

# LOCATION-LOCATION ROUTING PROBLEM AND ITS APPLICATION ON REFUGEE CAMPS

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By  
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Location-Location Routing Problem and Its Application on Refugee  
Camps

By Gül Çulhan Kumcu

May 2019

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

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## ABSTRACT

# LOCATION-LOCATION ROUTING PROBLEM AND ITS APPLICATION ON REFUGEE CAMPS

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In the classical Location Routing Problem (LRP), the customers are at fixed and known locations. Given the known customer locations, in LRP models, decisions are taken for distribution center locations and corresponding vehicle routes. However; for some public applications the locations of customers can also be decision variables coming from a discrete set. In this study we consider such an application where the locations of demand nodes will be determined while considering the distribution center location(s) and corresponding vehicle routes. To the best of our knowledge this variant of LRP has not been defined in the location literature before. We refer this problem as Location-Location Routing Problem(L-LRP). We observe that, refugee camp location and management problem is a direct application of the L-LRP. In refugee camps certain public services are required to protect health, safety, dignity, etc. of the refugees. Thus, authorities should plan regular public service visits to the refugee camps to provide these services. In the refugee camp location problem authorities decide the locations of hosting institutions and routes of service providers originated from these institutions. Actually, in addition; authorities also decide the locations of these refugee camps. For the L-LRP, a linear mixed integer mathematical formulation is developed. To obtain results in shorter times with preserving solution qualities, a two-stage math-heuristic algorithm is presented. The computational analysis of mathematical formulation and heuristic algorithm are conducted on a real data set obtained from Southern part of Turkey.

*Keywords:* Location routing, refugee camp location, integer programming, two-stage heuristic algorithm.

## ÖZET

# YER SEÇİMİ-YER SEÇİMİ ROTALAMA PROBLEMİ VE MÜLTECİ KAMPLARI ÜZERİNDEKİ UYGULAMASI

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Klasik Yer Seçimi Rotalama Probleminde (YRP), talep noktaları sabit ve bilinen konumdadırlar. Bilinen talep konumları ile kararlar depoların yer seçimleri ve araç rotalamaları için alınmaktadır. Ancak bazı kamusal problemlerde, talep noktalarının yerleştirilmesi de karar değişkeni haline gelebilmektedir. Bu çalışmada depo yer seçimleri ve araç rotalamalarının yanı sıra talep noktalarının yer seçimi de göz önünde bulundurulmuştur. Yazarların bilgisine göre YRP kararlarına ek olarak talep noktalarının da yer seçiminin yapıldığı bir çalışma henüz literatürde bulunmamaktadır. Bu problem Yer Seçimi-Yer Seçimi Rotalama Problemi (Y-YRP) olarak adlandırılmıştır. Bu çalışmada gösterileceği üzere, mülteci kampı yerleştirme problemi Y-YRP'nin direkt bir uygulama alanıdır. Mültecilerin sağlığını, güvenliğini, itibarını, vb. korumak için mülteci kamplarına birden fazla kamusal hizmet sunulmaktadır. Dolayısıyla, yetkililer bu hizmetleri sağlamak için mülteci kamplarını düzenli olarak ziyaret etmelidir. Mülteci kampı yerleştirme probleminde yetkililer mülteci kamplarına hizmet veren kuruluşların yer seçimine ve hizmet götüren çalışanların rotalamalarına karar vermektedir. Buna ek olarak, yetkililer aslında mülteci kamplarının konumlarını da belirlemektedir. Dolayısıyla mülteci kampı yerleştirme problemi Y-YRP'nin direkt bir uygulama alanıdır. Y-YRP için tam sayılı dorusal programlama ile matematiksel bir model geliştirilmiştir. Sonuçları daha kısa sürede elde etmek için iki aşamalı optimizasyon tabanlı sezgisel bir algoritma sunulmuştur. Matematiksel modelin ve sezgisel algoritmanın performansı Türkiye'nin güney bölgesinden elde edilen gerçek veriler üzerinde test edilmiştir.

*Anahtar sözcükler:* Yer seçimi rotalama, mülteci kampı yer seçimi, tam sayılı programlama, iki aşamalı sezgisel algoritma.

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# Chapter 1

## Introduction

In the classical Location Routing Problem (LRP), the customers are at fixed and known locations. Given the known customer locations, in LRP models, decisions are taken for distribution center locations and corresponding vehicle routes for serving customers. Many extensions and applications of LRP are reviewed in the literature. In these studies the demand points are assumed to be of known locations. However; for some public applications the locations of customers can also be decision variables coming from a discrete set. This thesis addresses such an application where the locations of demand nodes will also be determined while considering the distribution center location(s) and corresponding vehicle routes. To the best of the authors' knowledge this variant of the LRP has not been defined in the location literature before. This problem is referred as Location-Location Routing Problem (L-LRP).

