a non-opened distribution center under each scenario for all distribution centers.

Constraints (12) guarantee that for every warehouse, every distribution center, every route, and under each scenario; no item is sent from a warehouse to a distribution center though a route if that warehouse is not opened or if that warehouse not in an operating condition or if the road does not connect these warehouse and distribution center to each other. These constraints also ensure that since no item is sent from a warehouse no item is pre-positioned in that warehouse. Hence no item is pre-positioned at a warehouse if that warehouse is not opened.

Constraints (13) guarantee that for every distribution center, every demand point, every road, and under each scenario; no item is sent from a distribution center to a demand point though a road under a scenario if that distribution center is not opened, or if that distribution center not in an operating condition, or if the route does not connect these distribution center and demand point to each other. These constraints also ensure that since no item is sent from a distribution center no item is pre-positioned to that distribution center. Hence no item is pre-positioned at a distribution center if that distribution center is not opened.

Constraints (14) ensure that for every warehouse, every distribution center, every route, and under each scenario; no item is sent from a warehouse to a distribution center through a route if that route is not used under that scenario.

Constraints (15) guarantee that for every distribution center, every demand point, every route, and under each scenario; no item is sent from a distribution center to a demand point through a route if that road is not used under that scenario.

Constraints (16)-(24) are the set constraints including binary and non-negative decision variables.

Model 1.2. Equity-Based Baseline Model

In Model 1.2., the objective function is changed to minimize maximum expected demand weighted arrival time for truck and helicopter deliveries to demand points as well as the penalized weighted arrival time of unsatisfied demand over all scenarios rather than the expected total demand weighted arrival time version of objective function in Model 1.1.

In the frame of this new model; a new decision variable and a new constraint are defined in addition to existing variables and constraints in Model 1.1.

The additional decision variable wm_s denotes the maximum demand weighted arrival time for truck and helicopter deliveries at any demand point including penalized weighted arrival time of unsatisfied demand under each scenario. Using this variable, the following constraint is added to the model:

$$wm_s \geq (st_{jdrs} * ca_{rd}) + (pn_{ds} * cah) + (ud_{ds} * cau) \ \forall\ j \in J\ ,\ \forall\ d \in D\ ,$$

$$\forall\ r \in R\ ,\ \forall\ s \in S \qquad (25)$$

Constraints (25) ensure that variable wm_s is greater than or equal to sum of weighted arrival time to each demand point from every distribution center though each truck route and weighted arrival time to each demand with helicopter as well as the penalized weighted arrival time of unsatisfied demand under each scenario, if any.

The objective function of Model 1.2 is then as follows:

$$\min \sum_{s \in S} (pr_s * wm_s) \qquad (26)$$

Objective function (26) minimizes maximum expected arrival time for truck and helicopter deliveries to demand points as well as penalized weighted arrival time of unsatisfied demand under each scenario.

Model 1.2 is solved to minimize objective function (26), subject to constraints (2)-(25).

3.2. Deterministic Benchmark Models

We formulate two deterministic models as benchmarks to the proposed stochastic models in Section 3.1 to observe and represent the differences in results and decisions in case (i) no vulnerability is assumed, and (ii) road vulnerability is integrated into the model as an expected inflation in travel time, and facility vulnerability is integrated into the model as an expected deflation in the service capacities of the warehouses and distribution centers, rather than as binary discrete scenario sets.

The first of these models does not take road and facility vulnerabilities or demand uncertainty into account. In the second deterministic model, inspired by Baskaya [26], road vulnerability is reflected into the mathematical models by assuming that all roads are still traversable after the disaster, but travel time on these roads is increased by an additional percentage. Additionally, in the second model, warehouse and facility vulnerabilities affect the service capacities of these facilities and facility capacities are decreased by a certain percentage depending on their vulnerability.

Model 2.1. Efficiency-Based Model with No Road or Facility Vulnerabilities

Models with no road or facility vulnerabilities (Models 2.1 and 2.2) provide lower bounds on the objective function of Model 1.1 and 1.2, respectively. The main aim in formulating these models is to observe the effect of incorporating road and facility vulnerabilities on the objective values and the facility location and inventory pre-positioning decisions.

The main differences in the formulation of Model 2.1, as opposed to Model 1.1, are the following:

- The scenario set S is no longer considered. Scenario indices are removed from all second-stage parameters and decision variables.
- All second stage binary parameters take a value of 1, as all warehouses and road segments are assumed to be in operating condition.

The resulting mathematical model is as follows:

$$\min \sum_{j \in J} \sum_{d \in D} \sum_{r \in R} (st_{jdr} * ca_{rd}) + \sum_{d \in D} (pn_d * cah)$$

$$+ \sum_{d \in D} (ud_d * cau) \quad (27)$$

subject to

$$\sum_{i\in I} (f_i * x_i) + \sum_{i\in I} ((p + In) * y_i) + \sum_{j\in J} (fd_j * m_j) \leq B_1 \tag{28}$$

$$y_i * vt \leq c_i \;\forall\; i \in I \tag{29}$$

$$\sum_{j\in J} (q_j * p) + \sum_{j\in J} (q_j * In) + \sum_{i\in I} \sum_{j\in J} \sum_{r\in R} (v_{ijr} * In)$$

$$+ \sum_{i\in I} \sum_{j\in J} \sum_{r\in R} (bd_{ijr} * ((v_{ijr} * vt)/vtr) * bl * pb)$$

$$+ \sum_{j\in J} \sum_{d\in D} \sum_{r\in R} (gd_{jdr} * ((st_{jdr} * vt)/vtr) * bl * pb)$$

$$+\sum_{d\in D} (((pn_d * vt)/vh) * kl * hd * kp) + \sum_{d\in D} (pn_d * p) \leq B_2 \tag{30}$$

$$\sum_{i\in I} \sum_{r\in R} ((q_j + v_{ijr}) * vt) \leq cd_j * m_j \;\forall\; j \in J \tag{31}$$

$$\sum_{j\in J} \sum_{r\in R} (v_{ijr}) \leq y_i \;\forall\; i \in I \tag{32}$$

$$v_{ijr} \leq y_i * b_{ijr} \;\forall\; i \in I, \forall\; j \in J, \forall\; r \in R \tag{33}$$

$$q_j + \sum_{i\in I} \sum_{r\in R} (v_{ijr}) \geq \sum_{d\in D} \sum_{r\in R} (st_{jdr}) \;\forall\; j \in J \tag{34}$$

$$\sum_{j\in J} \sum_{r\in R} (st_{jdr}) + pn_d + ud_d \geq wd_d \;\forall\; d \in D \tag{35}$$

$$\sum_{d\in D} (pn_d) \leq 0.1 * \sum_{d\in D} (w_d) \tag{36}$$

$$q_j \leq Mk * m_j \;\forall\; j \in J \tag{37}$$

$$v_{ijr} \leq Mk * b_{ijr} * x_i \;\forall\; i \in I, \forall\; j \in J, \forall\; r \in R \tag{38}$$

$$st_{jdr} \leq Mk * g_{jdr} * m_j \;\forall\; j \in J, \forall\; d \in D, \forall\; r \in R \tag{39}$$

$$x_i \in \{0,1\} \;\forall\; i \in I \tag{40}$$

$$m_j \in \{0,1\} \;\forall\; j \in J \tag{41}$$

$$y_i \geq 0 \;\forall\; i \in I \tag{42}$$

$v_{ijr} \geq 0 \; \forall \; i \in I \,, \forall \; j \in J \,, \forall \; r \in R$ (43)

$st_{jdr} \geq 0 \;\; \forall \; j \in J \,, \forall \; d \in D \,, \forall \; r \in R$ (44)

$q_j \geq 0 \;\; \forall \; j \in J \,, \forall \; s \in S$ (45)

$pn_d \geq 0 \;\; \forall \; d \in D$ (46)

$ud_d \geq 0 \;\; \forall \; d \in D$ (47)

Model 2.2. Equity-Based Model with No Road or Facility Vulnerabilities

In Model 2.2, the objective function is changed to minimize maximum demand weighted arrival time for truck and helicopter deliveries to demand points as well as the weighted penalty for the arrival time of unsatisfied demand.

In frame of this new model; a new variable *wm*, which represents the maximum demand weighted arrival time for truck and helicopter deliveries to demand points as well as the weighted penalty for the arrival time of unsatisfied demand, is introduced. In addition, the following constraint is added into Model 2.1 to calculate the value of *wm*:

$wm \geq (st_{jdr} * ca_{rd}) + (pn_d * cah) + (ud_d * cau) \;\; \forall \; j \in J \,, \forall \; d \in D \,, \forall \; r \in R$ (48)

$\min \; wm$ (49)

The resulting objective function (49) is the minimization of *wm* and the model is subject to constraints (28)-(48).

Model 3.1. Efficiency-Based Model with Deterministic Vulnerabilities

The third model is formulated using deterministic road and facility vulnerabilities for warehouses and distribution centers, which are used to inflate the travel times on the roads and to deflate the capacities of the warehouses and distribution centers. In addition, demand is considered as deterministic and assumed to be equal to expected demand of different demand values under different magnitudes of disaster.

To incorporate road vulnerability into travel times, we define a new parameter, cai_{rd}, which represents the inflated total arrival time on route *r* at demand point *d*. To calculate cai_{rd}, arrival times ca_{rd} in the previous models are multiplied by $1/(1-vr_r))$, where vr_r is the vulnerability of road segment *r*. It is assumed that road vulnerability affects arrival times on roads, and hence arrival time increases as road vulnerability increases.

In mathematical terms, the following equation adjusts the arrival time of route *r* at demand point *d*:

$$cai_{rd} = ca_{rd} * (1/(1 - vr_r)) \quad (50)$$

In the objective function, the term ca_{rd} is replaced by cai_{rd}.

To incorporate facility vulnerability, we introduce the following additional parameters:

vn_i: expected facility vulnerability for warehouse *i*

vl_j: expected facility vulnerability for distribution center *j*

Warehouse and distribution center service capacity constraints (constraints 6 and 8 in Model 1.1) are then modified as follows:

$$\sum_{j \in J} \sum_{r \in R} (v_{ijr}) \leq y_i * (1 - vn_i) \quad \forall\, i \in I \quad (51)$$

$$q_j + \sum_{i \in I} \sum_{r \in R} (v_{ijr} * (1 - (vl_j)) \geq \sum_{d \in D} \sum_{r \in R} (st_{jdr}) \; \forall\, j \in J \quad (52)$$

<u>Model 3.2. Equity-Based Model with Deterministic Vulnerabilities</u>

As in Model 2.2, Model 3.2 involves the change of the objective function to minimization of the maximum expected demand weighted arrival time for truck and helicopter deliveries to demand points as well as the weighted penalty for the arrival time of unsatisfied demand.

As in Model 2.2, we define wm as the maximum of summation of demand weighted arrival time for truck and helicopter deliveries to demand points as well as the weighted penalty for the arrival time of unsatisfied demand and define the constraint:

$$wm \geq (st_{jdr} * ca_{rd}) + (pn_d * 0.333) + (ud_d * 1{,}000) \text{ for } \forall\, j \in J, \forall\, d \in D, \forall\, r \in R$$

(53)

The objective function of Model 3.2 is defined as:

$$\min wm \qquad (54)$$

3.3. Solution Approach

The number of potential scenarios in Model 1.1 and 1.2 are too large to handle. If we have |R| road segments, |I| potential warehouse locations and |J| potential distribution center locations, there are $2^{|R|x|I|x|J|}$ potential scenarios, which makes the model impossible to solve optimally even for very small instances.

Hence we use a sample average approximation heuristic as described by Kleywegt et al. [37] and Ahmed and Shapiro [38], which works in the following way:

(i) We perform a set of *rp* replications, in each of which a model with *sp* scenarios are formed. To determine the values of *rp* and *sp*, we perform preliminary experiments and construct confidence intervals on the value of the objective function for each (*rp,sp*) pair.

(ii) Once the values of *rp* and *sp* are determined, we sample a large number of *N*>>*sp* scenarios by fixing the first-stage decisions in each of the *rp* replications. Out of these, we pick the solution that yields the smallest expected objective value; which is the resulting heuristic solution.

The idea here is to sample through as many scenarios as possible, so that the expected objective value is an accurate approximation of the original objective function. Hence, we would like to have the values of *rp* and *sp* as high as possible in

Step (i) and the value of N should be as high as possible in Step (ii). However, increasing the values of these parameters may lead to significant increases in the computational burden. Thus, to resolve this trade-off, we determine these values after performing preliminary experiments in Chapter 5.1.

CHAPTER 4

A CASE STUDY BASED ON A POTENTIAL EARTHQUAKE DISASTER IN ISTANBUL, TURKEY

The proposed mathematical models are applied on a potential earthquake scenario affecting the European side of Istanbul where the great majority of Istanbul's population resides with a total population of 9,162,919 [52].

Istanbul has suffered greatly from a major Earthquake in 1999 and since main commercial and industrial facilities of Turkey are located in Istanbul, large-scale fatalities and economic damage occurred. A study conducted within the framework of Istanbul Seismic Risk Mitigation and Emergency Preparedness Project [9] estimates that with a probability greater than 62%, a large earthquake will occur in Istanbul within the next 30 years. Additionally, the occurrence of a large earthquake within 10 years is greater than 20%. The study further estimates that in case of a 7.5 Richter scale earthquake in Istanbul, nearly 70,000 deaths, 120,000 heavily injured people, 400,000 lightly injured people, and economic damage around 50 billion USD is expected.

4.1. Model Settings and Assumptions

4.1.1. Data Sets and Parameters

In this chapter, model settings as well as the parameters regarding the application of mathematical models to a potential earthquake in Istanbul, Turkey are explained in detail.

This part of the study explains how distances, paths and routes, road vulnerabilities and their vulnerability scenario settings, transportation and arrival times, demand amounts, potential facility locations and their vulnerability scenario settings, facility storage capacities, facility fixed costs, relief item volumes, relief item costs as well as first and second stage budgets are obtained.

4.1.1.1. Distances between Districts of Istanbul

The distances between districts are taken from Baskaya [26], where Google Maps is utilized to find the distances between districts. A district center is determined for each district and represented with a latitude and longitude coordinate (N°; E°). Coordinate of each district center is obtained by calculating the population weighted average of coordinates of neighborhoods in this district. The mukhtar office (headman office) of each neighborhood is assumed as the center of that neighborhood and the coordinate of the mukhtar office is used as the coordinate of each neighborhood. In Google Maps, distances between the district centers are found by utilizing these coordinates. Coordinates of district centers and distances between districts of Istanbul from Baskaya [26] are presented in the Tables A1 and A2 of Appendix A, respectively.

4.1.1.2. Path and Route Generation

In the model, a direct path between a warehouse-distribution center pair is assumed and hence items are first transferred from the districts where warehouses are located to the districts where the distribution centers are located. On the other hand, deliveries from distribution centers to demand points are assumed to be made through routes that visit multiple districts. Delivery trucks start the route from distribution centers and follow a pre-determined route comprising two or three demand points. If the path is blocked at some point of these routes, the demand point(s) sequenced after this district in the route cannot receive the delivery, even if the remaining road segments are not blocked.

Direct paths starting from warehouses and reaching to distribution centers are determined based on the distances between districts that potential warehouses and potential distribution centers to be located. Three, four or five direct paths are determined to start from each potential warehouse to set of different potential distribution centers. The distribution centers that are closest to a specific warehouse are allocated to that warehouse and hence pre-determined roads between warehouses and distribution centers are formed. Each distribution center is allocated to at least two potential warehouses in this setting.

Route sets starting from distribution centers and reaching out to demand points are determined based on distances as well. The demand point closest to the distribution center is appointed as the first demand point of the route and the other demand point closest to that first demand point is appointed as the second demand point, similarly another demand point closest to the second demand point in the route is appointed as the third demand point of the route. To avoid duplication, if a demand point is appointed as the first point in a route starting from a specific distribution center, then in another route, another demand point is appointed as the first demand point starting from the same distribution center. Each demand point is allocated to at least two potential distribution centers.

The maximum route length is restricted to 40 kilometers with two exceptions. Two of the roads reaching out to Silivri and Catalca districts are longer than 40 kilometers, since these two districts are quite distant from other districts. Maximum number of demand points that can be assigned to a route is restricted to three. Therefore, some routes can be comprised of only two demand points, while other may include three demand points.

For all roads and routes, the origin district is also the first district that is visited throughout this route. Some districts are both potential warehouse and distribution center locations and all districts are also demand points. Hence, a road starting from a warehouse in a specific district first visits the distribution center in this district. Similarly, a road that starts from a specific distribution center firstly visits the demand point in this same specific district. Distance and travel times through the visits in the same district are assumed to be zero.

The pre-determined roads and routes are presented in Tables B1 and B2 of Appendix B for roads connecting warehouses to distribution centers and for routes connecting distribution centers to demand points, respectively along with the distances.

4.1.1.3. Road Vulnerabilities

In order to obtain data regarding facility and road vulnerabilities of Istanbul in case of an earthquake, “The Study on A Disaster Prevention / Mitigation Basic Plan in Istanbul Including Seismic Microzonation in the Republic of Turkey” report [10] prepared by Japan International Cooperation Agency (JICA) and Istanbul Metropolitan Municipality (IMM) is utilized.

In JICA & IMM Report [10], four different earthquake damage models are generated according to research on the North Anatolian Fault (NAF). Model A is the most probable damage model among these four damage scenarios and moment magnitude (Mw) is assumed to be 7.5. In model B, moment magnitude is assumed to be 7.4. Model C is the worst case scenario with an assumed moment magnitude of 7.7 and model D assumes the moment magnitude (Mw) as 6.9. Among these four models, data of model A and model C are used in this thesis study, since these models correspond to the most probable and worst case scenarios, respectively. 25 districts of Istanbul (all districts on the European side) are taken into consideration.

Vulnerabilities of roads between districts are regarded as the probability that these roads are blocked due to building collapse, debris generation, road failure, etc., and these data are taken from Baskaya [26], where the vulnerabilities of roads are calculated according to road blockage probability of roads of 7 to 15 meters wide [10]. In JICA & IMM Report [10], roads are segmented into six categories, namely red, orange, yellow, green, blue, and gray for which the vulnerability values are over 0.5, between 0.3 and 0.5, is between 0.2 and 0.3, between 0.1 and 0.2, between 0.05 and 0.1 and between 0 and 0.05, respectively. This segmentation is presented in Figure 4.1.

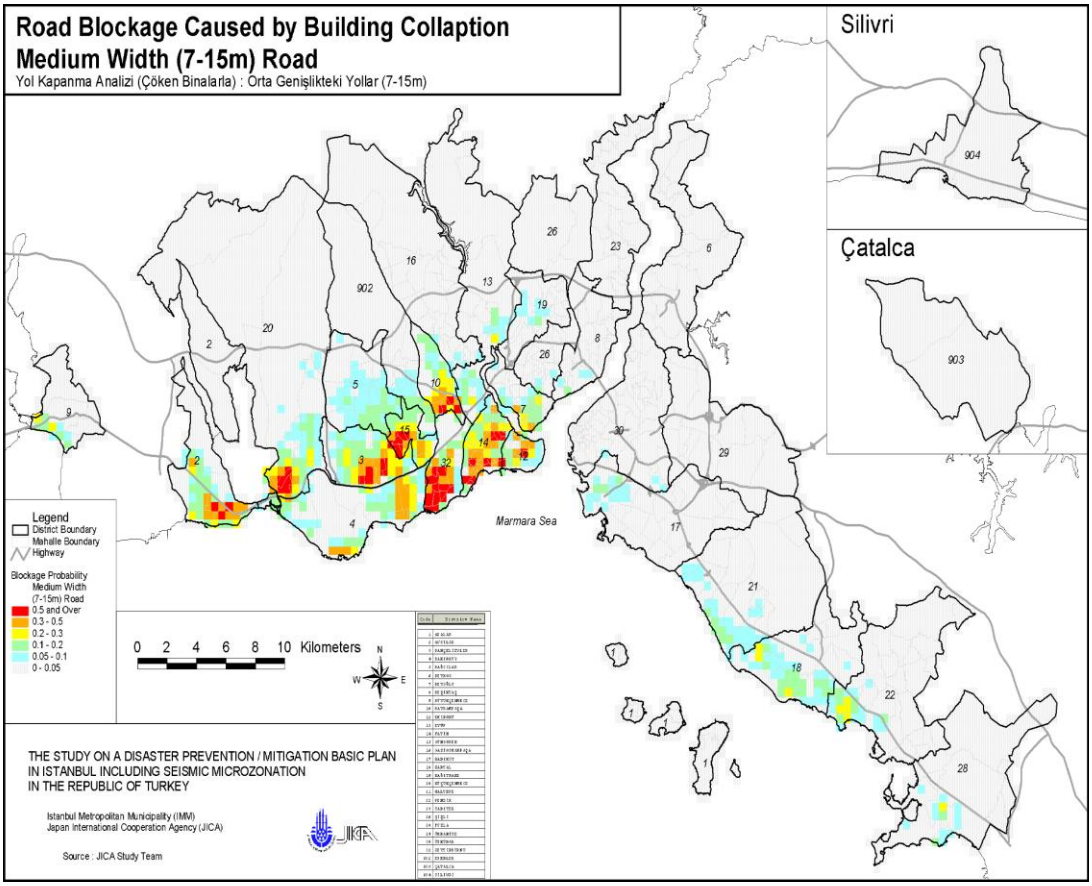

Figure 4.1: Road Vulnerabilities for Medium Width (7-15m) Road Segmentation [26]

The total vulnerability of a path connecting two districts is found by multiplying the road vulnerability of each type of road in the path with the length of that type of road (number of grids) and then summing up this multiplication for all type of roads. This total is then divided by the total length of all roads in the path (total number of grids). Detailed calculation in Baskaya [26] is shown in equation (55).

Total Vulnerability of a 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) (55)

Low, average, and high vulnerabilities used as the coefficient of each road segment [26] are shown in Table 4.1.

Table 4.1: Road Vulnerability Coefficients from Baskaya [26]

	Vulnerability Coefficient		
	Low Vulnerability	Average Vulnerability	High Vulnerability
Red	0.5	0.75	0.99
Orange	0.3	0.4	0.5
Yellow	0.2	0.25	0.3
Green	0.1	0.15	0.2
Blue	0.05	0.075	0.1
Gray	0	0.025	0.05

Road vulnerabilities for each district pairs are shown in Table C1 of Appendix C, where average and high vulnerabilities are summed to calculate total road vulnerabilities.

4.1.1.4. Road Vulnerability Scenario Generation

In this thesis study, road vulnerabilities are integrated into the mathematical models as binary parameters. For every road between districts, a number of random scenarios are generated in excel. In each scenario, condition of a road takes value of 1 or 0. If the road condition is 1, then the road is not blocked and can be used for item transportation under that specific scenario and similarly if road condition is 0, then the road is blocked and cannot be used under that specific scenario for item transportation. In generating the scenarios, percentage of scenarios where a road condition takes a value of 0 is approximately equal to the vulnerability of that road.

These sets are generated first by using the RAND function of excel to create random numbers between 0 and 1. Then IF function of Excel is used to specify that if the cell value is less than road vulnerability then in a new spreadsheet a new cell value of 0 is appointed similarly if the cell value is greater than or equal to road vulnerability then a new cell value of 1 is appointed in a new spreadsheet. By this way scenario sets are created in which percentage of time the road condition takes value of 0 is approximately equal to road vulnerability and in the same way percentage of time road condition takes value of 1 is approximately equal to percentage of time road is not blocked.

The vulnerabilities of the pre-determined routes are presented in Tables D1 and D2 of Appendix D.

4.1.1.5. Transportation and Arrival Times

Transportation with truck delivery is assumed to be made with an average speed of 30 km/hour. Travel time between districts in terms of hours is calculated accordingly. While the delivery is made directly from warehouses to distribution centers, delivery from distribution centers to demand points is made through pre-determined routes. Travel time from warehouse to distribution center is calculated by dividing the distance between warehouses and distribution centers to the average speed of 30 km/hour.

Arrival time at a distribution center is considered as the longest travel time from any warehouse which serves this distribution center. It is assumed that once all the delivery is made to a distribution center, this distribution center starts transporting the item to demand points through pre-determined routes. Arrival time at the demand point at the start of a route is equal to the sum of the arrival time at the distribution center serving it and the total travel time from distribution center to that demand point. Arrival time at a demand point not at the start of a route is equal to arrival time at the preceding demand point in the route plus the travel time from the preceding demand point to that demand point. Travel and arrival times at the warehouses, distribution centers, and demand points are given in Table E1 of Appendix E.

For the deterministic models 3.1 and 3.2, arrival times are inflated to reflect expected road vulnerability into the mathematical model. Hence, arrival times that are presented in Table E1 of Appendix E are multiplied by 1/ (1-road vulnerability).

Inflated travel and arrival times at the warehouses, distribution centers, and demand points roads are given in Table E2 of Appendix E.

4.1.1.6. Demand

We consider the distribution of a single relief item (tent). In the model, each district is assumed as a demand point, so there are a total of 25 demand points. Demand for each relief item is determined based on the percentage of people affected as well as the percentage of damaged buildings in each district. In the JICA & IMM Report [10], expected percentage of dead and severely injured people as well as percentage of heavily and moderately damaged buildings are given for each district of Istanbul under two different damage scenarios. While model A is the most probable damage scenario, model C is the worst case scenario and demand for the item is generated separately under these two different scenarios. It is assumed that one tent is allocated to every four persons. Demand for tents is calculated by subtracting the number of deaths from total population and then multiplying this number with the percentage of moderately and severely damaged buildings, and finally dividing this number by four. Populations of districts are taken from the 2013 population census report of the Turkish Statistics Institute [52].

Demand for tent in a district = ((District Population-(District Population *Percentage of Death))*Percentage of Heavily and Moderately Damaged Buildings)/4 = ((District Population –Total Number of Deaths) * Percentage of Heavily and Moderately Damaged Buildings)/4 (56)

Figures showing affected population as well as demand for each district according to demage Models A and C are presented in Tables 4.2 and 4.3, respectively.

Table 4.2: Affected Population and Demand for Relief Item Under Damage Scenario A of JICA & IMM Report [10]

Demand for tent: ((A-(A*C))*F)/4:((A-B)*F)/4:G (Equation 56)

District No	District	Population	Death		Severly Injured		Buildings	Demand (Units)	Demand (Volume-m3)
			Number	%	Number	%	Heaviliy+Moderately Damaged	Tent	Tent
		A	B	C	D	E	F	G	H
1	AVCILAR	407,240	7,330	1.80%	10,995	2.70%	29.70%	29,693	8,366.09
2	ATASEHIR	405,974	1,353	0.33%	2,571	0.63%	8.50%	8,598	2,422.54
3	BAHCELIEVLER	602,931	7,235	1.20%	9,647	1.60%	29.20%	43,486	12,252.12
4	BAKIRKOY	220,974	3,978	1.80%	6,187	2.80%	36.60%	19,855	5,594.20
5	BAGCILAR	752,250	6,018	0.80%	8,275	1.10%	16.40%	30,596	8,620.29
6	BASAKSEHIR	333,047	4,330	1.30%	8,104	2.43%	19.53%	16,052	4,522.75
7	BEYLIKDUZU	244,760	5,385	2.20%	11,748	4.80%	23.90%	14,303	4,029.78
8	BEYOGLU	245,219	3,188	1.30%	5,150	2.10%	18.70%	11,315	3,187.99
9	BESIKTAS	186,570	933	0.50%	2,239	1.20%	9.80%	4,548	1,281.43
10	BUYUKCEKMECE	211,000	4,642	2.20%	10,128	4.80%	23.90%	12,330	3,473.95
11	BAYRAMPASA	269,677	4,045	1.50%	6,472	2.40%	24.40%	16,204	4,565.35
12	ESENYURT	624,733	13,744	2.20%	29,987	4.80%	23.90%	36,507	10,285.73
13	EYUP	361,531	2,531	0.70%	5,061	1.40%	16.00%	14,360	4,045.93
14	FATIH	425,875	6,814	1.60%	8,518	2.00%	31.00%	32,477	9,150.46
15	GUNGOREN	306,854	3,375	1.10%	5,523	1.80%	26.70%	20,257	5,707.47
16	GAZIOSMANPASA	495,006	1,485	0.30%	2,970	0.60%	8.70%	10,734	3,024.33
17	KAGITHANE	428,755	1,715	0.40%	3,430	0.80%	9.60%	10,249	2,887.64
18	KUCUKCEKMECE	740,090	7,401	1.00%	9,621	1.30%	20.10%	36,818	10,373.37
19	SARIYER	335,598	336	0.10%	1,007	0.30%	3.60%	3,017	850.14
20	SULTANGAZI	505,190	2,863	0.57%	5,389	1.07%	13.10%	16,451	4,635.13
21	SISLI	274,420	1,098	0.40%	2,470	0.90%	8.30%	5,672	1,598.09
22	ZEYRINBURNU	292,313	5,554	1.90%	8,185	2.80%	34.00%	24,375	6,867.52
23	ESENLER	461,621	3,231	0.70%	5,539	1.20%	14.60%	16,731	4,714.02
24	CATALCA	65,811	132	0.20%	197	0.30%	6.80%	1,117	314.59
25	SILIVRI	155,923	1,715	1.10%	3,742	2.40%	10.40%	4,009	1,129.65
TOTAL		9,353,362	100,430		173,157			439,753	123,901

Table 4.3: Affected Population and Demand for Relief Item Under Damage Scenario C of JICA & IMM Report [10]

Demand for tent: ((A-(A*C))*F)/4:((A-B)*F)/4:G (Equation 56)

District No	District	Population	Death		Severly Injured		Buildings	Demand (Units)	Demand (Volume-m3)
			Number	%	Number	%	Heaviliy+Moderately Damaged	Tent	Tent
		A	B	C	D	E	F	G	H
1	AVCILAR	407,240	8,145	2.00%	12,217	3.00%	33.50%	33,424	9,417.27
2	ARNAVUTKOY	215,531	754	0.35%	1,185	0.55%	8.75%	4,698	1,323.73
3	BAHCELIEVLER	602,931	8,441	1.40%	10,250	1.70%	34.40%	51,126	14,404.79
4	BAKIRKOY	220,974	4,419	2.00%	6,850	3.10%	40.80%	22,089	6,223.45
5	BAGCILAR	752,250	6,770	0.90%	9,779	1.30%	19.30%	35,969	10,134.38
6	BASAKSEHIR	333,047	6,328	1.90%	11,990	3.60%	24.90%	20,338	5,730.31
7	BEYLIKDUZU	244,760	6,609	2.70%	14,196	5.80%	27.30%	16,254	4,579.52
8	BEYOGLU	245,219	3,678	1.50%	5,640	2.30%	20.80%	12,560	3,538.81
9	BESIKTAS	186,570	1,306	0.70%	2,612	1.40%	11.40%	5,280	1,487.65
10	BUYUKCEKMECE	211,000	5,697	2.70%	12,238	5.80%	27.30%	14,012	3,947.86
11	BAYRAMPASA	269,677	4,854	1.80%	7,012	2.60%	27.40%	18,142	5,111.42
12	ESENYURT	624,733	16,868	2.70%	36,235	5.80%	27.30%	41,487	11,688.91
13	EYUP	361,531	2,892	0.80%	5,784	1.60%	17.20%	15,421	4,345.00
14	FATIH	425,875	7,240	1.70%	8,943	2.10%	34.40%	36,003	10,143.74
15	GUNGOREN	306,854	4,296	1.40%	6,444	2.10%	31.70%	23,978	6,755.72
16	GAZIOSMANPASA	495,006	1,980	0.40%	3,465	0.70%	10.00%	12,326	3,472.75
17	KAGITHANE	428,755	2,144	0.50%	4,288	1.00%	11.00%	11,732	3,305.44
18	KUCUKCEKMECE	740,090	8,141	1.10%	10,361	1.40%	22.50%	41,172	11,600.25
19	SARIYER	335,598	671	0.20%	1,342	0.40%	4.10%	3,433	967.25
20	SULTANGAZI	505,190	3,536	0.70%	6,231	1.23%	14.83%	18,603	5,241.39
21	SISLI	274,420	1,647	0.60%	3,019	1.10%	9.90%	6,751	1,902.13
22	ZEYRINBURNU	292,313	6,723	2.30%	9,062	3.10%	38.50%	27,488	7,744.75
23	ESENLER	461,621	4,155	0.90%	6,463	1.40%	17.30%	19,785	5,574.54
24	CATALCA	65,811	197	0.30%	263	0.40%	7.50%	1,230	346.62
25	SILIVRI	155,923	2,183	1.40%	4,678	3.00%	11.50%	4,420	1,245.34
TOTAL		9,162,919	119,675		200,546			497,721	140,233

4.1.1.7. Potential Warehouse and Distribution Center Locations

Potential districts are identified for locating warehouses and distribution centers in European side of Istanbul. In order to identify the potential facility locations, volume weighted total demands (m^3) for all districts are calculated. Additionally, two threshold values are calculated for warehouses and distribution centers to decide which districts to include as potential warehouses and distribution centers, respectively.Since Model C of JICA & IMM Report [10] simulates a more severe earthquake damage scenario, potential facilities are determined based on volume weighted demands in this model. However, the threshold values are calculated using the volume weighted demands of Model A [10]. Model A represents a less severe but more probable demage scenario, therefore the average volume weighted demand and hence threshold value is lower in Model A compared to Model C. Considering a lower threshold value enhances the set for potential facility locations and enables considering all possibly feasible districts for locating facilities.

The threshold values are calculated as follows:

Warehouse threshold value = 0.75*(Average Volume Weighted Demand of 25 Districts According to Model A) (57)

Distribution Center threshold value = 0.75*(Average Volume Weighted Demand of 25 Districts according to Model A-Standard Deviation of Volume Weighted Demand of 25 Districts According to Model A) (58)

Threshold value for warehouses is 3,680 and hence districts with more volume weighted demand (according to demage scenario C of JICA & IMM Report [10]) than the threshold value are included as potential warehouse locations in the model.

Similarly, the threshold value for distribution centers is 1,234. However, an exception is made for the Silivri district, whose volume weighted demand is 1,245.34, by not including it as a potential distribution center since its volume weighted demand is very close to the threshold value.

Volume weighted demand for districts under Models A and C as well as their average and standard deviations are given in Table F1 of Appendix F.

Furthermore, potential warehouse and distribution center locations are presented in Tables F2 and F3 of Appendix F, respectively.

4.1.1.8. Facility Vulnerabilities

JICA & IMM Report [10] is utilized to obtain reliable data on facility vulnerabilities of the potential warehouses and distribution centers. In the JICA & IMM Report [10], building damage rates are provided for districts of Istanbul under damage models A and C. In this study, summation of percentage of heavily and moderately damaged buildings are taken into consideration for facility vulnerability calculation. Since JICA & IMM Report [10] was published in 2002, only the districts of that time were included in the report. However, in 2008, some parts of different districts were united to create new districts. Vulnerability of newly created districts were assumed to be the same as the district that they are originated from or assumed to be equal to average vulnerability of districts that they are originated from. The facility vulnerabilities of 25 districts that are included in the mathematical model are given in Table G1 and G2 of Appendix G for earthquake scenarios A and C in the JICA & IMM Report [10].

