MULTI PERIOD, MULTIPLE COMMODITY OPTIMAL INVENTORY POSITIONING AND ROUTING OF RELIEF ITEMS

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MULTI PERIOD, MULTIPLE COMMODITY OPTIMAL INVENTORY POSITIONING AND ROUTING OF RELIEF ITEMS

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ÖZET

ÇOK PERİYODLU, ÇOK MALZEMELİ AFET SONRASI OPTİMAL ENVANTER KONUMLAMA VE ROTALAMA

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Endüstri Mühendisliği, Yüksek Lisans

Lisansüstü Eğitim Enstitüsü

Tez Yöneticisi: Yrd. Doç. Dr. Mahmut Ali Gökçe

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İnsani yardım lojistiği afet ve acil durum öncesi depolanmış veya tedarik edilmiş gıda, su, giyecek vb. malzemelerin afetzedelere ulaştırılması ile ilgilenir. Son dönemlerde, özellikle doğal afetlerin artan etki ve sıklığı sebepleriyle, bu alana yöneylem araştırmacıları tarafından artan bir ilgi gösterilmiştir. Literatürde, çeşitli senaryolar için, afet ve acil durum sonrası için tahminlere dayalı en iyi depo yer seçimi ve insani yardım malzemesi dağıtımı modelleri bulunabilir. Ne yazık ki, afetlerde görülen rassallık (yeri ve/veya şiddeti) ve ikincil (artçı) afetler, çoğu zaman önceden yapılmış depolama ve dağıtım planlarını optimalden uzaklaştırır. İnsani yardım malzemesi dağıtım probleminin, afet sonrası oluşan gerçek koşullara göre hızlı bir şekilde, depolardaki envanter seviye ve karışımı yeniden düzenlenerek çözülmesi ciddi iyileştirmeler getirecektir. Bu çalışmada, gerçekleşecek bir doğal afetten hemen sonra kullanılmak için çok periyodlu, çok malzemeli optimal envanter konumlaması ve rotalama yapan bir bir model oluşturulmuştur. Oluşturulan model, ticari lojistik problemlerinde sıkça kullanılan ve talep tatmin seviyesinde tutarlı iyileştirmeler gösteren yatay dağıtımlar yaparak toplam dağıtım sürecinde iyileştirmelere ulaşmıştır. Bu modelin yarı-üretilmiş bir veri seti ile çözümü ve bu çözüm üzerine yapılmış çıkarımlar sunulmuştur.

Anahtar Kelimeler: İnsani Yardım Lojistiği, Matematiksel Modelleme, Envanter planlama, Araç Rotalama, Afet ve Acil Durum İşlemler Yönetimi

ABSTRACT

MULTI PERIOD, MULTIPLE COMMODITY OPTIMAL INVENTORY POSITIONING AND ROUTING OF RELIEF ITEMS

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Humanitarian logistics deals with planning and implementing flow of relief goods such as food, clothing water etc. from storage to victims of the disaster. Due to big unexpected disasters during the last couple of decades, humanitarian logistics has attracted significant research attention from the field of Operations Research. Models that finds out the best possible storage locations and/or optimal distribution of the stored goods, based on the estimated demand after a disaster exists. Unfortunately, sometimes the stochastic nature of disasters, (either in location or intensity or both) and secondary disasters, leaves plans made beforehand hardly optimal. The relief efforts, then, must continue based on location-inventory decisions made optimally for another problem. An important opportunity exists, if the problem of reconfiguration of mix and inventory of items can be solved optimally and quickly after the actual disaster happens. This study proposes a novel model that utilizes multiple period, multiple commodity optimal inventory positioning and routing for relief items. Proposed model includes a concept adapted from commercial logistics called lateral shipments and shown to make improvements in the overall relief distribution. Solution to the problem with a portion of a real life data set and conclusions drawn are presented.

Keywords: Humanitarian logistics, Mathematical Modeling, Inventory, Vehicle Routing, Disaster Operations Management

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To my father, mother, sister

and my mentor, my academic role-model Dr. Mahmut Ali Gökçe

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CHAPTER 1

Introduction

After the very first disaster that humankind had encountered and suffered from, we have started to ready ourselves and our surroundings to a potential disaster. With the involvement of operations management in the field, the name *disaster operations management* was adopted. Over the years scientists worked on better ways to be prepared for a disaster and the fastest ways to recover from one (or unfortunately multiple). However even if the initial damage is not fatal, the aftermath of a large disaster is more than capable of significant disruptions on the modern-day systems we rely on, and if such systems are to be rendered useless the disaster is capable of being more damaging in the long run than its initial shock. With the advancements of the technology in all fields mankind has increased the level of quality in its lifetime. Technological advancements produced systems that help people achieve a higher level of comfort of life. However, these advancements also gave birth to many new types of disasters called generally technological or man-made disasters that may easily match the destruction of a natural disaster if not exceed it.

The first step to be prepared for a disaster and its aftermath starts with obtaining as much as knowledge we can have on the disaster itself. Most of the time, even with the technological state that we are in gathering information on disasters, their effects and mostly the probability of their occurrence is still no better than highly educated guesses. However due to the destructive nature of disasters the data gathering process in the aftermath of a disaster is, understandably, loses its priority to rescue as many survivors and infrastructure as possible from the initial shock. This is by far one the biggest problem of the field of disaster operations management. During the aid efforts in the first couple of hours of the initial shock, most of the rescue activities, debris removal, infrastructure damage assessment and recovery, initial logistics efforts on both relief materials and rescue personnel, gas explosions, fires etc. causes the very critical initial data to be disturbed and dysfunctional. The previously mentioned data is often generated, in a backwards fashion by the NGOs and governments that are handling the aftermath of the disaster.

In the literature on disaster operations management, the definition of the term *disaster* is crucial to define the scope of the field. The definition of a disaster by United Nations is "*a serious disruption of the functioning society, causing widespread human, material, or environmental losses which exceed the ability of affected society to cope using only its own resources*". In the highly cited lecture (Van Wassenhove 2006 p.476) a disaster is a "*disruption that physically affects a system a whole and threatens its priorities and goals*".

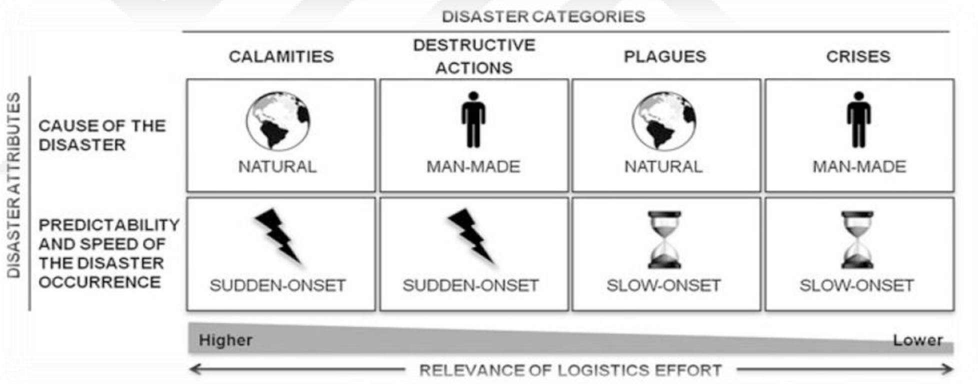

Figure 1: *Types of Disasters (A. Cozzolino (2012)*

Figure 1 (A. Cozzolino (2012) categorizes the disasters based on two major attributes; which are "cause of the disaster" and "the predictability and speed of the disaster occurrence". There are total of four categories listed in Figure 1. They are also sorted based on their relevance of logistics effort requirements.

The Centre for Research on the Epidemiology of Disasters (CRED) was established in 1973 as a non-profit institution. CRED became a World Health Organization Collaborating Centre in 1980 and has expanded its support of the WHO Global Programme for Emergency Preparedness and Response. Since then, it has increased its international network substantially. It has collaborative status with the United Nations Department of Humanitarian Affairs (UN-DHA). It also works in collaboration with the European Union Humanitarian Office (ECHO), the International Federation of the Red Cross and Red Crescent, the Office of Foreign Disaster Assistance (OFDA-USAID) as well as with non-governmental agencies such as the International Committee of the Red Cross and Red Croissant (ICRCRC, Switzerland). During the 1990's, the Centre actively promoted the International Decade for Natural Disaster Reduction (IDNDR).

CRED's definition of disaster is "*situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance (definition considered in EM-DAT); An unforeseen and often sudden event that causes great damage, destruction and human suffering. Though often caused by nature, disasters can have human origins.*"

EM-DAT classifies disasters in groups and subgroups. The classification is comprehensive and widely accepted. Table 1 below shows two disaster groups; natural and technological and gives information on the subgroups along with their definitions and disaster main types.

Disaster Group	Disaster Subgroup	Definition	Disaster Main Type
Natural	Geophysical	A hazard originating from solid earth. This term is used interchangeably with the term geological hazard.	Earthquake
			Mass Movement
			Volcanic Activity
	Meteorological	A hazard caused by short-lived, micro to meso scale extreme weather and atmospheric conditions that last from minutes to days.	Extreme
			Fog
			Storm
	Hydrological	A hazard caused by the occurrence, movement, and the distribution of surface and subsurface water.	Flood
			Landslide
			Wave Action
	Climatological	A hazard caused by long-lived, meso to macro scale atmospheric processes ranging from intra-seasonal to multi-decadal climate variability.	Drought
			Glacial Lake
			Wildfire
	Biological	A hazard caused by the exposure to living organism and their toxic substances (e.g. venom, mold) or vector-borne diseases that they may carry.	Epidemic
			Insect Infestation
			Animal Accident
	Extraterrestrial	A hazard caused by asteroids, meteoroids, and comets as they pass near-earth, enter the Earth's atmosphere, and/or strike the Earth, and by changes in the interplanar conditions that effect the Earth's magnetosphere, ionosphere, and thermosphere.	Impact
			Space Weather
Technological	Industrial Accident		Chemical Spill
			Collapse
			Explosion
			Fire
			Gas Leak
			Poisoning
			Radiation
			Oil Spill
			Other
	Transport Accident		Air
			Road
			Rail
			Water
	Miscellaneous Accident		Collapse
			Explosion
			Fire
			Other

Table 1: *General Classification of Disasters by EM-DAT*

The United Nations Office of Disaster Risk Reduction (UNISDR) and Centre for Research on the Epidemiology of Disasters (CRED) have released their review of disaster events in 2018. The report shows data on death tolls and number of people affected by disaster type from nine disaster types taken from EM-DAT (International Disaster Database).

Death Toll by Disaster Type (2018 vs average 21st Century)		
Event	**2018**	**Average (2000-2017)**
Drought	0	1,361
Earthquake	4,321	46,173
Extreme Temperature	536	10,414
Flood	2,859	5,424
Landslide	282	929
Mass movement (dry)	17	20
Storm	1,593	12,722
Volcanic Activity	878	31
Wildfire	247	71
Total	10,733	77,144

Table 2: *Death Toll by Disaster Type*

Total Number of People Affected by Disaster Type (2018 vs average 21st Century)		
Event	**2018**	**Average (2000-2017)**
Drought	9,368,345	58,734,128
Earthquake	1,517,138	6,783,729
Extreme Temperature	396,798	6,368,470
Flood	35,385,178	86,696,923
Landslide	54,908	263,831
Mass movement (dry)	0	286
Storm	12,884,845	34,083,106
Volcanic Activity	1,908,770	169,308
Wildfire	256,635	19,243
Total	61,772,617	193,312,310

Table 3: *Total Number of People Affected by Disaster Type*

Tables 2 and 3 show the death toll and the total number of effected people based on disaster type. These tables also give a comparison of these numbers based on 2018 value and average of 2000-2017 period. Both tables clearly show the effect of disaster operations management studies making a difference. Almost all the values for 2018 are significantly below the average of past seventeen years.

The type of a disaster also dictates the steps to prepare for that specific type of disaster along with its response and recovery processes. As an example, an outbreak of a deadly disease is likely to call for quarantine and certain protocols of isolation over a large portion of area and a significant number of people. On the other hand, an earthquake or a flood requires the survivors of the disaster to stay together for easier evacuation and distribution of relief goods. There is also the fact that almost any one disaster can trigger another disaster (or disasters) by either its initial shock or its after effects. Continuing from the previous example, aftermath of a flood is highly likely to create a perfect environment for a deadly bacterium to thrive and start an outbreak. As the examples show the nature of disaster operations management and humanitarian logistics must deal with the highly volatile and unpredictable nature of the disasters.

The term "humanitarian logistics" covers a significant workload of disaster operations management span. The term is defined by Thomas and Kopczak (2005 p. 2) as "Specifically, the activities of 'planning, implementing and controlling the efficient, cost-effective flow of and storage of goods and materials as well as related information, from point of origin to point of consumption for the purpose of alleviating the suffering of vulnerable people' are known as 'humanitarian logistics'."

This study will define the humanitarian logistics as "The set of activities that are performed before, during, and after a disaster with the goal of preventing loss of human life, reducing its impact on both the economy and daily lives of the population, and returning to a state of normalcy as disaster operations management".

Research on humanitarian logistics is commonly categorized under three different major categories based on time frames; preparation (pre-disaster), response (post-disaster) and recovery phase. Figure 2 below shows the Disaster Management Cycle.