This thesis gives the detailed description of L-LRP and formulates a mathematical formulation to solve the problem. The problem definition and optimization model is generic and they can be used in any LRP problem where decision makers can locate the demand nodes. In this thesis, as an application area to L-LRP, refugee camp location problem is selected and analyzed in detail.

In refugee camps certain public services are required to protect health, safety,

dignity, etc. of the refugees. Thus, authorities should plan regular public service visits to the refugee camps to provide these services. In the refugee camp location problem authorities decide the locations of hosting institutions, and routes of service providers originate from these institutions. Actually, in addition, authorities also decide the locations of these refugee camps. Thus refugee camp location problem is a direct application of the L-LRP.

The thesis presents L-LRP with application on refugee camp location problem. The aim of this study is to determine the locations of refugee camps, locations of hosting institutions giving service to refugee camps and routes of service providers visiting the camps. The goal is minimizing total route length of service providers from all service types. In order to achieve this, a linear integer mathematical formulation is developed according to problem specific requirements which make use of the LRP. Additionally, in order to obtain results in shorter times while preserving solution qualities, a two-stage math-heuristic algorithm is introduced in which the data set is downsized first, and L-LRP is solved with the generated small data set second. As mentioned, problem definition and proposed solution techniques can be implemented to any L-LRP application. Refugee camp location problem is just a case study for the proposed problem.

The remainder of this study is organized as follows: in Chapter 2, Refugee Crisis is analyzed with facts and figures belonging to different years. Syrian Refugee Crisis and its reflections on Turkey is discussed with special focus on Syrians living in refugee camps. The locations and functioning of refugee camps in Turkey are analyzed.

In Chapter 3, L-LRP is defined and the L-LRP decisions are matched with refugee camp location decisions. Since refugee camp location problem is a humanitarian application, in Chapter 4 humanitarian LRP literature is reviewed with investigating the contributions of the problem studied in this work.

In Chapter 5, a linear integer mathematical model is presented for the problem. For the formulation, problem specific terms are used for refugee camp location

problem. The sets and parameters are explained in detail with analysis of objective function and constraints. The details of the presented model are explained in this chapter. In Chapter 6, the computational results of the mathematical formulation are evaluated considering different data and parameter settings. This chapter reveals the necessity of a heuristic algorithm to solve the problem in higher dimensions in reasonable solution duration.

In Chapter 7, the details of the proposed two-stage math-heuristic algorithm are discussed. The first stage of the heuristic algorithm downsizes the data set. In the second stage, L-LRP is solved with a smaller data set obtained from the first stage. Chapter 8 is devoted to the computational studies of the heuristic algorithm and comparison of it with the mathematical formulation in terms of solution times and qualities.

Finally, the thesis ends with a brief summary of work done and some future research directions in Chapter 9.

## Chapter 2

# Refugee Crisis

The United Nations High Commissioner for Refugees (UNHCR) defines refugees as “people who have fled war, violence, conflict or persecution and have crossed an international border to find safety in another country” [6]. Political, national, religious, etc. issues can be reasons of persecution. Fear of violence in their own country results in citizens to seek asylum in other countries and become a refugee. Currently, more than 25.4 million people take shelter in host countries and people from five countries constitute the two-third of the refugees worldwide [7]. These countries are Syria, Afghanistan, South Sudan, Myanmar and Somalia.

Figure 2.1 shows the refugee population and its proportion of world population between years 1980 and 2017. 1992 is the year that refugee proportion of world population reaches its highest level, whereas 2017 is the year that largest number of people seeking asylum in host countries. Compared to 2005, refugee population in 2017 has nearly doubled, whereas world population only has increased by 15% [1]. Between years 2011 to 2017, there is a sharp increase in total refugee population mainly because of Syrian Refugee Crisis resulted by Syrian Civil War.