For the deterministic models 3.1 and 3.2, average vulnerability coefficients of two damage models A and C are taken as expected facility vulnerability. These expected vulnerability coefficients that are integrated as parameters to Model 3.1 and Model 3.2 are presented in table G3 of Appendix G.

4.1.1.9. Incorporation of Facility Vulnerabilities into the Scenarios

As with road vulnerabilities, we incorporate facility vulnerability into the stochastic mathematical model as binary parameters. For every facility (warehouses and distribution centers), random scenario sets are generated, the average of which reflect the damage percentages of Models A and C of the JICA & IMM Report [10].

We generate a set of scenarios, the percentage of time facility condition takes value of 0 is approximately equal to the facility vulnerability value.

In these scenario sets, the facility condition takes value of 1 or 0. If the facility condition is 1 then the facility is not damaged and can be used for item pre-positioning and transportation under that specific scenario and similarly if facility condition is 0, then facility is damaged and cannot be used under that scenario. These sets are generated first by using the RAND function of Excel to create random numbers between 0 and 1. Then IF function of excel is used to specify that if the cell value is less than facility vulnerability then in a new spreadsheet a new cell value of 0 is appointed similarly if the cell value is greater than or equal to facility vulnerability then a new cell value of 1 is appointed in a new spreadsheet. By this way a set of scenarios is created in which percentage of time the facility condition takes value of 0 is approximately equal to facility vulnerability and in the same way percentage of time facility condition takes value of 1 is approximately equal to percentage of time facility is not damaged.

4.1.1.10. Facility Storage Capacities and Facility Costs

Storage capacities of potential facilities (potential warehouses and potential distribution centers) in terms of volume (m^3) are calculated by multiplying the volume weighted demand (m^3) of the district that the facility is to be opened according to damage Model C by a pre-determined constant.

The constant that is to be multiplied by volume weighted demand of each potential facility district is calculated as follows:

Storage Capacity Constant for Warehouses = 5*(Total Volume Weighted Demand of All Districts According to Model C /Total Volume Weighted Demand of Potential Warehouse Districts According to Model C) (59)

Storage Capacity Constant for Distribution Centers = 5*(Total Volume Weighted Demand of All Districts According to Model C/Total Volume Weighted Demand of Potential Distribution Center Districts According to Model C) (60)

Storage capacity of each potential facility is then calculated by multiplying the volume weighted demand of the district that the facility is to be opened with the constant value calculated in Equations (59) and (60) for warehouses and distribution centers, respectively.

Storage Capacity for a Potential Warehouse = (Storage Capacity Constant for Warehouses)*(Volume Weighted Demand of District that Warehouse is to be Opened According to Model C) (61)

Storage Capacity for a Potential Distribution Center = (Storage Capacity Constant for Distribution Centers)*(Volume Weighted Demand of District that Distribution Center is to be Opened According to Model C) (62)

Fixed cost of opening and operating a warehouse and distribution center is assumed as 10 TL/m^3 of storage capacity. Hence, the cost is positively related with storage capacity in terms of volume.

Storage capacities of potential facilities that are the potential warehouses and potential distribution centers are presented in Tables H1 and H2 of Appendix H, respectively, in terms of volume (m^3) as well as the fixed opening and operating costs of warehouses and distribution centers.

4.1.1.11. Relief Item Volumes and Costs

Sheltering becomes an essential need for survival after disasters, and therefore emergency tent is considered as the relief item in frame of this study. The tent specifications in the website of International Federation of Red Cross and Red Crescent Societies [53] are considered in frame of this study. The tent has storage (shipment) volume of 0.28175 m^3 with a price of 310 CHF (approximately 930 TL).

One tent is allocated to each 4-person family. The inventory keeping cost is assumed to be 25% of item procurement cost, since this is the commonly accepted ratio for inventory keeping cost over value of inventory on hand as a thump up practice [54].

4.1.1.12. Budget

A total of 600,000,000 TL is assumed as the total budget for earthquake disaster management of Istanbul's European side. First stage and second stage budgets are determined after preliminary runs of the mathematical model with a very large initial first and second budget of 1,000,000,000,000 TL. After several compilations of the mathematical model by gradually lowering the second stage budget, it is seen that below the second stage budget value of 150,000,000 TL, the model is infeasible; therefore, the second stage budgets is determined as 150,000,000 TL. Additionally, first stage budget is determined as 450,000,000 TL since below this fisrts stage budget level with the second stage budget of 150,000,000 TL the model results in infeasibility.

First stage budget covers warehouse and distribution center opening and operating costs as well as item pre-positioning and inventory keeping costs. Hence, first stage pre-disaster costs are covered by the first stage budget. Second stage budget covers item outsourcing to distribution centers and item delivery costs to demand points either with trucks and helicopter delivery. In the second stage, items are first transferred from warehouses to distribution centers, and then from distribution centers to demand points. It is possible to outsource items to distribution centers rather than transferring from warehouses, and also transfer relief item via helicopters to demand points from a 100 km distant location with a separate stock.

CHAPTER 5

PRELIMINARY EXPERIMENTS AND COMPUTATIONAL RESULTS

In this chapter, we first present the preliminary experiments conducted to determine the parameter values of the sample average approximation heuristics. Afterwards, we discuss the results of the baseline settings, and sensitivity analysis of the problem parameters, as well as comparison of the proposed methods to benchmark approaches.

All mathematical models in this chapter are solved using CPLEX 12.6 through GAMS 23.9.

5.1. Preliminary Experiments

Since the number of potential vulnerability scenarios are too large to solve the models optimally, we use a sample average approximation heuristic to find near-optimal solutions. To set the parameter values of the heuristic (number of replications and number of scenarios in each replication), we conduct preliminary experiments and vary these parameters to find the best pair in terms of how accurately the objective values are represented as well as the CPU times.

We generate the following pair of number of replications and number of scenarios in each replication, and solve Model 1.1 with under these settings: (1) 10 replications, each with 30 scenarios, (2) 20 replications, each with 30 scenarios, (3) 10 replications, each with 60 scenarios, (4) 20 replications, each with 60 scenarios, (5) 20 replications, each with 120 scenarios, (6) 50 replications, each with 120 scenarios, and (5) 100 replications, each with 120 scenarios. The maximum size of a subset is 120 scenarios, since Model 1.1 cannot be solved with more scenarios in a single run. The objective function values are obtained for each run of stochastic Model 1.1 with the different scenario sets, which are presented in Table I1, I2 and I3 of Appendix I.

Average objective function values as well as 95% confidence interval limits are calculated for each model solved with different scenario sets through the scenario subsets which are presented in Table 5.1. The confidence interval of objective function values of Model 1.1 with different scenario sets are calculated with one sample *t test* utilizing Minitab software.

The choice of the two parameters depends on the trade-off between two different measures. As a first measure, for each scenario, the difference of confidence interval upper and lower limits of the objective function values is divided by the average of these objective function values, which is then used as an indicator of deviation of objective function value based on scenarios set size. A smaller ratio means that the objective function value deviation is less, and hence the actual objective function is represented more accurately. The ratios of different scenario sets are presented in the fifth column of Table 5.1. As can be observed, the ratio varies between 11.04% (for the set with 10 replications and 30 scenarios in each replication) and 1.19% (for the set with 100 replications and 120 scenarios in each replication).

While solving a scenario set with higher number of replications and scenario subsets increases the accuracy of the approximation, the CPU times increase as a result. For example, while the set with 10 replications and 30 scenarios in each replication takes 833 seconds to run, the run time of the set with 100 replications, each with 120 scenarios is 97,037 seconds.

As a result of our preliminary experiments, we select to proceed with 50 replications, each with 120 scenarios, as both the width of the confidence interval (2.57% of the mean) and the total CPU time (46,525 seconds) are acceptable. While increasing the number of replications decreases the confidence interval width ratio to 1.19%, the CPU time, which exceeds a day, poses an important burden on the computations.

In the second part of the heuristic approach, each of the 50 different first stage decisions regarding warehouse and distribution center locations and item pre-positioning amounts in the warehouses are then integrated as parameters into the same model with 1,000 newly generated vulnerability scenarios. Since model size is too large to solve in a single run, the 1,000 scenario sets are divided into10 subsets, each having 100 different scenarios. Each of these new models are solved 10 times with the 10 different vulnerability scenario subsets. Average objective function values of 10 runs for 10 different vulnerability scenario sub-sets are calculated for each separate model. In this solution setting, second stage scenario sets of 1,000 are the same for each of these 50 separate models, but each of these 50 models have different first stage decisions. First stage solutions of the model having the minimum average second stage objective function value of 10 runs for 10 different vulnerability scenario subsets is regarded as the heuristic solution to the problem.

The objective function values of the 10 set runs as well as the average of 10 set runs for these 50 different models are represented in Table J1 of Appendix J for Model 1.1.

Table 5.1: Confidence Intervals for the Average Objective Function Values of Changing Number of Scenarios and Replications of the Preliminary Experiments

Stochastic Model 1.1 with Different Scenario Sets	Objective Function Value for the 95% CI Upper Limit	Objective Function Value for the 95% CI Lower Limit	Mean Objective Function Value	(Objective Function Value 95% CI Size)/Mean Objective Function Value	Average CPU Time per Replication (Seconds)	Total CPU Time for All Replications (Seconds)
300 scenarios (10 replications each having 30 scenarios)	107,886,848	96,595,845	102,241,346	11.04%	83.30	833.04
600 scenarios (20 replications each having 30 scenarios)	104,069,924	95,642,813	99,856,368	8.44%	86.23	1,724.53
600 scenarios (10 replications each having 60 scenarios)	110,197,039	103,360,139	106,778,589	6.40%	249.76	2,497.57
1,200 scenarios (20 replications each having 60 scenarios)	109,444,371	103,088,541	106,266,456	5.98%	244.11	4,882.24
2,400 scenarios (20 sets each having 120 scenarios)	114,855,930	109,856,598	112,356,264	4.45%	936.63	18,732.69
6,000 scenarios (50 replications each having 120 scenarios)	112,482,822	109,624,361	111,053,592	2.57%	930.51	46,525.74
12,000 scenarios (100 replications each having 120 scenarios)	111,162,612	109,086,956	110,124,784	1.19%	970.37	97,037.14

5.2. Computational Results Under the Baseline Settings

Since the 39th replication has the minimum average second stage objective function value of 10 runs for 10 different vulnerability scenario sub-sets, first stage decisions of 39th model are considered as the heuristic solution for Model 1.1. The first stage decisions of the 39th model are provided in Tables 5.2, 5.3 and 5.4.

Table 5.2: Warehouse Locations and Pre-positioned Item Amounts in Warehouses for Model 1.1

Warehouse	Pre-positioned Amounts
BAGCILAR	103,582
BEYLIKDUZU	92,925
ESENLER	48,446
EYUP	88,166
SULTANGAZI	48,042
TOTAL	381,161

Table 5.3: Distribution Center Locations for Model 1.1

Opened Distribution Centers	
arnavutkoy	buyukcekmece
avcilar	esenler
bagcilar	esenyurt
bahcelievler	eyup
basaksehir	gaziosmanpasa
bayrampasa	gungoren
besiktas	kagithane
beylikduzu	sisli
beyoglu	sultangazi

Table 5.4: Optimal Solution Statistics for Model 1.1

Average Objective Function Value	113,955,346
Average Helicopter Delivery (Units)	46,652
Average Helicopter Delivery %	10.00%
Average Outsourced Amount (Units)	1,560
Average Outsourced Amount %	0.33%
Average Unsatisfied Demand (Units)	113,864
Average Unsatisfied Demand %	24.41%
Average Total Demand (Units)	466,521

In Table 5.4, average objective function value, average helicopter delivery amount, average helicopter delivery percentage ,average outsourced amount, average outsourced amount percentage, average unsatisfied demand amount, average unsatisfied demand percentage are calculated per scenario. Solution statistics are the average results of 1,000 scenarios.

In the baseline model, 5 warehouses are opened, namely Bagcilar, Beylikduzu, Esenler, Eyup and Sultangazi, with the pre-positioned item amounts of 103,582 units, 92,925 units, 48,446 units, 88,166 units and 48,042 units, respectively. Total amount of items pre-positioned in opened warehouses is 381,161 units. Additionally, 18 distribution centers are opened, which are Arnavutkoy, Avcilar, Bagcilar, Bahcelievler, Basaksehir, Bayrampasa, Besiktas, Beylikduzu, Beyoglu, Buyukcekmece, Esenler, Esenyurt, Eyup, Gaziosmanpasa, Gungoren, Kagithane, Sisli, Sultangazi. The baseline model results in 10% average helicopter delivery which is the upper limit for helicopter delivery. Also on the average 0.33% of total demand is outsourced to distribution centers not from warehouses but from outside resources and average unsatisfied demand percentage is 24.41%.

Deterministic mathematical models 2.1, 2.2 and 3.1, 3.2 are extensively explained in Section 3.2 of this study. These models are also solved using CPLEX software directly with single runs. Since these models are deterministic, model size is adequate to solve with a single run. The results of these models and their comparison to the baseline case are given in Chapter 5.3.

5.3. Sensitivity Analysis and Comparison to Benchmarks

The baseline model formed in this study is the stochastic Model 1.1. In order to observe the effect of objective function (efficiency-based vs. equity-based) as well as the values of main parameters such as budget, capacity and vulnerability on the results, benchmark models are formed and solved. These benchmark models are formed in the same model setting as Model 1.1 and the solution method is the same for these stochastic benchmark models (sample average approximation method) as extensively explained in Chapter 3.3 of this study.

First benchmark is Model 1.2, where the objective function is changed to minimize the maximum expected demand weighted arrival time rather than minimizing total expected demand weighted arrival time. The results of Model 1.2 are presented in Tables 5.5, 5.6, and 5.7.

Comparing the results of Model 1.2 to those of stochastic Model 1.1, we observe that the number of opened warehouses increases from 5 to 13. However, total units of items pre-positioned in warehouses at the pre-disaster stage decreases from 381,161 to 375,923 units. Number of distribution centers are also increases from 18 to 22 in Model 1.2 compared to Model 1.1. Hence, by changing objective from minimizing total expected demand weighted arrival time (efficiency-based) to minimizing maximum expected demand weighted arrival time (equity-based), a higher number of warehouses are opened with less stock units, which is in line with the requirements of an equity based objective; to decrease the arrival times for every demand point, a larger number of warehouses and distribution centers are opened so that items are pre-positioned closer to the demand points and transportation times are less.

Delivery with helicopter is restricted as 10% of total demand in all mathematical models and both stochastic Model 1.1 and 1.2 result in 10% cargo air-craft delivery.

Units of relief item outsourced from distribution centers decreases from 1,560 units to 820 units, which correspond to 0.33 % and 0.18 % of total demand for stochastic Models 1.1 and stochastic Model 1.2, respectively.

Unsatisfied demand increases from 113,864 units to 139,981 corresponding to 24.41% and 30.01% of the total demand for stochastic Model 1.1 and 1.2, respectively. This increase is also expected, as the equity-based objective increases the transportation costs and due to the budget limit for the second stage, less demand can be satisfied.

The objective function value of efficiency based Model 1.1 is 113,955,346, and the equity based objective value of Model 1.1 is 30,030,778. The objective function value of equity based Model 1.2 is 6,562,855 and the efficiency based objective of Model 1.2 is 139,642,879.

Table 5.5: Warehouse Locations and Pre-positioned Item Amounts in Warehouses for Model 1.2

Warehouse	Pre-positioned Amounts
AVCILAR	15,862
BAGCILAR	43,148
BAHCELIEVLER	8,194
BASAKSEHIR	20,702
BEYLIKDUZU	33,680
BUYUKCEKMECE	36,413
ESENLER	48,207
ESENYURT	25,054
EYUP	30,199
FATIH	22,724
KUCUKCEKMECE	37,870
SULTANGAZI	39,031
ZEYTINBURNU	14,841
TOTAL	375,923

Table 5.6: Distribution Center Locations for Model 1.2

Opened Distribution Centers	
arnavutkoy	esenler
avcilar	esenyurt
bagcilar	eyup
bahcelievler	fatih
bakirkoy	gaziosmanpasa
basaksehir	gungoren
bayrampasa	kagithane
besiktas	kucukcekmece
beylikduzu	sisli
beyoglu	sultangazi
buyukcekmece	zeytinburnu

Table 5.7: Optimal Solution Statistics for Model 1.2

Average Objective Function Value	6,562,855
Average Helicopter Delivery (Units)	46,652
Average Helicopter Delivery %	10.00%
Average Outsourced Amount (Units)	820
Average Outsourced Amount %	0.18%
Average Unsatisfied Demand (Units)	139,981
Average Unsatisfied Demand %	30.01%
Average Total Demand (Units)	466,521

In addition to Model 1.2, the main parameters of stochastic Model 1.1 are changed by keeping everything else constant to analyze the effect on the results. For this end, Model 1.1 is solved with different budget, facility capacity and road and facility vulnerability parameters.

In the benchmark model with budget change, the first and second stage budgets are increased by two-thirds and the total budget is increased from 600,000,000 TL to

1,000,000,000 TL. Specifically, model first stage budget is increased from 450,000,000 TL to 750,000,000 TL and the second stage budget is increased from 150,000,000 TL to 250,000,000 TL. In the benchmark model, budget is increased rather than decreased, since in the original model minimum possible budgets that make the solution feasible were used. The results of the benchmark model with budget change are presented in Tables 5.8, 5.9, and 5.10.

By increasing the first and second stage budgets, we observe that compared to Model 1.1 number of opened warehouses increases from 5 to 13 and total units of items pre-positioned in the warehouses at the pre-disaster stage increases from 381,161 to 634,445 units. Hence, by increasing the budget, a higher number of warehouses are opened with more stock units. Similarly, number of distribution centers is also increased from 18 to 22 as result of increasing the budget.

The objective function value decreases from 113,955,346 to 17,828,255 when budget of Model 1.1 is increased 66.67%, which corresponds to an 84.35% decrease in the objective function value.

The main reason for the decrease in the objective function is the decrease in unsatisfied demand. Unsatisfied demand deceases from 113,864 units to 17,732 units; these amounts correspond to 24.41% and 3.80% of the total demand for Model 1.1 with initial and increased budget parameters, respectively. Hence, by increasing the budget, more demand can be satisfied by opening more facilities, pre-positioning more items and by means of more efficient transportation.

Units of relief item outsourced to distribution centers decreases from 1,560 units to 768 units; these amounts correspond to 0.33 % and 0.16% of total demand for Model 1.1 with initial and increased budget parameters, respectively.

Table 5.8: Warehouse Locations and Pre-positioned Item Amounts in Warehouses for Model 1.1 with Budget Change

Warehouse	Pre-positioned Amounts
AVCILAR	45,504
BAGCILAR	78,843
BASAKSEHIR	46,253
BAYRAMPASA	18,588
BEYLIKDUZU	45,715
BUYUKCEKMECE	52,052
ESENLER	60,149
ESENYURT	44,765
EYUP	63,974
FATIH	35,938
KUCUKCEKMECE	44,454
SULTANGAZI	70,771
ZEYTINBURNU	27,439
TOTAL	634,445

Table 5.9: Distribution Center Locations for Model 1.1 with Budget Change

Opened Distribution Centers	
arnavutkoy	esenler
avcilar	esenyurt
bagcilar	eyup
bahcelievler	fatih
bakirkoy	gaziosmanpasa
basaksehir	gungoren
bayrampasa	kagithane
besiktas	kucukcekmece
beylikduzu	sisli
beyoglu	sultangazi
buyukcekmece	zeytinburnu

Table 5.10: Optimal Solution Statistics for Model 1.1 with Budget Change

Average Objective Function Value	17,828,255
Average Helicopter Delivery (Units)	46,629
Average Helicopter Delivery %	9.99%
Average Outsourced Amount (Units)	768
Average Outsourced Amount %	0.16%
Average Unsatisfied Demand (Units)	17,732
Average Unsatisfied Demand %	3.80%
Average Total Demand (Units)	466,521

Another benchmark model is solved by changing the capacity and fixed opening and operating costs of potential warehouses and distribution centers. Here, both warehouse and distribution center capacities as well as the fixed opening and operating costs are increased by 30%, and integrated in this way into the benchmark model. The increased facility capacities and fixed costs are presented in Tables K1 and K2 of the Appendix K. The solutions of the benchmark model with facility capacity and fixed cost change are presented in Tables 5.11, 5.12, and 5.13.

By increasing the potential warehouse and distribution center capacities as well as fixed opening and operating costs, number of open warehouses decreases from 5 to 4. Compared to the baseline in fact, all warehouses except Esenler are opened. Total amount of items pre-positioned in warehouses at the pre-disaster stage decreases from 381,161 to 379,736 units. Number of distribution centers stays at 18. Open distribution centers are identical to those under Model 1.1.

Units of relief item outsourced to distribution centers increases from 1,560 units to 2,702 units; these amounts correspond to 0.33 % and 0.58 % of total demand for Model 1.1 with initial and increased facility capacity and fixed cost parameters, respectively.

Unsatisfied demand increases from 113,864 units to 114,201 units these amounts correspond to 24.41% and 24.48 % of the total demand for Model 1.1 with initial and increased facility capacity and fixed cost parameters, respectively.

The objective function value increases from 113,955,346 to 114,307,243 when capacity and fixed cost parameters of Model 1.1 is increased by 30% which corresponds to a 0.31% increase in objective function. Hence, we can conclude that capacity and fixed cost changes do not significantly affect the facility location and item pre-positioning decisions.

Table 5.11: Warehouse Locations and Pre-positioned Item Amounts in Warehouses for Model 1.1 with Capacity and Fixed Cost Change

Warehouse	Pre-positioned Amounts
BAGCILAR	136,546
BEYLIKDUZU	92,771
EYUP	51,191
SULTANGAZI	99,229
TOTAL	379,736

Table 5.12: Distribution Center Locations for Model 1.1 with Capacity and Fixed Cost Change

Opened Distribution Centers	
arnavutkoy	buyukcekmece
avcilar	esenler
bagcilar	esenyurt
bahcelievler	eyup
basaksehir	gaziosmanpasa
bayrampasa	gungoren
besiktas	kagithane
beylikduzu	sisli
beyoglu	sultangazi

Table 5.13: Optimal Solution Statistics for Model 1.1 with Capacity and Fixed Cost Change

Average Objective Function Value	114,307,243
Average Helicopter Delivery (Units)	46,652
Average Helicopter Delivery %	10.00%
Average Outsourced Amount (Units)	2,702
Average Outsourced Amount %	0.58%
Average Unsatisfied Demand (Units)	114,201
Average Unsatisfied Demand %	24.48%
Average Total Demand (Units)	466,521

Vulnerability is also another important parameter affecting the model results; therefore, the baseline model is benchmarked by changing the road and facility vulnerabilities while keeping everything else the same. In the original model, summation of average and high vulnerabilities for each road is used as total road vulnerability, as shown in Tables C1, D1, and D2 of Appendices C and D. In the benchmark model, only high vulnerabilities for each road are used rather than summation of high and average road vulnerabilities as in Model 1.1, lowered road vulnerabilities are presented in Tables L1 and L2 of Appendix L. Similarly, in the benchmark model, only the percentage of heavily damaged buildings are taken into consideration rather than summation of heavily and moderately damaged building coefficients as in Model 1.1 and these new facility vulnerability values are presented in Tables M1 and M2 of Appendix M. Results of the benchmark model with road and facility vulnerability changes are presented in Tables 5.14, 5.15, and 5.16.

By decreasing the vulnerability coefficients of roads and potential facilities, it is observed that number of opened warehouses are identical to those in the baseline model and total units of items pre-positioned to warehouses at the pre-disaster stage slightly increases from 381,161 to 381,725 units. However, number of distribution centers decreases from 18 to 16.

Units of relief item outsourced in the distribution centers decreases from 1,560 units to 1,523 units, which correspond to 0.33 % and 0.3265 % of total demand for Model 1.1 with initial and with lower road and potential facility vulnerabilities parameters, respectively.

The decrease in the objective function value is mainly due to the decrease in the unsatisfied demand, which decreases from 113,864 units to 67,709 units, corresponding to 24.41% and 14.51% of the total demand for the original model and the one with lower road and potential facility vulnerabilities parameters, respectively. The main reason behind why unsatisfied demand is lower due to a larger number of roads being traversable, as well as a larger number of relief facilities are functioning and hence a larger number of demand points being reachable with the same budget.

The objective function value decreases from 113,955,346 to 67,805,631 when the vulnerability coefficients of roads and potential facilities parameters of Model 1.1 are lowered which corresponds to a 40.50% decrease in the objective function.

Table 5.14: Warehouse Locations and Pre-positioned Item Amounts in Warehouses for Model 1.1 with Lower Road and Facility Vulnerabilities

Warehouse	Pre-positioned Amounts-Units
BAGCILAR	77,544
BEYLIKDUZU	71,362
ESENLER	84,982
EYUP	59,424
SULTANGAZI	88,414
TOTAL	381,725

Table 5.15: Distribution Center Locations for Model 1.1 with Lower Road and Facility Vulnerabilities

Opened Distribution Centers	
arnavutkoy	buyukcekmece
bagcilar	esenler
bahcelievler	esenyurt
basaksehir	eyup
bayrampasa	gungoren
besiktas	kagithane
beylikduzu	sisli
beyoglu	sultangazi

Table 5.16: Optimal Solution Statistics for Model 1.1 with Lower Road and Facility Vulnerabilities

Average Objective Function Value	67,805,631
Average Helicopter Delivery (Units)	46,652
Average Helicopter Delivery %	10.00%
Average Outsourced Amount (Units)	1,523
Average Outsourced Amount %	0.3265%
Average Unsatisfied Demand (Units)	67,709
Average Unsatisfied Demand %	14.51%
Average Total Demand (Units)	466,521

Apart from the aforementioned stochastic benchmark models, two different deterministic benchmark models are also formed (as described in Section 3.2) and solved to observe the effects of (i) ignoring road and facility vulnerabilities when making the facility location, item pre-positioning, and relief transportation decisions, and (ii) incorporating road vulnerabilities as constant travel time increase and incorporating facility vulnerabilities as constant service capacity decrease into the models.

In the first deterministic benchmark model, road and facility vulnerabilities as well as demand uncertainty are not taken into account. The resulting model is solved with the objectives of minimizing total expected demand weighted arrival time (Model2.1) and minimizing maximum demand weighted arrival time (Model 2.2). Results of Model 2.1 are presented in Tables 5.17, 5.18, and 5.19. Similarly, results of Model 2.2 are presented in Tables 5.20, 5.21, and 5.22.

Comparing Model 2.1 to the baseline case, we observe that the number of opened warehouses decreases from 5 to 4, and the total units of items pre-positioned in the warehouses at the pre-disaster stage slightly increases from 381,161 to 385,213 units. Additionally, number of distribution centers decreases from 18 to 6. The decrease in the number of open warehouses and distribution centers underlines the effect of ignoring road vulnerability, which allows satisfying more demand with fewer facilities due to increased efficiency of transportation. It also shows that if vulnerabilities and demand uncertainty are ignored, far fewer facilities are opened than is actually necessary.

Under Model 2.1, virtually no units are outsourced at the distribution centers. Despite this fact, total unsatisfied demand decreases from 113,864 units to 34,654 units, which corresponds to 7.43% of the total demand.

Compared to the baseline case, the objective function value decreases from 113,955,346 to 34,869,071. This implies that the optimal objective function value is underestimated by 69.40% when road and facility vulnerabilities are ignored, which further underlines the importance of incorporating vulnerabilities and demand uncertainty into the models.

When the objective function of model 2.1 is changed to minimize maximum demand weighted arrival time in model 2.2, the solution of model 2.2 is almost identical to solution of model 2.1 only the units of relief item pre-positioned to warehouse ESENLER has slightly increases from 110,584 to 113,115 and unit of item pre-positioned to EYUP decreases from 88,166 units to 85,634.

Comparing Model 1.2 to model 2.2, it is seen that number of opened warehouses decreases from 13 to 4 and number of distribution centers decreases from 22 to 6.

Also the total units of relief item pre-positioned in warehouses at pre-disaster stage increases from 375,923 to 385,213. In the model with no vulnerability, fewer number of warehouses are opened with higher amount of stocks. While the percentage of outsourced items corresponds to 0.18% of total demand in Model 1.2 this percentage is 0.0004% in Model 2.2. Additionally, unsatisfied demand is decreased to 34,654 units in Model 2.2 compared to 139,981 units in Model 1.2. While the ratio of unsatisfied demand is 30.01% in Model 1.2, this ratio is 7.43% in Model 2.2. While the objective function value was 6,562,855, in Model 1.2 the objective function value of model 2.2 is 1,400,961 in case no vulnerability is considered. Hence, when vulnerability is not considered, the equity-based objective is underestimated by a factor of nearly 78.7%.

Table 5.17: Warehouse Locations and Pre-positioned Item Amounts in Warehouses for Model 2.1

Warehouse	Pre-positioned Amounts-Units
BUYUKCEKMECE	80,108
ESENLER	110,584
EYUP	88,166
SULTANGAZI	106,355
TOTAL	385,213

Table 5.18: Distribution Center Locations for Model 2.1

Opened Distribution Centers	
arnavutkoy	beylikduzu
bayrampasa	esenler
besiktas	gaziosmanpasa

Table 5.19: Optimal Solution Statistics for Model 2.1

Objective Function Value	34,869,071
Helicopter Delivery (Units)	46,652
Helicopter Delivery %	10.00%
Outsourced Amount (Units)	2.00
Outsourced Amount %	0.0004%
Unsatisfied Demand (Units)	34,654
Unsatisfied Demand %	7.43%
Total Demand (Units)	466,521

Table 5.20: Warehouse Locations and Item Pre-positioned Item Amounts in Warehouses for Model 2.2

Warehouse	Pre-positioned Amounts-Units
BUYUKCEKMECE	80,108
ESENLER	113,115
EYUP	85,634
SULTANGAZI	106,355
TOTAL	385,213

Table 5.21: Distribution Center Locations for Model 2.2

Opened Distribution Centers	
arnavutkoy	beylikduzu
bayrampasa	esenler
besiktas	gaziosmanpasa

Table 5.22: Optimal Solution Statistics for Model 2.2

Objective Function Value	1,400,961
Helicopter Delivery (Units)	46,652
Helicopter Delivery %	10.00%
Outsourced Amount (Units)	2
Outsourced Amount %	0.0004%
Unsatisfied Demand (Units)	34,654
Unsatisfied Demand %	7.43%
Total Demand (Units)	466,521

In the second deterministic model, vulnerability is integrated into the model as percentage factor that increases the travel time on a road [26], rather than using binary discrete scenario sets. Also, facility vulnerability is incorporated into the model as a percentage factor that decreases the service capacities of facilities. This deterministic model also takes expected demand uncertainty into account. This model is solved with the objectives of minimizing total expected demand weighted arrival time as well as minimizing maximum demand weighted arrival time. These two versions (Models 3.1 and 3.2) are explained in Section 3.2 of this study.

The solutions of Model 3.1 are presented in Tables 5.23, 5.24, and 5.25. Similarly, the solutions to Model 3.2 are summarized in Tables 5.26, 5.27, and 5.28.

The results of Model 3.1 show that compared to the baseline case, number of opened warehouses decreases from 5 to 4. Furthermore, total units of items pre-positioned in warehouses increases from 381,161 to 384,497 units. The number of open distribution centers decreases from 18 to 7. Hence, as in the case of ignoring vulnerabilities, treating vulnerability as a percentage factor that increases the travel time and lowers service capacities of facilities results in significantly fewer facilities opened than necessary.

The objective function value for Model 3.1 is 138,724,153 which corresponds to a 21.74% increase compared to the baseline case. This is mainly due to the increase in the unsatisfied demand from 113,864 units to 138,538 units, which represents 29.70% of the total demand. The main reason behind this increase is the significant increase in travel times, which substantially contributes to the usage of the second sage budget, thereby preventing further demand from being satisfied. When the objective function is changed to minimize the maximum demand weighted arrival time, the number of open warehouses further decreases to 3, and the number of open distribution centers further decreases from 7 to 2. This decrease from Model 3.1 to Model 3.2 is in contrast to the increase from Model 1.1 to Model 1.2. The units of item pre-positioned at warehouses also slightly decreases from 384,497 to 384,416.

Comparing Model 1.2 to Model 3.2, it is observed that the number of open warehouses decreases from 13 to 3, and the number of open distribution centers decreases from 22 to 2. Additionally, unsatisfied demand is increases to 417,372 units in Model 3.2, compared to 139,981 units in Model 1.2. While the ratio of unsatisfied demand is 30.01% in Model 1.2, this ratio is 89.54% in Model 3.2. The objective function value also increases from 6,562,855 in Model 1.2 to 16,713,289 in Model 3.2. The main factor causing these is the inflated travel times on the roads as well as the requirement of equity, which together allow for the satisfaction of only a small part of the demand, hence increasing the objective function value due to the penalty for unsatisfied demand.

Table 5.23: Warehouse Locations and Pre-positioned Item Amounts in Warehouses for Model 3.1

Warehouse	Pre-positioned Amounts
BAGCILAR	76,860
ESENLER	113,115
EYUP	88,166
SULTANGAZI	106,355
TOTAL	384,497

Table 5.24: Distribution Center Locations for Model 3.1

Opened Distribution Centers	
arnavutkoy	kagithane
bagcilar	sisli
esenler	sultangazi
gaziosmanpasa	

Table 5.25: Optimal Solution Statistics for Model 3.1

Objective Function Value	138,724,153
Helicopter Delivery (Units)	46,652
Helicopter Delivery %	10.00%
Outsourced Amount (Units)	103
Outsourced Amount %	0.0221%
Unsatisfied Demand (Units)	138,538
Unsatisfied Demand %	29.70%
Total Demand (Units)	466,521

Table 5.26: Warehouse Locations and Pre-positioned Item Amounts in Warehouses for Model 3.2

Warehouse	Pre-positioned Amounts-Units
BAGCILAR	205,641
BAHCELIEVLER	164,950
KUCUKCEKMECE	13,825
TOTAL	384,416

Table 5.27: Distribution Center Locations for Model 3.2

Distribution Centers	
bahcelievler	bakirkoy

Table 5.28: Optimal Solution Statistics for Model 3.2

Objective Function Value	16,713,289
Helicopter Delivery (Units)	46,652
Helicopter Delivery %	10.00%
Outsourced Amount (Units)	35
Outsourced Amount %	0,0075%
Unsatisfied Demand (Units)	417,732
Unsatisfied Demand %	89.54%
Total Demand (Units)	466,521

Including the baseline Model 1.1 and benchmark models a total of 9 models are solved in frame of this study.

Figures 5.1 and 5.2 show total number of times each warehouse and distribution center is opened in these 9 solutions.