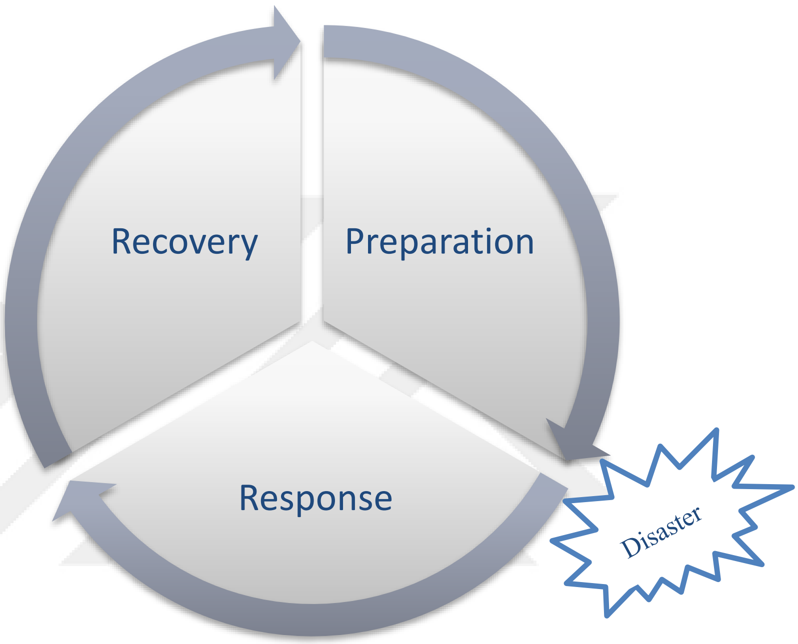

Figure 2: *Disaster Management Cycle*

This cycle displays the order of time frames of humanitarian logistics following each other and their position related with the instant of the disaster. While there are quite a different number of studies on all of those three categories, there are also some studies that envelop two of three of those phases.

Slow-onset disasters differ from the sudden-onset disasters on every phase of the disaster management cycle. The most noticeable difference is as the names suggest the moment of disaster. Preparation phase for sudden-onset disasters ends with the moment of disaster and the response phase begins. For slow-onset disasters this separation line is much blurrier. It is almost impossible to set an exact time as the moment of disaster for slow-onset disasters. The recovery phase for a slow-onset disaster is also much longer than a sudden-onset disaster. This is due to the impact of a sudden-onset disaster being more visible and more likely to be equated to monetary values.

The preparation phase of a disaster is a time period with unknown length. The main objective of this phase is to identify and assess the potential risks of different types of disasters and take actions towards minimizing the impact of the upcoming disaster(s) on economy, infrastructure, and everyday human lives. In this phase, given that there are always limited resources and the unknown nature of a disaster, it is best to focus the preparations on the most likely disaster types. In the case of Turkey, by looking at the past data, earthquakes are the most likely natural disasters with long list of past occurrences with high number of casualties and significant monetary damage. It should be noted that even the best preparation will not be able to prevent the possible losses in a disaster but will help save many lives. For this reason, the importance of planning spent on the preparation phase should never be underestimated.

The main difference of the response and recovery phases from the preparation phase is that the type of the disaster and its effects are now mostly known, hence the number of possible of scenarios are diminished quite substantially. The response phase requires swift decision making and precise actions. With each passing minute the likelihood of damage accumulation and number of potential lives lost increase dramatically. Hence the importance of fast and good decision making here is paramount. However also in this phase it is quite hard to make correct decisions due to chaos and difficulties of obtaining real time data on the disaster's impact on multiple systems. The first step of this phase always is the situation assessment. After a healthy assessment is made the possible scenarios that are pre-designed in the preparation phase are initiated. This phase is also critical on the subject that it requires the highest possible connection between different actors that play critical parts in the fitting pre-designed scenario. Such actors are likely to include government agencies, NGOs and army. Many of the studies that include this phase must deal with a considerable amount of uncertainty due to the previously mentioned difficulty of access to real time data and the ever-changing nature of a large-scale disaster.

Any plans made before the moment of the disaster are made on the predictions and scarce amount of past data on similar but not same disasters. These plans will never be perfect solutions and will require re-planning based on the disaster information. This study proposes a model that will update the humanitarian work efforts based on the information gathered during and after the disaster. This will eliminate the need to re-plan during the response phase and will shift the re-planning effort to the preparation phase where time will not be a concern that may cost lives.

Response phase of a disaster is chaotic and a time-intensive period. The main goal in this phase is to save as many lives as possible. This requires triage, debris removal, search and rescue and other data-disruptive operations. Data collection is never a priority during this phase and this creates a contradiction with this phase being the crucial about data precision. The amount of disturbance caused during this phase can be reversed to reach for the original data before the disturbance although scale of the disaster makes this process exponentially more difficult. Data for this period is gathered best by large NGOs like Red Crescent, Red Cross or military.

In the response phase a common rule of 72 hours applies to many types of disasters. The rule suggest under most major sudden-onset natural disasters such as earthquakes, the chance of survival drops to less than %10 after 72 hours.

The recovery phase differs from the previous two phases due its nature of comprising a larger time period which almost all the effects of the disaster are known, and medium and long terms plans are possible. The longevity of this phase depends on a large variety of factors such as the type and the magnitude of the disaster, success rate of the preparedness and response phases, ongoing coordination of the previously mentioned actors, the level of damage that the infrastructure suffered and its ability to recover and so on. The recovery phase may even take up to several years given that lack of preparedness along with a fragile infrastructure.

1.1 Motivation

INFORM, is a global, open-source risk assessment for humanitarian crises and disasters. It is a collaborative project of the Inter-Agency Standing Committee (IASC) and the European Commission. INFORM Global Risk Index 2018 among 191 listed Turkey is ranked at 45.

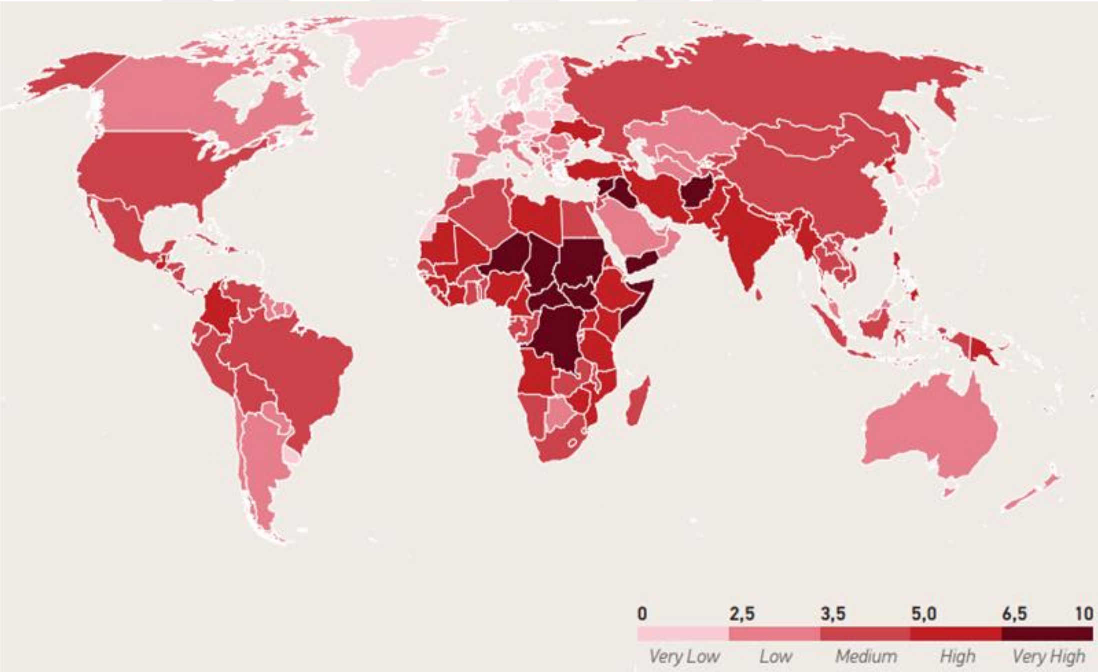

Figure 3: *INFORM Global Risk Index 2018 Report – World Map*

As of 20.05.2019, INFORM evaluates that Turkey's rank has declined to 49 and has a declining trend based on the last three years. The project includes risk profiles for every country included in the program which then further details the rank under three categories; Hazard & Exposure, Vulnerability and Lack of Coping Capacity. Figure 4 and 5 below show the data taken on the subject from INFORMS Country Risk Profile for Turkey.

	Value	*Rank*	*Trend (3 years)*
INFORM Risk	**4.9**	**49**	↑
Hazard & Exposure	**7.1**	**17**	↑
Vulnerability	**5.1**	**47**	→
Lack of Coping Capacity	**3.2**	**139**	→

Figure 4: *INFORM Global Risk Index 2018 Report - Ranking*

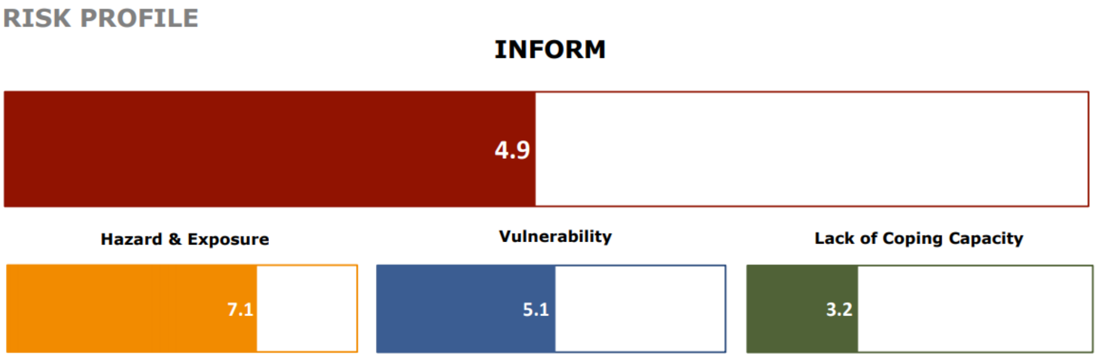

Figure 5: *INFORM Global Risk Index 2018 Report – Risk Profile*

AFAD, The Disaster and Emergency Management Authority, is the agency that governs the pre and post disaster efforts by the authority of the Turkey. Based on the yearly report that AFAD published in 2018, the following table shows the major disasters happened in Turkey between the years of 1990 and 2017.

Type of Incident	Province / Region		Date	Loss of Life	Injury
Avalanche	Southeast Anatolia	(14 incidents)	1992	328	53
Avalanche	East and Southeast Anatolia	(31 incidents)	1993	135	95
Earthquake	Erzincan		13.05.1992	653	3.850
Mudslide	Isparta		13.07.1995	74	46
Earthquake	Afyon		26.02.4917	94	240
Flood	İzmir		04.11.1995	63	117
Earthquake	Çorum		14.08.1996	0	6
Flood	Western Blacksea		21.05.1998	10	47
Earthquake	Adana		27.07.1999	145	1.600
Earthquake	İzmit Bay		17.08.1999	17.480	43.953
Earthquake	Düzce		12.11.1999	763	4.498
Earthquake	Afyon		03.02.2002	42	327
Earthquake	Bingöl		13.04.4780	177	520
Flood / Landslide	Rize		26.08.2010	14	-
Earthquake	Van	(2 incidents)	23.10.2011	644	1.966
Flood	Samsun		03.07.2012	13	21
Landslide	Siirt		17.11.2016	16	-

Table 4: *Major Disasters in Turkey between 1990-2017*

As it is evident of Table 4, more than half of the major disasters that had struck Turkey were earthquakes. Geographically Turkey has one of most active fault lines in the world. The figure below shows the recorded earthquakes in and around Turkey that are recorded by AFAD between 1990 and 2017.