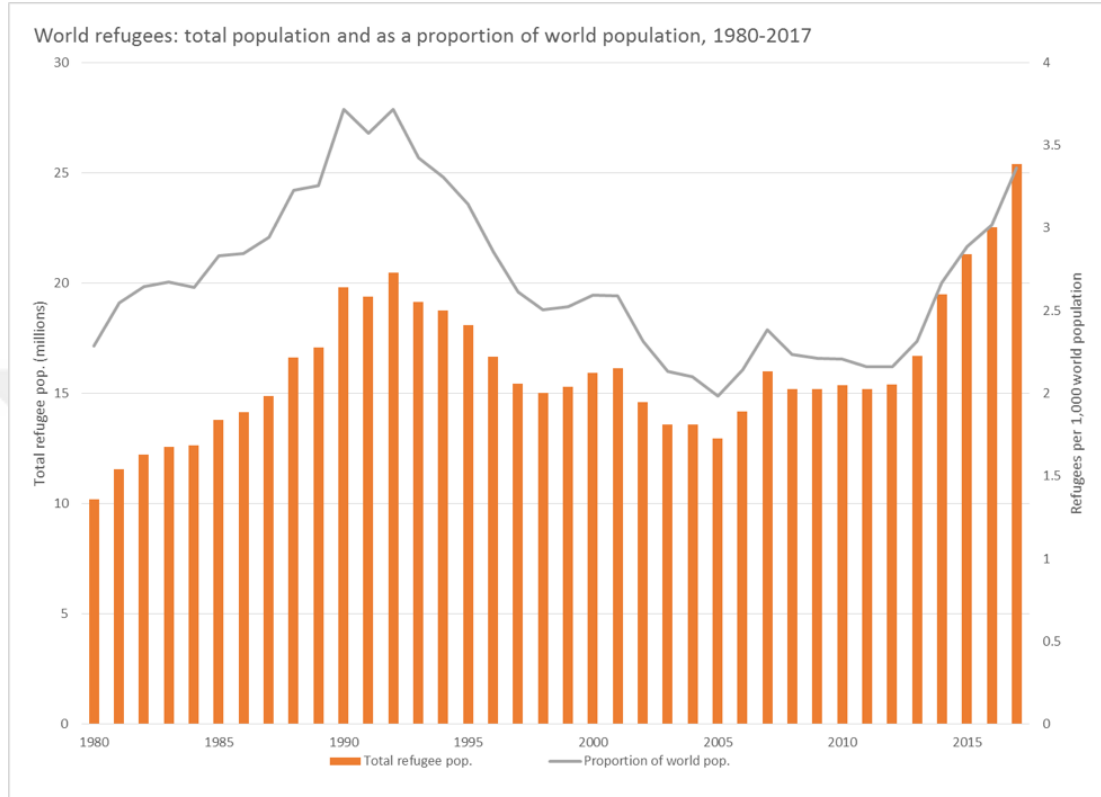


Figure 2.1: Refugee proportion of world population [1]

By the end of 2017, Turkey was the host country having the largest number of refugees in its borders with nearly 3.5 million refugees. Pakistan, Uganda and Lebanon followed Turkey but hosting less than 1.5 million refugees. Thus, Turkey is the host country facing the refugee crisis most intensive, especially after 2011. 57% of the refugees came from three countries as South Sudan, Afghanistan and Syria with 2.4, 2.6 and 6.3 million refugees, respectively. As a consequence of Syrian Civil War, there is a huge number of Syrians seeking asylum in host countries, which will be the subject throughout this study.



## 2.1 Syrian Refugees in World

Syrian Civil War has started in March, 2011 and many Syrians left their homeland to escape from violence. The war has affected not only Syrians but also whole world since refugees began to seek asylum in foreign countries. Since then, Syrian Refugee Crisis has become one of the biggest man-made disasters. Figure 2.2 shows that even if more than 8 years have passed from the beginning of the war, number of Syrian refugees continue to increase. According to UNHCR [8], there are more than six and a half million Syrian refugees throughout the world as of May, 2019. These numbers prove that the refugee crisis is not a temporary issue, especially for host countries.

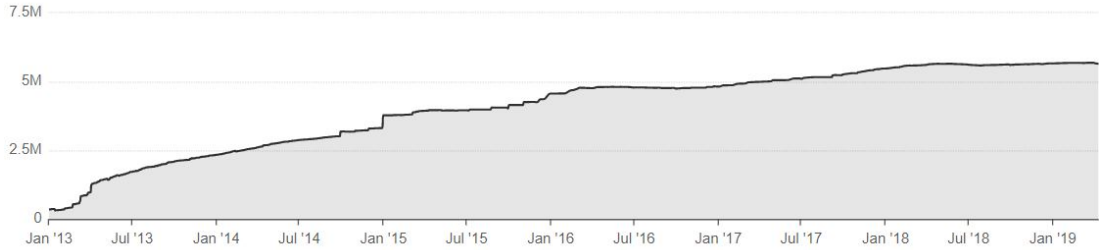


Figure 2.2: Number of Syrian Refugees from 2013 to 2019 [2]

From the beginning of the civil war, Syrians have fled across the whole world. Mainly they have spread to their neighborhood countries as Turkey, Lebanon, Jordan, Iraq and Egypt. Number of Syrians in neighbor countries is shown in Figure 2.3. Within neighborhood countries, Turkey is the host having the largest number of refugees in its borders with more than three and a half million Syrians. 62.4% of the Syrian refugees live inside Turkey. Lebanon and Jordan follow Turkey having 16.7% and 11.7% of Syrian refugees, respectively.