Figure 5.1: Total Number of Times Each Warehouse is Opened in 9 Different Models

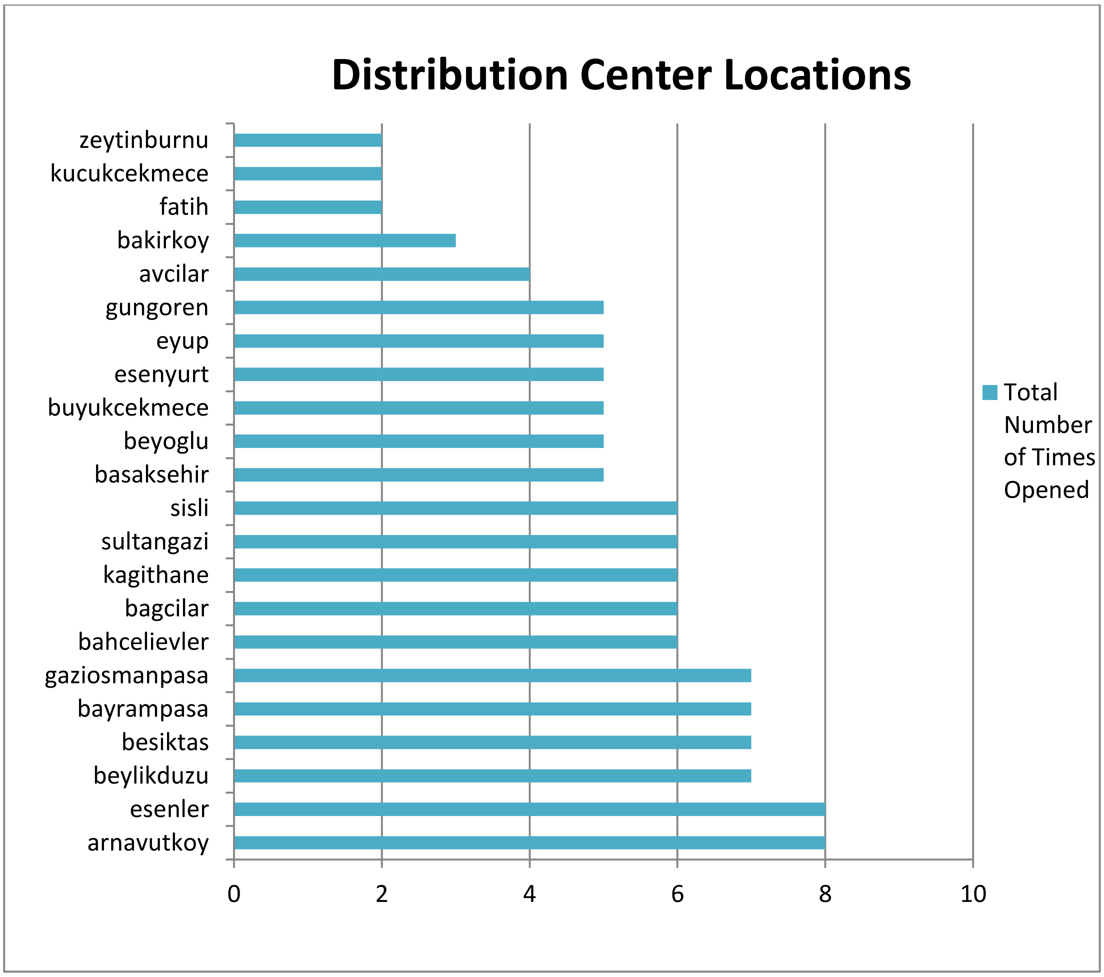

Figure 5.2: Total Number of Times Each Distribution Center is Opened in 9 Different Models

The solutions of nine different models show that Eyup, Sultangazi, Bagcilar, Esenler and Belikduzu are opened as warehouses in eight out of nine, eight out of nine, seven out of nine, seven out of nine and five out of nine solutions, respectively. These are the warehouses listed among the opened warehouses in most of the model solutions. All these warehouses are also included in the solution of baseline model.

On the other hand, Gungoren, Bakirkoy, Bayrampasa, Zeyinburnu, Fatih, Esenyurt, Basaksehir, Bahcelievler and Avcilar are not listed among the opened warehouses in most of the solutions. As a matter of fact these warehouses are listed two, one or zero times in the warehouse list of the optimal solutions. None of these locations are included in the optimal warehouse locations of the baseline model.

The solutions of the nine models list Arnavutkoy and Esenler in the distribution center list in eight out of nine times; Beylikduzu, Besiktas, Bayrampasa and Gaziosmanpasa are listed seven out of nine times in the distribution center list. Additionnaly, Bahcelievler, Bagcilar, Kagithane, Sultangazi and Sisli are listed six out of 9 times in the distribution center list. All these distribution centers are also included in the solution of baseline model.

On the other hand, Avcilar is listed in four out of nine solutions in the distribution center list whereas Bakirkoy is listed in three out of nine solutions, Fatih, Kucukcekmece and Zeytinburnu are listed in two out of nine solutions. Except for Avcilar, none of these distribution centers are included among the optimal distribution center locations of the baseline model.

Table 5.29 shows the percentage of unsatisfied demand under each model. Comparing the percentages of unsatisfied demand under each model, it is seen that while the deterministic model with no vulnerability results in 7.43% percentage of unsatisfied demand, when vulnerability is incorporated percentage of unsatisfied demand increases significantly to 24.41% in the baseline model. Additionally, it is also important to note that when vulnerability is incorporated in terms of discrete binary stochastic parameters then the resulting unsatisfied demand percentage is 24.41% in the baseline model which is less compared to the case where vulnerability is incorporated into the model in terms of expected deterministic constraints. In this case percentage of unsatisfied demand is 29.70% in the deterministic model with expected vulnerability.

Furthermore, models with efficiency based objective results in lower unsatisfied demand percentages compared to equity based models when vulnerability is incorporated. However, when vulnerability is not incorporated, then the percentage of unsatisfied demand is the same under these two different objectives.

While increasing the budget significantly decreases the unsatisfied demand from 24.41% in the baseline model to 3.80% , increasing the facility capacities and facility opening fixed costs does not improve the percentage of unsatisfied demand but rather this percentage is slightly increased from 24.41% to 24.48%.The major reason why unsatisfied demand is not improved when facility capacities increased is that in this case facility opening fixed costs are also increased and this situation leads to opening of slightly less number of facilities. Benchmarking the model with lower facility and supply network vulnerabilities results in lower percentage of unsatisfied demand as expected.

Table 5.29: Percentage of Unsatisfied Demand Under Each Model

Models	**Unsatisfied Demand %**
Baseline Model with (Efficiency Based Objective)	24.41%
Benchmark Model with Objective Function Change (Equity Based Objective)	30.01%
Benchmark Model with Budget Change	3.80%
Benchmark Model with Capacity Change	24.48%
Benchmark Model with Vulnerability Change	14.51%
Deterministic Model with No Vulnerability (Efficiency Based Objective)	7.43%
Deterministic Model with No Vulnerability (Equity Based Objective)	7.43%
Deterministic Model with Expected Vulnerability (Efficiency Based Objective)	29.70%
Deterministic Model with Expected Vulnerability (Equity Based Objective)	89.54%

The computational experiments in this part allow us to derive a set of policy-based implications, which can be summarized as follows:

- A specific set of potential warehouses and distribution centers can be regarded as critical facilities, as these are opened in almost all of our experiments, regardless of the way vulnerability is treated, whether uncertainty is involved, and budget and capacity levels.
- When equity is of concern, more facilities are opened to deliver commodities to the demand points from closer locations.
- Our results are quite sensitive to how vulnerability is estimated. Hence, substantial effort should be spent to estimate it accurately.
- While total budget plays an important role in how the decisions are made, the resulting decisions are quite robust in terms of the changes in capacity and fixed facility opening costs.
- When vulnerability is ignored, the objective function is substantially underestimated, and a significantly lower number of facilities are opened than necessary.
- If vulnerability is incorporated as inflated travel times and deflated facility service capacities rather than roads being closed and facilities being non-functioning, respectively, objective values are overestimated and significantly fewer facilities are opened.

CHAPTER 6

CONCLUSIONS AND REMARKS

In this study, a two-stage stochastic optimization model is developed for the design of a humanitarian logistics relief network. Whereas in the first stage of the proposed model pre-disaster stage preparedness decisions (warehouse and distribution center location and item pre-positioning) are made; in the second stage post-disaster stage response decisions (relief transportation and outsourcing) are determined depending on the actual disaster outcome pre-identified possible routes.

Since epicenter and magnitude of a disaster cannot be known in advance, it is important to incorporate uncertainty and possible outcomes of a disaster into the model. Due to the uncertain nature of disasters condition of relief transportation network, condition of pre-positioned facilities as well as demand at different areas are all treated as stochastic parameters. Vulnerability of roads and facilities are considered as binary, that is, a road or facility either operates in full capacity or is out-of-use in the aftermath of the disaster. The demand is also assumed to be different under different scenarios of disaster magnitude and epicenter.

We formulate a two-stage stochastic programming model for the aforementioned problem. The efficiency-based objective function of the model minimizes total expected demand-weighted arrival time through both truck and helicopter deliveries and also the expected penalty of weighted unsatisfied demand to all demand points. We also consider an equity-based objective which minimizes the maximum expected demand-weighted arrival time as well as the penalty of weighted unsatisfied demand overall demand points. Both models take into account budgets for the pre- and post-disaster stages as well as facility capacity constraints. The major difference and contribution of this study is the incorporation of facility and transportation network vulnerability into the pre-positioning and distribution models in the first and second stages. Most of the studies in the literature treat vulnerability as a deterministic parameter and assume its affect only on travel/arrival times only. However, our study considers the fact that rather than affecting arrival time, road vulnerability actually affects the functioning of a road. Our scenario-based approach considers the cases where a road becomes damaged and cannot be used for item delivery, which is a more grounded approach. In addition to road vulnerabilities, our study also included warehouse and distribution center vulnerabilities in the same way by generating discrete scenario sets.

Due to the potentially large number of scenarios, which makes solving the two-stage model to optimality impossible, we use a sample average approximation heuristic to find near optimal solutions. Our preliminary experiments reveal that the 95% confidence interval for the optimal objective values are around 2.5% of the mean, underlining the quality of our solutions.

Eventually, the proposed humanitarian logistics network design model is applied to a possible earthquake scenario in Istanbul region of Turkey. JICA & IMM [10] report is used to generate data on demand as well as facility vulnerabilities. Additionally road lengths and road vulnerabilities of Baskaya [26] are used as input parameters in this study.

We evaluate the effect of various policies on the proposed network by conducting a detailed sensitivity analysis. The proposed model is solved by varying the budget, facility capacities, road and facility vulnerabilities, and the objective function. Additionally, two different deterministic models are formed to observe the effect of ignoring vulnerabilities and incorporating them as additional travel time and lowered facility service levels. Our computational results show that a number of facilities are critical in all experiments, that the number of open facilities need to be increased when an equity-based objective is used, and the decisions and objective function value are far from optimal when vulnerability is ignored or incorporated in a different way.

This study provides a direction to develop successful disaster management policies. In the study it is shown that how different mathematical modeling approaches, as well as how vulnerability and demand uncertainty is incorporated affects the decisions as well as key performance indicators. Additionally, the case study on a potential earthquake in Istanbul provides key districts to consider as relief facility locations and also provides guidance on receiving and interpreting parametric data on a potential earthquake in Istanbul. The proposed mathematical model can be adapted include different relief items as well as the study can be applied to different type of disasters by updating parameters accordingly.

Future work regarding this study may include integration of sheltering and evacuation plan to pre-positioning and relief distribution models. The evacuation operation may also involve manpower planning. This study also does not provide a detailed routing solution, thus a future study may consider different vehicle and helicopter types with different capacities as well as vehicle and helicopter handling times. Furthermore, rather than forming a restricted set of pre-determined routes a future study may consider developing dynamic scenario based routing solutions between facilities and demand points which may result in less number of facilities needed to open. Additionally, instead of opening distribution centers along with warehouses in the pre-disaster stage, opening temporary distribution centers in the post-disaster stage depending on the actualized disaster scenario can also be considered. In this case public places such as schools can be used as temporary distribution centers. Considering relief transportation and road repair decisions simultaneously can also be a more realistic approach to obtain better solutions. In our study, we used an equity based objective to benchmark the baseline model. A future study may consider utilizing signal to noise ratios as an alternative for the equity based objective to simulate variability.

REFERENCES

[1] The United Nations Office for Disaster Risk Reduction. (2007). Terminology. Retrieved July 06, 2016, from https://www.unisdr.org/we/inform/terminology.

[2] International Federation of Red Cross and Red Crescent Societies. What is a disaster? Retrieved July 06, 2016, from http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/what-is-a-disaster/.

[3] International Disaster Database of Center for Research on the Epidemiology of Disasters (EMDAT).(2016).Advanced Search. Retrieved July 06, 2016, from http://www.emdat.be/advanced_search/index.html.

[4] Wisner, B., & Adams, J. (2003). Environmental health in emergencies and disasters: a practical guide. *World Health Organization.* Retrieved July 07, 2016, from https://www.researchgate.net/publication/242467342_Environmental_Health_in_Emergencies_and_Disasters_A_Practical_Guide.

[5] Thomas, A., & Mizushima, M. (2005). Logistics training: necessity or luxury*? Forced Mitigation. Review,* 22, 60–61. Retrieved July 07, 2016, from http://www.fritzinstitute.org/PDFs/FMR18/FMR22fritz.pdf.

[6] Van Wassenhove, L.N. (2006). Humanitarian aid logistics: supply chain management in high gear. *The Journal of the Operational Research Society,* 57 (5), 475-489. Retrieved July 21, 2016, from http://www.jstor.org/stable/4102445.

[7] Balcik, B., & Beamon, B.M. (2008). Facility location in humanitarian relief. *International Journal of Logistics Research and Applications: A Leading Journal of Supply Chain Management,* 11 (2), 101-121.

[8] Turkish Republic Country Report on Disaster Management. (2008). Retrieved July 07, 2016 from http://www.preventionweb.net/files/8359_8359TurkeyDRM2008.pdf.

[9] Elgin, K.G. (2015,March). *Istanbul Seismic Risk Mitigation and Emergency Preparedness Project*. Presented at meeting of the UN World Conference on Disaster Risk Reduction, Sendai, Japan. Retrieved July 07, 2016 from http://www.wcdrr.org/conference/events/1161.

[10] Japan International Cooperation Agency, & Istanbul Metropolitan Municipality.(2002). The Study on A Disaster Prevention / Mitigation Basic Plan in Istanbul including Seismic Micronization in the Republic of Turkey.

[11] Turkish Economy Policy Research Foundation (TEPAV).City Based Domestic Income Prediction. Retrieved July 07, 2016 from http://www.tepav.org.tr/tr/haberler/s/4052.

[12] Altay, N., & Green, W. G. (2006). OR/MS research in disaster operations management. *European Journal of Operational Research,* 175 (1), 475-493.

[13] Galindo, G., & Batta, R. (2013). Review of recent developments in OR/MS research in disaster operations management. *European Journal of Operational Research,* 230 (2), 201–211.

[14] Duran, S., Gutierrez, M. A., & Keskinocak, P. (2011). Pre-positioning of Emergency Items for CARE International, *Interfaces,* 41(3), 223-237.

[15] Mete, H. O., & Zabinsky, Z. B. (2010). Stochastic optimization of medical supply location and distribution in disaster management. *Int. J. Production Economics,* 126 (1), 76-84.

[16] Tzeng, G.H., Cheng, H.J., & Huang, T. D. (2007). Multi-objective optimal planning for designing relief delivery systems. *Transportation Research Part E: Logistics and Transportation Review*, 43 (6), 673–686.

[17] Rawls, C. G., & Turnquist, M. A. (2010). Pre-positioning of emergency supplies for disaster response. *Transportation Research Part B: Methodological,* 44 (4), 521–534.

[18] Rawls, C. G., & Turnquist, M. A. (2011). Pre-positioning for emergency response with service quality constraints. *OR Spectrum*, 33, 481-498.

[19] Rawls, C. G., & Turnquist, M. A. (2012). Pre-positioning and dynamic delivery planning for short term response following a natural disaster. *Socio-Economic Planning Science*, 46 (1), 46-54.

[20] Abounacer, R., Rekik, M., & Renaud, J. (2014). An exact solution approach for multi-objective location–transportation problem for disaster response. *Computers &Operations Research*, 41, 83–93.

[21] Wisetjindawat, W., Ito, H., & Fujita, M. (2015).). Integrating Stochastic Failure of Road Network and Road Recovery Strategy into Planning of Goods Distribution After a Large-Scale Earthquake. *Journal of the Transportation Research Board, Transportation Research Board, Washington, D.C.*, 2532 , 56–63. DOI: 10.3141/2532-07.

[22] Bozkurt M. (2011). *The Effects of Natural Disaster Trends on the Pre-positioning Implementation in Humanitarian Logistics Networks*. (Unpublished master's thesis). Middle East Technical University, Ankara, Turkey.

[23] Gormez, N., Koksalan, M., & Salman, F.S. (2011). Locating disaster response facilities in Istanbul. *The Journal of the Operational Research Society*, 62 (7),1239-1252.

[24] Renkli, G. (2013). *Pre-positioning Disaster Response Facilities and Relief Items Considering Probabilistic Constraints: A Case Study on Istanbul Region,* Unpublished (Unpublished master's thesis). Middle East Technical University, Ankara, Turkey.

[25] Konu, A.S. (2014). *Humanitarian Logistics: Pre-positioning of Relief Items in Istanbul.* Unpublished master's thesis). Middle East Technical University, Ankara, Turkey.

[26] Baskaya, S. (2015). *Pre-positioning of Relief Items in Humanitarian Logistics Considering Lateral Transshipment Opportunities.* (Unpublished master's thesis). Middle East Technical University, Ankara, Turkey.

[27] Liberatore, F., Ortuño, M. T., Tirado, G., Vitoriano, B., & Scaparra, M. P. (2014). A hierarchical compromise model for the joint optimization of recovery operations and distribution of emergency goods in Humanitarian Logistics. *Computers & Operations Research*, 42, 3–13.

[28] Afshar, A., & Haghani, A. (2012). Modeling integrated supply chain logistics in real-time large-scale disaster relief operations. *Socio-Economic Planning Sciences*, 46 (4), 327-338.

[29] Liu, Y., & Guo, B. (2014). A Lexicographic Approach to Post Disaster Relief Logistics Planning Considering Fill Rates and Costs under Uncertainty. *Hindawi Publishing Corporation Mathematical Problems in Engineering*, Volume 2014, Article ID 939853, 17 pages. Retrieved March 15, 2015, from http://dx.doi.org/10.1155/2014/939853.

[30] Ozdamar, L., & Demir, O. (2012). A hierarchical clustering and routing procedure for large scale disaster relief logistics planning. *Transportation Research Part E: Logistics and Transportation Review*, 48 (3), 591–602.

[31] Ozdamar, L., Demir, O., Bakir, E., & Yilmaz, S. (2013). Hierarchical optimization for helicopter mission planning in large-scale emergencies. *Yeditepe University*. Retrieved August 25, 2016, from https://www.researchgate.net/publication/284443617.

[32] Cui, J., An, S., & Zhao, M. (2014). A Generalized Minimum Cost Flow Model for Multiple Emergency Flow Routing. *Hindawi Publishing Corporation Mathematical Problems in Engineering*, Volume 2014, Article ID 832053, 12 pages. Retrieved March 15, 2015, from http://dx.doi.org/10.1155/2014/832053.

[33] Ahmadi, M., Seifi, A., & Tootooni, B. (2015). A humanitarian logistics model for disaster relief operation considering network failure and standard relief time: A case study on San Francisco district. *Transportation Research Part E: Logistics and Transportation Review*, 75, 145–163.

[34] Salmeron, J., & Apte, A. (2010). Stochastic Optimization for Natural Disaster Asset Prepositioning. *Production and Operation Management*, 19 (5), 561-574.

[35] Huang, M., Balcik, B., & Smilowitz, K.R. (2012). Models for relief routing: Equity, efficiency and efficacy. *Transportation Research Part E: Logistics and Transportation Review,* 48 (1), 2–18.

[36] Barbarosoglu, G., & Arda, Y. (2004). A two-stage stochastic programming frame work for transportation planning in disaster response. *Journal of the Operational Research Society*, 55 (1), 43–53.

[37] Kleywegt, A.J., Shapiro, A., & Homem-De-Mello, T. (2001). The Sample Average Approximation Method for Stochastic Discrete Optimization. *SIAM Journal on Optimization,* 12 (2), 479-502.

[38] Ahmed, S., & Shapiro, A. (2002). The Sample Average Approximation Method for Stochastic Programs with Integer Recourse. *Technical Report, H. Milton Stewart School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, GA, USA.*

[39] Klibi, W., Ichoua, S., & Martel, A. (2013). Prepositioning Emergency Supplies to Support Disaster Relief: A Stochastic Programming Approach. *Technical Report CIRRELT*, 2013-19, Montreal, QC, Canada.

[40] Chang, M.S., Tseng, Y.L., Chen, J.W., (2007). A scenario planning approach for the flood emergency logistics preparation problem under uncertainty. *Transportation Research Part E: Logistics and Transportation Review,*43 (6), 737–754.

[41] Garrido, R. A., Lamas, P., & Pino, F. J. (2015). A stochastic programming approach for floods emergency logistics. *Transportation Research Part E: Logistics and Transportation Review,* 75,18–31.

[42] Salman, F. S., & Yucel, E. (2015). Emergency facility location under random network damage: insights from the Istanbul case. *Computers and Operations Research*, 62, 266–281.

[43] Barahona, F., Ettl, M., Petrik, M., & Rimshnick, P. M. (2013). Agile logistics simulation and optimization for managing disaster responses. *2013 Winter Simulations Conference (WSC)*. Washington, DC, USA, 3340-3351. IEEE.

[44] Garrido, R. A. (2013). Optimal Emergency Resources Deployment under a terrorist threat: The Hazmat case and beyond. In R. A. Garrido, R. Batta, & C. Kwon (Eds.), *Handbook of OR/MS Models in Hazardous Materials Transportation, International Series in Operations Research & Management Science* (pp. 245-267). New York, NY: Springer Science+Business Media.

[45] Rodríguez-Espíndola, O., & Gaytán, J. (2015).Scenario-based preparedness plan for floods. *Nat Hazards*, 76 (2),1241–1262.

[46] Günsped Lojistik.Truck Dimensions. Retrieved July 06, 2016, from http://gunsped.com.tr/faydali-bilgileri/tir-olculeri/

[47] Natural Resources Canada. (2016). Fuel Efficiency Benchmarking in Canada's Trucking Industry. Retrieved July 06, 2016, from http://www.nrcan.gc.ca/energy/efficiency/transportation/commercial-vehicles/reports/7607

[48] Shell. Fuel Pump Sales Prices. Retrieved July 31, 2016, from http://www.shell.com.tr/products-services/on-the-road/fuels/fuel-pricing.html.

[49] Doruk Air. AN-12 Cargo Airplane Technical Information. Retrieved July 06, 2016, from http://www.dorukair.com.tr/en/cargo-aircraft.

[50] Fuel and air transport: A report for the European Commission.(2008).*Air Transport Department, Cranfield University*. Retrieved July 31, 2016, from http://ec.europa.eu/transport/modes/air/doc/fuel_report_final.pdf.

[51] Benzinal.com. Fuel Prices. Retrieved July 31, 2016, from http://benzinal.com/akaryakit-fiyatlari/istanbul/anadolu/gaz-yagi.

[52] Turkish Statistics Institute, TÜIK. (2013). *Address Based Population Registration System Results.* Retrieved July 06, 2016, from http://www.tuik.gov.tr/Kitap.do?metod=KitapDetay&KT_ID=11&KITAP_ID=139

[53] International Federation of Red Cross and Red Crescent Societies. (2015). Shelter and construction materials, Shelters, tent, kits, accessories. Retrieved July 06, 2016, from http://procurement.ifrc.org/catalogue/detail.aspx?volume=1&groupcode=111&familycode=111001&categorycode=TENT&productcode=HSHETENT01

[54] Lokad, Inventory Forecasting Software for Commerce.(2013).Inventory Costs (Ordering Costs, Carrying Costs).Definition and Formula. Retrieved July 06, 2016, from https://www.lokad.com/definition-inventory-costs

APPENDIX A

COORDINATES OF DISTRICT CENTERS AND DISTANCES BETWEEN DISTRICTS [26]

Table A1: Coordinates of District Centers

	Districts	**North°**	**East°**	**Side of District**
1	Arnavutkoy	41.193.645	28.731.335	Europe
2	Avcilar	41.000.478	28.716.310	Europe
3	Bagcilar	41.040.667	28.844.080	Europe
4	Bahcelievler	41.006.842	28.843.080	Europe
5	Bakirkoy	40.979.960	28.849.001	Europe
6	Basaksehir	41.088.674	28.758.063	Europe
7	Bayrampasa	41.050.186	28.901.553	Europe
8	Besiktas	41.063.548	29.018.029	Europe
9	Beylikduzu	40.994.109	28.643.696	Europe
10	Beyoglu	41.041.741	28.964.738	Europe
11	Buyucekmece	41.023.188	28.568.587	Europe
12	Catalca	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	Eyup	41.081.415	28.928.268	Europe
16	Fatih	41.015.024	28.938.128	Europe
17	Gaziosmanpasa	41.072.693	28.904.717	Europe
18	Gungoren	41.018.545	28.875.030	Europe
19	Kagithane	41.080.627	28.984.613	Europe
20	Kucukcekmece	41.020.645	28.788.865	Europe
21	Sariyer	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	Sisli	41.058.648	28.987.405	Europe
25	Zeytinburnu	40.996.988	28.903.160	Europe

Table A2: Distances Between European Side Districts of Istanbul (km)

Distances(km)	Arnavutkoy	Avcilar	Bagcilar	Bahcelievler
Arnavutkoy	0	36.6	24.9	29.1
Avcilar	38.5	0	21.6	21
Bagcilar	25	19.4	0	4.4
Bahcelievler	27.8	16.7	4.7	0
Bakirkoy	37.3	16.6	8.3	4.7
Basaksehir	18.4	21	13.5	18.3
Bayrampasa	24.4	25.4	9.6	14.3
Besiktas	34.2	32.6	20.7	20.9
Beylikduzu	34	10.6	28.1	27.5
Beyoglu	33.6	29.5	16.4	16.6
Buyukcekmece	36.3	17.9	34.3	38.7
Catalca	36.6	38.7	47.6	52
Esenler	25.3	26.3	4	6.8
Esenyurt	29.9	7.5	24.2	24.9
Eyup	22.7	30.9	15.6	19.1
Fatih	29.9	25	12.8	10.4
Gaziosmanpasa	22.2	28.6	9.3	15
Gungoren	28.9	18.3	5	3.8
Kagithane	30.1	30.4	18.4	18.6
Kucukcekmece	27.5	12	8	7.2
Sariyer	34.5	40	26.3	28.3
Silivri	73	58.5	73.5	77.9
Sultangazi	17.6	34.8	13.4	17.3
Sisli	34.9	30.5	18.6	18.7
Zeytinburnu	36	23.5	10.3	8.8

Table A2 (continued): Distances Between European Side Districts of Istanbul (km)

Distances(km)	Bakirkoy	Basaksehir	Bayrampasa	Besiktas
Arnavutkoy	38.2	19	25.5	39.7
Avcilar	18.4	22.5	26.4	33.1
Bagcilar	8.2	14.9	8.9	20.8
Bahcelievler	4.6	17.6	10.2	24.9
Bakirkoy	0	21.7	11.8	23.7
Basaksehir	25.5	0	19.9	31.6
Bayrampasa	13.5	19.7	0	14.9
Besiktas	20.6	30	13.6	0
Beylikduzu	24.9	23.9	32.9	39.6
Beyoglu	16.4	26.9	9.9	7.8
Buyukcekmece	32.3	30.2	40.1	47
Catalca	58	43.4	53.3	64.3
Esenler	9.8	15.6	4.2	16.8
Esenyurt	25.2	20	29.2	40
Eyup	18.9	21.6	7.1	13.4
Fatih	11.4	22.1	6.1	13.3
Gaziosmanpasa	16.7	20.5	3.8	15.4
Gungoren	6.2	18.6	6	20.3
Kagithane	18.4	27.7	11.9	5.3
Kucukcekmece	11.4	12.1	16.1	29
Sariyer	28	32.3	21.5	11
Silivri	72.8	69.3	79.2	87.6
Sultangazi	21.1	22.1	8	20.4
Sisli	18.5	27.9	12	4.2
Zeytinburnu	7.4	25.7	9.9	17

Table A2 (continued): Distances Between European Side Districts of Istanbul (km)

Distances(km)	Beylikduzu	Beyoglu	BuyukCekmece	Catalca
Arnavutkoy	33.4	36.6	34.2	38.1
Avcilar	10.3	29.2	14.7	35.9
Bagcilar	28.1	16.9	32.5	48.7
Bahcelievler	25.4	21	29.9	51.4
Bakirkoy	25.3	17.1	29.8	51
Basaksehir	31.9	27.7	36.6	51.5
Bayrampasa	33.9	9.9	38.6	53.5
Besiktas	41.3	8.3	45.8	63.8
Beylikduzu	0	35.7	10.8	32.1
Beyoglu	38.2	0	42.6	60.7
Buyukcekmece	11.2	43.1	0	21.3
Catalca	32	60.4	21.5	0
Esenler	29.8	12.9	34.5	49.4
Esenyurt	6.6	36.1	10.1	31.3
Eyup	35.8	8.4	40.5	55.4
Fatih	33.7	6.4	41	55.9
Gaziosmanpasa	34.6	10.4	39.4	55.1
Gungoren	27	13.1	31.5	52.4
Kagithane	42	5.8	46.8	61.7
Kucukcekmece	20.7	25.1	25.2	46.4
Sariyer	46.5	16.1	51.2	66.1
Silivri	51.8	83.7	42.1	33.2
Sultangazi	34.9	17.8	39.6	54.6
Sisli	39.2	4.1	43.6	61.7
Zeytinburnu	32.3	11.9	36.7	59.5

Table A2 (continued): Distances Between European Side Districts of Istanbul (km)

Distances(km)	Esenler	Esenyurt	Eyup	Fatih
Arnavutkoy	25.4	29.3	23.8	30.9
Avcilar	26.9	7.4	32.2	24.4
Bagcilar	5.4	24.9	13.4	12.1
Bahcelievler	7	23.2	20.2	11.8
Bakirkoy	10.5	23.1	20.9	12.1
Basaksehir	16.1	27.7	21.8	22.8
Bayrampasa	4.9	29.7	6.8	6.2
Besiktas	16	39.1	14.3	13.5
Beylikduzu	29.3	6.8	35	30.9
Beyoglu	11.7	36	8.3	6.2
Buyukcekmece	35.6	12.4	41.2	38.3
Catalca	48.8	33.1	54.5	55.5
Esenler	0	25.6	10.7	8.1
Esenyurt	25.4	0	31.1	31.3
Eyup	9	31.5	0	11.8
Fatih	8.1	31.5	11.1	0
Gaziosmanpasa	6.4	30.4	3.1	9.4
Gungoren	3.7	24.8	13.8	7.4
Kagithane	13.7	37.8	6.6	11.2
Kucukcekmece	12.8	18.5	19.3	20.3
Sariyer	23	42.2	14.6	20.9
Silivri	74.8	82.9	80.4	78.9
Sultangazi	10.9	30.7	6.3	16.4
Sisli	13.6	37	8.1	8.9
Zeytinburnu	9.3	30	14.2	6.7

Table A2 (continued): Distances Between European Side Districts of Istanbul (km)

Distances(km)	Gaziosmanpasa	Gungoren	Kagithane	Kucukcekmece
Arnavutkoy	23.1	30	32.1	27.8
Avcilar	31.5	29	31.6	12.9
Bagcilar	11.1	4.9	19.3	7.1
Bahcelievler	15.2	4.3	23.4	7.1
Bakirkoy	16.5	6.5	22.1	10.3
Basaksehir	21	19	28.7	12.1
Bayrampasa	4	7.1	12.2	18.3
Besiktas	15.7	16.5	4.8	26.3
Beylikduzu	34.2	27	38.1	19.4
Beyoglu	10.7	12.2	6.1	23.1
Buyukcekmece	40.5	41.5	45.5	27.3
Catalca	53.7	54.7	61.4	46.1
Esenler	6.7	3.9	15.3	14.2
Esenyurt	30.3	27.3	38	19.8
Eyup	3.6	13.6	7	20.2
Fatih	9	6.6	11.8	20.7
Gaziosmanpasa	0	11	10.9	19.8
Gungoren	10.2	0	15.7	9.2
Kagithane	10.4	14.3	0	24
Kucukcekmece	17.3	9.7	26.2	0
Sariyer	16.7	23.9	10	33.7
Silivri	79.7	80.7	86	67.4
Sultangazi	5.2	15.5	13.2	17.7
Sisli	10.5	14.4	3.3	24.1
Zeytinburnu	12.5	5.5	15.4	15.5

Table A2 (continued): Distances Between European Side Districts of Istanbul (km)

Distances(km)	Sariyer	Silivri	Sultangazi	Sisli
Arnavutkoy	38.6	66.8	18.7	37.1
Avcilar	44.3	49.3	30.7	30.5
Bagcilar	26.5	67.1	12.9	18.2
Bahcelievler	32.3	64.5	16.7	22.3
Bakirkoy	32	64.4	20	19
Basaksehir	33.9	69.9	20.2	29
Bayrampasa	23.2	71.9	8.2	11.2
Besiktas	10.5	80.4	17.7	4.2
Beylikduzu	47.1	45.4	33.4	37
Beyoglu	16.5	77.2	17	4.1
Buyukcekmece	53.3	35.1	39.7	44.4
Catalca	66.6	33.2	52.9	61.7
Esenler	24.2	67.8	10.1	14.2
Esenyurt	43.2	44.6	29.5	37.4
Eyup	15.5	73.8	6.3	8.4
Fatih	21.6	72.7	13.1	8.6
Gaziosmanpasa	16.9	73.5	4.4	10.9
Gungoren	28.5	70.8	14.9	15
Kagithane	11.3	80.1	13.1	3.1
Kucukcekmece	31.3	59.8	17.7	26.4
Sariyer	0	84.5	18	11.8
Silivri	92.5	0	78.9	85
Sultangazi	19.8	77.2	0	19.4
Sisli	12.2	78.2	17.7	0
Zeytinburnu	25.3	77.9	17.1	13.8

Table A2 (continued): Distances Between European Side Districts of Istanbul (km)

Distances(km)	Zeytinburnu
Arnavutkoy	31.2
Avcilar	26.4
Bagcilar	10.9
Bahcelievler	8.1
Bakirkoy	7.8
Basaksehir	23.3
Bayrampasa	8.3
Besiktas	15.8
Beylikduzu	33.7
Beyoglu	11.4
Buyukcekmece	42.7
Catalca	56
Esenler	7.6
Esenyurt	32.6
Eyup	14.1
Fatih	5.5
Gaziosmanpasa	12.3
Gungoren	5.1
Kagithane	13.5
Kucukcekmece	16.1
Sariyer	23.2
Silivri	81.6
Sultangazi	16.7
Sisli	13.6
Zeytinburnu	0