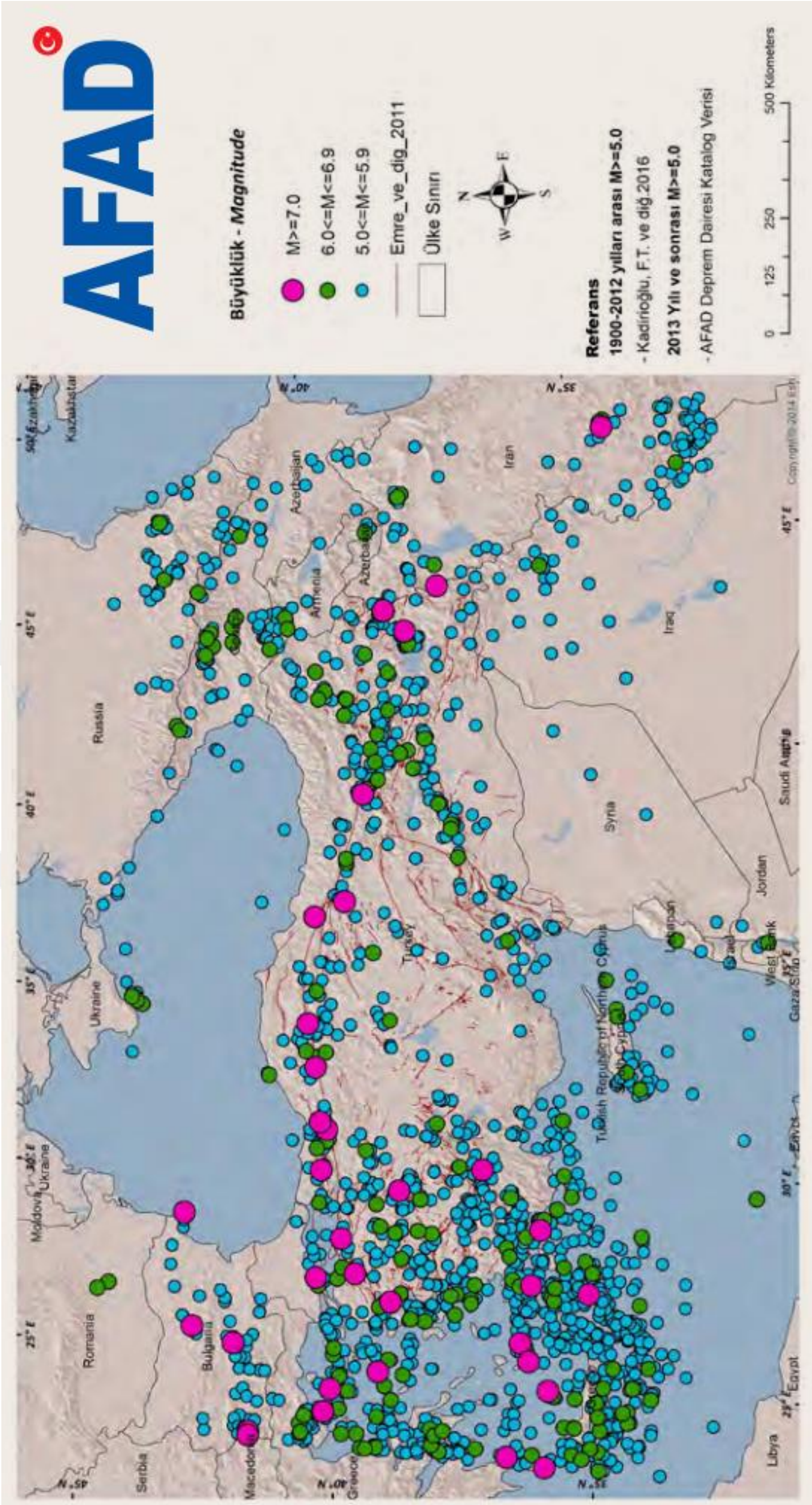

Figure 6: *Earthquakes over 5M$_W$ between 1990-2017*

The most common medium of measurement for earthquakes is called *Richter Magnitude Scale*. Charles F. Richter developed and presented the measurement scale in his article in 1935. Table below shows the typical effects of earthquakes based on their magnitude.

Magnitude	**Description**	**Average earthquake effects**	**Average frequency of occurrence globally**
1.0–1.9	Micro	Microearthquakes, not felt, or felt rarely. Recorded by seismographs	Continual/several million per year
2.0–2.9	Minor	Felt slightly by some people. No damage to buildings.	Over one million per year
3.0–3.9		Often felt by people, but very rarely causes damage. Shaking of indoor objects can be noticeable.	Over 100,000 per year
4.0–4.9	Light	Noticeable shaking of indoor objects and rattling noises. Felt by most people in the affected area. Slightly felt outside. Generally causes none to minimal damage. Moderate to significant damage very unlikely. Some objects may fall off shelves or be knocked over.	10,000 to 15,000 per year
5.0–5.9	Moderate	Can cause damage of varying severity to poorly constructed buildings. At most, none to slight damage to all other buildings. Felt by everyone.	1,000 to 1,500 per year
6.0–6.9	Strong	Damage to a moderate number of well-built structures in populated areas. Earthquake-resistant structures survive with slight to moderate damage. Poorly designed structures receive moderate to severe damage. Felt in wider areas; up to hundreds of miles/kilometers from the epicenter. Strong to violent shaking in epicentral area.	100 to 150 per year
7.0–7.9	Major	Causes damage to most buildings, some to partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt across great distances with major damage mostly limited to 250 km from epicenter.	10 to 20 per year
8.0–8.9	Great	Major damage to buildings, structures likely to be destroyed. Will cause moderate to heavy damage to sturdy or earthquake-resistant buildings. Damaging in large areas. Felt in extremely large regions.	One per year
9.0 and greater		At or near total destruction – severe damage or collapse to all buildings. Heavy damage and shaking extends to distant locations. Permanent changes in ground topography.	One per 10 to 50 years

Table 5: *Typical Effects of Earthquakes of Various Magnitudes*

The same annual report of AFAD from 2018 also gives information of response capacities based on machinery, people, vehicles etc.

Figure 7: *Response Capacity of AFAD*

One of the most destructive disaster that had ever struck Turkey happened on 17th August 1999. An earthquake that is recorded as 7.5Mw (moment magnitude scale) at 03:02AM. The earthquake lasted for 45 seconds. The official records show 17.480 dead and 43.953 injured people along with, 285.211 residential home, and 42.902 workplaces ruined. The earthquake was one of the biggest of the region. 52 countries have sent aid including search and rescue parties, rations, and humanitarian aid materials ranging from blankets to full on prefabricated houses. The recovery phase has been officially completed after 14 years with the removal of last prefabricated house complex and relocation of its residents.

Studies that use optimization tools like mathematical modelling and heuristics are often used on preparation and response phases. Disaster management at preparation and response phases consists of sub-topics that are; casualty transport, debris removal, evacuation and relief distribution. Relief distribution aspect of disaster management can be further divided into topics like inventory pre-positioning of relief goods, delivery routing, staff allocation, and inventory planning and resource allocation.

This study will focus on the relief distribution problem in the aftermath of a possible disaster affecting Istanbul. This problem requires specific approaches to common vehicle routing problem (VRP) regarding to the nature of a disaster. While a common VRP problem only has to be constructed and solved once for the start of the planning horizon and remains same unless a disruptive and unforeseen change occurs, the relief distribution after a disaster is more than likely to require several major changes given the nature of a disaster being able to be disruptive even after the initial shock.

The remainder of this thesis is organized as follows. In Chapter 2, relevant work on disaster operations management and humanitarian logistics are reviewed. The problem and its proposed solution are defined in Chapter 3. Mathematical model developed in this study is represented in Chapter 4. Computational results obtained by the proposed solution are given in Chapter 5. Lastly, Chapter 6 concludes the study with conclusions drawn from the results and future study issues.

CHAPTER 2

Literature Review

Following the introduction, in this chapter relevant articles published throughout the years in disaster relief literature are reviewed.

The starting point for a relief distribution problem however is quite similar to the common VRP problem. Desrochers et al. (1990) gave a classification of VRPs on several properties. In addition, Desrochers et al. (1998) contains reviews and extensions on the VRP. One of the very first approaches to use of a VRP in and post-disaster situation has been proposed by Knott (1987). The model that has been introduced with the objective of maximizing the amount of food delivered along with minimizing the transportation costs. Ray (1987) is another model that introduced a single-commodity, multi-modal network flow for a capacitated network over a multi-period planning horizon. This model's objective is to minimize the food storage and transportation costs.

One of the more complex approach with the use of multi-commodity, multi-modal network flow models has presented by Oh and Haghani (1996). This research study considered a range of commodities, which had presented a challenge that is much closer to a real-life example than its predecessors. The study proposes two heuristic algorithms and findings are presented using artificially generated data sets.

Another similar approach is the multi-items, multi-vehicles, multi-periods, soft time windows, and a split and prioritized delivery strategy scenario multi-objective integer programming model of Lin Yen-Hung et al. (2011) Their study proposed a multi-commodity, multi-vehicle, multi-period and multi-objective model for delivery of prioritized commodities to disaster-relief operations.

The main shortcoming of both of this valuable work is the homogenous vehicle fleet which will not represent the real-life challenges of disaster relief distribution efforts.

Evacuation and casualty transport aspects are major parts of disaster relief management. While it is not within the scope of this study, Abdelgawad and Abdulhai (2009) is a good reference to evacuation as a network design problem along with Urbina and Wolshon (2002) being another respectable study on specifically focusing on hurricane evacuation. Furthermore, Jotshi et al. (2009) developed a robust methodology for the dispatching and routing of emergency vehicles with the support of data fusion. Key factors such as patient priorities, (triage) and distance are used to dispatch and route emergency vehicles to pick up locations then to appropriate hospitals found by the analysis. The casualty transportation aspect had also been studied along with relief distribution due to the ease that will create since the transportation of both can be handled with the same vehicle fleet. Barbarosoğlu et al. (2002) proposes a mathematical model which aims to plan helicopter missions during disaster relief operations. The problem is dissected into two parts where the first part is reserved for top level decisions such as the pilot-helicopter assignments and total number of tours that can be done by each helicopter. The second part handles decisions like the rescue plans of each helicopter tour, the routing of helicopters, loading/unloading, delivery, trans-shipment etc.

While majority of the papers handles either the relief distribution or the casualty transportation, very few research papers studied both of the objectives at the same time. Those studies are Yi and Özdamar (2007), Yi and Kumar (2007), Özdamar (2011) and Özdamar and Demir (2012).

Tzeng et al. (2007) developed a multi-objective relief-distribution model for designing relief delivery systems using a real-life case. Their model featured three objectives including minimization of total costs, minimization of the total travel time, and maximization of the minimal satisfaction of fairness during the planning horizon. Another study Nolz et. al. (2011) developed a multi-objective model for relief aid distribution in a post-natural-disaster situation. This is also a model that utilizes three objective functions, including minimizing distribution risk, maximizing the coverage provided by the logistics system and minimizing the total travel time.

Yi and Özdamar (2007) presents a mixed integer multi-commodity network flow model to ensure coordination of logistics support along with casualty evacuation. This model differs from its counterparts due to the choice that the model treats vehicles as integer commodity flows instead of the usual approach of binary variables. This creates the need for an additional process on the output of the model.

Another additional layer of complexity for the relief distribution problems is that the points of delivery are subject to change. While the emergency muster areas are pre-determined by law, multiple types of disasters are easily capable of rendering such places unusable.

Gong and Batta (2007) allocates ambulances in a post-disaster relief operation. The study includes a clustering algorithm to divide the disaster struck areas, along with the allocation and reallocation of an ambulance fleet. Yi and Kumar (2007) describes a meta-heuristic of ant colony optimization which decomposes the problem into a vehicle route construction and a multi-commodity dispatch problem. The first problem (Gong and Batta (2007) uses a network flow-based model where the vehicles are handled as integral commodities just as the other commodities. The second problem takes the casualty numbers in nodes and treats them as supplies for the casualty evacuation.

Özdamar (2011) proposes an efficient helicopter operations coordination system. The system has two parts; a mathematical model and a Route Management Procedure to process the output of the mathematical model. The model is designed in a way to answer the specific restrictions of aviation even for large scale helicopters. The model uses helicopters both for the transportation of commodities and casualties, Özdamar and Demir (2012) presents a hierarchical cluster and routing procedure with the aim of ensuring coordination of the vehicle routings for distribution and casualty evacuation in a large-scale post-disaster environment. The first step of the solution uses a multi-level clustering algorithm to obtain small clusters of demand nodes at each period (time bucket). This allows for an optimal solution for the second part of the problem which is now a cluster routing problem. Each problem for each cluster is then mapped as a capacitated network flow model and gets solved optimally.

All the previous examples consider both the relief goods distribution along with casualty transportation. While this consideration has benefits like the previously mentioned possibility of using the same vehicle fleet for the transportation of both goods and casualties, there are significant amount of practical problems that are more than likely to occur. In a post disaster environment, the vehicle fleet is almost always will be a heterogeneous mix. This will limit the number of vehicles that are suitable for the purposes of transporting both the relief goods and casualties such as trucks and similar heavy load vehicles not being well equipped to handle the transportation of wounded people with critical condition or ambulances lacking the sufficient enough cargo space for relief goods that are not of medical use such as boxes containing food or clothing supplies.

While still being based on the preparedness level, the magnitude and the type of the disaster it is widely stated that the first 72 hours after the moment of the disaster are the most crucial. This article decides to use a vehicle fleet that is more suited to transport relief goods rather than casualties, hence leaving the more crucial vehicles like ambulances to solely on the task of transporting casualties.

Özdamar et. al. (2004) presents a model that is to be integrated into a natural disaster logistics Decision Support System. This model uses the dynamic time-dependent transportation problem which requires to be solved repetitively every time a new information about the changes on the demand of relief goods are introduced. With the new information the model adjusts the distribution amounts and the vehicle routes according to the new situation generated by the new information and makes the changes accordingly. However, this model also allows the changes to be implemented *within* the time intervals. This changes the current delivery schedules in motion and is likely to cause problems such as distribution inconsistencies which may very well result in unfairness in the satisfaction of the relief goods distribution not to mention the increase costs.

As it is evident so far on the topic of relief distribution there are quite a few different alternatives on the method of delivery. This variety is understandable, due to the chaotic nature of a disasters being, more than, capable of rendering one or more alternative methods of delivery to be useless. Under such circumstances relief distribution models must differ from the regular logistic distribution problems. Unfortunately, the differences do not end here. The intensity of relief material demands proportional to the time that this demand emerges is also a lot larger than a regular distribution problem, where most of the time the demand varies between some well estimated limits.