APPENDIX B

THE PRE-DETERMINED ROADS AND ROUTES

Table B1: The Pre-determined Roads Between Warehouses and Distribution Centers

Warehouse	Distribution Center	Road No	Distance (km)
AVCILAR	beylikduzu	R1	10.3
AVCILAR	esenyurt	R2	7.4
AVCILAR	kucukcekmece	R3	12.9
BAHCELIEVLER	bagcilar	R4	4.7
BAHCELIEVLER	gungoren	R5	4.3
BAHCELIEVLER	bakirkoy	R6	4.6
BAKIRKOY	bahcelievler	R7	4.7
BAKIRKOY	gungoren	R8	6.5
BAKIRKOY	zeytinburnu	R9	7.8
BAGCILAR	bahcelievler	R10	4.4
BAGCILAR	gungoren	R11	4.9
BAGCILAR	esenler	R12	5.4
BAGCILAR	basaksehir	R13	14.9
BASAKSEHIR	bagcilar	R14	13.5
BASAKSEHIR	kucukcekmece	R15	12.1
BASAKSEHIR	esenler	R16	16.1
BASAKSEHIR	arnavutkoy	R17	18.4
BEYLIKDUZU	avcilar	R18	10.6
BEYLIKDUZU	esenyurt	R19	6.8
BEYLIKDUZU	buyukcekmece	R20	10.8
BUYUKCEKMECE	avcilar	R21	17.9

Table B1 (continued): The Pre-determined Roads Between Warehouses and Distribution Centers

Warehouse	Distribution Center	Road No	Distance (km)
BUYUKCEKMECE	beylikduzu	R22	11.2
BUYUKCEKMECE	esenyurt	R23	12.4
BAYRAMPASA	esenler	R24	4.9
BAYRAMPASA	gaziosmanpasa	R25	4
BAYRAMPASA	fatih	R26	6.2
BAYRAMPASA	sultangazi	R27	8.2
BAYRAMPASA	eyup	R28	6.8
ESENYURT	avcilar	R29	7.5
ESENYURT	beylikduzu	R30	6.6
ESENYURT	buyukcekmece	R31	10.1
EYUP	gaziosmanpasa	R32	3.6
EYUP	sultangazi	R33	6.3
EYUP	kagithane	R34	7
EYUP	beyoglu	R35	8.4
EYUP	besiktas	R36	13.4
EYUP	sisli	R37	8.4
FATIH	bayrampasa	R38	6.1
FATIH	beyoglu	R39	6.4
FATIH	zeytinburnu	R40	5.5
FATIH	besiktas	R41	13.3
FATIH	kagithane	R42	11.8
FATIH	sisli	R43	8.6
GUNGOREN	bagcilar	R44	5
GUNGOREN	bahcelievler	R45	3.8
GUNGOREN	esenler	R46	3.7
KUCUKCEKMECE	bagcilar	R47	8
KUCUKCEKMECE	bahcelievler	R48	7.2
KUCUKCEKMECE	gungoren	R49	9.7
KUCUKCEKMECE	basaksehir	R50	12.1
SULTANGAZI	bayrampasa	R51	8
SULTANGAZI	eyup	R52	6.3

Table B1 (continued): The Pre-determined Roads Between Warehouses and Distribution Centers

Warehouse	Distribution Center	Road No	Distance (km)
SULTANGAZI	gaziosmanpasa	R53	5.2
SULTANGAZI	arnavutkoy	R54	17.6
ZEYTINBURNU	fatih	R55	6.7
ZEYTINBURNU	bakirkoy	R56	7.4
ZEYTINBURNU	esenler	R57	9.3
ESENLER	bayrampasa	R58	4.2
ESENLER	gungoren	R59	3.9
ESENLER	bagcilar	R60	4
AVCILAR	avcilar	R61	0
BAHCELIEVLER	bahcelievler	R62	0
BAKIRKOY	bakirkoy	R63	0
BAGCILAR	bagcilar	R64	0
BASAKSEHIR	basaksehir	R65	0
BEYLIKDUZU	beylikduzu	R66	0
BUYUKCEKMECE	buyukcekmece	R67	0
BAYRAMPASA	bayrampasa	R68	0
ESENYURT	esenyurt	R69	0
EYUP	eyup	R70	0
FATIH	fatih	R71	0
GUNGOREN	gungoren	R72	0
KUCUKCEKMECE	kucukcekmece	R73	0
SULTANGAZI	sultangazi	R74	0
ZEYTINBURNU	zeytinburnu	R75	0
ESENLER	esenler	R76	0

Table B2: The Pre-determined Routes Between Distribution Centers and Demand Points

Distribution Center	Demand Points	Road No	Distance (km)
arnavutkoy	Sultangazi	R77	18.7
	Gaziosmanpasa	R77	5.2
	Eyup	R77	3.1
arnavutkoy	Basaksehir	R78	19
	Kucukcekmece	R78	12.1
	Bahcelievler	R78	7.2
arnavutkoy	Gaziosmanpasa	R79	23.1
	Bayrampasa	R79	3.8
	Esenler	R79	4.9
avcilar	Esenyurt	R80	7.4
	Beylikduzu	R80	6.6
	Buyukcekmece	R80	10.8
avcilar	Kucukcekmece	R81	12.9
	Bahcelievler	R81	7.2
	Gungoren	R81	4.2
avcilar	Beylikduzu	R82	10.3
	Esenyurt	R82	6.8
	Buyukcekmece	R82	10.1
bagcilar	Bahcelievler	R83	4.4
	Gungoren	R83	4.3
	Esenler	R83	3.7
bagcilar	Kucukcekmece	R84	7.1
	Bakirkoy	R84	11.4
	Zeytinburnu	R84	8.1
bagcilar	Gungoren	R85	4.9
	Bayrampasa	R85	6
	Gaziosmanpasa	R85	4
bahcelievler	Bakirkoy	R86	4.6
	Zeytinburnu	R86	7.8
	Fatih	R86	6.7
bahcelievler	Gungoren	R87	4.3
	Esenler	R87	3.7
	Bayrampasa	R87	4.2

Table B2 (continued): The Pre-determined Routes Between Distribution Centers and Demand Points

Distribution Center	Demand Points	Road No	Distance (km)
bahcelievler	Bagcilar	R88	4.7
	Kucukcekmece	R88	7.1
	Avcilar	R88	12
bakirkoy	Bahcelievler	R89	4.7
	Gungoren	R89	4.3
	Esenler	R89	3.7
bakirkoy	Zeytinburnu	R90	7.8
	Fatih	R90	6.7
	Bayrampasa	R90	6.1
bakirkoy	Bagcilar	R91	8.3
	Kucukcekmece	R91	7.1
	Avcilar	R91	12
basaksehir	Kucukcekmece	R92	12.1
	Bahcelievler	R92	7.2
	Gungoren	R92	4.3
basaksehir	Bagcilar	R93	13.5
	Esenler	R93	5.4
	Bayrampasa	R93	4.2
basaksehir	Esenler	R94	16.1
	Gaziosmanpasa	R94	6.7
	Eyup	R94	3.1
bayrampasa	Gaziosmanpasa	R95	4
	Eyup	R95	3.1
	Sultangazi	R95	6.3
bayrampasa	Esenler	R96	4.9
	Gungoren	R96	3.9
	Bahcelievler	R96	3.8
bayrampasa	Fatih	R97	6.2
	Zeytinburnu	R97	5.5
	Bakirkoy	R97	7.4
besiktas	Sisli	R98	4.2
	Kagithane	R98	3.3
	Beyoglu	R98	5.8

Table B2 (continued): The Pre-determined Routes Between Distribution Centers and Demand Points

Distribution Center	Demand Points	Road No	Distance (km)
besiktas	Sariyer	R99	10.5
	Eyup	R99	14.6
	Gaziosmanpasa	R99	3.6
besiktas	Kagithane	R100	4.8
	Sisli	R100	3.1
	Fatih	R100	8.9
beylikduzu	Esenyurt	R101	6.8
	Avcilar	R101	7.5
	Kucukcekmece	R101	12.9
beylikduzu	Buyukcekmece	R102	10.8
	Catalca	R102	21.3
beylikduzu	Avcilar	R103	10.6
	Esenyurt	R103	7.4
	Buyukcekmece	R103	10.1
beyoglu	Sisli	R104	4.1
	Kagithane	R104	3.3
	Besiktas	R104	5.3
beyoglu	Fatih	R105	6.2
	Bayrampasa	R105	6.1
	Gaziosmanpasa	R105	4
beyoglu	Kagithane	R106	6.1
	Eyup	R106	6.6
	Sultangazi	R106	6.3
buyukcekmece	Esenyurt	R107	12.4
	Beylikduzu	R107	6.6
	Avcilar	R107	10.6
buyukcekmece	Catalca	R108	21.3
	Silivri	R108	33.2
buyukcekmece	Silivri	R109	35.1
	Catalca	R109	33.2
buyukcekmece	Beylikduzu	R110	11.2
	Kucukcekmece	R110	19.4
	Bahcelievler	R110	7.2

Table B2 (continued): The Pre-determined Routes Between Distribution Centers and Demand Points

Distribution Center	Demand Points	Road No	Distance (km)
esenler	Gungoren	R111	3.9
	Bahcelievler	R111	3.8
	Bagcilar	R111	4.7
esenler	Bayrampasa	R112	4.2
	Gaziosmanpasa	R112	4
	Eyup	R112	3.1
esenler	Bagcilar	R113	4
	Kucukcekmece	R113	7.1
	Bahcelievler	R113	7.2
esenyurt	Beylikduzu	R114	6.6
	Avcilar	R114	10.6
	Kucukcekmece	R114	12.9
esenyurt	Buyukcekmece	R115	10.1
	Beylikduzu	R115	11.2
	Avcilar	R115	10.6
esenyurt	Avcilar	R116	7.5
	Beylikduzu	R116	10.3
	Buyukcekmece	R116	10.8
eyup	Gaziosmanpasa	R117	3.6
	Bayrampasa	R117	3.8
	Esenler	R117	4.9
eyup	Kagithane	R118	7
	Sisli	R118	3.1
	Beyoglu	R118	4.1
eyup	Sultangazi	R119	6.3
	Gaziosmanpasa	R119	5.2
	Bayrampasa	R119	3.8
fatih	Bayrampasa	R120	6.1
	Gaziosmanpasa	R120	4
	Eyup	R120	3.1
fatih	Zeytinburnu	R121	5.5
	Bakirkoy	R121	7.4
	Bahcelievler	R121	4.7

Table B2 (continued): The Pre-determined Routes Between Distribution Centers and Demand Points

Distribution Center	Demand Points	Road No	Distance (km)
fatih	Beyoglu	R122	6.4
	Sisli	R122	4.1
	Kagithane	R122	3.3
gaziosmanpasa	Eyup	R123	3.1
	Sultangazi	R123	6.3
	Bayrampasa	R123	8
gaziosmanpasa	Bayrampasa	R124	3.8
	Esenler	R124	4.9
	Gungoren	R124	3.9
gaziosmanpasa	Sultangazi	R125	4.4
	Eyup	R125	6.3
	Kagithane	R125	7
gungoren	Esenler	R126	3.7
	Bayrampasa	R126	4.2
	Gaziosmanpasa	R126	4
gungoren	Esenler	R127	3.7
	Bagcilar	R127	4
	Bahcelievler	R127	4.4
gungoren	Bahcelievler	R128	3.8
	Bakirkoy	R128	4.6
	Zeytinburnu	R128	7.8
kagithane	Sisli	R129	3.1
	Beyoglu	R129	4.1
	Fatih	R129	6.2
kagithane	Besiktas	R130	5.3
	Sariyer	R130	10.5
	Eyup	R130	14.6
kagithane	Beyoglu	R131	5.8
	Sisli	R131	4.1
	Besiktas	R131	4.2
kucukcekmece	Bahcelievler	R132	7.2
	Gungoren	R132	4.3
	Esenler	R132	3.7

Table B2 (continued): The Pre-determined Routes Between Distribution Centers and Demand Points

Distribution Center	Demand Points	Road No	Distance (km)
kucukcekmece	Bahçelievler	R133	7.2
	Bakırkoy	R133	4.6
	Zeytinburnu	R133	7.8
kucukcekmece	Bagcilar	R134	8
	Gungoren	R134	4.9
	Esenler	R134	3.7
sultangazi	Gaziosmanpasa	R135	5.2
	Eyup	R135	3.1
sultangazi	Arnavutkoy	R136	17.6
	Basaksehir	R136	19
sultangazi	Bayrampasa	R137	8
	Esenler	R137	4.9
	Gungoren	R137	3.9
sisli	Beyoglu	R138	4.1
	Kagithane	R138	6.1
	Besiktas	R138	5.3
sisli	Eyup	R139	8.1
	Gaziosmanpasa	R139	3.6
	Bayrampasa	R139	3.8
sisli	Kagithane	R140	3.3
	Besiktas	R140	5.3
	Sariyer	R140	10.5
zeytinburnu	Fatih	R141	6.7
	Beyoglu	R141	6.4
	Sisli	R141	4.1
zeytinburnu	Fatih	R142	6.7
	Bayrampasa	R142	6.1
	Gaziosmanpasa	R142	4
zeytinburnu	Bakirkoy	R143	7.4
	Bahcelievler	R143	4.7
	Gungoren	R143	4.3
arnavutkoy	Arnavutkoy	R77	0
arnavutkoy	Arnavutkoy	R78	0

Table B2 (continued): The Pre-determined Routes Between Distribution Centers and Demand Points

Distribution Center	Demand Points	Road No	Distance (km)
arnavutkoy	Arnavutkoy	R79	0
avcilar	Avcilar	R80	0
avcilar	Avcilar	R81	0
avcilar	Avcilar	R82	0
bagcilar	Bagcilar	R83	0
bagcilar	Bagcilar	R84	0
bagcilar	Bagcilar	R85	0
bahcelievler	Bahcelievler	R86	0
bahcelievler	Bahcelievler	R87	0
bahcelievler	Bahcelievler	R88	0
bakirkoy	Bakirkoy	R89	0
bakirkoy	Bakirkoy	R90	0
bakirkoy	Bakirkoy	R91	0
basaksehir	Basaksehir	R92	0
basaksehir	Basaksehir	R93	0
basaksehir	Basaksehir	R94	0
bayrampasa	Bayrampasa	R95	0
bayrampasa	Bayrampasa	R96	0
bayrampasa	Bayrampasa	R97	0
besiktas	Besiktas	R98	0
besiktas	Besiktas	R99	0
besiktas	Besiktas	R100	0
beylikduzu	Beylikduzu	R101	0
beylikduzu	Beylikduzu	R102	0
beylikduzu	Beylikduzu	R103	0
beyoglu	Beyoglu	R104	0
beyoglu	Beyoglu	R105	0
beyoglu	Beyoglu	R106	0
buyukcekmece	Buyukcekmece	R107	0
buyukcekmece	Buyukcekmece	R108	0
buyukcekmece	Buyukcekmece	R109	0
buyukcekmece	Buyukcekmece	R110	0
esenler	Esenler	R111	0

Table B2 (continued): The Pre-determined Routes Between Distribution Centers and Demand Points

Distribution Center	Demand Points	Road No	Distance (km)
esenler	Esenler	R112	0
esenler	Esenler	R113	0
esenyurt	Esenyurt	R114	0
esenyurt	Esenyurt	R115	0
esenyurt	Esenyurt	R116	0
eyup	Eyup	R117	0
eyup	Eyup	R118	0
eyup	Eyup	R119	0
fatih	Fatih	R120	0
fatih	Fatih	R121	0
fatih	Fatih	R122	0
gaziosmanpasa	Gaziosmanpasa	R123	0
gaziosmanpasa	Gaziosmanpasa	R124	0
gaziosmanpasa	Gaziosmanpasa	R125	0
gungoren	Gungoren	R126	0
gungoren	Gungoren	R127	0
gungoren	Gungoren	R128	0
kagithane	Kagithane	R129	0
kagithane	Kagithane	R130	0
kagithane	Kagithane	R131	0
kucukcekmece	Kucukcekmece	R132	0
kucukcekmece	Kucukcekmece	R133	0
kucukcekmece	Kucukcekmece	R134	0
sultangazi	Sultangazi	R135	0
sultangazi	Sultangazi	R136	0
sultangazi	Sultangazi	R137	0
sisli	Sisli	R138	0
sisli	Sisli	R139	0
sisli	Sisli	R140	0
zeytinburnu	Zeytinburnu	R141	0
zeytinburnu	Zeytinburnu	R142	0
zeytinburnu	Zeytinburnu	R143	0

APPENDIX C

ROAD VULNERABILITIES FOR EACH DISTRICT PAIR [26]

Table C1: Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Arnavutkoy	Arnavutkoy	0	0	0	0
Arnavutkoy	Avcilar	0.006	0.033	0.059	0.092
Arnavutkoy	Bagcilar	0.005	0.03	0.055	0.085
Arnavutkoy	Bahcelievler	0.045	0.082	0.119	0.201
Arnavutkoy	Bakirkoy	0.068	0.112	0.156	0.268
Arnavutkoy	Basaksehir	0	0.025	0.05	0.075
Arnavutkoy	Bayrampasa	0.012	0.038	0.064	0.102
Arnavutkoy	Besiktas	0.031	0.066	0.1	0.166
Arnavutkoy	Beylikduzu	0	0.025	0.05	0.075
Arnavutkoy	Beyoglu	0.003	0.028	0.053	0.081
Arnavutkoy	Buyukcekmece	0.004	0.03	0.056	0.086
Arnavutkoy	Catalca	0	0.025	0.05	0.075
Arnavutkoy	Esenler	0.004	0.029	0.054	0.083
Arnavutkoy	Esenyurt	0	0.025	0.05	0.075
Arnavutkoy	Eyup	0.001	0.026	0.051	0.077
Arnavutkoy	Fatih	0.052	0.093	0.134	0.227
Arnavutkoy	Gaziosmanpasa	0	0.025	0.05	0.075
Arnavutkoy	Gungoren	0.043	0.083	0.122	0.205
Arnavutkoy	Kagithane	0.002	0.027	0.052	0.079
Arnavutkoy	Kucukcekmece	0.006	0.032	0.057	0.089
Arnavutkoy	Sariyer	0	0.025	0.05	0.075
Arnavutkoy	Silivri	0	0.025	0.05	0.075
Arnavutkoy	Sultangazi	0	0.025	0.05	0.075
Arnavutkoy	Sisli	0.028	0.063	0.098	0.161
Arnavutkoy	Zeytinburnu	0.039	0.076	0.113	0.189

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Avcilar	Arnavutkoy	0.006	0.033	0.059	0.092
Avcilar	Avcilar	0	0	0	0
Avcilar	Bagcilar	0.067	0.109	0.15	0.259
Avcilar	Bahcelievler	0.115	0.174	0.233	0.407
Avcilar	Bakirkoy	0.092	0.14	0.188	0.328
Avcilar	Basaksehir	0.011	0.038	0.066	0.104
Avcilar	Bayrampasa	0.113	0.169	0.224	0.393
Avcilar	Besiktas	0.064	0.103	0.143	0.246
Avcilar	Beylikduzu	0.024	0.051	0.079	0.13
Avcilar	Beyoglu	0.112	0.164	0.215	0.379
Avcilar	Buyukcekmece	0.022	0.051	0.08	0.131
Avcilar	Catalca	0.014	0.041	0.069	0.11
Avcilar	Esenler	0.008	0.034	0.06	0.094
Avcilar	Esenyurt	0.027	0.058	0.088	0.146
Avcilar	Eyup	0.087	0.132	0.176	0.308
Avcilar	Fatih	0.105	0.155	0.206	0.361
Avcilar	Gaziosmanpasa	0.095	0.142	0.188	0.33
Avcilar	Gungoren	0.105	0.157	0.209	0.366
Avcilar	Kagithane	0.076	0.119	0.162	0.281
Avcilar	Kucukcekmece	0.138	0.198	0.257	0.455
Avcilar	Sariyer	0.058	0.097	0.135	0.232
Avcilar	Silivri	0.006	0.032	0.058	0.09
Avcilar	Sultangazi	0.006	0.033	0.059	0.092
Avcilar	Sisli	0.076	0.119	0.162	0.281
Avcilar	Zeytinburnu	0.113	0.167	0.221	0.388
Bagcilar	Arnavutkoy	0.005	0.03	0.055	0.085
Bagcilar	Avcilar	0.067	0.109	0.15	0.259
Bagcilar	Bagcilar	0	0	0	0
Bagcilar	Bahcelievler	0.085	0.125	0.165	0.29
Bagcilar	Bakirkoy	0.144	0.213	0.28	0.493
Bagcilar	Basaksehir	0.005	0.03	0.055	0.085
Bagcilar	Bayrampasa	0.057	0.087	0.117	0.204
Bagcilar	Besiktas	0.061	0.104	0.146	0.25
Bagcilar	Beylikduzu	0.053	0.09	0.127	0.217

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Bagcilar	Beyoglu	0.085	0.135	0.184	0.319
Bagcilar	Buyukcekmece	0.047	0.084	0.121	0.205
Bagcilar	Catalca	0.003	0.028	0.053	0.081
Bagcilar	Esenler	0.036	0.061	0.086	0.147
Bagcilar	Esenyurt	0.003	0.028	0.053	0.081
Bagcilar	Eyup	0.037	0.064	0.092	0.156
Bagcilar	Fatih	0.111	0.163	0.215	0.378
Bagcilar	Gaziosmanpasa	0.025	0.051	0.078	0.129
Bagcilar	Gungoren	0.19	0.28	0.368	0.648
Bagcilar	Kagithane	0.065	0.108	0.151	0.259
Bagcilar	Kucukcekmece	0.05	0.08	0.111	0.191
Bagcilar	Sariyer	0.005	0.03	0.055	0.085
Bagcilar	Silivri	0.002	0.027	0.052	0.079
Bagcilar	Sultangazi	0.016	0.042	0.068	0.11
Bagcilar	Sisli	0.072	0.119	0.164	0.283
Bagcilar	Zeytinburnu	0.2	0.281	0.361	0.642
Bahcelievler	Arnavutkoy	0.045	0.082	0.119	0.201
Bahcelievler	Avcilar	0.115	0.174	0.233	0.407
Bahcelievler	Bagcilar	0.085	0.125	0.165	0.29
Bahcelievler	Bahcelievler	0	0	0	0
Bahcelievler	Bakirkoy	0.208	0.296	0.382	0.678
Bahcelievler	Basaksehir	0.03	0.062	0.094	0.156
Bahcelievler	Bayrampasa	0.209	0.285	0.361	0.646
Bahcelievler	Besiktas	0.08	0.127	0.174	0.301
Bahcelievler	Beylikduzu	0.089	0.139	0.188	0.327
Bahcelievler	Beyoglu	0.19	0.278	0.365	0.643
Bahcelievler	Buyukcekmece	0.082	0.131	0.18	0.311
Bahcelievler	Catalca	0.058	0.1	0.142	0.242
Bahcelievler	Esenler	0.087	0.127	0.167	0.294
Bahcelievler	Esenyurt	0.1	0.155	0.21	0.365
Bahcelievler	Eyup	0.077	0.122	0.166	0.288
Bahcelievler	Fatih	0.115	0.165	0.215	0.38
Bahcelievler	Gaziosmanpasa	0.11	0.164	0.216	0.38
Bahcelievler	Gungoren	0.2	0.281	0.36	0.641

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Bahcelievler	Kagithane	0.1	0.154	0.206	0.36
Bahcelievler	Kucukcekmece	0.096	0.138	0.179	0.317
Bahcelievler	Sariyer	0.046	0.083	0.12	0.203
Bahcelievler	Silivri	0.04	0.078	0.114	0.192
Bahcelievler	Sultangazi	0.052	0.086	0.121	0.207
Bahcelievler	Sisli	0.109	0.167	0.224	0.391
Bahcelievler	Zeytinburnu	0.294	0.403	0.511	0.914
Bakirkoy	Arnavutkoy	0.068	0.112	0.156	0.268
Bakirkoy	Avcilar	0.092	0.14	0.188	0.328
Bakirkoy	Bagcilar	0.144	0.213	0.28	0.493
Bakirkoy	Bahcelievler	0.208	0.296	0.382	0.678
Bakirkoy	Bakirkoy	0	0	0	0
Bakirkoy	Basaksehir	0.01	0.037	0.064	0.101
Bakirkoy	Bayrampasa	0.173	0.238	0.302	0.54
Bakirkoy	Besiktas	0.056	0.098	0.139	0.237
Bakirkoy	Beylikduzu	0.072	0.114	0.156	0.27
Bakirkoy	Beyoglu	0.204	0.3	0.393	0.693
Bakirkoy	Buyukcekmece	0.065	0.106	0.146	0.252
Bakirkoy	Catalca	0.047	0.084	0.12	0.204
Bakirkoy	Esenler	0.179	0.246	0.311	0.557
Bakirkoy	Esenyurt	0.077	0.12	0.164	0.284
Bakirkoy	Eyup	0.099	0.149	0.198	0.347
Bakirkoy	Fatih	0.208	0.309	0.408	0.717
Bakirkoy	Gaziosmanpasa	0.122	0.178	0.233	0.411
Bakirkoy	Gungoren	0.263	0.369	0.473	0.842
Bakirkoy	Kagithane	0.068	0.112	0.156	0.268
Bakirkoy	Kucukcekmece	0.063	0.095	0.128	0.223
Bakirkoy	Sariyer	0.048	0.087	0.126	0.213
Bakirkoy	Silivri	0.032	0.065	0.098	0.163
Bakirkoy	Sultangazi	0.106	0.158	0.21	0.368
Bakirkoy	Sisli	0.177	0.261	0.343	0.604
Bakirkoy	Zeytinburnu	0.232	0.35	0.465	0.815
Basaksehir	Arnavutkoy	0	0.025	0.05	0.075
Basaksehir	Avcilar	0.011	0.038	0.066	0.104

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Basaksehir	Bagcilar	0.005	0.03	0.055	0.085
Basaksehir	Bahcelievler	0.03	0.062	0.094	0.156
Basaksehir	Bakirkoy	0.01	0.037	0.064	0.101
Basaksehir	Basaksehir	0	0	0	0
Basaksehir	Bayrampasa	0.024	0.052	0.081	0.133
Basaksehir	Besiktas	0.03	0.065	0.1	0.165
Basaksehir	Beylikduzu	0	0.025	0.05	0.075
Basaksehir	Beyoglu	0.034	0.071	0.107	0.178
Basaksehir	Buyukcekmece	0.004	0.029	0.055	0.084
Basaksehir	Catalca	0	0.025	0.05	0.075
Basaksehir	Esenler	0.002	0.027	0.052	0.079
Basaksehir	Esenyurt	0	0.025	0.05	0.075
Basaksehir	Eyup	0.001	0.026	0.051	0.077
Basaksehir	Fatih	0.054	0.096	0.138	0.234
Basaksehir	Gaziosmanpasa	0	0.025	0.05	0.075
Basaksehir	Gungoren	0.032	0.067	0.101	0.168
Basaksehir	Kagithane	0.002	0.027	0.052	0.079
Basaksehir	Kucukcekmece	0.007	0.033	0.059	0.092
Basaksehir	Sariyer	0	0.025	0.05	0.075
Basaksehir	Silivri	0	0.025	0.05	0.075
Basaksehir	Sultangazi	0	0.025	0.05	0.075
Basaksehir	Sisli	0.034	0.071	0.107	0.178
Basaksehir	Zeytinburnu	0.051	0.092	0.132	0.224
Bayrampasa	Arnavutkoy	0.012	0.038	0.064	0.102
Bayrampasa	Avcilar	0.113	0.169	0.224	0.393
Bayrampasa	Bagcilar	0.057	0.087	0.117	0.204
Bayrampasa	Bahcelievler	0.209	0.285	0.361	0.646
Bayrampasa	Bakirkoy	0.173	0.238	0.302	0.54
Bayrampasa	Basaksehir	0.024	0.052	0.081	0.133
Bayrampasa	Bayrampasa	0	0	0	0
Bayrampasa	Besiktas	0.083	0.136	0.187	0.323
Bayrampasa	Beylikduzu	0.014	0.041	0.068	0.109
Bayrampasa	Beyoglu	0.103	0.162	0.219	0.381
Bahcelievler	Basaksehir	0.03	0.062	0.094	0.156

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Bahcelievler	Bayrampasa	0.209	0.285	0.361	0.646
Bahcelievler	Besiktas	0.08	0.127	0.174	0.301
Bahcelievler	Beylikduzu	0.089	0.139	0.188	0.327
Bahcelievler	Beyoglu	0.19	0.278	0.365	0.643
Bahcelievler	Buyukcekmece	0.082	0.131	0.18	0.311
Bahcelievler	Catalca	0.058	0.1	0.142	0.242
Bahcelievler	Esenler	0.087	0.127	0.167	0.294
Bahcelievler	Esenyurt	0.1	0.155	0.21	0.365
Bahcelievler	Eyup	0.077	0.122	0.166	0.288
Bahcelievler	Fatih	0.115	0.165	0.215	0.38
Bahcelievler	Gaziosmanpasa	0.11	0.164	0.216	0.38
Bahcelievler	Gungoren	0.2	0.281	0.36	0.641
Bahcelievler	Kagithane	0.1	0.154	0.206	0.36
Bahcelievler	Kucukcekmece	0.096	0.138	0.179	0.317
Bahcelievler	Sariyer	0.046	0.083	0.12	0.203
Bahcelievler	Silivri	0.04	0.078	0.114	0.192
Bahcelievler	Sultangazi	0.052	0.086	0.121	0.207
Bahcelievler	Sisli	0.109	0.167	0.224	0.391
Bahcelievler	Zeytinburnu	0.294	0.403	0.511	0.914
Bakirkoy	Arnavutkoy	0.068	0.112	0.156	0.268
Bakirkoy	Avcilar	0.092	0.14	0.188	0.328
Bakirkoy	Bagcilar	0.144	0.213	0.28	0.493
Bakirkoy	Bahcelievler	0.208	0.296	0.382	0.678
Bakirkoy	Bakirkoy	0	0	0	0
Bakirkoy	Basaksehir	0.01	0.037	0.064	0.101
Bakirkoy	Bayrampasa	0.173	0.238	0.302	0.54
Bakirkoy	Besiktas	0.056	0.098	0.139	0.237
Bakirkoy	Beylikduzu	0.072	0.114	0.156	0.27
Bakirkoy	Beyoglu	0.204	0.3	0.393	0.693
Bakirkoy	Buyukcekmece	0.065	0.106	0.146	0.252
Bakirkoy	Catalca	0.047	0.084	0.12	0.204
Bakirkoy	Esenler	0.179	0.246	0.311	0.557
Bakirkoy	Esenyurt	0.077	0.12	0.164	0.284
Bakirkoy	Eyup	0.099	0.149	0.198	0.347

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Bakirkoy	Fatih	0.208	0.309	0.408	0.717
Bakirkoy	Gaziosmanpasa	0.122	0.178	0.233	0.411
Bakirkoy	Gungoren	0.263	0.369	0.473	0.842
Bakirkoy	Kagithane	0.068	0.112	0.156	0.268
Bakirkoy	Kucukcekmece	0.063	0.095	0.128	0.223
Bakirkoy	Sariyer	0.048	0.087	0.126	0.213
Bakirkoy	Silivri	0.032	0.065	0.098	0.163
Bakirkoy	Sultangazi	0.106	0.158	0.21	0.368
Bakirkoy	Sisli	0.177	0.261	0.343	0.604
Bakirkoy	Zeytinburnu	0.232	0.35	0.465	0.815
Basaksehir	Arnavutkoy	0	0.025	0.05	0.075
Basaksehir	Avcilar	0.011	0.038	0.066	0.104
Basaksehir	Bagcilar	0.005	0.03	0.055	0.085
Basaksehir	Bahcelievler	0.03	0.062	0.094	0.156
Basaksehir	Bakirkoy	0.01	0.037	0.064	0.101
Basaksehir	Basaksehir	0	0	0	0
Basaksehir	Bayrampasa	0.024	0.052	0.081	0.133
Basaksehir	Besiktas	0.03	0.065	0.1	0.165
Basaksehir	Beylikduzu	0	0.025	0.05	0.075
Basaksehir	Beyoglu	0.034	0.071	0.107	0.178
Basaksehir	Buyukcekmece	0.004	0.029	0.055	0.084
Basaksehir	Catalca	0	0.025	0.05	0.075
Basaksehir	Esenler	0.002	0.027	0.052	0.079
Basaksehir	Esenyurt	0	0.025	0.05	0.075
Basaksehir	Eyup	0.001	0.026	0.051	0.077
Basaksehir	Fatih	0.054	0.096	0.138	0.234
Basaksehir	Gaziosmanpasa	0	0.025	0.05	0.075
Basaksehir	Gungoren	0.032	0.067	0.101	0.168
Basaksehir	Kagithane	0.002	0.027	0.052	0.079
Basaksehir	Kucukcekmece	0.007	0.033	0.059	0.092
Basaksehir	Sariyer	0	0.025	0.05	0.075
Basaksehir	Silivri	0	0.025	0.05	0.075
Basaksehir	Sultangazi	0	0.025	0.05	0.075
Basaksehir	Sisli	0.034	0.071	0.107	0.178

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Basaksehir	Zeytinburnu	0.051	0.092	0.132	0.224
Bayrampasa	Arnavutkoy	0.012	0.038	0.064	0.102
Bayrampasa	Avcilar	0.113	0.169	0.224	0.393
Bayrampasa	Bagcilar	0.057	0.087	0.117	0.204
Bayrampasa	Bahcelievler	0.209	0.285	0.361	0.646
Bayrampasa	Bakirkoy	0.173	0.238	0.302	0.54
Bayrampasa	Basaksehir	0.024	0.052	0.081	0.133
Bayrampasa	Bayrampasa	0	0	0	0
Bayrampasa	Besiktas	0.083	0.136	0.187	0.323
Bayrampasa	Beylikduzu	0.014	0.041	0.068	0.109
Bayrampasa	Beyoglu	0.103	0.162	0.219	0.381
Beyoglu	Fatih	0.115	0.16	0.205	0.365
Beyoglu	Gaziosmanpasa	0.02	0.048	0.075	0.123
Beyoglu	Gungoren	0.122	0.185	0.246	0.431
Beyoglu	Kagithane	0.007	0.032	0.057	0.089
Beyoglu	Kucukcekmece	0.041	0.072	0.104	0.176
Beyoglu	Sariyer	0	0.025	0.05	0.075
Beyoglu	Silivri	0.017	0.047	0.078	0.125
Beyoglu	Sultangazi	0.001	0.026	0.051	0.077
Beyoglu	Sisli	0.043	0.075	0.107	0.182
Beyoglu	Zeytinburnu	0.2	0.297	0.391	0.688
Buyukcekmece	Arnavutkoy	0.004	0.03	0.056	0.086
Buyukcekmece	Avcilar	0.022	0.051	0.08	0.131
Buyukcekmece	Bagcilar	0.047	0.084	0.121	0.205
Buyukcekmece	Bahcelievler	0.082	0.131	0.18	0.311
Buyukcekmece	Bakirkoy	0.065	0.106	0.146	0.252
Buyukcekmece	Basaksehir	0.004	0.029	0.055	0.084
Buyukcekmece	Bayrampasa	0.015	0.043	0.07	0.113
Buyukcekmece	Besiktas	0.057	0.095	0.133	0.228
Buyukcekmece	Beylikduzu	0.013	0.042	0.07	0.112
Buyukcekmece	Beyoglu	0.061	0.1	0.139	0.239
Buyukcekmece	Buyukcekmece	0	0	0	0
Buyukcekmece	Catalca	0	0.025	0.05	0.075
Buyukcekmece	Esenler	0.004	0.03	0.056	0.086

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Buyukcekmece	Esenyurt	0.011	0.039	0.067	0.106
Buyukcekmece	Eyup	0.003	0.029	0.055	0.084
Buyukcekmece	Fatih	0.069	0.11	0.151	0.261
Buyukcekmece	Gaziosmanpasa	0.003	0.029	0.054	0.083
Buyukcekmece	Gungoren	0.091	0.141	0.191	0.332
Buyukcekmece	Kagithane	0.056	0.095	0.133	0.228
Buyukcekmece	Kucukcekmece	0.084	0.133	0.182	0.315
Buyukcekmece	Sariyer	0.002	0.028	0.053	0.081
Buyukcekmece	Silivri	0	0.025	0.05	0.075
Buyukcekmece	Sultangazi	0.003	0.029	0.054	0.083
Buyukcekmece	Sisli	0.058	0.097	0.135	0.232
Buyukcekmece	Zeytinburnu	0.08	0.126	0.171	0.297
Catalca	Arnavutkoy	0	0.025	0.005	0.03
Catalca	Avcilar	0.014	0.041	0.069	0.11
Catalca	Bagcilar	0.003	0.028	0.053	0.081
Catalca	Bahcelievler	0.058	0.1	0.142	0.242
Catalca	Bakirkoy	0.047	0.084	0.12	0.204
Catalca	Basaksehir	0	0.025	0.05	0.075
Catalca	Bayrampasa	0.01	0.037	0.063	0.1
Catalca	Besiktas	0.018	0.049	0.079	0.128
Catalca	Beylikduzu	0.004	0.031	0.057	0.088
Catalca	Beyoglu	0.019	0.05	0.081	0.131
Catalca	Buyukcekmece	0	0.025	0.05	0.075
Catalca	Catalca	0	0	0	0
Catalca	Esenler	0.001	0.026	0.051	0.077
Catalca	Esenyurt	0.005	0.031	0.057	0.088
Catalca	Eyup	0.001	0.026	0.051	0.077
Catalca	Fatih	0.025	0.058	0.09	0.148
Catalca	Gaziosmanpasa	0	0.025	0.05	0.075
Catalca	Gungoren	0.02	0.052	0.083	0.135
Catalca	Kagithane	0.002	0.027	0.052	0.079
Catalca	Kucukcekmece	0.045	0.082	0.12	0.202
Catalca	Sariyer	0	0.025	0.05	0.075
Catalca	Silivri	0	0.025	0.05	0.075

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Catalca	Sultangazi	0	0.025	0.05	0.075
Catalca	Sisli	0.017	0.047	0.078	0.125
Catalca	Zeytinburnu	0.037	0.076	0.113	0.189
Esenler	Arnavutkoy	0.004	0.029	0.054	0.083
Esenler	Avcilar	0.008	0.034	0.06	0.094
Esenler	Bagcilar	0.036	0.061	0.086	0.147
Esenler	Bahcelievler	0.087	0.127	0.167	0.294
Esenler	Bakirkoy	0.179	0.246	0.311	0.557
Esenler	Basaksehir	0.002	0.027	0.052	0.079
Esenler	Bayrampasa	0.2	0.28	0.359	0.639
Esenler	Besiktas	0.071	0.119	0.166	0.285
Esenler	Beylikduzu	0.015	0.043	0.072	0.115
Esenler	Beyoglu	0.089	0.143	0.196	0.339
Esenler	Buyukcekmece	0.004	0.03	0.056	0.086
Esenler	Catalca	0.001	0.026	0.051	0.077
Esenler	Esenler	0	0	0	0
Esenler	Esenyurt	0.001	0.026	0.051	0.077
Esenler	Eyup	0.038	0.066	0.094	0.16
Esenler	Fatih	0.146	0.211	0.274	0.485
Esenler	Gaziosmanpasa	0.014	0.039	0.064	0.103
Esenler	Gungoren	0.2	0.294	0.385	0.679
Esenler	Kagithane	0.078	0.128	0.177	0.305
Esenler	Kucukcekmece	0.016	0.043	0.07	0.113
Esenler	Sariyer	0.005	0.03	0.055	0.085
Esenler	Silivri	0.002	0.028	0.053	0.081
Esenler	Sultangazi	0.011	0.036	0.061	0.097
Esenler	Sisli	0.072	0.121	0.169	0.29
Esenler	Zeytinburnu	0.158	0.231	0.302	0.533
Esenyurt	Arnavutkoy	0	0.025	0.05	0.075
Esenyurt	Avcilar	0.027	0.058	0.088	0.146
Esenyurt	Bagcilar	0.003	0.028	0.053	0.081
Esenyurt	Bahcelievler	0.1	0.155	0.21	0.365
Esenyurt	Bakirkoy	0.077	0.12	0.164	0.284
Esenyurt	Basaksehir	0	0.025	0.05	0.075

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Esenyurt	Bayrampasa	0.016	0.044	0.071	0.115
Esenyurt	Besiktas	0.063	0.102	0.141	0.243
Esenyurt	Beylikduzu	0	0.025	0.05	0.075
Esenyurt	Beyoglu	0.067	0.108	0.148	0.256
Esenyurt	Buyukcekmece	0.011	0.039	0.067	0.106
Esenyurt	Catalca	0.005	0.031	0.057	0.088
Esenyurt	Esenler	0.001	0.026	0.051	0.077
Esenyurt	Esenyurt	0	0	0	0
Esenyurt	Eyup	0.001	0.026	0.051	0.077
Esenyurt	Fatih	0.076	0.119	0.162	0.281
Esenyurt	Gaziosmanpasa	0	0.025	0.05	0.075
Esenyurt	Gungoren	0.104	0.159	0.213	0.372
Esenyurt	Kagithane	0.001	0.026	0.051	0.077
Esenyurt	Kucukcekmece	0.1	0.153	0.206	0.359
Esenyurt	Sariyer	0	0.025	0.05	0.075
Esenyurt	Silivri	0.003	0.029	0.055	0.084
Esenyurt	Sultangazi	0	0.025	0.05	0.075
Esenyurt	Sisli	0.063	0.103	0.142	0.245
Esenyurt	Zeytinburnu	0.047	0.087	0.126	0.213
Eyup	Arnavutkoy	0.001	0.026	0.051	0.077
Eyup	Avcilar	0.087	0.132	0.176	0.308
Eyup	Bagcilar	0.037	0.064	0.092	0.156
Eyup	Bahcelievler	0.077	0.122	0.166	0.288
Eyup	Bakirkoy	0.099	0.149	0.198	0.347
Eyup	Basaksehir	0.001	0.026	0.051	0.077
Eyup	Bayrampasa	0.065	0.096	0.127	0.223
Eyup	Besiktas	0.014	0.04	0.067	0.107
Eyup	Beylikduzu	0.001	0.026	0.051	0.077
Eyup	Beyoglu	0.033	0.065	0.096	0.161
Eyup	Buyukcekmece	0.003	0.029	0.055	0.084
Eyup	Catalca	0.001	0.026	0.051	0.077
Eyup	Esenler	0.038	0.066	0.094	0.16
Eyup	Esenyurt	0.001	0.026	0.051	0.077
Eyup	Eyup	0	0	0	0

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Eyup	Fatih	0.048	0.08	0.113	0.193
Eyup	Gaziosmanpasa	0.017	0.044	0.071	0.115
Eyup	Gungoren	0.075	0.121	0.166	0.287
Eyup	Kagithane	0.036	0.061	0.086	0.147
Eyup	Kucukcekmece	0.01	0.036	0.062	0.098
Eyup	Sariyer	0.007	0.032	0.057	0.089
Eyup	Silivri	0.002	0.027	0.052	0.079
Eyup	Sultangazi	0.011	0.037	0.063	0.1
Eyup	Sisli	0.007	0.032	0.057	0.089
Eyup	Zeytinburnu	0.081	0.131	0.18	0.311
Fatih	Arnavutkoy	0.052	0.093	0.134	0.227
Fatih	Avcilar	0.105	0.155	0.206	0.361
Fatih	Bagcilar	0.111	0.163	0.215	0.378
Fatih	Bahcelievler	0.115	0.165	0.215	0.38
Fatih	Bakirkoy	0.208	0.309	0.408	0.717
Fatih	Basaksehir	0.054	0.096	0.138	0.234
Fatih	Bayrampasa	0.25	0.359	0.466	0.825
Fatih	Besiktas	0.033	0.065	0.098	0.163
Fatih	Beylikduzu	0.074	0.116	0.158	0.274
Fatih	Beyoglu	0.115	0.16	0.205	0.365
Fatih	Buyukcekmece	0.069	0.11	0.151	0.261
Fatih	Catalca	0.025	0.058	0.09	0.148
Fatih	Esenler	0.146	0.211	0.274	0.485
Fatih	Esenyurt	0.076	0.119	0.162	0.281
Fatih	Eyup	0.048	0.08	0.113	0.193
Fatih	Fatih	0	0	0	0
Fatih	Gaziosmanpasa	0.11	0.165	0.219	0.384
Fatih	Gungoren	0.176	0.251	0.325	0.576
Fatih	Kagithane	0.039	0.072	0.106	0.178
Fatih	Kucukcekmece	0.07	0.109	0.147	0.256
Fatih	Sariyer	0.039	0.072	0.106	0.178
Fatih	Silivri	0.039	0.073	0.108	0.181
Fatih	Sultangazi	0.073	0.118	0.163	0.281
Fatih	Sisli	0.097	0.138	0.18	0.318

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Fatih	Zeytinburnu	0.2	0.285	0.369	0.654
Gaziosmanpasa	Arnavutkoy	0	0.025	0.05	0.075
Gaziosmanpasa	Avcilar	0.095	0.142	0.188	0.33
Gaziosmanpasa	Bagcilar	0.025	0.051	0.078	0.129
Gaziosmanpasa	Bahcelievler	0.11	0.164	0.216	0.38
Gaziosmanpasa	Bakirkoy	0.122	0.178	0.233	0.411
Gaziosmanpasa	Basaksehir	0	0.025	0.05	0.075
Gaziosmanpasa	Bayrampasa	0.063	0.094	0.125	0.219
Gaziosmanpasa	Besiktas	0.017	0.043	0.069	0.112
Gaziosmanpasa	Beylikduzu	0	0.025	0.05	0.075
Gaziosmanpasa	Beyoglu	0.02	0.048	0.075	0.123
Gaziosmanpasa	Buyukcekmece	0.003	0.029	0.054	0.083
Gaziosmanpasa	Catalca	0	0.025	0.05	0.075
Gaziosmanpasa	Esenler	0.014	0.039	0.064	0.103
Gaziosmanpasa	Esenyurt	0	0.025	0.05	0.075
Gaziosmanpasa	Eyup	0.017	0.044	0.071	0.115
Gaziosmanpasa	Fatih	0.11	0.165	0.219	0.384
Gaziosmanpasa	Gaziosmanpasa	0	0	0	0
Gaziosmanpasa	Gungoren	0.09	0.141	0.191	0.332
Gaziosmanpasa	Kagithane	0.022	0.049	0.075	0.124
Gaziosmanpasa	Kucukcekmece	0.033	0.062	0.091	0.153
Gaziosmanpasa	Sariyer	0	0.025	0.05	0.075
Gaziosmanpasa	Silivri	0.002	0.027	0.052	0.079
Gaziosmanpasa	Sultangazi	0	0.025	0.05	0.075
Gaziosmanpasa	Sisli	0.025	0.053	0.081	0.134
Gaziosmanpasa	Zeytinburnu	0.094	0.146	0.197	0.343
Gungoren	Arnavutkoy	0.043	0.083	0.122	0.205
Gungoren	Avcilar	0.105	0.157	0.209	0.366
Gungoren	Bagcilar	0.19	0.28	0.368	0.648
Gungoren	Bahcelievler	0.2	0.281	0.36	0.641
Gungoren	Bakirkoy	0.263	0.369	0.473	0.842
Gungoren	Basaksehir	0.032	0.067	0.101	0.168
Gungoren	Bayrampasa	0.246	0.352	0.455	0.807
Gungoren	Besiktas	0.079	0.13	0.18	0.31

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Gungoren	Beylikduzu	0.1	0.153	0.206	0.359
Gungoren	Beyoglu	0.122	0.185	0.246	0.431
Gungoren	Buyukcekmece	0.091	0.141	0.191	0.332
Gungoren	Catalca	0.02	0.052	0.083	0.135
Gungoren	Esenler	0.2	0.294	0.385	0.679
Gungoren	Esenyurt	0.104	0.159	0.213	0.372
Gungoren	Eyup	0.075	0.121	0.166	0.287
Gungoren	Fatih	0.176	0.251	0.325	0.576
Gungoren	Gaziosmanpasa	0.09	0.141	0.191	0.332
Gungoren	Gungoren	0	0	0	0
Gungoren	Kagithane	0.113	0.172	0.231	0.403
Gungoren	Kucukcekmece	0.123	0.178	0.233	0.411
Gungoren	Sariyer	0.046	0.085	0.123	0.208
Gungoren	Silivri	0.015	0.045	0.075	0.12
Gungoren	Sultangazi	0.057	0.097	0.137	0.234
Gungoren	Sisli	0.085	0.139	0.191	0.33
Gungoren	Zeytinburnu	0.367	0.522	0.673	1,195
Kagithane	Arnavutkoy	0.002	0.027	0.052	0.079
Kagithane	Avcilar	0.076	0.119	0.162	0.281
Kagithane	Bagcilar	0.065	0.108	0.151	0.259
Kagithane	Bahcelievler	0.1	0.154	0.206	0.36
Kagithane	Bakirkoy	0.068	0.112	0.156	0.268
Kagithane	Basaksehir	0.002	0.027	0.052	0.079
Kagithane	Bayrampasa	0.053	0.084	0.116	0.2
Kagithane	Besiktas	0.01	0.038	0.065	0.103
Kagithane	Beylikduzu	0.059	0.098	0.137	0.235
Kagithane	Beyoglu	0.007	0.032	0.057	0.089
Kagithane	Buyukcekmece	0.056	0.095	0.133	0.228
Kagithane	Catalca	0.002	0.027	0.052	0.079
Kagithane	Esenler	0.078	0.128	0.177	0.305
Kagithane	Esenyurt	0.001	0.026	0.051	0.077
Kagithane	Eyup	0.036	0.061	0.086	0.147
Kagithane	Fatih	0.039	0.072	0.106	0.178
Kagithane	Gaziosmanpasa	0.022	0.049	0.075	0.124

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Kagithane	Gungoren	0.113	0.172	0.231	0.403
Kagithane	Kagithane	0	0	0	0
Kagithane	Kucukcekmece	0.043	0.074	0.106	0.18
Kagithane	Sariyer	0.004	0.029	0.054	0.083
Kagithane	Silivri	0	0.025	0.05	0.075
Kagithane	Sultangazi	0.008	0.033	0.058	0.091
Kagithane	Sisli	0.006	0.031	0.056	0.087
Kagithane	Zeytinburnu	0.087	0.143	0.199	0.342
Kucukcekmece	Arnavutkoy	0.006	0.032	0.057	0.089
Kucukcekmece	Avcilar	0.138	0.198	0.257	0.455
Kucukcekmece	Bagcilar	0.05	0.08	0.111	0.191
Kucukcekmece	Bahcelievler	0.096	0.138	0.179	0.317
Kucukcekmece	Bakirkoy	0.063	0.095	0.128	0.223
Kucukcekmece	Basaksehir	0.007	0.033	0.059	0.092
Kucukcekmece	Bayrampasa	0.017	0.044	0.071	0.115
Kucukcekmece	Besiktas	0.036	0.067	0.098	0.165
Kucukcekmece	Beylikduzu	0.095	0.147	0.198	0.345
Kucukcekmece	Beyoglu	0.041	0.072	0.104	0.176
Kucukcekmece	Buyukcekmece	0.084	0.133	0.182	0.315
Kucukcekmece	Catalca	0.045	0.082	0.12	0.202
Kucukcekmece	Esenler	0.016	0.043	0.07	0.113
Kucukcekmece	Esenyurt	0.1	0.153	0.206	0.359
Kucukcekmece	Eyup	0.01	0.036	0.062	0.098
Kucukcekmece	Fatih	0.07	0.109	0.147	0.256
Kucukcekmece	Gaziosmanpasa	0.033	0.062	0.091	0.153
Kucukcekmece	Gungoren	0.123	0.178	0.233	0.411
Kucukcekmece	Kagithane	0.043	0.074	0.106	0.18
Kucukcekmece	Kucukcekmece	0	0	0	0
Kucukcekmece	Sariyer	0.007	0.033	0.058	0.091
Kucukcekmece	Silivri	0.041	0.078	0.114	0.192
Kucukcekmece	Sultangazi	0.011	0.038	0.064	0.102
Kucukcekmece	Sisli	0.038	0.069	0.1	0.169
Kucukcekmece	Zeytinburnu	0.098	0.152	0.204	0.356
Sariyer	Arnavutkoy	0	0.025	0.05	0.075

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Sariyer	Avcilar	0.058	0.097	0.135	0.232
Sariyer	Bagcilar	0.005	0.03	0.055	0.085
Sariyer	Bahcelievler	0.046	0.083	0.12	0.203
Sariyer	Bakirkoy	0.048	0.087	0.126	0.213
Sariyer	Basaksehir	0	0.025	0.05	0.075
Sariyer	Bayrampasa	0.029	0.056	0.084	0.14
Sariyer	Besiktas	0	0.025	0.05	0.075
Sariyer	Beylikduzu	0	0.025	0.05	0.075
Sariyer	Beyoglu	0	0.025	0.05	0.075
Sariyer	Buyukcekmece	0.002	0.028	0.053	0.081
Sariyer	Catalca	0	0.025	0.05	0.075
Sariyer	Esenler	0.005	0.03	0.055	0.085
Sariyer	Esenyurt	0	0.025	0.05	0.075
Sariyer	Eyup	0.007	0.032	0.057	0.089
Sariyer	Fatih	0.039	0.072	0.106	0.178
Sariyer	Gaziosmanpasa	0	0.025	0.05	0.075
Sariyer	Gungoren	0.046	0.085	0.123	0.208
Sariyer	Kagithane	0.004	0.029	0.054	0.083
Sariyer	Kucukcekmece	0.007	0.033	0.058	0.091
Sariyer	Sariyer	0	0	0	0
Sariyer	Silivri	0	0.025	0.05	0.075
Sariyer	Sultangazi	0	0.025	0.05	0.075
Sariyer	Sisli	0	0.025	0.05	0.075
Sariyer	Zeytinburnu	0.044	0.086	0.127	0.213
Silivri	Arnavutkoy	0	0.025	0.05	0.075
Silivri	Avcilar	0.006	0.032	0.058	0.09
Silivri	Bagcilar	0.002	0.027	0.052	0.079
Silivri	Bahcelievler	0.04	0.078	0.114	0.192
Silivri	Bakirkoy	0.032	0.065	0.098	0.163
Silivri	Basaksehir	0	0.025	0.05	0.075
Silivri	Bayrampasa	0.008	0.034	0.06	0.094
Silivri	Besiktas	0.016	0.046	0.077	0.123
Silivri	Beylikduzu	0.003	0.029	0.055	0.084
Silivri	Beyoglu	0.017	0.047	0.078	0.125

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Silivri	Buyukcekmece	0	0.025	0.05	0.075
Silivri	Catalca	0	0.025	0.05	0.075
Silivri	Esenler	0.002	0.028	0.053	0.081
Silivri	Esenyurt	0.003	0.029	0.055	0.084
Silivri	Eyup	0.002	0.027	0.052	0.079
Silivri	Fatih	0.039	0.073	0.108	0.181
Silivri	Gaziosmanpasa	0.002	0.027	0.052	0.079
Silivri	Gungoren	0.015	0.045	0.075	0.12
Silivri	Kagithane	0	0.025	0.05	0.075
Silivri	Kucukcekmece	0.041	0.078	0.114	0.192
Silivri	Sariyer	0	0.025	0.05	0.075
Silivri	Silivri	0	0	0	0
Silivri	Sultangazi	0.002	0.027	0.053	0.08
Silivri	Sisli	0.035	0.069	0.102	0.171
Silivri	Zeytinburnu	0.047	0.084	0.121	0.205
Sultangazi	Arnavutkoy	0	0.025	0.05	0.075
Sultangazi	Avcilar	0.006	0.033	0.059	0.092
Sultangazi	Bagcilar	0.016	0.042	0.068	0.11
Sultangazi	Bahcelievler	0.052	0.086	0.121	0.207
Sultangazi	Bakirkoy	0.106	0.158	0.21	0.368
Sultangazi	Basaksehir	0	0.025	0.05	0.075
Sultangazi	Bayrampasa	0.033	0.062	0.09	0.152
Sultangazi	Besiktas	0.008	0.034	0.059	0.093
Sultangazi	Beylikduzu	0	0.025	0.05	0.075
Sultangazi	Beyoglu	0.001	0.026	0.051	0.077
Sultangazi	Buyukcekmece	0.003	0.029	0.054	0.083
Sultangazi	Catalca	0	0.025	0.05	0.075
Sultangazi	Esenler	0.011	0.036	0.061	0.097
Sultangazi	Esenyurt	0	0.025	0.05	0.075
Sultangazi	Eyup	0.011	0.037	0.063	0.1
Sultangazi	Fatih	0.073	0.118	0.163	0.281
Sultangazi	Gaziosmanpasa	0	0.025	0.05	0.075
Sultangazi	Gungoren	0.057	0.097	0.137	0.234
Sultangazi	Kagithane	0.008	0.033	0.058	0.091

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Sultangazi	Kucukcekmece	0.011	0.038	0.064	0.102
Sultangazi	Sariyer	0	0.025	0.05	0.075
Sultangazi	Silivri	0.002	0.027	0.053	0.08
Sultangazi	Sultangazi	0	0	0	0
Sultangazi	Sisli	0.001	0.026	0.051	0.077
Sultangazi	Zeytinburnu	0.1	0.155	0.21	0.365
Sisli	Arnavutkoy	0.028	0.063	0.098	0.161
Sisli	Avcilar	0.076	0.119	0.162	0.281
Sisli	Bagcilar	0.072	0.119	0.164	0.283
Sisli	Bahcelievler	0.109	0.167	0.224	0.391
Sisli	Bakirkoy	0.177	0.261	0.343	0.604
Sisli	Basaksehir	0.034	0.071	0.107	0.178
Sisli	Bayrampasa	0.05	0.082	0.113	0.195
Sisli	Besiktas	0	0.025	0.05	0.075
Sisli	Beylikduzu	0.061	0.1	0.14	0.24
Sisli	Beyoglu	0.043	0.075	0.107	0.182
Sisli	Buyukcekmece	0.058	0.097	0.135	0.232
Sisli	Catalca	0.017	0.047	0.078	0.125
Sisli	Esenler	0.072	0.121	0.169	0.29
Sisli	Esenyurt	0.063	0.103	0.142	0.245
Sisli	Eyup	0.007	0.032	0.057	0.089
Sisli	Fatih	0.097	0.138	0.18	0.318
Sisli	Gaziosmanpasa	0.025	0.053	0.081	0.134
Sisli	Gungoren	0.085	0.139	0.191	0.33
Sisli	Kagithane	0.006	0.031	0.056	0.087
Sisli	Kucukcekmece	0.038	0.069	0.1	0.169
Sisli	Sariyer	0	0.025	0.05	0.075
Sisli	Silivri	0.035	0.069	0.102	0.171
Sisli	Sultangazi	0.001	0.026	0.051	0.077
Sisli	Sisli	0	0	0	0
Sisli	Zeytinburnu	0.075	0.129	0.182	0.311
Zeytinburnu	Arnavutkoy	0.039	0.076	0.113	0.189
Zeytinburnu	Avcilar	0.113	0.167	0.221	0.388
Zeytinburnu	Bagcilar	0.2	0.281	0.361	0.642

Table C1 (continued): Road Vulnerability Coefficients Between Districts

From District	To District	Low Vulnerability	Avrage Vulnerability	High Vulnerability	High and Avrage Vulnerability
Zeytinburnu	Bahcelievler	0.294	0.403	0.511	0.914
Zeytinburnu	Bakirkoy	0.232	0.35	0.465	0.815
Zeytinburnu	Basaksehir	0.051	0.092	0.132	0.224
Zeytinburnu	Bayrampasa	0.204	0.291	0.377	0.668
Zeytinburnu	Besiktas	0.068	0.119	0.17	0.289
Zeytinburnu	Beylikduzu	0.086	0.133	0.18	0.313
Zeytinburnu	Beyoglu	0.2	0.297	0.391	0.688
Zeytinburnu	Buyukcekmece	0.08	0.126	0.171	0.297
Zeytinburnu	Catalca	0.037	0.076	0.113	0.189
Zeytinburnu	Esenler	0.158	0.231	0.302	0.533
Zeytinburnu	Esenyurt	0.047	0.087	0.126	0.213
Zeytinburnu	Eyup	0.081	0.131	0.18	0.311
Zeytinburnu	Fatih	0.2	0.285	0.369	0.654
Zeytinburnu	Gaziosmanpasa	0.094	0.146	0.197	0.343
Zeytinburnu	Gungoren	0.367	0.522	0.673	1,195
Zeytinburnu	Kagithane	0.087	0.143	0.199	0.342
Zeytinburnu	Kucukcekmece	0.098	0.152	0.204	0.356
Zeytinburnu	Sariyer	0.044	0.086	0.127	0.213
Zeytinburnu	Silivri	0.047	0.084	0.121	0.205
Zeytinburnu	Sultangazi	0.1	0.155	0.21	0.365
Zeytinburnu	Sisli	0.075	0.129	0.182	0.311
Zeytinburnu	Zeytinburnu	0	0	0	0

APPENDIX D

ROAD VULNERABILITIES FOR PRE-DETERMINED ROUTES BETWEEN FACILITIES AND DEMAND POINTS

Table D1: Road Vulnerability Coefficients Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Warehouses to Distribution Centers

Warehouse	Distribution Center	Road Vulnerability	Road No
AVCILAR	beylikduzu	0.13	R1
AVCILAR	esenyurt	0.146	R2
AVCILAR	kucukcekmece	0.455	R3
BAHCELIEVLER	bagcilar	0.29	R4
BAHCELIEVLER	gungoren	0.641	R5
BAHCELIEVLER	bakirkoy	0.678	R6
BAKIRKOY	bahcelievler	0.678	R7
BAKIRKOY	gungoren	0.842	R8
BAKIRKOY	zeytinburnu	0.815	R9
BAGCILAR	bahcelievler	0.29	R10
BAGCILAR	gungoren	0.648	R11
BAGCILAR	esenler	0.147	R12
BAGCILAR	basaksehir	0.085	R13
BASAKSEHIR	bagcilar	0.085	R14
BASAKSEHIR	kucukcekmece	0.092	R15
BASAKSEHIR	esenler	0.079	R16
BASAKSEHIR	arnavutkoy	0.075	R17
BEYLIKDUZU	avcilar	0.13	R18
BEYLIKDUZU	esenyurt	0.075	R19
BEYLIKDUZU	buyukcekmece	0.112	R20
BUYUKCEKMECE	avcilar	0.131	R21

Table D1 (continued): Road Vulnerability Coefficients Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Warehouses to Distribution Centers

Warehouse	Distribution Center	Road Vulnerability	Road No
BUYUKCEKMECE	beylikduzu	0.112	R22
BUYUKCEKMECE	esenyurt	0.106	R23
BAYRAMPASA	esenler	0.639	R24
BAYRAMPASA	gaziosmanpasa	0.219	R25
BAYRAMPASA	fatih	0.825	R26
BAYRAMPASA	sultangazi	0.152	R27
BAYRAMPASA	eyup	0.223	R28
ESENYURT	avcilar	0.146	R29
ESENYURT	beylikduzu	0.075	R30
ESENYURT	buyukcekmece	0.106	R31
EYUP	gaziosmanpasa	0.115	R32
EYUP	sultangazi	0.1	R33
EYUP	kagithane	0.147	R34
EYUP	beyoglu	0.161	R35
EYUP	besiktas	0.107	R36
EYUP	sisli	0.089	R37
FATIH	bayrampasa	0.825	R38
FATIH	beyoglu	0.365	R39
FATIH	zeytinburnu	0.654	R40
FATIH	besiktas	0.163	R41
FATIH	kagithane	0.178	R42
FATIH	sisli	0.318	R43
GUNGOREN	bagcilar	0.648	R44
GUNGOREN	bahcelievler	0.641	R45
GUNGOREN	esenler	0.679	R46
KUCUKCEKMECE	bagcilar	0.191	R47
KUCUKCEKMECE	bahcelievler	0.317	R48
KUCUKCEKMECE	gungoren	0.411	R49
KUCUKCEKMECE	basaksehir	0.092	R50
SULTANGAZI	bayrampasa	0.152	R51
SULTANGAZI	eyup	0.1	R52

Table D1 (continued): Road Vulnerability Coefficients Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Warehouses to Distribution Centers

Warehouse	Distribution Center	Road Vulnerability	Road No
SULTANGAZI	gaziosmanpasa	0.075	R53
SULTANGAZI	arnavutkoy	0.075	R54
ZEYTINBURNU	fatih	0.654	R55
ZEYTINBURNU	bakirkoy	0.815	R56
ZEYTINBURNU	esenler	0.533	R57
ESENLER	bayrampasa	0.639	R58
ESENLER	gungoren	0.679	R59
ESENLER	bagcilar	0.147	R60
AVCILAR	avcilar	0	R61
BAHCELIEVLER	bahcelievler	0	R62
BAKIRKOY	bakirkoy	0	R63
BAGCILAR	bagcilar	0	R64
BASAKSEHIR	basaksehir	0	R65
BEYLIKDUZU	beylikduzu	0	R66
BUYUKCEKMECE	buyukcekmece	0	R67
BAYRAMPASA	bayrampasa	0	R68
ESENYURT	esenyurt	0	R69
EYUP	eyup	0	R70
FATIH	fatih	0	R71
GUNGOREN	gungoren	0	R72
KUCUKCEKMECE	kucukcekmece	0	R73
SULTANGAZI	sultangazi	0	R74
ZEYTINBURNU	zeytinburnu	0	R75
ESENLER	esenler	0	R76

Table D2: Road Vulnerability Coefficients Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
arnavutkoy	Sultangazi	0.075	R77
	Gaziosmanpasa	0.075	R77
	Eyup	0.115	R77
arnavutkoy	Basaksehir	0.075	R78
	Kucukcekmece	0.092	R78
	Bahcelievler	0.317	R78
arnavutkoy	Gaziosmanpasa	0.075	R79
	Bayrampasa	0.219	R79
	Esenler	0.639	R79
avcilar	Esenyurt	0.146	R80
	Beylikduzu	0.075	R80
	Buyukcekmece	0.112	R80
avcilar	Kucukcekmece	0.455	R81
	Bahcelievler	0.317	R81
	Gungoren	0.641	R81
avcilar	Beylikduzu	0.13	R82
	Esenyurt	0.075	R82
	Buyukcekmece	0.106	R82
bagcilar	Bahcelievler	0.29	R83
	Gungoren	0.641	R83
	Esenler	0.679	R83
bagcilar	Kucukcekmece	0.191	R84
	Bakirkoy	0.223	R84
	Zeytinburnu	0.815	R84
bagcilar	Gungoren	0.648	R85
	Bayrampasa	0.807	R85
	Gaziosmanpasa	0.219	R85
bahcelievler	Bakirkoy	0.678	R86
	Zeytinburnu	0.815	R86
	Fatih	0.654	R86

Table D2 (continued): Road Vulnerability Coefficients Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
bahcelievler	Gungoren	0.641	R87
	Esenler	0.679	R87
	Bayrampasa	0.639	R87
bahcelievler	Bagcilar	0.29	R88
	Kucukcekmece	0.191	R88
	Avcilar	0.455	R88
bakirkoy	Bahcelievler	0.678	R89
	Gungoren	0.641	R89
	Esenler	0.679	R89
bakirkoy	Zeytinburnu	0.815	R90
	Fatih	0.654	R90
	Bayrampasa	0.825	R90
bakirkoy	Bagcilar	0.493	R91
	Kucukcekmece	0.191	R91
	Avcilar	0.455	R91
basaksehir	Kucukcekmece	0.092	R92
	Bahcelievler	0.317	R92
	Gungoren	0.641	R92
basaksehir	Bagcilar	0.085	R93
	Esenler	0.147	R93
	Bayrampasa	0.639	R93
basaksehir	Esenler	0.079	R94
	Gaziosmanpasa	0.103	R94
	Eyup	0.115	R94
bayrampasa	Gaziosmanpasa	0.219	R95
	Eyup	0.115	R95
	Sultangazi	0.1	R95
bayrampasa	Esenler	0.639	R96
	Gungoren	0.679	R96
	Bahcelievler	0.641	R96

Table D2 (continued): Road Vulnerability Coefficients Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
bayrampasa	Fatih	0.825	R97
	Zeytinburnu	0.654	R97
	Bakirkoy	0.815	R97
besiktas	Sisli	0.075	R98
	Kagithane	0.087	R98
	Beyoglu	0.089	R98
besiktas	Sariyer	0.075	R99
	Eyup	0.089	R99
	Gaziosmanpasa	0.115	R99
besiktas	Kagithane	0.103	R100
	Sisli	0.087	R100
	Fatih	0.318	R100
beylikduzu	Esenyurt	0.075	R101
	Avcilar	0.146	R101
	Kucukcekmece	0.455	R101
beylikduzu	Buyukcekmece	0.112	R102
	Catalca	0.075	R102
beylikduzu	Avcilar	0.13	R103
	Esenyurt	0.146	R103
	Buyukcekmece	0.106	R103
beyoglu	Sisli	0.182	R104
	Kagithane	0.087	R104
	Besiktas	0.103	R104
beyoglu	Fatih	0.365	R105
	Bayrampasa	0.825	R105
	Gaziosmanpasa	0.219	R105
beyoglu	Kagithane	0.089	R106
	Eyup	0.147	R106
	Sultangazi	0.1	R106