For a standard commercial logistic distribution problem goods are cycled at a near constant rate at the inventories of the warehouses. In the relief distribution case, goods are stored for an indefinite period of time in the case of an unpredictable event. This causes additional problems since relief goods such as vaccines, water, rations etc. all have their expirations dates.

On the topic of disaster relief distribution, the approach that has the most practical use along with promisingly positive results is the re-configuring of pre-designed models on relief distribution. This re-configuring is used by taking the pre-designed model for a certain place, for a certain type and magnitude of disaster and performs a reconfiguration based on the recently acquired data at the post-disaster phase. This approach provides solid answers to the previously mentioned challenges of a disaster relief distribution problem. The reason for such approach is the nature of a disaster is almost certainly going to change multiple the model parameters dramatically based on its impact. As examples; emergency muster areas, pre-determined vehicles, major roads, and warehouses may be rendered useless from the disaster.

The models that may have been constructed before a disaster rarely stays valid since both the type and the severity of the disaster is subject to unforeseeable changes. This situation can be countered by a model that quickly reconfigures the goods mix and their distribution.

Being able to deliver relief goods after any type of disaster has struck is a major logistics problem. Unlike a general logistics problem where there is a monetary cost associated with the lateness, this time the cost will have direct effect on victims' survivability. This aspect alone is more than enough to complicate the problem however this is not the only challenge. This study considers the situation where there are multiple types of commodities stored in different depots and there are multiple types of vehicles that will be utilized for delivery which also includes lateral shipments.

In this study a common concept used in the commercial logistical operations called "*lateral shipments*" is used. Lateral transshipment is defined as a local warehouse which provides stocked items to another local warehouse which is out of stock or to prevent out-of-stock occurrences. In other words, these local warehouses exchange their inventory on the same echelon level. The term came up with the usage of transshipments where cargo moved from one ship to another for the purpose of furthering or ease of the cargo's transportation. In the case of logistics involving commercial logistics, the term expanded in meaning with the use of land vehicles and storage facilities.

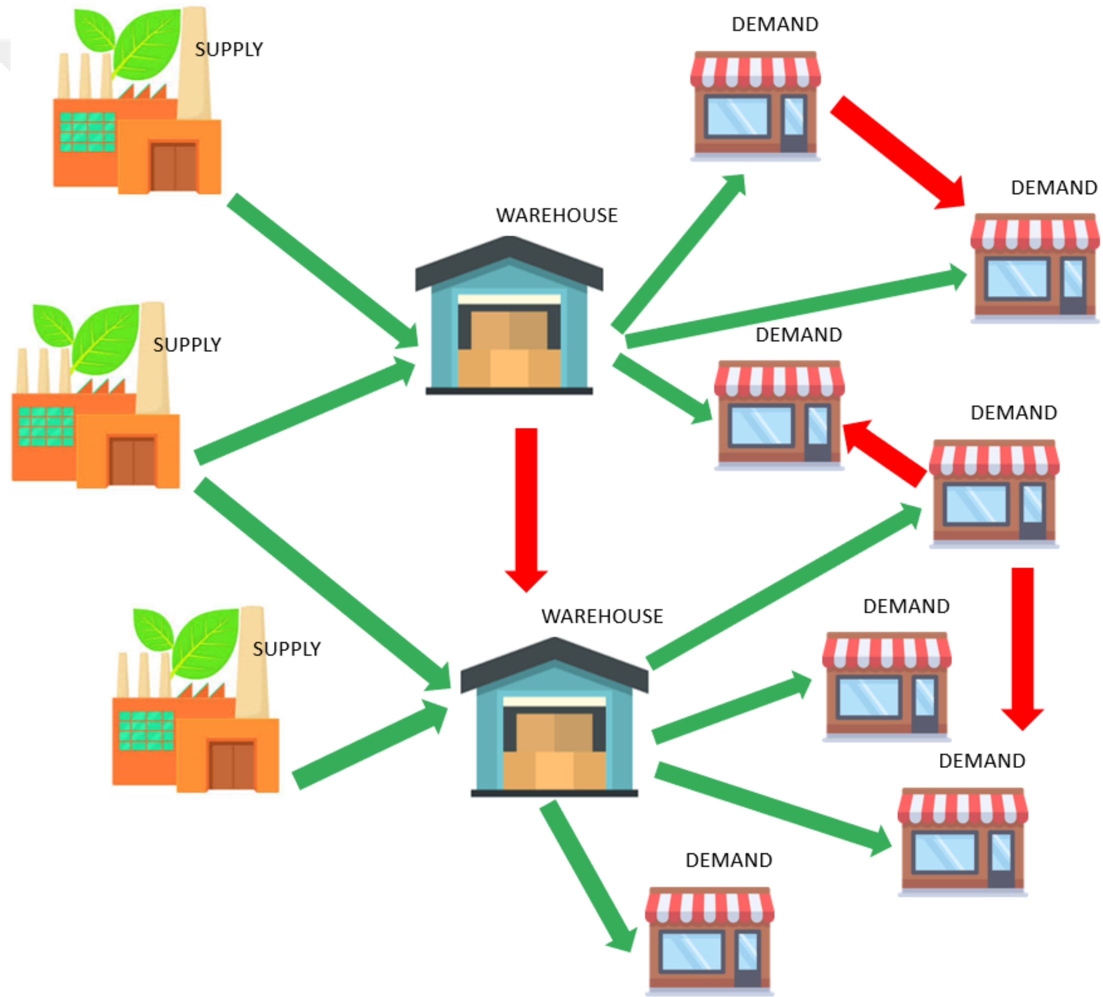

Figure 8: *Lateral Shipment in Commercial Logistics*

Figure 3 above illustrates a commercial logistics network containing supply, warehouse, and demand nodes. The green arrows are the main supply routes from supply points to warehouses and to each demand point. Red arrows show the possible routes that are lateral transshipments from one warehouse to another.

The lateral transhipments are a commonly used practice in commercial logistics systems between both same or different tier echelons. In the humanitarian logistics aspect of logistics, lateral transhipments are not utilized. The use of a lateral move between nodes that hold multiple-item inventories is expected to increase the responsiveness of the model and lower the total travel times and costs.

The aftermath of a disaster is almost always followed by a significant chaos. Using limited resources available, the demand of relief goods must be satisfied in the best possible way. This study uses an objective function that will minimize the summation of transportation, and shortage costs. While loss of human life is not measurable by any currency the problem requires a certain quantifiable measure to calculate its effectiveness.

The problem does not allow backorders due to the nature of the victims being in dire need of the relief materials that are to be delivered. In contrast to a general VRP approach, in this model any type of vehicle can end their tour for the period in any depot, not necessarily being the depot that they have started their tour and each vehicle depending on its type can travel up to a certain number of nodes based on the vehicle type. As it is for every inventory problem, inventory balance for all depots and vehicles must be maintained at all periods

Table 4 below gives example studies containing lateral transshipments.

Authors (Year)	# of Echelons	# of Items	Review	Policy
Lee (1987)	Two	Single	Continuous	(S-1,S)
Tagaras (1989)	Single	Single	Periodic	Order-up-to
Axsäter (1990)	Two	Single	Continuous	(S-1,S)
Tagaras and Cohen (1992)	Single	Single	Periodic	Order-up-to
Yanagi and Sasaki (1992)	Single	Single	Continuous	(S-1,S)
Sherbrooke(1992)	Two	Single	Continuous	(S-1,S)
Archibald et al. (1997)	Single	Multi	Periodic	Order-up-to
Needham and Evers (1998)	Two	Single	Continuous	(r,q)
Tagaras (1999)	Single	Single	Periodic	Order-up-to
Alfredsson and Verrijdt (1999)	Two	Single	Continuous	(S-1,S)
Grahovac and Cahravarty (2001)	Two	Single	Continuous	(S-1,S)
Kukreja et al. (2001)	Single	Single	Continuous	(S-1,S)
Evers (2001)	Single	Single	Continuous	(r,q)
Herer et al. (2002)	Single	Single	Periodic	Order-up-to
Xu et al. (2003)	Single	Single	Continuous	(r,q)
Axsäter (2003)	Single	Single	Continuous	(r,q)
Wong et al. (2005a)	Single	Single	Continuous	(S-1,S)

Table 6: *List of Studies using Lateral Shipments*

Table 4 containing list of studies using lateral shipments includes many works from commercial logistics examples using generated and/or real-life data proving that the use of lateral shipments is an increase in the overall demand satisfaction level. Demand satisfaction corresponds to satisfying the vital needs of people who have been injured and/or dire need of medical supplies.

Table 5 below shows the research performed in the area of Disaster Relief Distribution throughout the years. All the research built upon itself and generated more complex models, models that perform multiple and even integrated tasks such as evacuation along disaster relief distribution. It can be seen from the table that most of the models are using multiple locations along with multiple types of commodity. Although these aspects combined in a single model poses large amount of complexity, the reality of a disaster situation is much more chaotic. Adding consideration of multiple periods to the model generates a chance to make use of incoming data at the response phase and will make the model a more efficient at overall disaster relief. Fleet type used by these studies varies however use of heterogeneous is not common practice. The reasoning and potential gains of this aspect of the model is same as the use of multiple periods. Lastly on the case of use of lateral shipments, none of the models considered such an approach. This study adapts the previously explained concept of lateral shipment from commercial logistics to disaster relief distribution.

The proposed model, with the use of a multiple location, multiple commodity, multiple period, heterogeneous fleet and with the addition of lateral shipments is a valid candidate among the studies on Table 5.

Literature		Multiple Locations	Multiple Commodity	Multiple Period	Fleet Type	Lateral Shipments
Authors	Year					
Oh and Haghani	1996	Y	Y	Y	Homogeneous	N
Barbarosoglu et al.	2002	Y	Y	N	Heterogeneous	N
Ozdamar et al.	2004	Y	Y	Y	Heterogeneous	N
Yi and Özdamar	2007	N	Y	Y	Homogeneous	N
Yi and Kumar	2007	N	Y	Y	Homogeneous	N
Tzeng et al.	2007	Y	Y	Y	Homogeneous	N
Jotshi et al.	2009	Y	N	N	Homogeneous	N
Gong and Batta	2009	Y	N	Y	Homogeneous	N
Özdamar	2011	N	Y	N	Homogeneous	N
Lin Yen-Hung et al.	2011	Y	Y	Y	Homogeneous	N
The Proposed Model	**2019**	**Y**	**Y**	**Y**	**Heterogeneous**	**Y**

Table 7: *Summary of Disaster Relief Research*

CHAPTER 3

Problem and Proposed Solution

This study will focus on the relief distribution problem in the aftermath of a possible disaster on Istanbul. Istanbul is the most populated city in Turkey and 7th on the world with its currently home to 15.067.724 people. Istanbul as a settlement is believed to be as old as 5000BCE. The city has been a capital for some of the most prosperous empires. With Istanbul's population density is 2.523 people per square kilometre and with the population growth of 3.45%, it is easy to say that Istanbul is a very crowded city. With Istanbul being such a large city and due to its geographic location, the city carries a very large risk of being the victim of another major earthquake.

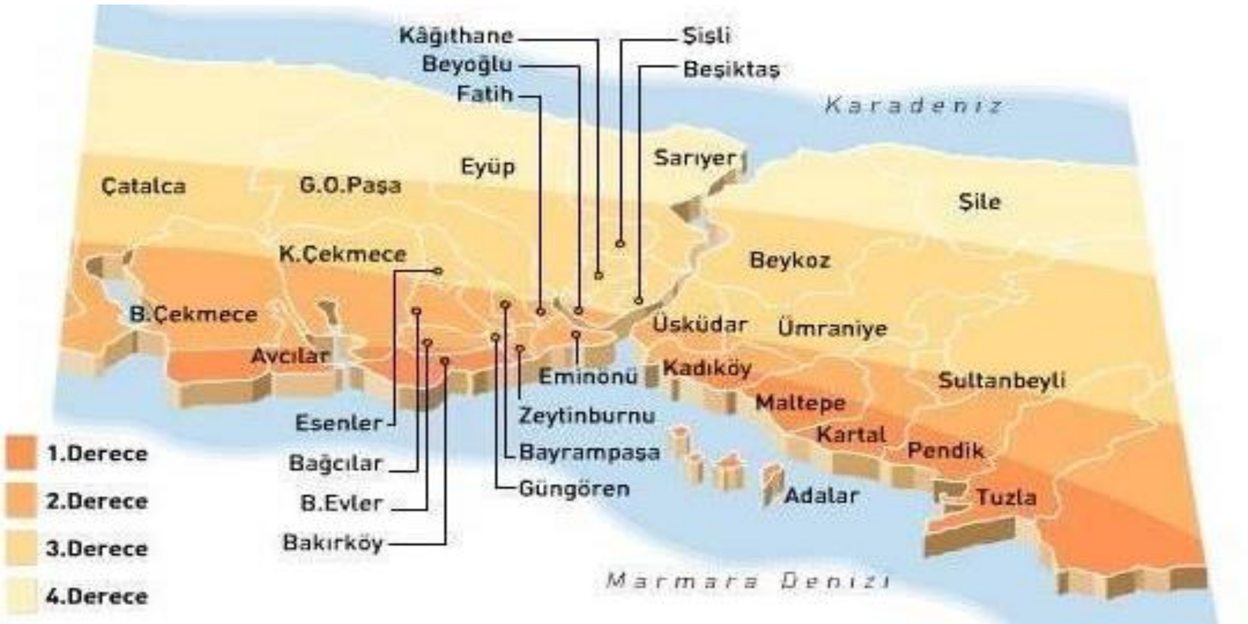

Figure 9: *Disaster Risk Map for Istanbul*

The problem of the study focuses on the city of Istanbul as a whole. As it can be seen from Figure 4 Istanbul has four risk zones. Darker shades indicate a higher risk areas and paler shades indicating lower risk areas. Given the history of Istanbul having a major earthquake in 1999, the area is considered a high-risk zone and another major earthquake is expected. This fact along with the ever increasing and already a very large population of the city, its importance in the economy of Turkey demands careful planning in the case of a such disaster.