Table D2 (continued): Road Vulnerability Coefficients Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
buyukcekmece	Esenyurt	0.106	R107
	Beylikduzu	0.075	R107
	Avcilar	0.13	R107
buyukcekmece	Catalca	0.075	R108
	Silivri	0.075	R108
buyukcekmece	Silivri	0.075	R109
	Catalca	0.075	R109
buyukcekmece	Beylikduzu	0.112	R110
	Kucukcekmece	0.345	R110
	Bahcelievler	0.317	R110
esenler	Gungoren	0.679	R111
	Bahcelievler	0.641	R111
	Bagcilar	0.29	R111
esenler	Bayrampasa	0.639	R112
	Gaziosmanpasa	0.219	R112
	Eyup	0.115	R112
esenler	Bagcilar	0.147	R113
	Kucukcekmece	0.191	R113
	Bahcelievler	0.317	R113
esenyurt	Beylikduzu	0.075	R114
	Avcilar	0.13	R114
	Kucukcekmece	0.455	R114
esenyurt	Buyukcekmece	0.106	R115
	Beylikduzu	0.112	R115
	Avcilar	0.13	R115
esenyurt	Avcilar	0.146	R116
	Beylikduzu	0.13	R116
	Buyukcekmece	0.112	R116

Table D2 (continued): Road Vulnerability Coefficients Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
eyup	Gaziosmanpasa	0.115	R117
	Bayrampasa	0.219	R117
	Esenler	0.639	R117
eyup	Kagithane	0.147	R118
	Sisli	0.087	R118
	Beyoglu	0.182	R118
eyup	Sultangazi	0.1	R119
	Gaziosmanpasa	0.075	R119
	Bayrampasa	0.219	R119
fatih	Bayrampasa	0.825	R120
	Gaziosmanpasa	0.219	R120
	Eyup	0.115	R120
fatih	Zeytinburnu	0.654	R121
	Bakirkoy	0.815	R121
	Bahcelievler	0.641	R121
fatih	Beyoglu	0.365	R122
	Sisli	0.182	R122
	Kagithane	0.087	R122
gaziosmanpasa	Eyup	0.115	R123
	Sultangazi	0.1	R123
	Bayrampasa	0.152	R123
gaziosmanpasa	Bayrampasa	0.219	R124
	Esenler	0.639	R124
	Gungoren	0.679	R124
gaziosmanpasa	Sultangazi	0.075	R125
	Eyup	0.1	R125
	Kagithane	0.147	R125
gungoren	Esenler	0.679	R126
	Bayrampasa	0.639	R126
	Gaziosmanpasa	0.219	R126

Table D2 (continued): Road Vulnerability Coefficients Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
gungoren	Esenler	0.679	R127
	Bagcilar	0.147	R127
	Bahcelievler	0.29	R127
gungoren	Bahcelievler	0.641	R128
	Bakirkoy	0.678	R128
	Zeytinburnu	0.815	R128
kagithane	Sisli	0.087	R129
	Beyoglu	0.182	R129
	Fatih	0.365	R129
kagithane	Besiktas	0.103	R130
	Sariyer	0.075	R130
	Eyup	0.089	R130
kagithane	Beyoglu	0.089	R131
	Sisli	0.182	R131
	Besiktas	0.075	R131
kucukcekmece	Bahcelievler	0.317	R132
	Gungoren	0.641	R132
	Esenler	0.679	R132
kucukcekmece	Bahçelievler	0.317	R133
	Bakırkoy	0.678	R133
	Zeytinburnu	0.815	R133
kucukcekmece	Bagcilar	0.191	R134
	Gungoren	0.648	R134
	Esenler	0.679	R134
sultangazi	Gaziosmanpasa	0.075	R135
	Eyup	0.115	R135
sultangazi	Arnavutkoy	0.1	R136
	Basaksehir	0.075	R136

Table D2 (continued): Road Vulnerability Coefficients Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
sultangazi	Bayrampasa	0.075	R137
	Esenler	0.152	R137
	Gungoren	0.639	R137
sisli	Beyoglu	0.679	R138
	Kagithane	0.182	R138
	Besiktas	0.089	R138
sisli	Eyup	0.103	R139
	Gaziosmanpasa	0.089	R139
	Bayrampasa	0.115	R139
sisli	Kagithane	0.219	R140
	Besiktas	0.087	R140
	Sariyer	0.103	R140
zeytinburnu	Fatih	0.075	R141
	Beyoglu	0.654	R141
	Sisli	0.365	R141
zeytinburnu	Fatih	0.182	R142
	Bayrampasa	0.654	R142
	Gaziosmanpasa	0.825	R142
zeytinburnu	Bakirkoy	0.219	R143
	Bahcelievler	0.815	R143
	Gungoren	0.678	R143
arnavutkoy	Arnavutkoy	0.641	R77
arnavutkoy	Arnavutkoy	0	R78
arnavutkoy	Arnavutkoy	0	R79
avcilar	Avcilar	0	R80
avcilar	Avcilar	0	R81
avcilar	Avcilar	0	R82
bagcilar	Bagcilar	0	R83
bagcilar	Bagcilar	0	R84
bagcilar	Bagcilar	0	R85

Table D2 (continued): Road Vulnerability Coefficients Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
bahcelievler	Bahcelievler	0	R86
bahcelievler	Bahcelievler	0	R87
bahcelievler	Bahcelievler	0	R88
bakirkoy	Bakirkoy	0	R89
bakirkoy	Bakirkoy	0	R90
bakirkoy	Bakirkoy	0	R91
basaksehir	Basaksehir	0	R92
basaksehir	Basaksehir	0	R93
basaksehir	Basaksehir	0	R94
bayrampasa	Bayrampasa	0	R95
bayrampasa	Bayrampasa	0	R96
bayrampasa	Bayrampasa	0	R97
besiktas	Besiktas	0	R98
besiktas	Besiktas	0	R99
besiktas	Besiktas	0	R100
beylikduzu	Beylikduzu	0	R101
beylikduzu	Beylikduzu	0	R102
beylikduzu	Beylikduzu	0	R103
beyoglu	Beyoglu	0	R104
beyoglu	Beyoglu	0	R105
beyoglu	Beyoglu	0	R106
buyukcekmece	Buyukcekmece	0	R107
buyukcekmece	Buyukcekmece	0	R108
buyukcekmece	Buyukcekmece	0	R109
buyukcekmece	Buyukcekmece	0	R110
esenler	Esenler	0	R111
esenler	Esenler	0	R112
esenler	Esenler	0	R113
esenyurt	Esenyurt	0	R114
esenyurt	Esenyurt	0	R115

Table D2 (continued): Road Vulnerability Coefficients Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
esenyurt	Esenyurt	0	R116
eyup	Eyup	0	R117
eyup	Eyup	0	R118
eyup	Eyup	0	R119
fatih	Fatih	0	R120
fatih	Fatih	0	R121
fatih	Fatih	0	R122
gaziosmanpasa	Gaziosmanpasa	0	R123
gaziosmanpasa	Gaziosmanpasa	0	R124
gaziosmanpasa	Gaziosmanpasa	0	R125
gungoren	Gungoren	0	R126
gungoren	Gungoren	0	R127
gungoren	Gungoren	0	R128
kagithane	Kagithane	0	R129
kagithane	Kagithane	0	R130
kagithane	Kagithane	0	R131
kucukcekmece	Kucukcekmece	0	R132
kucukcekmece	Kucukcekmece	0	R133
kucukcekmece	Kucukcekmece	0	R134
sultangazi	Sultangazi	0	R135
sultangazi	Sultangazi	0	R136
sultangazi	Sultangazi	0	R137
sisli	Sisli	0	R138
sisli	Sisli	0	R139
sisli	Sisli	0	R140
zeytinburnu	Zeytinburnu	0	R141
zeytinburnu	Zeytinburnu	0	R142
zeytinburnu	Zeytinburnu	0	R143

APPENDIX E

TRAVEL TIMES AND ARRIVAL TIMES FOR DISTRIBUTION CENTERS AND DEMAND POINTS FOR MODELS 1.1, 1.2, 2.1, 2.2, 3.1 AND 3.2

Table E1: Travel Times and Arrival Times for Distribution Centers and Demand Points for Models 1.1, 1.2, 2.1 and 2.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
BASAKSEHIR	18.4	0.613	arnavutkoy	Sultangazi	18.7		18.7	0.623	37.1	1.237
			sultangazi	Gaziosmanpasa	5.2	R77	23.9	0.797	42.3	1.410
			gaziosmanpasa	Eyup	3.1		27	0.900	45.4	1.513
BASAKSEHIR	18.4	0.613	arnavutkoy	Basaksehir	19		19	0.633	37.4	1.247
			basaksehir	Kucukcekmece	12.1	R78	31.1	1.037	49.5	1.650
			kucukcekmece	Bahcelievler	7.2		38.3	1.277	56.7	1.890
BASAKSEHIR	18.4	0.613	arnavutkoy	Gaziosmanpasa	23.1		23.1	0.770	41.5	1.383
			gaziosmanpasa	Bayrampasa	3.8	R79	26.9	0.897	45.3	1.510
			bayrampasa	Esenler	4.9		31.8	1.060	50.2	1.673
BUYUKCEKMECE	17.9	0.597	avcilar	Esenyurt	7.4		7.4	0.247	25.3	0.843
			esenyurt	Beylikduzu	6.6	R80	14	0.467	31.9	1.063
			beylikduzu	Buyukcekmece	10.8		24.8	0.827	42.7	1.423
BUYUKCEKMECE	17.9	0.597	avcilar	Kucukcekmece	12.9		12.9	0.430	30.8	1.027
			kucukcekmece	Bahcelievler	7.2	R81	20.1	0.670	38	1.267
			bahcelievler	Gungoren	4.2		24.3	0.810	42.2	1.407
BUYUKCEKMECE	17.9	0.597	avcilar	Beylikduzu	10.3		10.3	0.343	28.2	0.940
			beylikduzu	Esenyurt	6.8	R82	17.1	0.570	35	1.167
			esenyurt	Buyukcekmece	10.1		27.2	0.907	45.1	1.503
BASAKSEHIR	13.5	0.450	bagcilar	Bahcelievler	4.4		4.4	0.147	17.9	0.597
			bahcelievler	Gungoren	4.3	R83	8.7	0.290	22.2	0.740
			gungoren	Esenler	3.7		12.4	0.413	25.9	0.863

Table E1 (continued): Travel Times and Arrival Times for Distribution Centers and Demand Points for Models 1.1, 1.2, 2.1 and 2.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
BASAKSEHIR	13.5	0.450	bagcilar	Kucukcekmece	7.1		7.1	0.237	20.6	0.687
			kucukcekmece	Bakirkoy	11.4	R84	18.5	0.617	32	1.067
			bakirkoy	Zeytinburnu	8.1		26.6	0.887	40.1	1.337
BASAKSEHIR	13.5	0.450	bagcilar	Gungoren	4.9		4.9	0.163	18.4	0.613
			gungoren	Bayrampasa	6	R85	10.9	0.363	24.4	0.813
			bayrampasa	Gaziosmanpasa	4		14.9	0.497	28.4	0.947
KUCUKCEKMECE	7.2	0.240	bahcelievler	Bakirkoy	4.6		58.5	1.950	72	2.400
			bakirkoy	Zeytinburnu	7.8	R86	66.3	2.210	79.8	2.660
			zeytinburnu	Fatih	6.7		73	2.433	86.5	2.883
KUCUKCEKMECE	7.2	0.240	bahcelievler	Gungoren	4.3		4.3	0.143	11.5	0.383
			gungoren	Esenler	3.7	R87	8	0.267	15.2	0.507
			esenler	Bayrampasa	4.2		12.2	0.407	19.4	0.647
KUCUKCEKMECE	7.2	0.240	bahcelievler	Bagcilar	4.7		4.7	0.157	11.9	0.397
			bagcilar	Kucukcekmece	7.1	R88	11.8	0.393	19	0.633
			kucukcekmece	Avcilar	12		23.8	0.793	31	1.033
ZEYTINBURNU	7.4	0.247	bakirkoy	Bahcelievler	4.7		4.7	0.157	12.1	0.403
			bahcelievler	Gungoren	4.3	R89	9	0.300	16.4	0.547
			gungoren	Esenler	3.7		12.7	0.423	20.1	0.670
ZEYTINBURNU	7.4	0.247	bakirkoy	Zeytinburnu	7.8		7.8	0.260	15.2	0.507
			zeytinburnu	Fatih	6.7	R90	14.5	0.483	21.9	0.730
			fatih	Bayrampasa	6.1		20.6	0.687	28	0.933

Table E1 (continued): Travel Times and Arrival Times for Distribution Centers and Demand Points for Models 1.1, 1.2, 2.1 and 2.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
ZEYTINBURNU	7.4	0.247	bakirkoy	Bagcilar	8.3		8.3	0.277	15.7	0.523
			bagcilar	Kucukcekmece	7.1	R91	15.4	0.513	22.8	0.760
			kucukcekmece	Avcilar	12		27.4	0.913	34.8	1.160
BAGCILAR	14.9	0.497	basaksehir	Kucukcekmece	12.1		12.1	0.403	27	0.900
			kucukcekmece	Bahcelievler	7.2	R92	19.3	0.643	34.2	1.140
			bahcelievler	Gungoren	4.3		23.6	0.787	38.5	1.283
BAGCILAR	14.9	0.497	basaksehir	Bagcilar	13.5		13.5	0.450	28.4	0.947
			bagcilar	Esenler	5.4	R93	18.9	0.630	33.8	1.127
			esenler	Bayrampasa	4.2		23.1	0.770	38	1.267
BAGCILAR	14.9	0.497	basaksehir	Esenler	16.1		16.1	0.537	31	1.033
			esenler	Gaziosmanpasa	6.7	R94	22.8	0.760	37.7	1.257
			gaziosmanpasa	Eyup	3.1		25.9	0.863	40.8	1.360
SULTANGAZI	8	0.267	bayrampasa	Gaziosmanpasa	4		4	0.133	12	0.400
			gaziosmanpasa	Eyup	3.1	R95	7.1	0.237	15.1	0.503
			eyup	Sultangazi	6.3		13.4	0.447	21.4	0.713
SULTANGAZI	8	0.267	bayrampasa	Esenler	4.9		4.9	0.163	12.9	0.430
			esenler	Gungoren	3.9	R96	8.8	0.293	16.8	0.560
			gungoren	Bahcelievler	3.8		12.6	0.420	20.6	0.687
SULTANGAZI	8	0.267	bayrampasa	Fatih	6.2		6.2	0.207	14.2	0.473
			fatih	Zeytinburnu	5.5	R97	11.7	0.390	19.7	0.657
			zeytinburnu	Bakirkoy	7.4		19.1	0.637	27.1	0.903

Table E1 (continued): Travel Times and Arrival Times for Distribution Centers and Demand Points for Models 1.1, 1.2, 2.1 and 2.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
EYUP	13.4	0.447	besiktas	Sisli	4.2	R98	4.2	0.140	17.6	0.587
			sisli	Kagithane	3.3		7.5	0.250	20.9	0.697
			kagithane	Beyoglu	5.8		13.3	0.443	26.7	0.890
EYUP	13.4	0.447	besiktas	Sariyer	10.5	R99	10.5	0.350	23.9	0.797
			sariyer	Eyup	14.6		25.1	0.837	38.5	1.283
			eyup	Gaziosmanpasa	3.6		28.7	0.957	42.1	1.403
EYUP	13.4	0.447	besiktas	Kagithane	4.8	R100	4.8	0.160	18.2	0.607
			kagithane	Sisli	3.1		7.9	0.263	21.3	0.710
			sisli	Fatih	8.9		16.8	0.560	30.2	1.007
BUYUKCEKMECE	11.2	0.373	beylikduzu	Esenyurt	6.8	R101	6.8	0.227	18	0.600
			esenyurt	Avcilar	7.5		14.3	0.477	14.3	0.477
			avcilar	Kucukcekmece	12.9		27.2	0.907	27.2	0.907
BUYUKCEKMECE	11.2	0.373	beylikduzu	Buyukcekmece	10.8	R102	10.8	0.360	22	0.733
			buyukcekmece	Catalca	21.3		32.1	1.070	43.3	1.443
BUYUKCEKMECE	11.2	0.373	beylikduzu	Avcilar	10.6	R103	10.6	0.353	21.8	0.727
			avcilar	Esenyurt	7.4		18	0.600	29.2	0.973
			esenyurt	Buyukcekmece	10.1		28.1	0.937	39.3	1.310
EYUP	8.4	0.280	beyoglu	Sisli	4.1	R104	4.1	0.137	12.5	0.417
			sisli	Kagithane	3.3		7.4	0.247	15.8	0.527
			kagithane	Besiktas	5.3		12.7	0.423	21.1	0.703

Table E1 (continued): Travel Times and Arrival Times for Distribution Centers and Demand Points for Models 1.1, 1.2, 2.1 and 2.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
EYUP	8.4	0.280	beyoglu	Fatih	6.2		6.2	0.207	14.6	0.487
			fatih	Bayrampasa	6.1	R105	12.3	0.410	20.7	0.690
			bayrampasa	Gaziosmanpasa	4		16.3	0.543	24.7	0.823
EYUP	8.4	0.280	beyoglu	Kagithane	6.1		6.1	0.203	14.5	0.483
			kagithane	Eyup	6.6	R106	12.9	0.430	21.3	0.710
			eyup	Sultangazi	6.3		19	0.633	27.4	0.913
BEYLIKDUZU	10.8	0.360	buyukcekmece	Esenyurt	12.4		12.4	0.413	23.2	0.773
			esenyurt	Beylikduzu	6.6	R107	19	0.633	29.8	0.993
			beylikduzu	Avcilar	10.6		29.6	0.987	40.4	1.347
BEYLIKDUZU	10.8	0.360	buyukcekmece	Catalca	21.3	R108	21.3	0.710	32.1	1.070
			catalca	Silivri	33.2		54.5	1.817	65.3	2.177
BEYLIKDUZU	10.8	0.360	buyukcekmece	Silivri	35.1	R109	35.1	1.170	45.9	1.530
			silivri	Catalca	33.2		68.3	2.277	79.1	2.637
BEYLIKDUZU	10.8	0.360	buyukcekmece	Beylikduzu	11.2		11.2	0.373	22	0.733
			beylikduzu	Kucukcekmece	19.4	R110	26.6	0.887	37.4	1.247
			kucukcekmece	Bahcelievler	7.2		37.8	1.260	48.6	1.620
BASAKSEHIR	16.1	0.537	esenler	Gungoren	3.9		3.9	0.130	20	0.667
			gungoren	Bahcelievler	3.8	R111	8.5	0.283	24.6	0.820
			bahcelievler	Bagcilar	4.7		12.4	0.413	28.5	0.950

Table E1 (continued): Travel Times and Arrival Times for Distribution Centers and Demand Points for Models 1.1, 1.2, 2.1 and 2.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
BASAKSEHIR	16.1	0.537	esenler	Bayrampasa	4.2		4.2	0.140	20.3	0.677
			bayrampasa	Gaziosmanpasa	4	R112	8.2	0.273	24.3	0.810
			gaziosmanpasa	Eyup	3.1		11.3	0.377	27.4	0.913
BASAKSEHIR	16.1	0.537	esenler	Bagcilar	4		4	0.133	20.1	0.670
			bagcilar	Kucukcekmece	7.1	R113	11.1	0.370	27.2	0.907
			kucukcekmece	Bahcelievler	7.2		18.3	0.610	34.4	1.147
BUYUKCEKMECE	12.4	0.413	esenyurt	Beylikduzu	6.6		6.6	0.220	19	0.633
			beylikduzu	Avcilar	10.6	R114	17.2	0.573	29.6	0.987
			avcilar	Kucukcekmece	12.9		30.1	1.003	42.5	1.417
BUYUKCEKMECE	12.4	0.413	esenyurt	Buyukcekmece	10.1		10.1	0.337	22.5	0.750
			buyukcekmece	Beylikduzu	11.2	R115	21.3	0.710	33.7	1.123
			beylikduzu	Avcilar	10.6		31.9	1.063	44.3	1.477
BUYUKCEKMECE	12.4	0.413	esenyurt	Avcilar	7.5		7.5	0.250	19.9	0.663
			avcilar	Beylikduzu	10.3	R116	17.8	0.593	30.2	1.007
			beylikduzu	Buyukcekmece	10.8		28.6	0.953	41	1.367
BAYRAMPASA	6.8	0.227	eyup	Gaziosmanpasa	3.6		3.6	0.120	10.4	0.347
			gaziosmanpasa	Bayrampasa	3.8	R117	7.4	0.247	14.2	0.473
			bayrampasa	Esenler	4.9		12.3	0.410	19.1	0.637
BAYRAMPASA	6.8	0.227	eyup	Kagithane	7		7	0.233	13.8	0.460
			kagithane	Sisli	3.1	R118	10.1	0.337	16.9	0.563
			sisli	Beyoglu	4.1		14.2	0.473	21	0.700

Table E1 (continued): Travel Times and Arrival Times for Distribution Centers and Demand Points for Models 1.1, 1.2, 2.1 and 2.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
BAYRAMPASA	6.8	0.227	eyup	Sultangazi	6.3		6.3	0.210	13.1	0.437
			sultangazi	Gaziosmanpasa	5.2	R119	11.5	0.383	18.3	0.610
			gaziosmanpasa	Bayrampasa	3.8		15.3	0.510	22.1	0.737
ZEYTINBURNU	6.7	0.223	fatih	Bayrampasa	6.1		6.1	0.203	12.8	0.427
			bayrampasa	Gaziosmanpasa	4	R120	10.1	0.337	16.8	0.560
			gaziosmanpasa	Eyup	3.1		13.2	0.440	19.9	0.663
ZEYTINBURNU	6.7	0.223	fatih	Zeytinburnu	5.5		5.5	0.183	12.2	0.407
			zeytinburnu	Bakirkoy	7.4	R121	12.9	0.430	19.6	0.653
			gungoren	Bahcelievler	4.7		17.6	0.587	24.3	0.810
ZEYTINBURNU	6.7	0.223	fatih	Beyoglu	6.4		6.4	0.213	13.1	0.437
			beyoglu	Sisli	4.1	R122	10.5	0.350	17.2	0.573
			sisli	Kagithane	3.3		13.8	0.460	20.5	0.683
SULTANGAZI	5.2	0.173	gaziosmanpasa	Eyup	3.1		3.1	0.103	8.3	0.277
			eyup	Sultangazi	6.3	R123	9.4	0.313	14.6	0.487
			sultangazi	Bayrampasa	8		17.4	0.580	22.6	0.753
SULTANGAZI	5.2	0.173	gaziosmanpasa	Bayrampasa	3.8		3.8	0.127	9	0.300
			bayrampasa	Esenler	4.9	R124	8.7	0.290	13.9	0.463
			esenler	Gungoren	3.9		12.6	0.420	17.8	0.593
SULTANGAZI	5.2	0.173	gaziosmanpasa	Sultangazi	4.4		4.4	0.147	9.6	0.320
			sultangazi	Eyup	6.3	R125	10.7	0.357	15.9	0.530
			eyup	Kagithane	7		17.7	0.590	22.9	0.763

Table E1 (continued): Travel Times and Arrival Times for Distribution Centers and Demand Points for Models 1.1, 1.2, 2.1 and 2.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
KUCUKCEKMECE	9.7	0.323	gungoren	Esenler	3.7		3.7	0.123	13.4	0.447
			esenler	Bayrampasa	4.2	R126	7.9	0.263	17.6	0.587
			bayrampasa	Gaziosmanpasa	4		11.9	0.397	21.6	0.720
KUCUKCEKMECE	9.7	0.323	gungoren	Esenler	3.7		3.7	0.123	13.4	0.447
			esenler	Bagcilar	4	R127	7.7	0.257	17.4	0.580
			bagcilar	Bahcelievler	4.4		12.1	0.403	21.8	0.727
KUCUKCEKMECE	9.7	0.323	gungoren	Bahcelievler	3.8		3.8	0.127	13.5	0.450
			bahcelievler	Bakirkoy	4.6	R128	8.4	0.280	18.1	0.603
			bakirkoy	Zeytinburnu	7.8		16.2	0.540	25.9	0.863
FATIH	11.8	0.393	kagithane	Sisli	3.1		3.1	0.103	14.9	0.497
			sisli	Beyoglu	4.1	R129	7.2	0.240	19	0.633
			beyoglu	Fatih	6.2		13.4	0.447	25.2	0.840
FATIH	11.8	0.393	kagithane	Besiktas	5.3		5.3	0.177	17.1	0.570
			besiktas	Sariyer	10.5	R130	15.8	0.527	27.6	0.920
			sariyer	Eyup	14.6		30.4	1.013	42.2	1.407
FATIH	11.8	0.393	kagithane	Beyoglu	5.8		5.8	0.193	17.6	0.587
			beyoglu	Sisli	4.1	R131	9.9	0.330	21.7	0.723
			sisli	Besiktas	4.2		14.1	0.470	25.9	0.863
AVCILAR	12.9	0.430	kucukcekmece	Bahcelievler	7.2		7.2	0.240	20.1	0.670
			bahcelievler	Gungoren	4.3	R132	11.5	0.383	24.4	0.813
			gungoren	Esenler	3.7		15.2	0.507	28.1	0.937

Table E1 (continued): Travel Times and Arrival Times for Distribution Centers and Demand Points for Models 1.1, 1.2, 2.1 and 2.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
AVCILAR	12.9	0.430	kucukcekmece	Bahcelievler	7.2		7.2	0.240	20.1	0.670
			bahcelievler	Bakirkoy	4.6	R133	11.8	0.393	24.7	0.823
			bakirkoy	Zeytinburnu	7.8		19.6	0.653	32.5	1.083
AVCILAR	12.9	0.430	kucukcekmece	Bagcilar	8		8	0.267	20.9	0.697
			bagcilar	Gungoren	4.9	R134	12.9	0.430	25.8	0.860
			gungoren	Esenler	3.7		16.6	0.553	29.5	0.983
BAYRAMPASA	8.2	0.273	sultangazi	Gaziosmanpasa	5.2	R135	5.2	0.173	13.4	0.447
			gaziosmanpasa	Eyup	3.1		8.3	0.277	16.5	0.550
BAYRAMPASA	8.2	0.273	sultangazi	Arnavutkoy	17.6	R136	17.6	0.587	25.8	0.860
			arnavutkoy	Basaksehir	19		36.6	1.220	44.8	1.493
BAYRAMPASA	8.2	0.273	sultangazi	Bayrampasa	8		8	0.267	16.2	0.540
			bayrampasa	Esenler	4.9	R137	12.9	0.430	21.1	0.703
			esenler	Gungoren	3.9		16.8	0.560	25	0.833
FATIH	8.6	0.287	sisli	Beyoglu	4.1		4.1	0.137	12.7	0.423
			beyoglu	Kagithane	6.1	R138	10.2	0.340	18.8	0.627
			kagithane	Besiktas	5.3		15.5	0.517	24.1	0.803
FATIH	8.6	0.287	sisli	Eyup	8.1		8.1	0.270	16.7	0.557
			eyup	Gaziosmanpasa	3.6	R139	11.7	0.390	20.3	0.677
			gaziosmanpasa	Bayrampasa	3.8		15.5	0.517	24.1	0.803

Table E1 (continued): Travel Times and Arrival Times for Distribution Centers and Demand Points for Models 1.1, 1.2, 2.1 and 2.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
FATIH	8.6	0.287	sisli	Kagithane	3.3		3.3	0.110	11.9	0.397
			kagithane	Besiktas	5.3	R140	8.6	0.287	17.2	0.573
			besiktas	Sariyer	10.5		19.1	0.637	27.7	0.923
BAKIRKOY	7.8	0.260	zeytinburnu	Fatih	6.7		6.7	0.223	14.5	0.483
			fatih	Beyoglu	6.4	R141	13.1	0.437	20.9	0.697
			beyoglu	Sisli	4.1		17.2	0.573	25	0.833
BAKIRKOY	7.8	0.260	zeytinburnu	Fatih	6.7		6.7	0.223	14.5	0.483
			fatih	Bayrampasa	6.1	R142	12.8	0.427	20.6	0.687
			bayrampasa	Gaziosmanpasa	4		16.8	0.560	24.6	0.820
BAKIRKOY	7.8	0.260	zeytinburnu	Bakirkoy	7.4		7.4	0.247	15.2	0.507
			bakirkoy	Bahcelievler	4.7	R143	12.1	0.403	19.9	0.663
			bahcelievler	Gungoren	4.3		16.4	0.547	24.2	0.807

Table E2: Inflated Travel Times and Arrival Times for Distribution Centers and Demand Points for Deterministic Models 3.1 and 3.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
BASAKSEHIR	19.892	0.663	arnavutkoy	Sultangazi	20.216		20.216	0.674	40.108	1.337
			sultangazi	Gaziosmanpasa	5.622	R77	25.838	0.861	45.730	1.524
			gaziosmanpasa	Eyup	3.503		29.341	0.978	49.233	1.641
BASAKSEHIR	19.892	0.663	arnavutkoy	Basaksehir	20.541		20.541	0.685	40.432	1.348
			basaksehir	Kucukcekmece	13.326	R78	33.867	1.129	53.758	1.792
			kucukcekmece	Bahcelievler	10.542		44.408	1.480	64.300	2.143
BASAKSEHIR	19.892	0.663	arnavutkoy	Gaziosmanpasa	24.973		24.973	0.832	44.865	1.495
			gaziosmanpasa	Bayrampasa	4.866	R79	29.839	0.995	49.730	1.658
			bayrampasa	Esenler	13.573		43.412	1.447	63.304	2.110
BUYUKCEKMECE	20.598	0.687	avcilar	Esenyurt	8.665		8.665	0.289	29.263	0.975
			esenyurt	Beylikduzu	7.135	R80	15.800	0.527	36.399	1.213
			beylikduzu	Buyukcekmece	12.162		27.962	0.932	48.561	1.619
BUYUKCEKMECE	20.598	0.687	avcilar	Kucukcekmece	23.670		23.670	0.789	44.268	1.476
			kucukcekmece	Bahcelievler	10.542	R81	34.211	1.140	54.810	1.827
			bahcelievler	Gungoren	11.699		45.911	1.530	66.509	2.217
BUYUKCEKMECE	20.598	0.687	avcilar	Beylikduzu	11.839		11.839	0.395	32.437	1.081
			beylikduzu	Esenyurt	7.351	R82	19.190	0.640	39.789	1.326
			esenyurt	Buyukcekmece	11.298		30.488	1.016	51.086	1.703
BASAKSEHIR	14.754	0.492	bagcilar	Bahcelievler	6.197		6.197	0.207	20.951	0.698
			bahcelievler	Gungoren	11.978	R83	18.175	0.606	32.929	1.098
			gungoren	Esenler	11.526		29.701	0.990	44.455	1.482

Table E2 (continued): Inflated Travel Times and Arrival Times for Distribution Centers and Demand Points for Deterministic Models 3.1 and 3.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
BASAKSEHIR	14.754	0.492	bagcilar	Kucukcekmece	8.776		8.776	0.293	23.530	0.784
			kucukcekmece	Bakirkoy	14.672	R84	23.448	0.782	38.202	1.273
			bakirkoy	Zeytinburnu	43.784		67.232	2.241	81.986	2.733
BASAKSEHIR	14.754	0.492	bagcilar	Gungoren	13.920		13.920	0.464	28.675	0.956
			gungoren	Bayrampasa	31.088	R85	45.009	1.500	59.763	1.992
			bayrampasa	Gaziosmanpasa	5.122		50.130	1.671	64.884	2.163
BAKIRKOY	14.596	0.487	bahcelievler	Bakirkoy	14.286		161.349	5.378	176.103	5.870
			bakirkoy	Zeytinburnu	42.162	R86	203.511	6.784	218.265	7.276
			zeytinburnu	Fatih	19.364		222.875	7.429	237.630	7.921
BAKIRKOY	14.596	0.487	bahcelievler	Gungoren	11.978		11.978	0.399	26.574	0.886
			gungoren	Esenler	11.526	R87	23.504	0.783	38.100	1.270
			esenler	Bayrampasa	11.634		35.139	1.171	49.735	1.658
BAKIRKOY	14.596	0.487	bahcelievler	Bagcilar	6.620		6.620	0.221	21.216	0.707
			bagcilar	Kucukcekmece	8.776	R88	15.396	0.513	29.992	1.000
			kucukcekmece	Avcilar	22.018		37.414	1.247	52.011	1.734
ZEYTINBURNU	40.000	1.333	bakirkoy	Bahcelievler	14.596		14.596	0.487	54.596	1.820
			bahcelievler	Gungoren	11.978	R89	26.574	0.886	66.574	2.219
			gungoren	Esenler	11.526		38.100	1.270	78.100	2.603
ZEYTINBURNU	40.000	1.333	bakirkoy	Zeytinburnu	42.162		42.162	1.405	82.162	2.739
			zeytinburnu	Fatih	19.364	R90	61.526	2.051	101.526	3.384
			fatih	Bayrampasa	34.857		96.383	3.213	136.383	4.546

Table E2 (continued): Inflated Travel Times and Arrival Times for Distribution Centers and Demand Points for Deterministic Models 3.1 and 3.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
ZEYTINBURNU	40.000	1.333	bakirkoy	Bagcilar	16.371		16.371	0.546	56.371	1.879
			bagcilar	Kucukcekmece	8.776	R91	25.147	0.838	65.147	2.172
			kucukcekmece	Avcilar	22.018		47.165	1.572	87.165	2.906
BAGCILAR	16.284	0.543	basaksehir	Kucukcekmece	13.326		13.326	0.444	29.610	0.987
			kucukcekmece	Bahcelievler	10.542	R92	23.868	0.796	40.152	1.338
			bahcelievler	Gungoren	11.978		35.845	1.195	52.130	1.738
BAGCILAR	16.284	0.543	basaksehir	Bagcilar	14.754		14.754	0.492	31.038	1.035
			bagcilar	Esenler	6.331	R93	21.085	0.703	37.369	1.246
			esenler	Bayrampasa	11.634		32.719	1.091	49.003	1.633
BAGCILAR	16.284	0.543	basaksehir	Esenler	17.481		17.481	0.583	33.765	1.126
			esenler	Gaziosmanpasa	7.469	R94	24.950	0.832	41.234	1.374
			gaziosmanpasa	Eyup	3.503		28.453	0.948	44.737	1.491
FATIH	34.857	1.162	bayrampasa	Gaziosmanpasa	5.122		5.122	0.171	39.979	1.333
			gaziosmanpasa	Eyup	3.503	R95	8.624	0.287	43.482	1.449
			eyup	Sultangazi	7.000		15.624	0.521	50.482	1.683
FATIH	34.857	1.162	bayrampasa	Esenler	13.573		13.573	0.452	48.431	1.614
			esenler	Gungoren	12.150	R96	25.723	0.857	60.580	2.019
			gungoren	Bahcelievler	10.585		36.308	1.210	71.165	2.372
FATIH	34.857	1.162	bayrampasa	Fatih	35.429		35.429	1.181	70.286	2.343
			fatih	Zeytinburnu	15.896	R97	51.325	1.711	86.182	2.873
			zeytinburnu	Bakirkoy	40.000		91.325	3.044	126.182	4.206