This study is proposing a multiple-period, multiple-location, multiple commodity, heterogeneous fleet adjustment of a VRP. The main gain of the model will be its use of lateral shipments, increasing the demand satisfaction. The proposed model is a Mixed Integer Problem. As it is stated on Toth and Vigo (2002) VRP and its variants are NP-hard problems. This fact increases the solution time exponentially with the increase in the set sizes.

Using an exact solution method can be justified by the nature of a disaster requiring precise answers to the overall distribution problem. On the contrary to a commercial logistics problem, a disaster relief distribution is an operation based on saving human lives and critical infrastructure.

3.1 Model Assumptions

This study, based on the risk evaluations made on Istanbul by many independent resources, is prepared in the case of an earthquake occurring at or near Istanbul. The model is repeated with different magnitudes which will have an exponentially related relationship with the amount of humanitarian aid demand and number of casualties. While in the case of an earthquake of a significant magnitude it is likely that some damage will be observed on the infrastructure as well, this study is performed under the assumption that none of the major roads are damaged beyond use.

The assumptions below pertain to the mathematical model.

i. There are heterogeneous vehicles available for the purpose of commodity delivery and the load of the vehicle does not change the speed of the vehicle.
ii. Road network after the disaster are known and are free of traffic to allow no wait times for the delivery vehicles.
iii. All the initial number and mix of vehicles starting points are known.
iv. All the initial demand amounts are known, and supply is readily available and there is enough commodity of all types at the warehouse.
v. All the vehicles are capable of loading and unloading operations at every node.

CHAPTER 4

Proposed Model

As mentioned above the proposed model is a multiple time-windowed heterogeneous fleet multiple location multiple commodity adjustment of a VRP. The sets, parameters and decision variables used for the model are as follows:

Sets and Indices

$i, j = 1, \ldots, M, M+1, \ldots, M+W$	*Set of nodes*
$k = 1, \ldots, K$	*Set of commodities*
$t = 0, \ldots, T$	*Set of time buckets*
$v = 1, \ldots, V_1, V_1+1, \ldots, V_1+V_2, \ldots, V_B$	*Set of vehicles*

Parameters

C_v	*Capacity of vehicle v (in volume)*
C_k	*Amount of capacity that 1 unit of commodity k occupies (in volume)*
M_v	*Maximum number of nodes that can be visited by vehicle v in any time bucket*
D_{ikt}	*Number of commodity type k demand at node i at time bucket t*
I_{ik0}	*Beginning inventory of node i of commodity type k at the time bucket 0*
N_{iv0}	*Number of type vehicles of v at depot i at the beginning of time bucket 0*
CS_k	*Cost of shortage for 1 unit of commodity type k for one time bucket*
CT_{ijv}	*Cost of travel from node i to node j by vehicle v*

Decision Variables

U_{ijkvt}

Amount of commodity type k unloaded from vehicle v arriving to node j from node i in time bucket t

L_{ijkvt}

Amount of commodity type k loaded from vehicle v arriving to node j from node i in time bucket t

Y_{ijvt}:

1 if the vehicle v travels from the node i to node j in time bucket t; 0 otherwise

Q^1_{ivt}

Total load of vehicle v when arriving to node i in the time bucket t

Q^2_{ivt}

Total load of vehicle v when leaving to node i in the time bucket t

I_{ikt}

Beginning inventory of node i of commodity type k in the time bucket t

B_{ikt}

Shortage amount of commodity type k in node i in time bucket t

N_{ivt}

Number of type vehicles of v at warehouse i at the beginning of time bucket t

Mathematical model is given below:

$$Min \ \sum_{i=1}^{M}\sum_{k=1}^{K}\sum_{t=1}^{T} B_{ikt} * \sum_{k=1}^{K} CS_k + \sum_{i=1}^{M+W}\sum_{j=1}^{M+W}\sum_{v=1}^{V_B}\sum_{t=1}^{T} CT_{ijv} * Y_{ijvt}$$

$subject\ to$

$$I_{ik(t+1)} = I_{ikt} + \sum_{j=1}^{M+W}\sum_{v=1}^{v_B} U_{jikvt} - D_{ikt} + B_{ikt} - \sum_{j=1}^{M+W}\sum_{v=1}^{v_B} L_{jikvt} \qquad \forall i,k,t \qquad (1)$$

$$Q_{ivt}^{1} = Q_{ivt}^{2} + \sum_{k=1}^{K}\sum_{i=1}^{M+W} \left(L_{jikvt} * C_k - U_{jikvt} * C_k\right) \qquad \forall i,j,v,t \qquad (2)$$

$$N_{iv(t+1)} = N_{ivt} + \sum_{j=1}^{M} Y_{jivt} - \sum_{j=1}^{M} Y_{ijvt} \quad \forall i = M, \dots, M+W \quad \forall v,t \quad where\ i \neq j \ (3)$$

$$\sum_{i=1}^{M+W}\sum_{j=M+1}^{M+W} Y_{ijvt} = \sum_{j=M+1}^{M+W}\sum_{i=1}^{M+W} Y_{jivt} \qquad \forall v,t \qquad (4)$$

$$\sum_{k=1}^{K} U_{ijkvt} + \sum_{k=1}^{K} L_{jikvt} \leq M * Y_{ijvt} \qquad \forall v,t,j = 1, \dots, M, i = M+1, \dots, M+W \quad (5)$$

$$\sum_{i=1}^{M+W}\sum_{j=1}^{M+W} Y_{ijvt} \leq M_v \qquad \forall\ v,t \qquad (6)$$

$$\sum_{i=1}^{M+W} Y_{iivt} \leq 1 \qquad \forall\, v, t \qquad (7)$$

$$Q_{ivt}^{1} \leq\ Q_{ivt}^{2} - \{(1 - Y_{jivt}) * M\} \qquad \forall\, i, j, v, t \quad where\ i \neq j \qquad (8)$$

$$Q_{ivt}^{1} \leq C_v \qquad \forall\, i, v\, , t \qquad (9)$$

$$Q_{ivt}^{2} \leq C_v \qquad \forall\, i, v\, , t \qquad (10)$$

$$U_{ijkvt}\ \leq C_v \qquad \forall\, i, j, k, v, t \qquad (11)$$

$$L_{ijkvt}\ \leq C_v \qquad \forall\, i, j, k, v, t \qquad (12)$$

$$\sum_{i=1}^{M+W} \sum_{l=1}^{M+W} Y_{ilvt} = \sum_{j=1}^{M+W} \sum_{i=1}^{M+W} Y_{jivt} \qquad \forall v, t \qquad (13)$$

The objective function in equation minimizes the summation of total shortage cost of all demand nodes and the travel cost of the vehicle fleet. By tuning the shortage cost of the commodities CS_k the model can easily be resolved to adjust the needs of the triage. Constraint (2) ensures that the amount of starting inventory of each commodity $I_{ik(t+1)}$ is calculated by adding the previous bucket's inventory I_{ikt} , demand of the node D_{ikt}, and to the amount of shipments unloaded at the depot on the same previous time bucket U_{jikvt} while subtracting the total outbound transfer from the same depot, the shortage amount and the amount of shipments unloaded at the depot on the same previous time bucket L_{jikvt}. By doing so for every consecutive time bucket the inventory is calculated accordingly for all the nodes. Constraint (2) calculates total load of vehicle *v* when arriving to node *i* in the time bucket *t*. It ensures that for any time bucket for any vehicle, the total load of vehicle arriving node *i* must be equal to that of the total capacity of the same vehicle leaving from node *i* plus the occupied capacity difference generated by the load/unload at node j. Number of vehicles at the beginning of any time bucket at any node must be the same as the previous time bucket's number of vehicles at the end of that previous time bucket. This equality is supplied with below constraint (3). Constraint (4) ensures that if any amount of commodity is transferred between two points then there must be a vehicle that has travelled from those two points. Constraint (5) allows the load/unload operations only if there has been a travel to that node. Constraint (6) limits the maximum number of nodes that can be visited from each node (or depot) to every other node for every vehicle. This value is dependent on the vehicle type in a moderately condensed traffic on a major road. Constraint (7) is to ensure that no vehicles are allowed to make a cycle on the same node. Constraint (8) limits the load of the incoming vehicle on node i with the leaving load of the same vehicle. Constraints (9) and (10) limit the load capacity of vehicles with the maximum capacity of the respective vehicle type. Constraints (11) and (12) limit the loading and unloading amount with the vehicle capacity. Lastly, constraint (13) is to ensure the routing of the vehicles along with constraint (8).

CHAPTER 5

Computational Results

This chapter will present the computational results obtained by the proposed model using a real-life data set along with a generated data set. The proposed model is coded on IBM ILOG CPLEX Optimization Studio can be found on Appendix A.

Sets	
i, j, l : Nodes	1,…,10 where nodes 9 and 10 are depots
k : Commodities	1,2,3
t : Time buckets	1,2,3
v : Vehicle Types	1,2

Table 8: *Selected Size for the Model*

Table 6 show the size of the model. The data set generated is complex enough to approximate a medium size neighbourhood with 8 demand nodes and two supply nodes. Three vehicles, which will be of two different vehicles types will be used for the transportation of three types of commodities during a three time-bucket window.

Generated distances are chosen from Güler, Ç.U. and M. Ermiş (2015). The data set contains real-life locations and distances obtained by Turkish Air Force Academy and additional information obtained from AFAD. This data set can be found on Appendix C. The generated data set uses 10 selected nodes from a populated district of Istanbul, namely Kadıköy. Kadıköy is an area around 25km^2 and has a registered population over 450.000.

Distances between the selected nodes are generated using ArcGIS program, considering the alternative roads and using the shortest possible distances. ArcGIS is a geographic information system for working with maps and geographic information. It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database.

Inventory of the demand points are taken to be 0 at the initial moment of the disaster as the model is planned for an earthquake, a disaster by its very nature unpredictable. It is also safe to make this assumption due to the fact that emergency muster points are chosen among places which do not have the main function of storage of relief goods but rather safe and easily accessible locations.

The supply-demand ratio (S/D) of relief goods for all types of commodities is initially chosen to be 1 and scenarios where this ratio was changed to 0,75, 1,5 and 2 were also investigated. Supply-demand ratio, when it becomes closer to 1 shows a closer number of stored commodities to the demand and will lead to a higher possibility of shortage among all commodities. The ratios closer to 1 are also instances that the possible storage locations could have been damaged and may have lost some of their storage capacities. All the parameters for the generated data sets can be found on Appendix B.

The model is solved using IBM ILGOG CPLEX Studio IDE 12.7.1 on a computer with AMD FX™-6100 Six-Core Processor 3.30GHz, 8.00GB RAM, Windows 10 with 64-bit operating system.

The proposed model had been tested on multiple instances simulating different scenarios representing different magnitudes of an earthquake at or around Istanbul. For each scenario, the associated impact factor of the respective magnitude of the earthquake is used as a multiplier for the amount of demand, an impact factor is used to multiply each node's demand.

Scenario	Magnitude	Impact Factor
1	6,5	0,25
2	7,0	0,50
3	7,5	1,0

Table 9: *Impact Factors of Scenarios*

Table 9 shows the impact factors of the scenarios. The deadliest earthquake to occur at or around Istanbul in the near future is 1999 Gölcük Earthquake and it had a magnitude of 7.6. Scenario 3 is chosen as a base scenario for the model to run with an impact factor of 1 to best represent a real-life case which the demand multiplier will not make a difference. The magnitude of an earthquake and its destructive power have an exponential relationship. a difference in magnitude of 1.0 is equivalent to a factor of 31.6 (= ($(10^{1.0})^{3/2}$) in the energy released; a difference in magnitude of 2.0 is equivalent to a factor of 1000 (= ($(10^{2.0})^{3/2}$) in the energy released. The impact factor values in Table 9 are chosen to represent a similar incremental relationship with the magnitude of an earthquake and the amount of demand change it will generate based on its destructive power.

S/D	Total Shortage	
0,5	1568	52,26 %
1,0	898	29,93 %
1,5	590	19,66 %
2,0	273	7,8 %

Table 10: *Shortage amounts based on S/D ratio*

Table 10 shows amount of aggregated shortage of all types of commodities based on the S/D ratio changes. S/D = 2 is the situation where the stored commodities are twice as many as to be needed at the first 72 hours.

Scenario	Total Shortage	Shortage
1	0	0,0 %
2	0	0,0 %
3	273	7,8 %

Table 11: *Total Shortage for Scenarios with S/D = 2*

While the shortage amount for scenario 3 can be considered high, when compared to the real-life situation of the referenced disaster in 1999, it is a considerable improvement. During the response and early stages of recovery phase more than 50 countries sent people, machinery and relief goods to Turkey. With a possible ratio of less than %10 on an aggregated shortage these results can be seen as a step towards the right direction.

Given that proposed model choses to perform lateral shipments with an objective function aiming to minimize the total sum of shortage and travel costs, it would make a sound deduction that the use of lateral shipments aided to reach a better objective function value. The proof that lateral shipments are performed can be seen that decision variable indicating amount of commodity type k loaded from vehicle *v* arriving to node *j* from node *i* in time bucket *t* L_{jikvt}, having non-zero values for nodes *i* that are not depots.

CHAPTER 6

Conclusion and Future Study

This study proposed a mathematical model for the re-configuration of the optimal mix and inventory for multiple-items, multiple locations in humanitarian relief distribution. A common concept in commercial logistics known as lateral shipment is implemented into the model with the aim of reducing overall shortage of relief goods and increasing the responsiveness of the distribution system. The proposed mathematical model used multiple types of relief goods, multiple points of supply and demand, and an heterogenous vehicle fleet. The problem in its basics is a VRP.

For its nature humanitarian logistic efforts differ on multiple crucial points from commercial logistics. While commercial logistic the most common goal is to minimize distribution costs, for the humanitarian logistics the goal is to distribute the relief goods at hand in a manner that will save the most amount of lives. The proposed model is proven to be making an optimal distribution of relief goods, allowing lateral shipments and split deliveries while minimizing the total of shortage and travel costs.

The next step for the model is to be tested with the full data set that contains 148 possible demand nodes, 12 transit nodes, and 7 supply nodes taken from Turkish Air Force Academy and AFAD. This data set will challenge the model with both its size and with the addition of transit nodes. Due to the geographic nature of Istanbul having two halves separated by a body of water and having multiple islands under the city’s govern, these transit points are both essential and challenging.

As for future research, there are several options. Evacuation of survivors is an integral operation on response phase of any disaster. It will require major adaptations vehicle fleet however being able to solve the problem of evacuation will provide a valuable insight. Another possible direction can be taken towards being able to incorporate possible secondary disasters to the study length. This will require major adaptations on multiple fronts of the model and its assumptions however such model is yet to be developed for a large-scale metropolitan city.

Appendices

Appendix A

CPLEX Code

```
/*********************************************
 * OPL 12.7.1.0 Model

*********************************************/

//                                      ***SETS***

int BigM=999999999;

{int} node1=...;                        // set of all nodes
{int} node2=...;                        // set of all nodes (same as above)
{int} node3=...;                        // set of warehouses
{int} commodity=...;                    // set of commodities
{int} vehicle=...;                      // set of vehicles
{int} time=...;                                 // set of time periods

//                                      ***PARAMETERS***

tuple D             /* D.ikt = demand of each node i of commodity k at time
period t*/
{
	int node1;
	int commodity;
	int time;
};

{D} dem=...;
float dem_value[dem]=...;

tuple CT      /* CT.ijv = cost of transportation*/
{
	int node1;
	int node2;
	int vehicle;
};

{CT} ct=...;
float CT_value[ct]=...;

tuple Inv     /* Initial inventory values*/
{
	int node1;
	int commodity;
};

{Inv} inv=...;
int Inv_value[inv]=...;
```

```
tuple M             /* M.v = Maximimum number of nodes that a vehicle can
travel*/
{
	int vehicle;
};

{M} m=...;
int M_value[m]=...;

tuple capV   /* C.v = vehicle capacity in volume*/
{
	int vehicle;
};

{capV} cv=...;
int capV_value[cv]=...;

tuple capK   /* C.k = commodity capacity in volume*/
{
	int commodity;
};

{capK} ck=...;
int capK_value[ck]=...;

tuple CS     /* CS.k = cost of shortage of commodity k*/
{
	int commodity;
};

{CS} cs=...;
float CS_value[cs]=...;

tuple N_initial     /* Initial vehicle numbers*/
{
	int node3;
	int vehicle;
};

{N_initial} numb=...;
int N_initial_value[numb]=...;

//                                         ***DECISION VARIABLES***

dvar int+ B[node1][commodity][time]; /*shortage amount*/

dvar int+ N[node3][vehicle][time]; /*number of vehicles at a depot at time
t*/

dvar int+ I[node1][commodity][time]; /*ending inventory at time t*/

dvar int+ U[node1][node2][commodity][vehicle][time];
/*amount of commodity type k unloaded from vehicle v arriving to node j
from node i in time bucket t*/

dvar int+ L[node1][node2][commodity][vehicle][time];
/*amount of commodity type k loaded from vehicle v arriving to node j from
node i in time bucket t*/
```

```
dvar int Y[node1][node2][vehicle][time] in 0..1;
/*1 if vehicle v travels from node i to node j at time t*/

dvar int+ Q_one[node1][vehicle][time];
/*Total load of vehicle v when arriving to node i in the time bucket t*/

dvar int+ Q_two[node1][vehicle][time];
/*Total load of vehicle v when leaving from node i in the time bucket t*/

//                                                         ***OBJECTIVE
FUNCTION***

minimize sum (i in node1, k in commodity, t in time)
              (     B[i][k][t] ) * sum(k in commodity) CS_value[<k>]  +
              /*Total Shortage Cost*/
              sum (i in node1, j in node2, v in vehicle, t in time)
              ( CT_value[<i,j,v>]  * Y[i][j][v][t]) ;
              /*Total Travel Cost*/


subject to
{
forall(i in node1, j in node2, k in commodity)
             /* Initial assignment for (1)  */
 {
       c1:
       I[i][k][1]==Inv_value[<i,k>] + sum(j in node1, v in
vehicle)(U[j][i][k][v][1]) - dem_value[<i,k,1>] + B[i][k][1] - sum(j in
node1, v in vehicle)(L[j][i][k][v][1]);
 }

forall(i in node1, j in node2, k in commodity, t in time: t < 3)       /*
(1)  */
 {
       c2:
       I[i][k][t+1] == I[i][k][t] + sum(j in node1, v in
vehicle)(U[j][i][k][v][t]) - dem_value[<i,k,t>] + B[i][k][t] - sum(j in
node1, v in vehicle)(L[j][i][k][v][t]);
 }

forall(i in node1, j in node2,v in vehicle, t in time: t < 3)
                                /* Initial assignment for (2)   */
 {
       c3:
       Q_one[i][v][1] == Q_two[j][v][1] + sum(i in node1 ,k in
commodity)((U[j][i][k][v][t]-L[j][i][k][v][t])* capK_value[<k>] );
 }

forall(i in node1, j in node2, v in vehicle, t in time)
       /* (2) */
 {
       c4:
       Q_one[i][v][t] == Q_two[i][v][t] + sum(i in node1 ,k in
commodity)((U[j][i][k][v][t]-L[j][i][k][v][t])* capK_value[<k>] );
 }


forall(i in node3, v in vehicle)
                          /* Initial assignment for (3)   */
```

```
 {
      c6:
      N[i][v][1] == N_initial_value[<i,v>] + sum(j in node3) Y[j][i][v][1]
- sum(j in node3) Y[i][j][v][1];
 }

forall(i in node3, v in vehicle, t in time: t<3)
                   /* (3) */
 {
      c7:
      N[i][v][t+1] == N[i][v][t] + sum(j in node1) Y[j][i][v][t+1] - sum(j
in node1) Y[i][j][v][t+1];
 }

forall(v in vehicle, t in time)
                                /* (4) */
 {
      c8:
      sum(i in node1, j in node3)(Y[i][j][v][t]) == sum(i in node1, j in
node3)(Y[j][i][v][t]);
 }

forall(i in node3, j in node1: i!=j, v in vehicle, t in time)
             /* (5)  */
 {
      c9:

      sum(k in commodity)(U[i][j][k][v][t] + L[j][i][k][v][t]) <= (BigM *
Y[i][j][v][t]);
 }

forall(v in vehicle, t in time)
                                /* (6) */
 {
      c10:
      sum(i in node1, j in node2: i!=j )Y[i][j][v][t] <= M_value[<v>];
 }

forall(i in node1, v in vehicle, t in time)                         /*
(8)   */
 {
      c16:
      sum(i in node1)Y[i][i][v][t] <= 0;
 }

forall(i in node1, j in node2:i!=j, v in vehicle, t in time)          /*
(9)         */
 {
      c12:
      Q_one[i][v][t] <= Q_two[i][v][t] + ( (1 - Y[i][j][v][t]) * BigM );
 }

 forall(i in node1, v in vehicle, t in time)                    /* (10)
*/
 {
      c13:
      Q_one[i][v][t] <= capV_value[<v>];
 }
```

```
 forall(i in node1, v in vehicle, t in time)                        /* (11)
*/
 {
      c14:
      Q_two[i][v][t] <= capV_value[<v>];
 }

 forall(i in node1, j in node2, v in vehicle,k in commodity, t in time)
                  /* (12) */
 {
      U[i][j][k][v][t] <= capV_value[<v>];
 }

 forall(i in node1, j in node2, v in vehicle,k in commodity, t in time)
                  /* (13) */
 {
      L[i][j][k][v][t] <= capV_value[<v>];
 }

 forall(v in vehicle)
      /* Initial assignment for (14) */
 {
   sum(i in node3, j in node1) Y[i][j][v][1] == 1;
 }

 forall(v in vehicle, t in time: t < 3)                             /* (14) */
 {
   sum(k in node1, i in node1) Y[i][k][v][t] == sum(i in node1, j in
node1) Y[j][i][v][t] ;
 }


}


/**********************************************
 * OPL 12.7.1.0 Data*********************************************/
SheetConnection sheetInput("AED-Thesis.xlsx");

// Full data set is below but gives out of bound error //

//SETS - Testbed
node1 from SheetRead(sheetInput,"Equal_Budget!A3:A12");          //all
nodes                    10 nodes
node2 from SheetRead(sheetInput,"Equal_Budget!A3:A12");          //all
nodes as above      10 nodes
node3 from SheetRead(sheetInput,"Equal_Budget!A11:A12");  //warehouses
             2 nodes
vehicle from SheetRead(sheetInput,"Equal_Budget!D3:D5");  //
                         3 vehicles
commodity from SheetRead(sheetInput,"Equal_Budget!B3:B5");       //
                                3 commodities
time from SheetRead(sheetInput,"Equal_Budget!C3:C5");            //
                                3 time periods

//Parameter Values - Testbed
//Indices
```

```
dem from SheetRead(sheetInput,"Equal_Budget!G3:I62");

ct from SheetRead(sheetInput,"Equal_Budget!N3:P302");

m from SheetRead(sheetInput,"Equal_Budget!AC3:AC5");

cv from SheetRead(sheetInput,"Equal_Budget!AC10:AC12");

ck from SheetRead(sheetInput,"Equal_Budget!AC16:AC18");

cs from SheetRead(sheetInput,"Equal_Budget!AC22:AC24");

inv from SheetRead(sheetInput,"Equal_Budget!AG3:AH32");

numb from SheetRead(sheetInput,"Equal_Budget!X3:Y32");


//Initial Values
dem_value from SheetRead(sheetInput,"Equal_Budget!J3:J62");

CT_value from SheetRead(sheetInput,"Equal_Budget!R3:R302");

M_value      from SheetRead(sheetInput,"Equal_Budget!AD3:AD5");

capV_value from SheetRead(sheetInput,"Equal_Budget!AD10:AD12");

capK_value from SheetRead(sheetInput,"Equal_Budget!AD16:AD18");

CS_value from SheetRead(sheetInput,"Equal_Budget!AD22:AD24");

Inv_value from SheetRead(sheetInput,"Equal_Budget!AI3:AI32");

N_initial_value from SheetRead(sheetInput,"Equal_Budget!AA3:AA32");
```

Appendix B

Data Sets

Sets				
i-j	k	t	v	depot
1	1	1	1	9
2	2	2	2	10
3	3	3	3	
4				
5				
6				
7				
8				
9				
10				

D.ikt			
i	k	t	value
1	1	1	24
1	1	2	20
1	2	1	25
1	2	2	8
1	3	1	53
1	3	2	31
2	1	1	53
2	1	2	11
2	2	1	0
2	2	2	44
2	3	1	29
2	3	2	0
3	1	1	28
3	1	2	26
3	2	1	83

3	2	2	63
3	3	1	2
3	3	2	28
4	1	1	33
4	1	2	37
4	2	1	19
4	2	2	23
4	3	1	20
4	3	2	35
5	1	1	35
5	1	2	41
5	2	1	22
5	2	2	25
5	3	1	23
5	3	2	12
6	1	1	0
6	1	2	13
6	2	1	8
6	2	2	43
6	3	1	63
6	3	2	95
7	1	1	25
7	1	2	13
7	2	1	14
7	2	2	19
7	3	1	36
7	3	2	86

8	1	1	32
8	1	2	56
8	2	1	24
8	2	2	25
8	3	1	48
8	3	2	47
9	1	1	0
9	1	2	0
9	2	1	0
9	2	2	0
9	3	1	0
9	3	2	0
10	1	1	0
10	1	2	0
10	2	1	0
10	2	2	0
10	3	1	0
10	3	2	0