Table E2 (continued): Inflated Travel Times and Arrival Times for Distribution Centers and Demand Points for Deterministic Models 3.1 and 3.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
FATIH	15.890	0.530	besiktas	Sisli	4.541		4.541	0.151	20.431	0.681
			sisli	Kagithane	3.614	R98	8.155	0.272	24.045	0.802
			kagithane	Beyoglu	6.367		14.522	0.484	30.412	1.014
FATIH	15.890	0.530	besiktas	Sariyer	11.351		11.351	0.378	27.241	0.908
			sariyer	Eyup	16.026	R99	27.378	0.913	43.268	1.442
			eyup	Gaziosmanpasa	4.068		31.445	1.048	47.336	1.578
FATIH	15.890	0.530	besiktas	Kagithane	5.351		5.351	0.178	21.241	0.708
			kagithane	Sisli	3.395	R100	8.747	0.292	24.637	0.821
			sisli	Fatih	13.050		21.796	0.727	37.687	1.256
BUYUKCEKMECE	12.613	0.420	beylikduzu	Esenyurt	7.351		7.351	0.245	19.964	0.665
			esenyurt	Avcilar	8.782	R101	16.134	0.538	16.134	0.538
			avcilar	Kucukcekmece	23.670		39.803	1.327	39.803	1.327
BUYUKCEKMECE	12.613	0.420	beylikduzu	Buyukcekmece	12.162	R102	12.162	0.405	24.775	0.826
			buyukcekmece	Catalca	23.027		35.189	1.173	47.802	1.593
BUYUKCEKMECE	12.613	0.420	beylikduzu	Avcilar	12.184		12.184	0.406	24.797	0.827
			avcilar	Esenyurt	8.665	R103	20.849	0.695	33.462	1.115
			esenyurt	Buyukcekmece	11.298		32.147	1.072	44.759	1.492
FATIH	10.079	0.336	beyoglu	Sisli	5.012		5.012	0.167	15.091	0.503
			sisli	Kagithane	3.614	R104	8.627	0.288	18.705	0.624
			kagithane	Besiktas	5.909		14.535	0.485	24.614	0.820

Table E2 (continued): Inflated Travel Times and Arrival Times for Distribution Centers and Demand Points for Deterministic Models 3.1 and 3.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
FATIH	10.079	0.336	beyoglu	Fatih	9.764		9.764	0.325	19.843	0.661
			fatih	Bayrampasa	34.857	R105	44.621	1.487	54.700	1.823
			bayrampasa	Gaziosmanpasa	5.122		49.743	1.658	59.821	1.994
FATIH	10.079	0.336	beyoglu	Kagithane	6.696		6.696	0.223	16.775	0.559
			kagithane	Eyup	7.737	R106	14.737	0.491	24.816	0.827
			eyup	Sultangazi	7.000		21.433	0.714	31.512	1.050
BEYLIKDUZU	12.162	0.405	buyukcekmece	Esenyurt	13.870		13.870	0.462	26.032	0.868
			esenyurt	Beylikduzu	7.135	R107	21.005	0.700	33.168	1.106
			beylikduzu	Avcilar	12.184		33.189	1.106	45.351	1.512
BEYLIKDUZU	12.162	0.405	buyukcekmece	Catalca	23.027	R108	23.027	0.768	35.189	1.173
			catalca	Silivri	35.892		58.919	1.964	71.081	2.369
BEYLIKDUZU	12.162	0.405	buyukcekmece	Silivri	37.946	R109	37.946	1.265	50.108	1.670
			silivri	Catalca	35.892		73.838	2.461	86.000	2.867
BEYLIKDUZU	12.162	0.405	buyukcekmece	Beylikduzu	12.613		12.613	0.420	24.775	0.826
			beylikduzu	Kucukcekmece	29.618	R110	40.160	1.339	52.322	1.744
			kucukcekmece	Bahcelievler	10.542		52.773	1.759	64.935	2.164
ZEYTINBURNU	19.914	0.664	esenler	Gungoren	12.150		12.150	0.405	32.064	1.069
			gungoren	Bahcelievler	10.585	R111	17.205	0.573	37.119	1.237
			bahcelievler	Bagcilar	6.620		29.354	0.978	49.269	1.642

Table E2 (continued): Inflated Travel Times and Arrival Times for Distribution Centers and Demand Points for Deterministic Models 3.1 and 3.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
ZEYTINBURNU	19.914	0.664	esenler	Bayrampasa	11.634		11.634	0.388	31.549	1.052
			bayrampasa	Gaziosmanpasa	5.122	R112	16.756	0.559	36.670	1.222
			gaziosmanpasa	Eyup	3.503		20.259	0.675	40.173	1.339
ZEYTINBURNU	19.914	0.664	esenler	Bagcilar	4.689		4.689	0.156	24.604	0.820
			bagcilar	Kucukcekmece	8.776	R113	13.466	0.449	33.380	1.113
			kucukcekmece	Bahcelievler	10.542		24.007	0.800	43.922	1.464
BUYUKCEKMECE	13.870	0.462	esenyurt	Beylikduzu	7.135		7.135	0.238	21.005	0.700
			beylikduzu	Avcilar	12.184	R114	19.319	0.644	33.189	1.106
			avcilar	Kucukcekmece	23.670		42.989	1.433	56.859	1.895
BUYUKCEKMECE	13.870	0.462	esenyurt	Buyukcekmece	11.298		11.298	0.377	25.168	0.839
			buyukcekmece	Beylikduzu	12.613	R115	23.910	0.797	37.780	1.259
			beylikduzu	Avcilar	12.184		36.094	1.203	49.964	1.665
BUYUKCEKMECE	13.870	0.462	esenyurt	Avcilar	8.782		8.782	0.293	22.652	0.755
			avcilar	Beylikduzu	11.839	R116	20.621	0.687	34.492	1.150
			beylikduzu	Buyukcekmece	12.162		32.783	1.093	46.654	1.555
BAYRAMPASA	8.752	0.292	eyup	Gaziosmanpasa	4.068		4.068	0.136	12.819	0.427
			gaziosmanpasa	Bayrampasa	4.866	R117	8.933	0.298	17.685	0.589
			bayrampasa	Esenler	13.573		22.507	0.750	31.258	1.042
BAYRAMPASA	8.752	0.292	eyup	Kagithane	8.206		8.206	0.274	16.958	0.565
			kagithane	Sisli	3.395	R118	11.602	0.387	20.353	0.678
			sisli	Beyoglu	5.012		16.614	0.554	25.366	0.846

Table E2 (continued): Inflated Travel Times and Arrival Times for Distribution Centers and Demand Points for Deterministic Models 3.1 and 3.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
BAYRAMPASA	8.752	0.292	eyup	Sultangazi	7.000		7.000	0.233	15.752	0.525
			sultangazi	Gaziosmanpasa	5.622	R119	12.622	0.421	21.373	0.712
			gaziosmanpasa	Bayrampasa	4.866		17.487	0.583	26.239	0.875
BAYRAMPASA	35.429	1.181	fatih	Bayrampasa	34.857		34.857	1.162	70.286	2.343
			bayrampasa	Gaziosmanpasa	5.122	R120	39.979	1.333	75.407	2.514
			gaziosmanpasa	Eyup	3.503		43.482	1.449	78.910	2.630
BAYRAMPASA	35.429	1.181	fatih	Zeytinburnu	15.896		15.896	0.530	51.325	1.711
			zeytinburnu	Bakirkoy	40.000	R121	55.896	1.863	91.325	3.044
			gungoren	Bahcelievler	13.092		68.988	2.300	104.416	3.481
BAYRAMPASA	35.429	1.181	fatih	Beyoglu	10.079		10.079	0.336	45.507	1.517
			beyoglu	Sisli	5.012	R122	15.091	0.503	50.520	1.684
			sisli	Kagithane	3.614		18.705	0.624	54.134	1.804
SULTANGAZI	5.622	0.187	gaziosmanpasa	Eyup	3.503		3.503	0.117	9.124	0.304
			eyup	Sultangazi	7.000	R123	10.503	0.350	16.124	0.537
			sultangazi	Bayrampasa	9.434		19.937	0.665	25.558	0.852
SULTANGAZI	5.622	0.187	gaziosmanpasa	Bayrampasa	4.866		4.866	0.162	10.487	0.350
			bayrampasa	Esenler	13.573	R124	18.439	0.615	24.061	0.802
			esenler	Gungoren	12.150		30.588	1.020	36.210	1.207
SULTANGAZI	5.622	0.187	gaziosmanpasa	Sultangazi	4.757		4.757	0.159	10.378	0.346
			sultangazi	Eyup	7.000	R125	11.757	0.392	17.378	0.579
			eyup	Kagithane	8.206		19.963	0.665	25.585	0.853

Table E2 (continued): Inflated Travel Times and Arrival Times for Distribution Centers and Demand Points for Deterministic Models 3.1 and 3.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
BAKIRKOY	41.139	1.371	gungoren	Esenler	11.526		11.526	0.384	52.666	1.756
			esenler	Bayrampasa	11.634	R126	23.161	0.772	64.300	2.143
			bayrampasa	Gaziosmanpasa	5.122		28.282	0.943	69.422	2.314
BAKIRKOY	41.139	1.371	gungoren	Esenler	11.526		11.526	0.384	52.666	1.756
			esenler	Bagcilar	4.689	R127	16.216	0.541	57.355	1.912
			bagcilar	Bahcelievler	6.197		22.413	0.747	63.552	2.118
BAKIRKOY	41.139	1.371	gungoren	Bahcelievler	10.585		10.585	0.353	51.724	1.724
			bahcelievler	Bakirkoy	14.286	R128	24.871	0.829	66.010	2.200
			bakirkoy	Zeytinburnu	42.162		67.033	2.234	108.172	3.606
FATIH	14.355	0.479	kagithane	Sisli	3.395		3.395	0.113	17.751	0.592
			sisli	Beyoglu	5.012	R129	8.408	0.280	22.763	0.759
			beyoglu	Fatih	9.764		18.171	0.606	32.527	1.084
FATIH	14.355	0.479	kagithane	Besiktas	5.909		5.909	0.197	20.264	0.675
			besiktas	Sariyer	11.351	R130	17.260	0.575	31.615	1.054
			sariyer	Eyup	16.026		33.286	1.110	47.642	1.588
FATIH	14.355	0.479	kagithane	Beyoglu	6.367		6.367	0.212	20.722	0.691
			beyoglu	Sisli	5.012	R131	11.379	0.379	25.734	0.858
			sisli	Besiktas	4.541		15.919	0.531	30.275	1.009
AVCILAR	23.670	0.789	kucukcekmece	Bahcelievler	10.542		10.542	0.351	34.211	1.140
			bahcelievler	Gungoren	11.978	R132	22.519	0.751	46.189	1.540
			gungoren	Esenler	11.526		34.046	1.135	57.716	1.924

Table E2 (continued): Inflated Travel Times and Arrival Times for Distribution Centers and Demand Points for Deterministic Models 3.1 and 3.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
AVCILAR	23.670	0.789	kucukcekmece	Bahcelievler	10.542	R133	10.542	0.351	34.211	1.140
			bahcelievler	Bakirkoy	14.286		24.827	0.828	48.497	1.617
			bakirkoy	Zeytinburnu	42.162		66.990	2.233	90.659	3.022
AVCILAR	23.670	0.789	kucukcekmece	Bagcilar	9.889	R134	9.889	0.330	33.558	1.119
			bagcilar	Gungoren	13.920		23.809	0.794	47.479	1.583
			gungoren	Esenler	11.526		35.336	1.178	59.005	1.967
BAYRAMPASA	9.670	0.322	sultangazi	Gaziosmanpasa	5.622	R135	5.622	0.187	15.291	0.510
			gaziosmanpasa	Eyup	3.503		9.124	0.304	18.794	0.626
BAYRAMPASA	9.670	0.322	sultangazi	Arnavutkoy	19.027	R136	19.027	0.634	28.697	0.957
			arnavutkoy	Basaksehir	20.541		39.568	1.319	49.237	1.641
BAYRAMPASA	9.670	0.322	sultangazi	Bayrampasa	9.434	R137	9.434	0.314	19.104	0.637
			bayrampasa	Esenler	13.573		23.007	0.767	32.677	1.089
			esenler	Gungoren	12.150		35.157	1.172	44.827	1.494
FATIH	12.610	0.420	sisli	Beyoglu	5.012	R138	5.012	0.167	17.622	0.587
			beyoglu	Kagithane	6.696		11.708	0.390	24.318	0.811
			kagithane	Besiktas	5.909		17.617	0.587	30.227	1.008
FATIH	12.610	0.420	sisli	Eyup	8.891	R139	8.891	0.296	21.501	0.717
			eyup	Gaziosmanpasa	4.068		12.959	0.432	25.569	0.852
			gaziosmanpasa	Bayrampasa	4.866		17.825	0.594	30.435	1.014

Table E2 (continued): Inflated Travel Times and Arrival Times for Distribution Centers and Demand Points for Deterministic Models 3.1 and 3.2

Warehouses	Maximum Distance from Warehouses to Distribution Centers-km	Road Travel Times from Warehouses to Distribution Centers-hour	Distribution Centers-Demand Points	Demand Points	Distances Between Districts of the Routes-km	Routes	Total Distances from Distribution Centers to Demand Points -km	Total Travel Times from Distribution Centers to Demand Points-hour	Total Distances from Warehouses to Demand Points-km	Total Travel Times from Warehouses to Demand Points-hour
FATIH	12.610	0.420332356	sisli	Kagithane	3.614		3.614	0.120	16.224	0.541
			kagithane	Besiktas	5.909	R140	9.523	0.317	22.133	0.738
			besiktas	Sariyer	11.351		20.874	0.696	33.484	1.116
BAKIRKOY	42.162	1.405	zeytinburnu	Fatih	19.364		19.364	0.645	61.526	2.051
			fatih	Beyoglu	10.079	R141	29.443	0.981	71.605	2.387
			beyoglu	Sisli	5.012		34.455	1.149	76.617	2.554
BAKIRKOY	42.162	1.405	zeytinburnu	Fatih	19.364		19.364	0.645	61.526	2.051
			fatih	Bayrampasa	34.857	R142	54.221	1.807	96.383	3.213
			bayrampasa	Gaziosmanpasa	5.122		59.343	1.978	101.505	3.384
BAKIRKOY	42.162	1.405	zeytinburnu	Bakirkoy	40.000		40.000	1.333	82.162	2.739
			bakirkoy	Bahcelievler	14.596	R143	54.596	1.820	96.758	3.225
			bahcelievler	Gungoren	11.978		66.574	2.219	108.736	3.625

APPENDIX F

VOLUME WEIGHTED DEMAND FOR EACH DISTRICT AND POTENTIAL FACILITY LOCATIONS

Table F1: Volume Weighted Demand for Districts of Istanbul Under Damage Scenario A and Demand Scenarios C of JICA & IMM Report [10]

DISTRICT	Volume Weighted Demand-Model A (m3)	Volume Weighted Demand-Model C (m3)
AVCILAR	8,366.09	9,417.27
ARNAVUTKOY	1,173.62	1,323.73
BAHCELIEVLER	12,252.12	14,404.79
BAKIRKOY	5,594.20	6,223.45
BAGCILAR	8,620.29	10,134.38
BASAKSEHIR	4,522.75	5,730.31
BEYLIKDUZU	4,029.78	4,579.52
BEYOGLU	3,187.99	3,538.81
BESIKTAS	1,281.43	1,487.65
BUYUKCEKMECE	3,473.95	3,947.86
BAYRAMPASA	4,565.35	5,111.42
ESENYURT	10,285.73	11,688.91
EYUP	4,045.93	4,345.00
FATIH	9,150.46	10,143.74
GUNGOREN	5,707.47	6,755.72
GAZIOSMANPASA	3,024.33	3,472.75
KAGITHANE	2,887.64	3,305.44
KUCUKCEKMECE	10,373.37	11,600.25
SARIYER	850.14	967.25
SULTANGAZI	4,635.13	5,241.39
SISLI	1,598.09	1,902.13
ZEYTINBURNU	6,867.52	7,744.75
ESENLER	4,714.02	5,574.54
CATALCA	314.59	346.62
SILIVRI	1,129.65	1,245.34
SUM	122,651.63	140,233.03
Average	4,906.07	5,609.32
St.Deviation	3,260.96	3,738.27

Table F2: Potential Warehouse Locations

DISTRICT
AVCILAR
BAHCELIEVLER
BAKIRKOY
BAGCILAR
BASAKSEHIR
BEYLIKDUZU
BUYUKCEKMECE
BAYRAMPASA
ESENYURT
EYUP
FATIH
GUNGOREN
KUCUKCEKMECE
SULTANGAZI
ZEYTINBURNU
ESENLER

Table F3: Potential Distribution Center Locations

DISTRICT
arnavutkoy
avcilar
bagcilar
bahcelievler
bakirkoy
basaksehir
bayrampasa
besiktas
beylikduzu
beyoglu
buyukcekmece
esenler
esenyurt
eyup
fatih
gaziosmanpasa
gungoren
kagithane
kucukcekmece
sultangazi
sisli
zeytinburnu

APPENDIX G

FACILITY VULNERABILITIES FOR EACH DISTRICT UNDER DAMAGE MODELS A AND C [10]

Table G1: Facility (Warehouse and Distribution Center) Vulnerability Coefficients for Districts According to Model A of JICA & IMM Report [10]

Previously Was Part of Which Districts	District No	District	Buildings
			Heaviliy+Moderately Damaged
	1	AVCILAR	29.70%
GAZIOSMANPASA, CATALCA	2	ARNAVUTKOY	7.75%
	3	BAHCELIEVLER	29.20%
	4	BAKIRKOY	36.60%
	5	BAGCILAR	16.40%
KUCUKCEKMECE, BUYUKCEKMECE, ESENLER	6	BASAKSEHIR	19.53%
BUYUKCEKMECE	7	BEYLIKDUZU	23.90%
	8	BEYOGLU	18.70%
	9	BESIKTAS	9.80%
	10	BUYUKCEKMECE	23.90%
	11	BAYRAMPASA	24.40%
BUYUKCEKMECE	12	ESENYURT	23.90%
	13	EYUP	16.00%
	14	FATIH	31.00%
	15	GUNGOREN	26.70%

Table G1 (continued): Facility (Warehouse and Distribution Center) Vulnerability Coefficients for Districts According to Model A of JICA & IMM Report [10]

Previously Was Part of Which Districts	District No	District	Buildings
			Heaviliy+Moderately Damaged
	16	GAZIOSMANPASA	8.70%
	17	KAGITHANE	9.60%
	18	KUCUKCEKMECE	20.10%
	19	SARIYER	3.60%
GAZIOSMANPASA, EYUP,ESENLER	20	SULTANGAZI	13.10%
	21	SISLI	8.30%
	22	ZEYRINBURNU	34.00%
	23	ESENLER	14.60%
	24	CATALCA	6.80%
	25	SILIVRI	10.40%

Table G2: Facility (Warehouse and Distribution Center) Vulnerability Coefficients for Districts According to Model C of JICA & IMM Report [10]

Previously Was Part of Which Districts	District No	District	Buildings
			Heaviliy+Moderately Damaged
	1	AVCILAR	33.50%
GAZIOSMANPASA, CATALCA	2	ARNAVUTKOY	8.75%
	3	BAHCELIEVLER	34.40%
	4	BAKIRKOY	40.80%
	5	BAGCILAR	19.30%
KUCUKCEKMECE, BUYUKCEKMECE, ESENLER	6	BASAKSEHIR	24.90%
BUYUKCEKMECE	7	BEYLIKDUZU	27.30%
	8	BEYOGLU	20.80%
	9	BESIKTAS	11.40%
	10	BUYUKCEKMECE	27.30%
	11	BAYRAMPASA	27.40%
BUYUKCEKMECE	12	ESENYURT	27.30%
	13	EYUP	17.20%
	14	FATIH	34.40%
	15	GUNGOREN	31.70%
	16	GAZIOSMANPASA	10.00%
	17	KAGITHANE	11.00%
	18	KUCUKCEKMECE	22.50%
	19	SARIYER	4.10%
GAZIOSMANPASA, EYUP,ESENLER	20	SULTANGAZI	14.83%
	21	SISLI	9.90%
	22	ZEYRINBURNU	38.50%
	23	ESENLER	17.30%
	24	CATALCA	7.50%
	25	SILIVRI	11.50%

Table G3: Average Facility (Warehouse and Distribution Center) Vulnerability Coefficients for Districts According to Models A and C of JICA & IMM Report [10]

Previously Was Part of Which Districts	District No	District	Buildings
			Heaviliy+Moderately Damaged
	1	AVCILAR	31.60%
GAZIOSMANPASA, CATALCA	2	ARNAVUTKOY	8.25%
	3	BAHCELIEVLER	31.80%
	4	BAKIRKOY	38.70%
	5	BAGCILAR	17.85%
KUCUKCEKMECE, BUYUKCEKMECE, ESENLER	6	BASAKSEHIR	22.22%
BUYUKCEKMECE	7	BEYLIKDUZU	25.60%
	8	BEYOGLU	19.75%
	9	BESIKTAS	10.60%
	10	BUYUKCEKMECE	25.60%
	11	BAYRAMPASA	25.90%
BUYUKCEKMECE	12	ESENYURT	25.60%
	13	EYUP	16.60%
	14	FATIH	32.70%
	15	GUNGOREN	29.20%
	16	GAZIOSMANPASA	9.35%
	17	KAGITHANE	10.30%
	18	KUCUKCEKMECE	21.30%
	19	SARIYER	3.85%
GAZIOSMANPASA, EYUP,ESENLER	20	SULTANGAZI	13.97%
	21	SISLI	9.10%
	22	ZEYRINBURNU	36.25%
	23	ESENLER	15.95%
	24	CATALCA	7.15%
	25	SILIVRI	10.95%

APPENDIX H

FACILITY CAPACITIES AND FIXED COSTS

Table H1: Storage Capacities (m^3) and Fixed Opening and Operating Costs (TL) for Potential Warehouses

Districts	Capacity (m^3)	Fixed Opening and Operating Cost (TL)
AVCILAR	53,839.59	538,395.88
BAHCELIEVLER	82,353.75	823,537.52
BAKIRKOY	35,580.15	355,801.55
BAGCILAR	57,939.34	579,393.45
BASAKSEHIR	32,760.78	327,607.85
BEYLIKDUZU	26,181.61	261,816.10
BUYUKCEKMECE	22,570.35	225,703.53
BAYRAMPASA	29,222.55	292,225.48
ESENYURT	66,826.75	668,267.52
EYUP	24,840.83	248,408.29
FATIH	57,992.86	579,928.60
GUNGOREN	38,623.21	386,232.12
KUCUKCEKMECE	66,319.88	663,198.85
SULTANGAZI	29,965.61	299,656.13
ZEYTINBURNU	44,277.58	442,775.76
ESENLER	31,870.27	318,702.69

Table H2: Storage Capacities (m^3) and Fixed Opening and Operating Costs (TL) for Potential Distribution Centers

Districts	Capacity (m^3)	Fixed Opening and Operating Cost (TL)
avcilar	47,961.66	479,616.61
arnavutkoy	6,741.68	67,416.78
bahcelievler	73,362.80	733,627.97
bakirkoy	31,695.70	316,956.98
bagcilar	51,613.83	516,138.28
basaksehir	29,184.13	291,841.32
beylikduzu	23,323.24	233,232.38
beyoglu	18,022.98	180,229.80
besiktas	7,576.50	75,765.03
buyukcekmece	20,106.24	201,062.39
bayrampasa	26,032.18	260,321.82
esenyurt	59,530.95	595,309.54
eyup	22,128.84	221,288.36
fatih	51,661.50	516,615.00
gungoren	34,406.53	344,065.30
gaziosmanpasa	17,686.53	176,865.33
kagithane	16,834.41	168,344.09
kucukcekmece	59,079.42	590,794.24
sultangazi	26,694.12	266,941.23
sisli	9,687.47	96,874.67
zeytinburnu	39,443.58	394,435.80
esenler	28,390.84	283,908.39

APPENDIX I

FUNCTION VALUES AND CPU TIMES FOR STOCHASTIC MODEL 1.1 WITH DIFFERENT SCENARIO SETS

Table 11: Objective Function Values for the Stochastic Model 1.1 Replications with 30 Scenarios

Models With Scenario Replications	MIP Solution	Final Solve	Best Possible	Absolute Gap	Relative Gap	CPU Time (Seconds)
30 Scenarios Replication1	98,663,702	98,663,702	98,663,702	0	0	90.26
30 Scenarios Replication 2	96,063,993	96,063,993	96,063,993	0	0	88.32
30 Scenarios Replication 3	93,242,197	93,242,197	93,242,197	0	0	87.58
30 Scenarios Replication 4	101,471,350	101,471,350	101,471,350	0	0	88.12
30 Scenarios Replication 5	104,586,729	104,586,729	104,586,729	0	0	27.89
30 Scenarios Replication 6	89,955,902	89,955,902	89,955,902	0	0	90.32
30 Scenarios Replication 7	108,226,976	108,226,976	108,226,976	0	0	92.24
30 Scenarios Replication 8	111,961,792	111,961,792	111,961,792	0	0	87.66
30 Scenarios Replication 9	104,293,068	104,293,068	104,293,068	0	0	93.02
30 Scenarios Replication 10	113,947,754	113,947,754	113,947,754	0	0	87.64
30 Scenarios Replication 11	91,337,644	91,337,644	91,337,644	0	0	91.72
30 Scenarios Replication 12	105,677,758	105,677,758	105,677,758	0	0	88.10
30 Scenarios Replication 13	101,132,006	101,132,006	101,132,006	0	0	93.41
30 Scenarios Replication 14	107,699,251	107,699,251	107,699,251	0	0	86.70
30 Scenarios Replication 15	99,910,269	99,910,269	99,910,269	0	0	90.73
30 Scenarios Replication 16	101,471,551	101,471,551	101,471,551	0	0	89.13
30 Scenarios Replication 17	101,877,983	101,877,983	101,877,983	0	0	86.98
30 Scenarios Replication 18	97,091,331	97,091,331	97,091,331	0	0	87.10
30 Scenarios Replication 19	73,031,465	73,031,465	73,031,465	0	0	88.27
30 Scenarios Replication 20	95,484,641	95,484,641	95,484,641	0	0	89.36
Average	99,856,368	99,856,368	99,856,368	0	0	86.23
Standart Deviation	9,003,047	9,003,047	9,003,047	0	0	13.88

Table I2: Objective Function Values for the Stochastic Model 1.1 Replications with 60 Scenarios

Models With Scenario Replications	MIP Solution	Final Solve	Best Possible	Absolute Gap	Relative Gap	CPU Time (Seconds)
60 Scenarios Replication 1	101,763,783	101,763,783	101,763,783	0	0	239.08
60 Scenarios Replication 2	101,097,067	101,097,067	101,097,067	0	0	231.61
60 Scenarios Replication 3	105,453,124	105,453,124	105,453,124	0	0	249.99
60 Scenarios Replication 4	109,306,735	109,306,735	109,306,735	0	0	259.89
60 Scenarios Replication 5	114,117,207	114,117,207	114,117,207	0	0	238.31
60 Scenarios Replication 6	101,288,947	101,288,947	101,288,947	0	0	250.42
60 Scenarios Replication 7	112,117,307	112,117,307	112,117,307	0	0	232.38
60 Scenarios Replication 8	107,994,081	107,994,081	107,994,081	0	0	266.29
60 Scenarios Replication 9	110,886,042	110,886,042	110,886,042	0	0	266.94
60 Scenarios Replication 10	103,761,596	103,761,596	103,761,596	0	0	262.67
60 Scenarios Replication 11	94,242,933	94,242,933	94,242,933	0	0	229.46
60 Scenarios Replication 12	120,330,981	120,330,981	120,330,981	0	0	237.81
60 Scenarios Replication 13	99,925,014	99,925,014	99,925,014	0	0	234.45
60 Scenarios Replication 14	116,566,698	116,566,698	116,566,698	0	0	247.67
60 Scenarios Replication 15	114,849,345	114,849,345	114,849,345	0	0	244.67
60 Scenarios Replication 16	102,374,255	102,374,255	102,374,255	0	0	261.04
60 Scenarios Replication 17	99,279,793	99,279,793	99,279,793	0	0	218.80
60 Scenarios Replication 18	104,847,457	104,847,457	104,847,457	0	0	225.10
60 Scenarios Replication 19	100,100,106	100,100,106	100,100,106	0	0	255.60
60 Scenarios Replication 20	105,026,638	105,026,638	105,026,638	0	0	230.07
Average	106,266,455	106,266,455	106,266,455	0	0	244.11
Standart Deviation	6,790,208	6,790,208	6,790,208	0	0	14.53

Table 13: Objective Function Values for the Stochastic Model 1.1 Replications with 120 Scenarios

Models With Scenario Replications	MIP Solution	Final Solve	Best Possible	Absolute Gap	Relative Gap	CPU Time (Seconds)
120 Scenarios Replication 1	113,639,605	113,639,605	113,639,605	0	0	774.72
120 Scenarios Replication 2	114,626,939	114,626,939	114,626,939	0	0	992.03
120 Scenarios Replication 3	114,718,545	114,718,545	114,718,545	0	0	1,015.45
120 Scenarios Replication 4	112,467,971	112,467,971	112,467,971	0	0	813.80
120 Scenarios Replication 5	115,468,793	115,468,793	115,468,793	0	0	864.94
120 Scenarios Replication 6	113,868,118	113,868,118	113,868,118	0	0	1,369.03
120 Scenarios Replication 7	115,241,762	115,241,762	115,241,762	0	0	1,161.40
120 Scenarios Replication 8	111,224,772	111,224,772	111,224,772	0	0	1,264.66
120 Scenarios Replication 9	109,311,195	109,311,195	109,311,195	0	0	867.52
120 Scenarios Replication 10	118,912,020	118,912,020	118,912,020	0	0	1,220.91
120 Scenarios Replication 11	101,380,716	101,380,716	101,380,716	0	0	843.41
120 Scenarios Replication 12	108,862,961	108,862,961	108,862,961	0	0	759.77
120 Scenarios Replication 13	113,369,892	113,369,892	113,369,892	0	0	778.41
120 Scenarios Replication 14	108,191,634	108,191,634	108,191,634	0	0	749.05
120 Scenarios Replication 15	117,145,217	117,145,217	117,145,217	0	0	1,063.97
120 Scenarios Replication 16	107,500,334	107,500,334	107,500,334	0	0	965.98
120 Scenarios Replication 17	109,446,576	109,446,576	109,446,576	0	0	752.24
120 Scenarios Replication 18	101,257,558	101,257,558	101,257,558	0	0	685.16
120 Scenarios Replication 19	121,269,938	121,269,938	121,269,938	0	0	937.08
120 Scenarios Replication 20	119,220,737	119,220,737	119,220,737	0	0	853.17

Table I3 (continued): Objective Function Values for the Stochastic Model 1.1 Replications with 120 Scenarios

Models With Scenario Replications	MIP Solution	Final Solve	Best Possible	Absolute Gap	Relative Gap	CPU Time (Seconds)
120 Scenarios Replication 21	102,883,866	102,883,866	102,883,866	0	0	806.51
120 Scenarios Replication 22	109,937,177	109,937,177	109,937,177	0	0	964.30
120 Scenarios Replication 23	113,787,512	113,787,512	113,787,512	0	0	723.03
120 Scenarios Replication 24	107,637,418	107,637,418	107,637,418	0	0	891.64
120 Scenarios Replication 25	116,537,367	116,537,367	116,537,367	0	0	938.26
120 Scenarios Replication 26	108,092,423	108,092,423	108,092,423	0	0	965.05
120 Scenarios Replication 27	108,991,746	108,991,746	108,991,746	0	0	770.74
120 Scenarios Replication 28	107,929,400	107,929,400	107,929,400	0	0	1,017.30
120 Scenarios Replication 29	113,912,440	113,912,440	113,912,440	0	0	1,101.36
120 Scenarios Replication 30	108,172,666	108,172,666	108,172,666	0	0	1,115.75
120 Scenarios Replication 31	106,540,115	106,540,115	106,540,115	0	0	749.13
120 Scenarios Replication 32	110,705,335	110,705,335	110,705,335	0	0	790.98
120 Scenarios Replication 33	105,152,280	105,152,280	105,152,280	0	0	1,240.34
120 Scenarios Replication 34	110,017,714	110,017,714	110,017,714	0	0	960.44
120 Scenarios Replication 35	112,924,777	112,924,777	112,924,777	0	0	1,060.32
120 Scenarios Replication 36	109,350,523	109,350,523	109,350,523	0	0	674.53
120 Scenarios Replication 37	119,498,088	119,498,088	119,498,088	0	0	811.81
120 Scenarios Replication 38	107,282,658	107,282,658	107,282,658	0	0	770.90
120 Scenarios Replication 39	119,484,487	119,484,487	119,484,487	0	0	1,188.55
120 Scenarios Replication 40	106,371,081	106,371,081	106,371,081	0	0	925.31

Table I3 (continued): Objective Function Values for the Stochastic Model 1.1 Replications with 120 Scenarios

Models With Scenario Replications	MIP Solution	Final Solve	Best Possible	Absolute Gap	Relative Gap	CPU Time (Seconds)
120 Scenarios Replication 41	118,044,768	118,044,768	118,044,768	0	0	1,164.18
120 Scenarios Replication 42	102,552,817	102,552,817	102,552,817	0	0	778.84
120 Scenarios Replication 43	100,703,770	100,703,770	100,703,770	0	0	1,128.44
120 Scenarios Replication 44	114,651,356	114,651,356	114,651,356	0	0	885.89
120 Scenarios Replication 45	109,663,191	109,663,191	109,663,191	0	0	1,294.05
120 Scenarios Replication 46	111,163,126	111,163,126	111,163,126	0	0	780.19
120 Scenarios Replication 47	113,050,548	113,050,548	113,050,548	0	0	779.15
120 Scenarios Replication 48	107,358,669	107,358,669	107,358,669	0	0	907.28
120 Scenarios Replication 49	113,026,383	113,026,383	113,026,383	0	0	833.86
120 Scenarios Replication 50	110,130,593	110,130,593	110,130,593	0	0	774.95
Average	111,053,592	111,053,592	111,053,592	0	0	930.51
Standart Deviation	5,029,016	5,029,016	5,029,016	0	0	177.04

APPENDIX J

SECOND STAGE OBJECTIVE FUNCTION VALUES FOR STOCHASTIC MODEL 1.1 WITH 1,000 SCENARIOS

Table J1: Objective Function Values for the Stochastic Model 1.1 with 1,000 Scenario Set for Second Stage