CT.ijv			
i	j	v	value
1	1	1	0
1	1	2	0
1	1	3	0
1	2	1	2,613
1	2	2	75,168
1	2	3	55,515
1	3	1	47,302
1	3	2	42,122
1	3	3	41,421
1	4	1	40,514

1	4	2	37,393
1	4	3	45,047
1	5	1	42,196
1	5	2	39,433
1	5	3	39,384
1	6	1	44,809
1	6	2	45,868
1	6	3	35,89
1	7	1	35,881
1	7	2	42,232
1	7	3	36,29
1	8	1	44,234
1	8	2	42,701
1	8	3	38,523
1	9	1	42,483
1	9	2	37,905
1	9	3	39,539
1	10	1	36,55
1	10	2	40,359
1	10	3	49,754
2	1	1	40,761
2	1	2	38,416
2	1	3	49,945
2	2	1	0
2	2	2	0
2	2	3	0
2	3	1	32,504
2	3	2	32,373
2	3	3	34,375
2	4	1	33,047
2	4	2	35,208
2	4	3	31,402
2	5	1	34,549
2	5	2	35,92
2	5	3	77,628
2	6	1	78,165
2	6	2	76,055
2	6	3	80,032
2	7	1	85,329
2	7	2	85,555
2	7	3	95
2	8	1	89,746
2	8	2	42,034
2	8	3	50,715
2	9	1	51,534
2	9	2	42,312

2	9	3	40,416
2	10	1	39,795
2	10	2	36,543
2	10	3	47,427
3	1	1	37,395
3	1	2	35,694
3	1	3	43,447
3	2	1	44,191
3	2	2	45,814
3	2	3	45,356
3	3	1	0
3	3	2	0
3	3	3	0
3	4	1	52,52
3	4	2	44,73
3	4	3	55,151
3	5	1	36,617
3	5	2	29,563
3	5	3	37,875
3	6	1	31,816
3	6	2	40,14
3	6	3	39,704
3	7	1	40,667
3	7	2	39,622
3	7	3	20,324
3	8	1	22,264
3	8	2	23,795
3	8	3	20,378
3	9	1	18,671
3	9	2	15,506
3	9	3	13,935
3	10	1	15,452
3	10	2	20,786
3	10	3	21,932
4	1	1	19,964
4	1	2	58,373
4	1	3	45,519
4	2	1	58,368
4	2	2	18,895
4	2	3	14,438
4	3	1	14,427
4	3	2	16,602
4	3	3	15,021
4	4	1	0
4	4	2	0
4	4	3	0

4	5	1	29,5
4	5	2	40,389
4	5	3	31,545
4	6	1	28,893
4	6	2	39,553
4	6	3	22,953
4	7	1	44,433
4	7	2	37,882
4	7	3	39,898
4	8	1	25,492
4	8	2	23,767
4	8	3	25,809
4	9	1	26,507
4	9	2	27,969
4	9	3	27,406
4	10	1	26,349
4	10	2	25,271
4	10	3	21,248
5	1	1	18,576
5	1	2	19,106
5	1	3	17,116
5	2	1	22,405
5	2	2	22,849
5	2	3	22,298
5	3	1	24,459
5	3	2	21,607
5	3	3	21,178
5	4	1	22,982
5	4	2	23,09
5	4	3	25,099
5	5	1	0
5	5	2	0
5	5	3	0
5	6	1	77,172
5	6	2	57,519
5	6	3	49,306
5	7	1	44,126
5	7	2	43,425
5	7	3	42,518
5	8	1	39,396
5	8	2	47,05
5	8	3	44,2
5	9	1	41,437
5	9	2	41,388
5	9	3	46,812
5	10	1	47,872

5	10	2	37,894
5	10	3	37,885
6	1	1	44,236
6	1	2	38,294
6	1	3	46,238
6	2	1	44,705
6	2	2	40,527
6	2	3	44,487
6	3	1	39,908
6	3	2	41,543
6	3	3	38,554
6	4	1	42,362
6	4	2	51,757
6	4	3	42,765
6	5	1	40,42
6	5	2	51,949
6	5	3	34,508
6	6	1	0
6	6	2	0
6	6	3	0
6	7	1	34,377
6	7	2	36,379
6	7	3	35,05
6	8	1	37,212
6	8	2	33,405
6	8	3	36,553
6	9	1	37,924
6	9	2	79,631
6	9	3	80,168
6	10	1	78,058
6	10	2	82,035
6	10	3	87,333
7	1	1	87,558
7	1	2	97,004
7	1	3	91,75
7	2	1	44,038
7	2	2	52,718
7	2	3	53,538
7	3	1	44,315
7	3	2	42,42
7	3	3	41,799
7	4	1	38,547
7	4	2	49,43
7	4	3	39,399
7	5	1	37,698
7	5	2	45,451

7	5	3	46,195
7	6	1	47,818
7	6	2	47,36
7	6	3	54,524
7	7	1	0
7	7	2	0
7	7	3	0
7	8	1	46,734
7	8	2	57,155
7	8	3	38,621
7	9	1	31,566
7	9	2	39,879
7	9	3	33,82
7	10	1	42,144
7	10	2	41,707
7	10	3	42,671
8	1	1	41,625
8	1	2	22,327
8	1	3	24,268
8	2	1	25,799
8	2	2	22,381
8	2	3	20,674
8	3	1	17,51
8	3	2	15,939
8	3	3	17,456
8	4	1	22,789
8	4	2	23,936
8	4	3	21,968
8	5	1	60,377
8	5	2	47,522
8	5	3	60,372
8	6	1	20,899
8	6	2	16,441
8	6	3	16,431
8	7	1	18,606
8	7	2	17,025
8	7	3	31,503
8	8	1	0
8	8	2	0
8	8	3	0
8	9	1	42,393
8	9	2	33,549
8	9	3	30,897
8	10	1	41,557
8	10	2	24,957
8	10	3	46,436

9	1	1	39,886
9	1	2	41,902
9	1	3	27,495
9	2	1	25,771
9	2	2	27,813
9	2	3	28,511
9	3	1	29,973
9	3	2	29,41
9	3	3	28,353
9	4	1	27,274
9	4	2	23,252
9	4	3	20,58
9	5	1	21,11
9	5	2	19,12
9	5	3	24,409
9	6	1	24,853
9	6	2	24,302
9	6	3	26,463
9	7	1	23,611
9	7	2	23,182
9	7	3	24,985
9	8	1	25,094
9	8	2	27,103
9	8	3	25,46
9	9	1	0
9	9	2	0
9	9	3	0
9	10	1	2,06
9	10	2	15,744
9	10	3	19,824
10	1	1	15,666
10	1	2	17,323
10	1	3	18,968
10	2	1	13,488
10	2	2	20,821
10	2	3	16,242
10	3	1	16,193
10	3	2	17,837
10	3	3	14,31
10	4	1	18,986
10	4	2	18,305
10	4	3	11,286
10	5	1	18,529
10	5	2	8,976
10	5	3	11,91
10	6	1	15,415

10	6	2	30,666
10	6	3	31,75
10	7	1	31,899
10	7	2	24,825
10	7	3	31,906
10	8	1	29,873
10	8	2	31,382
10	8	3	32,252
10	9	1	30,064
10	9	2	27,995
10	9	3	27,973
10	10	1	0
10	10	2	0
10	10	3	0

N.iv0			
i	**v**		**value**
1	**1**		0
1	**2**		0
1	**3**		0
2	**1**		0
2	**2**		0
2	**3**		0
3	**1**		**0**
3	**2**		**0**
3	**3**		**0**
4	**1**		**0**
4	**2**		**0**
4	**3**	**time**	**0**
5	**1**		**0**
5	**2**		**0**
5	**3**		**0**
6	**1**		**0**
6	**2**		**0**
6	**3**		**0**
7	**1**		**0**
7	**2**		**0**
7	**3**		**0**
8	**1**		**0**
8	**2**		**0**
8	**3**		**0**
9	**1**		1

9	**2**		0
9	**3**		1
10	**1**		0
10	**2**		0
10	**3**		1

M.v	
v	value
1	10
2	10
3	20

cap.v	
v	value
1	20
2	20
3	30

cap.k	
k	value
1	1
2	2
3	2

CS.k	
k	value
1	79
2	44
3	30

I.ik0		
i	k	value
1	1	0
1	2	0
1	3	0
2	1	0
2	2	0
2	3	0
3	1	0

3	2	0
3	3	0
4	1	0
4	2	0
4	3	0
5	1	0
5	2	0
5	3	0
6	1	0
6	2	0
6	3	0
7	1	0
7	2	0
7	3	0
8	1	0
8	2	0
8	3	0
9	1	500
9	2	500
9	3	500
10	1	500
10	2	500
10	3	500

Appendix C

Istanbul Case Data

Koordinatlar (Long/Lat)	Açık Adres
29.055275917053223, 40.91078830892701	Kınalıada Çınartepe Mevkii
29.126606583595276, 40.87153343490262	Büyükada Birlik Meydanı
29.113715887069702, 40.86111562999494	Büyükada Dilburnu Mevkii
28.71099829673767, 40.9780270298534	Ambarlı Mh. Fevzi Çakmak Cd. Mezarlık Sk. Ve İlkbahar Sk.
28.701052666696114, 40.98832114139735	Cihangir Mh. Osmanpaşa Cd. No:70, Meşrutiyet Cd. No:68
28.716673851013184, 40.97153872762437	Avcılar Deniz Otobüsü İskelesi, Şht. Asteğmen Mustafa Burcu Parkı Önü
28.725197999999978, 40.982589	Abdülkadir Uztürk İÖO
28.826673084655795, 41.017359680307145	YeniBosna Merkez Mah. Radar Mevkii
28.84684145450592, 41.0193314447438	Koca Sinan Merkez Mah Kemal Sunal Caddesi ile Yirmi Temmuz Sokak arası
28.830260038375854, 40.997625764296416	Fevzi Çakmak Mahallesi Fatih Cd ile Çakmak Sk. Kesişimi futbol sahası
28.847973346710205, 41.008042306709626	Soğanlı Mah. Kemal Sunal Cd. İle Öner Sk. Arası
28.879365921020508, 41.00239498804849	Bahçelievler mah. Güneş Sok Merter Spor tesisleri
28.82231999999999, 40.997749	Fevzi Çakmak Mahallesi Bahçelievler Belediyesi Teknik Hizmet Binası bahçesi
28.879666328430176, 41.022107895778014	Bahçelievler mah. Talat Paşa Cd Üzeri futbol alanı
28.849180340766907, 40.99922499068373	Şirinevler Mh. Saray Cd. Şeyh Şamil Parkı
28.85087013244629, 41.00020879928545	Şirinevler Mh. Çeşme Sk. Milli Egemenlik Parkı
28.854228258132935, 41.019780703503926	Cumhuriyet Mh. Çelik Hançer Cd. İki yanı
28.81542205810547, 41.00963318437629	YeniBosna Merkez Mah. Çıraklık eğitim okulu Değirmenbahçe Caddesine kadar olan yol
28.834619999999973, 40.996815	Kuleli İÖO
28.888442516326904, 40.99214356470819	Osmaniye Mah. Fildamı
28.888742923736572, 40.996888892498504	Osmaniye Mah. Cumartesi Semt Pazarı
28.810755014419556, 40.962578799529275	Yeşilköy Çarşamba Semt Pazarı
28.88359308242798, 40.997034648013155	Osmaniye Mah. Atatürk Spor ve Yaşam Köyü
28.79237651824951, 40.98082951984562	Şenlikköy (Florya) Şenlikköy Stadı
28.804242610931396, 40.96802295150544	Şenlikköy (Florya) Bakırköy Spor Antrenman Sahası
28.849260807037354, 40.988122725308315	Ataköy 9.Kısım Yüzücü Talat Yüzmen Sokak Zabıta Müdürlüğü Yanı Kapalı Yeşil Alan
28.874409198760986, 40.97142531841567	Ataköy Marina, Zeytinlik Mh., Bakırköy, Türkiye
28.863474999999994, 40.978426	Ataköy İÖO
28.90329122543335, 41.03260554614438	Terazidere Mh. 60ıncı yıl cad-Esenler Cd (60 yıl parkı)
28.90628457069397, 41.03897454589143	Altıntepsi mh. Yahya Kemal parkı
28.895695209503174, 41.04914586328584	Kocatepe Mh. Mega Center parkı bahçesi 12'lik yol boyu
28.918118476867676, 41.03502535306703	Orta Mahalle Çevreyolu Cd. Fatih Parkı
28.89574885368347, 41.05788368704237	Kartaltepe Mh. 50inci yıl cd. İrem Sk. Park
28.888893127441406, 41.063813419241896	Yıldırım Mh. Hudud yolu Çakmak sokak. Park
28.891596794128418, 41.05921044026309	Kocatepe Mh. İnönü Cd. Pınar Sk. M.Akif Ersoy Parkı

28.908827304840088, 41.04387024492739	İsmet Paşa Mh. Tuna Cd. S.Akpınar Parkı
28.887391090393066, 41.06233305868567	Parkada
28.894360000000006, 41.056504	Osmangazi İÖO
28.964504599571228, 41.048992131924244	Piyalepaşa Kadınlar Çeşmesi İOO yanındaki boş alan
28.96896243095398, 41.023840082904606	Arap Camii mh. Unkapanı köprüsü ile Galata köprüsü arası kıyı şeridi
28.948974609375, 41.041928193020084	Piri Mehmet Paşa Mh. Haliç kıyı şeridi çadırkent
28.96561235189438, 41.04757414545602	Beyoğlu sosyal meskenler parkı ve basketbol sahası
28.952732384204865, 41.03906153876293	Keçecipiri Mh. Okmeydanı Cd. Şükrü Urcan spor tesisleri
28.980109691619873, 41.03354029815758	Şehit Neşe Alten İOO yakınındaki boş alan
28.97616147994995, 41.04839743090627	Hacı Ahmet Mh. Cin Deresi Mevkii boş alan çadır kent
28.9409601688385, 41.04653238128972	Örnektepe, Sütlüce, Piripaşa, Keçecipiri Mh., Haliç kıyı şeridi
28.969885999999974, 41.034305	Ahmet Emin Yalman İÖO
28.610522747039795, 41.01265291266128	Atatürk Mh. Parmaksız Cd. Gönül Sk. Ve Zinde Sk. Arası boş arsa
28.60863447189331, 41.0107180356682	Atatürk Mh. Parmaksız Cd. Güneş Sk. Ve Esmeray Sk. Arası boş arsa
28.624556064605713, 41.02005187622756	Yıldıray Çınar Sk. Ve Şimşek Sk. Arası EGS Market önü ve arkasındaki boş alan
28.59990656375885, 41.01076661068138	Kordonboyu Cd. Albatros Parkı
28.538060188293457, 41.001245223739204	Mimar Sinan, Batıköy Mh. Şükran Cd ile Uğur Mumcu Cd. Arası
28.543392419815063, 41.00316418536696	Mimar Sinan, Batıköy Mh. Sinanoba park alanı
28.509950637817383, 41.000014467885975	Güzelce Mah. Kıyı Sok. Güzelce Marina
28.584600000000023, 41.0192	Büyükçekmece Lisesi
28.44838857650757, 41.14345293436719	Ferhatpaşa Mh. Havuz Mevkii
28.474159240722656, 41.13160730762188	Ferhatpaşa Mh. İstasyon Mevkii
28.97047519683838, 41.01870004887423	Eminönü İskelesi
28.86885166168213, 41.05161765243985	Birlik Mh. Deprem parkı
28.86980652809143, 41.05753581439155	Havaalanı Mh. Bölge Parkı
28.879365921020508, 41.05403271515935	Kemer Mh. Esenler Stadyumu içi ve çevresi
28.885427713394165, 41.04069819717101	Fevzi Çakmak Mh. İstanbul Ulaşım AŞ iç kısmı
28.89052391052246, 41.0261145211107	Davutpaşa Mh. Yıldız Teknik Üniversitesi içi kısmı
28.896961212158203, 41.02506229967663	Çifte Havuzlar Mh. Sarıgöl Cd. İç kısımları
28.89408500000002, 41.03329	Ayvalıdere İÖO
28.929834365844727, 41.04743861590552	Eyüp Stadyumu-Merkez Mh. Bülbülderesi Sk. No 3
28.934066891670227, 41.08242428937771	Veysel Karani Camii yanı Çırçır Mh. Zühal Sk.
28.91574740409851, 41.04825583463354	Rami Kışla Otopark-Yeni Mh. Talimhane Cd.
28.93347144126892, 41.04398352951965	Amcaza Vakfı arazisi Nişanca, Balcı yokuşu sk.
28.957643508911133, 41.08000622555256	Güzeltepe İETT garaj alanı Dikmen Sk.
28.937843441963196, 41.07967060096734	Alibeyköy İtfaiye önü Çırçır Mh. Atatürk Cd.
28.921197652816772, 41.081284009494674	Yeşilpınar Bölge Parkı Atatürk Bulvarı
28.933117389678955, 41.07978786758348	Refhan Tümer Lisesi yanı Çırçır Mh. Atatürk Cd.
28.883163928985596, 41.187180795161495	Göktürk Spor Tesisleri İstanbul Cd. Göktürk
28.939141631126404, 41.07129560612972	Karadolap Spor Kompleksi ve Kil Sk.
28.874495029449463, 41.196255473905886	Göktürk Göleti Yanı Piknik Alanı İstanbul Cd.
28.93883500000004, 41.072657	Alibeyköy İÖO
28.93876075744629, 41.027571404142776	Hatice Sultan Mh. Yeşil alan
28.932420015335083, 41.01002178987737	Seyitömer Mh. Çukurbostan Fındıkzade
28.93425464630127, 41.024584747478976	Fatih Mimar Sinan Stadı

28.921380043029785, 41.001196641707025	Namık Şevik Stadı
28.95650625228882, 41.00205491900372	Yenikapı Feribot İskelesi, Katip Kasım Mh.
28.95291999999995, 41.010812	Pertevniyal Lisesi
28.86336386203766, 41.025005641122355	Güneştepe Mh. Necip Fazıl Kısakürek Cd. Top sahası
28.87266844511032, 41.02511895818212	Merkez Mh. Atatürk Cd. No 19 Hasbahçe
28.896832466188016, 41.016271545923935	Tozkoporan Mh. Cevat Açıkalın Cd No 6, 75inci Yıl Parkı
28.86896163225174, 41.0225227344608	Soğanlı Cd. No 96 Aliya İzzet Begoviç Parkı
28.872600000000034, 41.026618	Güngören İÖO
29.036967158317566, 40.993580965416896	Hasanpaşa Mh. Kadıköy Belediyesi otopark alanı
29.03012752532959, 40.98310139326762	Caferağa Mh. Kadıköy Anadolu Lisesi, Dr. Esat Işık Cd.
29.024961590766907, 40.98448634722456	Caferağa Mh. Moda Sabit Pazarı ve Otoparkı
29.043179154396057, 40.993329928678584	Eğitim Mh. İETT otobüs garajı
29.0593421459198, 40.99065349370898	Dumlupınar Mh. Fenerbahçe Spor Tesisleri
29.055490493774414, 40.97963888113106	Göztepe Mh. Selamiçeşme Özgürlük Parkı
29.058022499084473, 40.969821367302615	Caddebostan Mh. Göztepe Parkı
29.083991646766663, 40.98474146714958	Sahrayıcedid Mah. Atatürk Cd. Cebe Sk.
29.059449434280396, 40.996735039105616	İstanbul Medeniyet Üniversitesi
29.094157218933105, 40.951705354397575	Bostancı İskelesi
29.018540382385254, 40.99619250059124	Haydarpaşa Garı
29.06122800000003, 40.983464	Faik Reşit Unat İÖO
29.19089913368225, 40.89192616676853	Kartal Stadyumu Yukarı Mh. Spor Cd.
29.173368215560913, 40.9127180097896	Mustafa Kemal Cd. Kavaklı Camii Yanı
29.234265089035034, 40.87378067478115	İDO Yalova Deniz Otobüsü İskelesi, Batı Mah.
29.187948000000006, 40.906264	Bedri Rahmi Eyüpoğlu İÖO
28.77858100000003, 41.032648	Mega Eğitim Kampüs Alanı - Halkalı 853 Ada 1 Parsel
28.809817000000066, 41.002727	Kartaltepe Mahallesi 782 ada ve 783 ada 1 ve 2 parsel
28.80718231201172, 41.02197029017439	İnönü Mahallesi Çınaryolu Mevki
28.788475000000062, 41.01593	Dr. İffet Onur İÖO
29.164795875549316, 40.957571727614564	Başıbüyük mah. B.Bakkalköy Cad. Kuyular Düzü Mevkii
29.1307532787323, 40.93918490046506	Altayçeşme mah. Tülay Sok. Zuhal sok. Arası
29.12252426147461, 40.940433000444465	İdealtepe Mah. Rıfkı Tongsır Cad. - 50.yıl parkı
29.136718511212848, 40.927845562832566	Bağlarbaşı Mah. Lisaltı Sok. - Yücelen Sok. - Ergenekon sok. Arası ECA. Elginkan anadolu Lisesinin ön ve arkası
29.133896827697754, 40.94630847893452	Aydınevler Mah. Başıbüyük Samandıra Yolu ile Büyükbakkalköy yolu arası (Derviş Bey sitesinin yanı)
29.11515399999996, 40.936506	Maltepe Anadolu Lisesi
29.271408319473267, 40.87627932126042	Kavakpınar Parkı Kavakpınar Mah. Güneş Sok.
29.291396141052246, 40.92697821221532	Yenişehir Mah. Yenişehir Parkı Mesut Yılmaz Mah. İ.Ö.O. Yanı
29.29354190826416, 40.924051838296826	Çamlık Parkı - Çamlık Mahallesi Necip Fazıl İ.Ö.O. Yanı
29.26154851913452, 40.89275342420696	Fevzi Çakmak Deprem Parkı Fevzi Çakmak Mah. Hukukçular Cad.
29.302918910980225, 40.92435988375906	Yenişehir Parkı Yenişehir Mah. Muhtarlığı Yanı
29.27602200000001, 40.899234	Pendik T.L. ve E.M.L.
29.142871499061584, 41.02192577065285	M.Sinan Mahallesi Gökçesu Sok. ve Günbatımı Sok. Kesişimi
29.281954765319824, 40.997002257926646	M.Sinan Mahallesi Karadeniz Cad. ve Özgürlük Cad. Kesişimi

29.261140999999952, 41.006723	Mevlana İÖO
29.31225299835205, 40.84572933263993	Alt İçmeler Mah. 16 Pafta 4079 Parsel
29.363794326782227, 40.89395374013669	Orhanlı Beldesi 3 Pafta 885 Parsel
29.32843600000001, 40.866845	İhsan Hayriye Hürdoğan İÖO
29.07784938812256, 41.04344947187736	Bahçelievler Mah. Bosna Bulvarı No:102/1
29.045416116714478, 41.03929014738882	Beylerbeyi Top Sahası (Bey Bostanı Sok. No:15)
29.05310869216919, 41.04794027612959	Çengelköy Güneş Sigorta Arazisi (Yalıboyu Cad.)
29.07428205013275, 41.051658106481824	Güzeltepe Mah. Yıldırım Beyazıd Parkı (Prof.Dr.Beynun Akyavaş Cad.)
29.069738388061523, 41.05487007801609	Güzeltepe Mah. Engin Cad.
29.074201583862305, 41.0569411906005	Bahçelievler Mah. Zübeyde Hanım Cad. (Bahçelievler Muhtarlık Binası Arkası)
29.07702863214479, 41.04635032331906	Bahçelievler Mah. Ata 2 Sitesi Ladin Cad. No:42 Yanı
29.079115390777588, 41.04067392070583	Bahçelievler Mah. Eski Otomobil Müzesi (Bosna Bulvarı No: 106)
29.055780172348022, 41.02357297290752	Kısıklı Millet Parkı
29.0688693523407, 41.00899359949879	Küçük Çamlıca 69 Evler Üstü boş arazi
29.067882299423218, 41.01279053773048	Küçük Çamlıca Üç Pınarlar Sabancı Villaları altı Koru Park olarak düzenlenmiş
29.064406156539917, 40.99709942813843	Ünalan Mahallesi Şeyh Şamil Lisesi Yanı boş arsa
29.050716161727905, 41.02413147439303	Emniyet Mahallesi Vezir Spor Tesisleri
29.060893999999962, 41.028932	Emniyet Mahallesi Nuri Bey Caddesi altındaki Türk Ticaret Banası arazisi
29.053785999999945, 41.02553	Emniyet Mahallesi Eski Papyon arazisi İETT garajı olarak kullanılıyor
29.070467948913574, 41.03503344591755	Ferah Mahallesi Çamlıca TV vericisinin Ferah Mahallesine Bakan Kısmı
29.018934667110443, 41.010147276580845	Selimiye Stadı
29.02214527130127, 41.004573007701815	Haydarpaşa Hukuk Fakültesi arkası
29.021008014678955, 41.02048898811825	Çavuşdere Eski Tanzim Satış Yeri
29.02534246444702, 41.02379961176257	Selamsız Mahallesi Çevik Kuvvet Yanı
29.026801586151123, 41.03181241281624	Fethi Paşa Korusu
29.068751335144043, 41.027603790400995	Büyük Çamlıca Korusu
29.062979221343994, 41.017356288799604	Küçük Çamlıca Korusu
29.041993618011475, 41.01261243464508	Validebağ Korusu
29.015772342681885, 41.02762807168645	Üsküdar İskelesi, Paşa Limanı Cd.
29.026540999999952, 41.020564	Üsküdar Cumhuriyet Kız Meslek Lisesi
29.075710999999956, 41.058731	4. Murat İÖO
28.911724090576172, 40.98664471163413	Kazlıçeşme Mah. Sahil Şeridi 1-2. Bölge
28.894445300102234, 41.00077154739775	Çırpıcı Çayırı (Çırpıcı Mah. Tramvay Son Durağı)
28.89478325843811, 40.99119607780847	Hasan Doğan Amatör Futbol Tesisi (Sümer Mah. Prof.Turan Güneş Cad.)
28.914741999999933, 40.997813	100. Yıl Ticaret Meslek Lisesi
28.819969210514046, 40.97991120245358	Atatürk Havalimanı
29.316023150787373, 40.910414462246585	Sabiha Gökçen Havalimanı

CHAPTER 7

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