Model No	Objective Function	Model No	Objective Function
1_1	117,366,554	3_2	117,323,857
1_2	117,959,748	3_3	116,309,933
1_3	116,827,191	3_4	116,882,067
1_4	107,978,425	3_5	121,295,443
1_5	116,536,564	3_6	124,465,556
1_6	120,828,572	3_7	122,977,842
1_7	134,419,764	3_8	117,787,762
1_8	119,348,946	3_9	107,493,988
1_9	122,095,729	3_10	123,719,265
1_10	126,701,524	4_1	113,022,172
2_1	107,837,081	4_2	118,267,174
2_2	121,841,895	4_3	108,709,574
2_3	120,761,439	4_4	112,181,886
2_4	108,385,963	4_5	105,133,642
2_5	124,776,058	4_6	116,015,179
2_6	122,620,198	4_7	119,136,176
2_7	128,333,461	4_8	110,446,820
2_8	130,963,259	4_9	106,527,979
2_9	119,874,800	4_10	133,253,632
2_10	113,159,553	5_1	120,689,583
3_1	112,808,093	5_2	120,830,873

Table J1 (continued): Objective Function Values for the Stochastic Model 1.1 with 1,000 Scenario Set for Second Stage

Model No	Objective Function	Model No	Objective Function
5_3	118,471,260	8_1	115,657,640
5_4	122,921,195	8_2	120,231,070
5_5	122,773,247	8_3	117,848,181
5_6	124,769,043	8_4	114,698,417
5_7	121,369,269	8_5	120,652,428
5_8	120,892,735	8_6	120,764,346
5_9	111,362,038	8_7	121,711,057
5_10	133,503,596	8_8	127,048,650
6_1	120,859,285	8_9	114,519,918
6_2	115,041,778	8_10	122,813,389
6_3	110,252,094	9_1	116,207,879
6_4	111,201,921	9_2	115,084,892
6_5	106,687,149	9_3	108,161,709
6_6	121,272,507	9_4	111,896,244
6_7	133,414,924	9_5	104,309,968
6_8	107,464,906	9_6	116,668,132
6_9	116,144,263	9_7	121,668,325
6_10	127,976,857	9_8	104,650,320
7_1	115,657,640	9_9	107,176,531
7_2	120,231,070	9_10	140,271,645
7_3	117,848,181	10_1	117,392,569
7_4	114,698,417	10_2	120,517,764
7_5	120,652,428	10_3	116,921,869
7_6	120,764,346	10_4	117,036,154
7_7	121,711,057	10_5	117,479,404
7_8	127,048,650	10_6	121,342,240
7_9	114,519,918	10_7	123,374,353
7_10	122,813,389	10_8	124,611,630

Table J1 (continued): Objective Function Values for the Stochastic Model 1.1 with 1,000 Scenario Set for Second Stage

Model No	Objective Function	Model No	Objective Function
10_9	113,857,755	13_7	133,112,421
10_10	120,805,504	13_8	118,960,427
11_1	121,106,463	13_9	122,715,597
11_2	119,492,939	13_10	123,657,430
11_3	117,680,987	14_1	134,055,165
11_4	110,941,642	14_2	143,834,035
11_5	120,284,207	14_3	132,875,901
11_6	122,363,939	14_4	143,973,244
11_7	132,707,966	14_5	133,349,528
11_8	114,574,863	14_6	137,648,493
11_9	118,755,046	14_7	144,664,873
11_10	140,200,723	14_8	143,355,885
12_1	122,114,129	14_9	137,766,804
12_2	120,066,282	14_10	148,984,869
12_3	118,770,413	15_1	115,332,815
12_4	111,727,271	15_2	117,684,012
12_5	120,171,699	15_3	115,546,892
12_6	123,865,835	15_4	120,407,854
12_7	137,162,492	15_5	120,205,403
12_8	115,066,765	15_6	123,476,031
12_9	123,571,261	15_7	119,550,284
12_10	137,507,372	15_8	116,847,642
13_1	115,354,749	15_9	106,372,502
13_2	116,377,168	15_10	131,605,251
13_3	118,789,548	16_1	118,480,333
13_4	106,493,321	16_2	115,883,563
13_5	118,561,033	16_3	109,322,736
13_6	121,332,302	16_4	111,509,171

Table J1 (continued): Objective Function Values for the Stochastic Model 1.1 with 1,000 Scenario Set for Second Stage

Model No	Objective Function	Model No	Objective Function
16_5	103,886,901	19_3	111,525,217
16_6	114,243,369	19_4	113,669,229
16_7	120,977,214	19_5	113,643,643
16_8	106,694,522	19_6	121,468,798
16_9	110,632,167	19_7	122,803,917
16_10	140,550,735	19_8	110,694,487
17_1	116,346,800	19_9	108,161,516
17_2	112,932,905	19_10	126,685,087
17_3	114,629,174	20_1	112,981,641
17_4	110,154,127	20_2	120,065,579
17_5	117,148,459	20_3	120,817,885
17_6	124,921,467	20_4	114,863,561
17_7	129,647,875	20_5	124,643,414
17_8	113,928,014	20_6	124,900,133
17_9	115,946,057	20_7	127,124,397
17_10	129,237,215	20_8	124,508,937
18_1	114,255,987	20_9	117,148,989
18_2	119,202,231	20_10	119,784,699
18_3	110,950,260	21_1	112,097,654
18_4	107,664,042	21_2	119,847,876
18_5	102,819,285	21_3	119,621,894
18_6	113,755,007	21_4	108,453,520
18_7	126,762,822	21_5	120,821,098
18_8	111,720,921	21_6	119,874,370
18_9	115,355,693	21_7	129,088,332
18_10	129,360,047	21_8	126,795,359
19_1	117,259,587	21_9	119,566,036
19_2	113,838,444	21_10	118,229,746

Table J1 (continued): Objective Function Values for the Stochastic Model 1.1 with 1,000 Scenario Set for Second Stage

Model No	Objective Function	Model No	Objective Function
22_1	116,764,520	24_9	107,322,378
22_2	116,361,498	24_10	127,858,795
22_3	106,844,373	25_1	111,352,028
22_4	109,086,113	25_2	123,136,751
22_5	101,006,546	25_3	116,114,695
22_6	115,004,850	25_4	109,416,934
22_7	124,141,897	25_5	109,998,978
22_8	105,119,851	25_6	115,673,316
22_9	110,825,370	25_7	125,748,217
22_10	136,955,146	25_8	120,520,496
23_1	118,855,328	25_9	117,951,281
23_2	113,777,706	25_10	125,312,381
23_3	109,351,027	26_1	115,908,347
23_4	112,274,365	26_2	120,161,047
23_5	107,367,459	26_3	119,779,135
23_6	121,820,682	26_4	114,549,410
23_7	129,336,842	26_5	122,534,388
23_8	107,042,548	26_6	120,173,291
23_9	113,202,020	26_7	122,273,267
23_10	128,746,219	26_8	126,685,903
24_1	115,507,544	26_9	114,770,297
24_2	114,079,404	26_10	126,174,742
24_3	111,072,646	27_1	111,582,531
24_4	115,859,343	27_2	120,244,221
24_5	113,212,709	27_3	110,633,817
24_6	124,218,974	27_4	109,283,915
24_7	125,531,141	27_5	106,229,656
24_8	109,495,225	27_6	116,083,439

Table J1 (continued): Objective Function Values for the Stochastic Model 1.1 with 1,000 Scenario Set for Second Stage

Model No	Objective Function	Model No	Objective Function
27_7	123,609,778	30_5	126,415,721
27_8	114,864,981	30_6	125,175,181
27_9	112,840,923	30_7	127,983,268
27_10	126,777,602	30_8	128,566,271
28_1	110,159,130	30_9	117,316,560
28_2	123,129,189	30_10	116,028,676
28_3	121,949,610	31_1	118,353,047
28_4	108,262,568	31_2	111,532,320
28_5	125,498,021	31_3	109,674,415
28_6	122,886,853	31_4	112,462,296
28_7	132,012,141	31_5	110,622,300
28_8	130,633,374	31_6	121,090,124
28_9	123,761,318	31_7	126,355,408
28_10	112,987,696	31_8	104,049,058
29_1	120,557,861	31_9	109,526,625
29_2	113,149,048	31_10	130,711,203
29_3	109,437,004	32_1	115,372,204
29_4	110,124,114	32_2	117,697,592
29_5	107,024,476	32_3	111,368,326
29_6	119,878,841	32_4	107,874,425
29_7	131,216,785	32_5	104,224,396
29_8	105,215,003	32_6	113,015,115
29_9	114,204,997	32_7	125,244,297
29_10	129,693,800	32_8	109,033,109
30_1	109,158,763	32_9	114,117,298
30_2	121,829,846	32_10	134,000,941
30_3	120,526,740	33_1	117,559,419
30_4	111,064,980	33_2	114,141,896

Table J1 (continued): Objective Function Values for the Stochastic Model 1.1 with 1,000 Scenario Set for Second Stage

Model No	Objective Function	Model No	Objective Function
33_3	111,067,184	36_1	120,209,424
33_4	113,020,099	36_2	111,832,653
33_5	112,532,744	36_3	110,014,737
33_6	120,762,841	36_4	111,374,943
33_7	123,504,221	36_5	109,153,576
33_8	111,408,538	36_6	120,091,417
33_9	109,294,949	36_7	128,839,911
33_10	125,490,363	36_8	103,558,494
34_1	118,070,757	36_9	111,883,957
34_2	120,843,322	36_10	131,722,685
34_3	115,797,731	37_1	117,292,300
34_4	118,535,923	37_2	118,510,546
34_5	115,006,060	37_3	109,496,598
34_6	119,961,596	37_4	113,575,315
34_7	121,546,037	37_5	104,087,011
34_8	122,849,876	37_6	116,419,508
34_9	112,420,194	37_7	122,071,570
34_10	123,434,363	37_8	113,569,969
35_1	116,275,011	37_9	113,174,393
35_2	118,928,936	37_10	136,750,410
35_3	113,576,634	38_1	119,529,191
35_4	112,324,887	38_2	120,961,185
35_5	109,042,924	38_3	118,413,183
35_6	115,046,769	38_4	117,871,328
35_7	120,523,351	38_5	118,586,941
35_8	115,040,091	38_6	121,371,105
35_9	113,471,110	38_7	125,156,300
35_10	133,987,939	38_8	126,223,152

Table J1 (continued): Objective Function Values for the Stochastic Model 1.1 with 1,000 Scenario Set for Second Stage

Model No	Objective Function	Model No	Objective Function
38_9	114,113,117	41_7	122,295,013
38_10	123,415,980	41_8	108,228,500
39_1	115,700,298	41_9	112,656,707
39_2	114,798,572	41_10	136,976,460
39_3	107,515,564	42_1	115,349,752
39_4	111,259,608	42_2	111,500,219
39_5	103,751,899	42_3	111,921,838
39_6	115,662,726	42_4	106,275,371
39_7	120,543,985	42_5	115,041,712
39_8	103,405,181	42_6	120,619,973
39_9	107,320,184	42_7	128,025,033
39_10	139,595,447	42_8	109,667,057
40_1	115,336,880	42_9	113,383,737
40_2	122,735,234	42_10	129,259,994
40_3	113,800,717	43_1	111,749,024
40_4	118,114,794	43_2	121,658,547
40_5	111,629,739	43_3	116,442,994
40_6	114,921,438	43_4	109,804,466
40_7	113,694,412	43_5	112,556,996
40_8	120,023,507	43_6	117,956,324
40_9	108,069,280	43_7	128,283,865
40_10	136,026,073	43_8	120,852,069
41_1	117,412,616	43_9	118,336,319
41_2	116,387,062	43_10	119,156,198
41_3	110,994,234	44_1	114,958,308
41_4	110,175,596	44_2	114,711,033
41_5	106,039,947	44_3	111,990,449
41_6	115,269,085	44_4	109,949,949

Table J1 (continued): Objective Function Values for the Stochastic Model 1.1 with 1,000 Scenario Set for Second Stage

Model No	Objective Function	Model No	Objective Function
44_5	113,042,535	47_3	112,698,339
44_6	121,058,824	47_4	116,584,383
44_7	127,696,217	47_5	116,444,561
44_8	111,848,196	47_6	124,131,098
44_9	112,848,880	47_7	122,456,551
44_10	120,131,612	47_8	112,564,518
45_1	115,235,211	47_9	106,606,882
45_2	111,889,113	47_10	127,525,459
45_3	111,918,731	48_1	111,842,364
45_4	106,666,593	48_2	122,191,540
45_5	115,304,466	48_3	118,082,755
45_6	121,488,138	48_4	116,222,830
45_7	128,319,148	48_5	117,178,911
45_8	110,609,297	48_6	120,564,123
45_9	113,686,573	48_7	118,211,642
45_10	128,604,807	48_8	120,805,677
46_1	108,283,695	48_9	107,595,100
46_2	121,557,042	48_10	131,471,475
46_3	120,966,861	49_1	116,369,256
46_4	108,548,844	49_2	112,955,118
46_5	124,997,917	49_3	113,239,892
46_6	122,357,104	49_4	108,135,709
46_7	128,258,028	49_5	115,453,927
46_8	129,820,684	49_6	121,537,415
46_9	119,061,388	49_7	127,571,196
46_10	114,428,559	49_8	112,976,015
47_1	116,119,176	49_9	114,852,875
47_2	114,515,756	49_10	129,306,639

Table J1 (continued): Objective Function Values for the Stochastic Model 1.1 with 1,000 Scenario Set for Second Stage

Model No	Objective Function
50_1	122,119,476
50_2	118,033,448
50_3	119,789,183
50_4	115,652,094
50_5	119,938,273
50_6	122,238,708
50_7	127,631,526
50_8	123,960,660
50_9	122,017,552
50_10	136,440,794

APPENDIX K

INCREASED FACILITY CAPACITIES AND FIXED COSTS FOR BENCHMARK MODEL

Table K1: 30% Increased Storage Capacities (m^3) and Fixed Opening and Operating Costs (TL) for Potential Warehouses

Districts	Capacity (m^3)	Fixed Opening and Operating Cost (TL)
AVCILAR	69,991.46	699,914.65
BAHCELIEVLER	107,059.88	1,070,598.77
BAKIRKOY	46,254.20	462,542.01
BAGCILAR	75,321.15	753,211.48
BASAKSEHIR	42,589.02	425,890.20
BEYLIKDUZU	34,036.09	340,360.93
BUYUKCEKMECE	29,341.46	293,414.60
BAYRAMPASA	37,989.31	379,893.12
ESENYURT	86,874.78	868,747.77
EYUP	32,293.08	322,930.77
FATIH	75,390.72	753,907.18
GUNGOREN	50,210.18	502,101.75
KUCUKCEKMECE	86,215.85	862,158.50
SULTANGAZI	38,955.30	389,552.97
ZEYTINBURNU	57,560.85	575,608.49
ESENLER	41,431.35	414,313.50

Table K2: 30% Increased Storage Capacities (m^3) and Fixed Opening and Operating Costs (TL) for Potential Distribution Centers

Districts	Capacity (m^3)	Fixed Opening and Operating Cost (TL)
avcilar	62,350.16	623,501.60
arnavutkoy	8,764.18	87,641.81
bahcelievler	95,371.64	953,716.36
bakirkoy	41,204.41	412,044.08
bagcilar	67,097.98	670,979.76
basaksehir	37,939.37	379,393.72
beylikduzu	30,320.21	303,202.09
beyoglu	23,429.87	234,298.73
besiktas	9,849.45	98,494.54
buyukcekmece	26,138.11	261,381.11
bayrampasa	33,841.84	338,418.36
esenyurt	77,390.24	773,902.40
eyup	28,767.49	287,674.87
fatih	67,159.95	671,599.50
gungoren	44,728.49	447,284.89
gaziosmanpasa	22,992.49	229,924.93
kagithane	21,884.73	218,847.32
kucukcekmece	76,803.25	768,032.51
sultangazi	34,702.36	347,023.60
sisli	12,593.71	125,937.07
zeytinburnu	51,276.65	512,766.55
esenler	36,908.09	369,080.90

APPENDIX L

LOWER ROAD VULNERABILITIES FOR PRE-DETERMINED ROUTES BETWEEN FACILITIES AND DEMAND POINTS

Table L1: Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Warehouses to Distribution Centers

Warehouse	Distribution Center	Road Vulnerability	Road No
AVCILAR	beylikduzu	0.079	R1
AVCILAR	esenyurt	0.088	R2
AVCILAR	kucukcekmece	0.257	R3
BAHCELIEVLER	bagcilar	0.165	R4
BAHCELIEVLER	gungoren	0.36	R5
BAHCELIEVLER	bakirkoy	0.382	R6
BAKIRKOY	bahcelievler	0.382	R7
BAKIRKOY	gungoren	0.473	R8
BAKIRKOY	zeytinburnu	0.465	R9
BAGCILAR	bahcelievler	0.165	R10
BAGCILAR	gungoren	0.368	R11
BAGCILAR	esenler	0.086	R12
BAGCILAR	basaksehir	0.055	R13
BASAKSEHIR	bagcilar	0.055	R14
BASAKSEHIR	kucukcekmece	0.059	R15
BASAKSEHIR	esenler	0.052	R16
BASAKSEHIR	arnavutkoy	0.05	R17
BEYLIKDUZU	avcilar	0.079	R18
BEYLIKDUZU	esenyurt	0.05	R19

Table L1 (continued): Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Warehouses to Distribution Centers

Warehouse	Distribution Center	Road Vulnerability	Road No
BEYLIKDUZU	buyukcekmece	0.07	R20
BUYUKCEKMECE	avcilar	0.08	R21
BUYUKCEKMECE	beylikduzu	0.07	R22
BUYUKCEKMECE	esenyurt	0.067	R23
BAYRAMPASA	esenler	0.359	R24
BAYRAMPASA	gaziosmanpasa	0.125	R25
BAYRAMPASA	fatih	0.466	R26
BAYRAMPASA	sultangazi	0.09	R27
BAYRAMPASA	eyup	0.127	R28
ESENYURT	avcilar	0.088	R29
ESENYURT	beylikduzu	0.05	R30
ESENYURT	buyukcekmece	0.067	R31
EYUP	gaziosmanpasa	0.071	R32
EYUP	sultangazi	0.063	R33
EYUP	kagithane	0.086	R34
EYUP	beyoglu	0.096	R35
EYUP	besiktas	0.067	R36
EYUP	sisli	0.057	R37
FATIH	bayrampasa	0.466	R38
FATIH	beyoglu	0.205	R39
FATIH	zeytinburnu	0.369	R40
FATIH	besiktas	0.098	R41
FATIH	kagithane	0.106	R42
FATIH	sisli	0.18	R43
GUNGOREN	bagcilar	0.368	R44
GUNGOREN	bahcelievler	0.36	R45
GUNGOREN	esenler	0.385	R46

Table L1 (continued): Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Warehouses to Distribution Centers

Warehouse	Distribution Center	Road Vulnerability	Road No
KUCUKCEKMECE	bagcilar	0.111	R47
KUCUKCEKMECE	bahcelievler	0.179	R48
KUCUKCEKMECE	gungoren	0.233	R49
KUCUKCEKMECE	basaksehir	0.059	R50
SULTANGAZI	bayrampasa	0.09	R51
SULTANGAZI	eyup	0.063	R52
SULTANGAZI	gaziosmanpasa	0.05	R53
SULTANGAZI	arnavutkoy	0.05	R54
ZEYTINBURNU	fatih	0.369	R55
ZEYTINBURNU	bakirkoy	0.465	R56
ZEYTINBURNU	esenler	0.302	R57
ESENLER	bayrampasa	0.359	R58
ESENLER	gungoren	0.385	R59
ESENLER	bagcilar	0.086	R60
AVCILAR	avcilar	0	R61
BAHCELIEVLER	bahcelievler	0	R62
BAKIRKOY	bakirkoy	0	R63
BAGCILAR	bagcilar	0	R64
BASAKSEHIR	basaksehir	0	R65
BEYLIKDUZU	beylikduzu	0	R66
BUYUKCEKMECE	buyukcekmece	0	R67
BAYRAMPASA	bayrampasa	0	R68
ESENYURT	esenyurt	0	R69
EYUP	eyup	0	R70
FATIH	fatih	0	R71
GUNGOREN	gungoren	0	R72
KUCUKCEKMECE	kucukcekmece	0	R73

Table L1 (continued): Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Warehouses to Distribution Centers

Warehouse	Distribution Center	Road Vulnerability	Road No
SULTANGAZI	sultangazi	0	R74
ZEYTINBURNU	zeytinburnu	0	R75
ESENLER	esenler	0	R76

Table L2: Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
arnavutkoy	Sultangazi	0.05	R77
	Gaziosmanpasa	0.05	R77
	Eyup	0.071	R77
arnavutkoy	Basaksehir	0.05	R78
	Kucukcekmece	0.059	R78
	Bahcelievler	0.179	R78
arnavutkoy	Gaziosmanpasa	0.05	R79
	Bayrampasa	0.125	R79
	Esenler	0.359	R79
avcilar	Esenyurt	0.088	R80
	Beylikduzu	0.05	R80
	Buyukcekmece	0.07	R80
avcilar	Kucukcekmece	0.257	R81
	Bahcelievler	0.179	R81
	Gungoren	0.36	R81
avcilar	Beylikduzu	0.079	R82
	Esenyurt	0.05	R82
	Buyukcekmece	0.067	R82
bagcilar	Bahcelievler	0.165	R83
	Gungoren	0.36	R83
	Esenler	0.385	R83
bagcilar	Kucukcekmece	0.111	R84
	Bakirkoy	0.128	R84
	Zeytinburnu	0.465	R84
bagcilar	Gungoren	0.368	R85
	Bayrampasa	0.455	R85
	Gaziosmanpasa	0.125	R85

Table L2 (continued): Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
bahcelievler	Bakirkoy	0.382	R86
	Zeytinburnu	0.465	R86
	Fatih	0.369	R86
bahcelievler	Gungoren	0.36	R87
	Esenler	0.385	R87
	Bayrampasa	0.359	R87
bahcelievler	Bagcilar	0.165	R88
	Kucukcekmece	0.111	R88
	Avcilar	0.257	R88
bakirkoy	Bahcelievler	0.382	R89
	Gungoren	0.36	R89
	Esenler	0.385	R89
bakirkoy	Zeytinburnu	0.465	R90
	Fatih	0.369	R90
	Bayrampasa	0.466	R90
bakirkoy	Bagcilar	0.28	R91
	Kucukcekmece	0.111	R91
	Avcilar	0.257	R91
basaksehir	Kucukcekmece	0.059	R92
	Bahcelievler	0.179	R92
	Gungoren	0.36	R92
basaksehir	Bagcilar	0.055	R93
	Esenler	0.086	R93
	Bayrampasa	0.359	R93
basaksehir	Esenler	0.052	R94
	Gaziosmanpasa	0.064	R94
	Eyup	0.071	R94

Table L2 (continued): Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
bayrampasa	Gaziosmanpasa	0.125	R95
	Eyup	0.071	R95
	Sultangazi	0.063	R95
bayrampasa	Esenler	0.359	R96
	Gungoren	0.385	R96
	Bahcelievler	0.36	R96
bayrampasa	Fatih	0.466	R97
	Zeytinburnu	0.369	R97
	Bakirkoy	0.465	R97
besiktas	Sisli	0.05	R98
	Kagithane	0.056	R98
	Beyoglu	0.057	R98
besiktas	Sariyer	0.05	R99
	Eyup	0.057	R99
	Gaziosmanpasa	0.071	R99
besiktas	Kagithane	0.065	R100
	Sisli	0.056	R100
	Fatih	0.18	R100
beylikduzu	Esenyurt	0.05	R101
	Avcilar	0.088	R101
	Kucukcekmece	0.257	R101
beylikduzu	Buyukcekmece	0.07	R102
	Catalca	0.05	R102
beylikduzu	Avcilar	0.079	R103
	Esenyurt	0.088	R103
	Buyukcekmece	0.067	R103

Table L2 (continued): Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
beyoglu	Sisli	0.107	R104
	Kagithane	0.056	R104
	Besiktas	0.065	R104
beyoglu	Fatih	0.205	R105
	Bayrampasa	0.466	R105
	Gaziosmanpasa	0.125	R105
beyoglu	Kagithane	0.057	R106
	Eyup	0.086	R106
	Sultangazi	0.063	R106
buyukcekmece	Esenyurt	0.067	R107
	Beylikduzu	0.05	R107
	Avcilar	0.079	R107
buyukcekmece	Catalca	0.05	R108
	Silivri	0.05	R108
buyukcekmece	Silivri	0.05	R109
	Catalca	0.05	R109
buyukcekmece	Beylikduzu	0.07	R110
	Kucukcekmece	0.198	R110
	Bahcelievler	0.179	R110
esenler	Gungoren	0.385	R111
	Bahcelievler	0.36	R111
	Bagcilar	0.165	R111
esenler	Bayrampasa	0.359	R112
	Gaziosmanpasa	0.125	R112
	Eyup	0.071	R112

Table L2 (continued): Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
esenler	Bagcilar	0.086	R113
	Kucukcekmece	0.111	R113
	Bahcelievler	0.179	R113
esenyurt	Beylikduzu	0.05	R114
	Avcilar	0.079	R114
	Kucukcekmece	0.257	R114
esenyurt	Buyukcekmece	0.067	R115
	Beylikduzu	0.07	R115
	Avcilar	0.079	R115
esenyurt	Avcilar	0.088	R116
	Beylikduzu	0.079	R116
	Buyukcekmece	0.07	R116
eyup	Gaziosmanpasa	0.071	R117
	Bayrampasa	0.125	R117
	Esenler	0.359	R117
eyup	Kagithane	0.086	R118
	Sisli	0.056	R118
	Beyoglu	0.107	R118
eyup	Sultangazi	0.063	R119
	Gaziosmanpasa	0.05	R119
	Bayrampasa	0.125	R119
fatih	Bayrampasa	0.466	R120
	Gaziosmanpasa	0.125	R120
	Eyup	0.071	R120
fatih	Zeytinburnu	0.369	R121
	Bakirkoy	0.465	R121
	Bahcelievler	0.382	R121

Table L2 (continued): Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
fatih	Beyoglu	0.205	R122
	Sisli	0.107	R122
	Kagithane	0.056	R122
gaziosmanpasa	Eyup	0.071	R123
	Sultangazi	0.063	R123
	Bayrampasa	0.09	R123
gaziosmanpasa	Bayrampasa	0.125	R124
	Esenler	0.359	R124
	Gungoren	0.385	R124
gaziosmanpasa	Sultangazi	0.05	R125
	Eyup	0.063	R125
	Kagithane	0.086	R125
gungoren	Esenler	0.385	R126
	Bayrampasa	0.359	R126
	Gaziosmanpasa	0.125	R126
gungoren	Esenler	0.385	R127
	Bagcilar	0.086	R127
	Bahcelievler	0.165	R127
gungoren	Bahcelievler	0.36	R128
	Bakirkoy	0.382	R128
	Zeytinburnu	0.465	R128
kagithane	Sisli	0.056	R129
	Beyoglu	0.107	R129
	Fatih	0.205	R129
kagithane	Besiktas	0.065	R130
	Sariyer	0.05	R130
	Eyup	0.057	R130

Table L2 (continued): Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
kagithane	Beyoglu	0.057	R131
	Sisli	0.107	R131
	Besiktas	0.05	R131
kucukcekmece	Bahcelievler	0.179	R132
	Gungoren	0.36	R132
	Esenler	0.385	R132
kucukcekmece	Bahçelievler	0.179	R133
	Bakırkoy	0.382	R133
	Zeytinburnu	0.465	R133
kucukcekmece	Bagcilar	0.111	R134
	Gungoren	0.368	R134
	Esenler	0.385	R134
sultangazi	Gaziosmanpasa	0.05	R135
	Eyup	0.071	R135
sultangazi	Arnavutkoy	0.05	R136
	Basaksehir	0.05	R136
sultangazi	Bayrampasa	0.09	R137
	Esenler	0.359	R137
	Gungoren	0.385	R137
sisli	Beyoglu	0.107	R138
	Kagithane	0.057	R138
	Besiktas	0.065	R138
sisli	Eyup	0.057	R139
	Gaziosmanpasa	0.071	R139
	Bayrampasa	0.125	R139

Table L2 (continued): Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
sisli	Kagithane	0.056	R140
	Besiktas	0.065	R140
	Sariyer	0.05	R140
zeytinburnu	Fatih	0.369	R141
	Beyoglu	0.205	R141
	Sisli	0.107	R141
zeytinburnu	Fatih	0.369	R142
	Bayrampasa	0.466	R142
	Gaziosmanpasa	0.125	R142
zeytinburnu	Bakirkoy	0.465	R143
	Bahcelievler	0.382	R143
	Gungoren	0.36	R143
arnavutkoy	Arnavutkoy	0	R77
arnavutkoy	Arnavutkoy	0	R78
arnavutkoy	Arnavutkoy	0	R79
avcilar	Avcilar	0	R80
avcilar	Avcilar	0	R81
avcilar	Avcilar	0	R82
bagcilar	Bagcilar	0	R83
bagcilar	Bagcilar	0	R84
bagcilar	Bagcilar	0	R85
bahcelievler	Bahcelievler	0	R86
bahcelievler	Bahcelievler	0	R87
bahcelievler	Bahcelievler	0	R88
bakirkoy	Bakirkoy	0	R89
bakirkoy	Bakirkoy	0	R90
bakirkoy	Bakirkoy	0	R91

Table L2 (continued): Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
basaksehir	Basaksehir	0	R92
basaksehir	Basaksehir	0	R93
basaksehir	Basaksehir	0	R94
bayrampasa	Bayrampasa	0	R95
bayrampasa	Bayrampasa	0	R96
bayrampasa	Bayrampasa	0	R97
besiktas	Besiktas	0	R98
besiktas	Besiktas	0	R99
besiktas	Besiktas	0	R100
beylikduzu	Beylikduzu	0	R101
beylikduzu	Beylikduzu	0	R102
beylikduzu	Beylikduzu	0	R103
beyoglu	Beyoglu	0	R104
beyoglu	Beyoglu	0	R105
beyoglu	Beyoglu	0	R106
buyukcekmece	Buyukcekmece	0	R107
buyukcekmece	Buyukcekmece	0	R108
buyukcekmece	Buyukcekmece	0	R109
buyukcekmece	Buyukcekmece	0	R110
esenler	Esenler	0	R111
esenler	Esenler	0	R112
esenler	Esenler	0	R113
esenyurt	Esenyurt	0	R114
esenyurt	Esenyurt	0	R115
esenyurt	Esenyurt	0	R116
eyup	Eyup	0	R117
eyup	Eyup	0	R118

Table L2 (continued): Lower Road Vulnerability Coefficients of Benchmark Model Used to Form the Scenario Sets for European Side of Istanbul for Roads Connecting Distribution Centers to Demand Points

Distribution Center	Demand Points	Road Vulnerability	Road No
eyup	Eyup	0	R119
fatih	Fatih	0	R120
fatih	Fatih	0	R121
fatih	Fatih	0	R122
gaziosmanpasa	Gaziosmanpasa	0	R123
gaziosmanpasa	Gaziosmanpasa	0	R124
gaziosmanpasa	Gaziosmanpasa	0	R125
gungoren	Gungoren	0	R126
gungoren	Gungoren	0	R127
gungoren	Gungoren	0	R128
kagithane	Kagithane	0	R129
kagithane	Kagithane	0	R130
kagithane	Kagithane	0	R131
kucukcekmece	Kucukcekmece	0	R132
kucukcekmece	Kucukcekmece	0	R133
kucukcekmece	Kucukcekmece	0	R134
sultangazi	Sultangazi	0	R135
sultangazi	Sultangazi	0	R136
sultangazi	Sultangazi	0	R137
sisli	Sisli	0	R138
sisli	Sisli	0	R139
sisli	Sisli	0	R140
zeytinburnu	Zeytinburnu	0	R141
zeytinburnu	Zeytinburnu	0	R142
zeytinburnu	Zeytinburnu	0	R143

APPENDIX M

LOWER FACILITY VULNERABILITIES FOR EACH DISTRICT UNDER DAMAGE MODELS A AND C [10]

Table M1: Facility (Warehouse and Distribution Center) Vulnerability Lower Coefficients of Benchmark Model for Districts According to Model A of JICA & IMM Report [10]

Previously Was Part of Which Districts	District No	District	Buildings
			Heaviliy Damaged
	1	AVCILAR	14.10%
GAZIOSMANPASA, CATALCA	2	ARNAVUTKOY	2.95%
	3	BAHCELIEVLER	13.10%
	4	BAKIRKOY	18.30%
	5	BAGCILAR	6.60%
KUCUKCEKMECE, BUYUKCEKMECE,ESENLER	6	BASAKSEHIR	8.63%
BUYUKCEKMECE	7	BEYLIKDUZU	10.50%
	8	BEYOGLU	8.80%
	9	BESIKTAS	4.10%
	10	BUYUKCEKMECE	10.50%
	11	BAYRAMPASA	12.30%
BUYUKCEKMECE	12	ESENYURT	10.50%
	13	EYUP	7.30%
	14	FATIH	16.00%
	15	GUNGOREN	11.80%

Table M1 (continued): Facility (Warehouse and Distribution Center) Vulnerability Lower Coefficients of Benchmark Model for Districts According to Model A of JICA & IMM Report [10]

Previously Was Part of Which Districts	District No	District	Buildings
			Heaviliy Damaged
	16	GAZIOSMANPASA	3.30%
	17	KAGITHANE	3.90%
	18	KUCUKCEKMECE	9.40%
	19	SARIYER	1.30%
GAZIOSMANPASA, EYUP,ESENLER	20	SULTANGAZI	5.53%
	21	SISLI	3.20%
	22	ZEYTINBURNU	16.60%
	23	ESENLER	6.00%
	24	CATALCA	2.60%
	25	SILIVRI	4.20%

Table M2: Facility (Warehouse and Distribution Center) Vulnerability Lower Coefficients of Benchmark Model for Districts According to Model C of JICA & IMM Report [10]

Previously Was Part of Which Districts	District No	District	Buildings Heaviliy Damaged
	1	AVCILAR	16.50%
GAZIOSMANPASA, CATALCA	2	ARNAVUTKOY	3.40%
	3	BAHCELIEVLER	16.20%
	4	BAKIRKOY	21.00%
	5	BAGCILAR	8.00%
KUCUKCEKMECE, BUYUKCEKMECE, ESENLER	6	BASAKSEHIR	10.13%
BUYUKCEKMECE	7	BEYLIKDUZU	12.40%
	8	BEYOGLU	10.00%
	9	BESIKTAS	4.80%
	10	BUYUKCEKMECE	12.40%
	11	BAYRAMPASA	14.10%
BUYUKCEKMECE	12	ESENYURT	12.40%
	13	EYUP	7.90%
	14	FATIH	18.10%
	15	GUNGOREN	14.60%
	16	GAZIOSMANPASA	3.90%
	17	KAGITHANE	4.50%
	18	KUCUKCEKMECE	10.70%
	19	SARIYER	1.50%
GAZIOSMANPASA, EYUP,ESENLER	20	SULTANGAZI	6.37%
	21	SISLI	3.90%
	22	ZEYTINBURNU	19.50%
	23	ESENLER	7.30%
	24	CATALCA	2.90%
	25	SILIVRI	4.80%