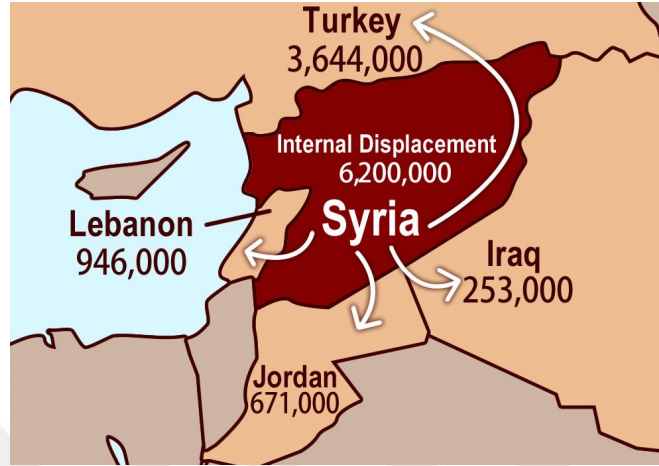


Figure 2.3: Number of Syrian refugees in neighbor countries [3]

In host countries, refugees mainly maintain their lives in urban and suburban areas. However, there is also a majority of Syrian refugees living inside the refugee camps. Especially refugee camps are shelter for refugees when they first entered to host country to seek asylum. Refugee camps are places where public services can be regularly provided to refugees compared to urban and suburban areas. Also, refugee camps are places where the authorities first face with the crisis and where they can take control.

Table 2.1 shows the percentage of Syrians living in refugee camps from March 2013 to March 2019. As the years passes, the percentage of Syrian refugees living inside the camps shows a downward trend. However; as it can be seen from March 2013, significant majority of the refugees live inside the camps at the first years of the crisis. Besides, even if eight years have passed from the beginning of the Syrian civil war, significant majority of Syrians still live in refugee camps. Since Turkey has the largest number of Syrians both inside and outside camps, the study continues with Syrian refugees in Turkey.

| Date       | Nb. of Registered Syrians (RS) | Nb. of Syrians Living Inside Camps (IC) | IC/RS (%) |
|------------|--------------------------------|-----------------------------------------|-----------|
| March 2013 | 421,151                        | 185,982                                 | 44.16%    |
| March 2014 | 2,512,891                      | 331,802                                 | 13.20%    |
| March 2015 | 3,875,481                      | 441,988                                 | 11.40%    |
| March 2016 | 4,771,616                      | 490,837                                 | 10.29%    |
| March 2017 | 4,990,077                      | 487,837                                 | 9.78%     |
| March 2018 | 5,603,259                      | 460,516                                 | 8.22%     |
| March 2019 | 5,681,543                      | 362,071                                 | 6.37%     |

Table 2.1: Percentage of Syrian refugees living in camps worldwide [5]

## 2.2 Reflections of Crisis in Turkey

Turkey is the host country having the largest number of refugees, especially because of Syrian population inside its borders. In Turkey, İstanbul, Hatay, Gaziantep and Şanlıurfa are cities where more than 300,000 refugees live. As stated, most of the refugees inside Turkey live in urban and suburban places. However, reaching regular public services to refugees in these places is not possible because of dispersed settlement. On the other hand, since refugee camps are asylum for many people in control of government, public services can be provided regularly and systematically. The remaining of the thesis proceeds with refugee camps in Turkey.

In Turkey, approximately 140,000 Syrians populate inside the camps and in the Southern part of Turkey, 13 refugee camps are placed for Syrians [9]. 11 of them are container camps, whereas there are two tent camps in Şanlıurfa as Suruç Tent Camp and Ceylanpınar Tent Camp. Figure 2.4 shows the provincial breakdown of Syrian refugees living inside camps. Adana, Gaziantep, Hatay, Kahramanmaraş, Kilis, Malatya, Osmaniye and Şanlıurfa are cities having refugee camps in Turkey. Sarıçam Container Camp is the refugee camp with the highest refugee population. Şanlıurfa is the city having the largest number of refugees inside its camps with

41,412 Syrians.

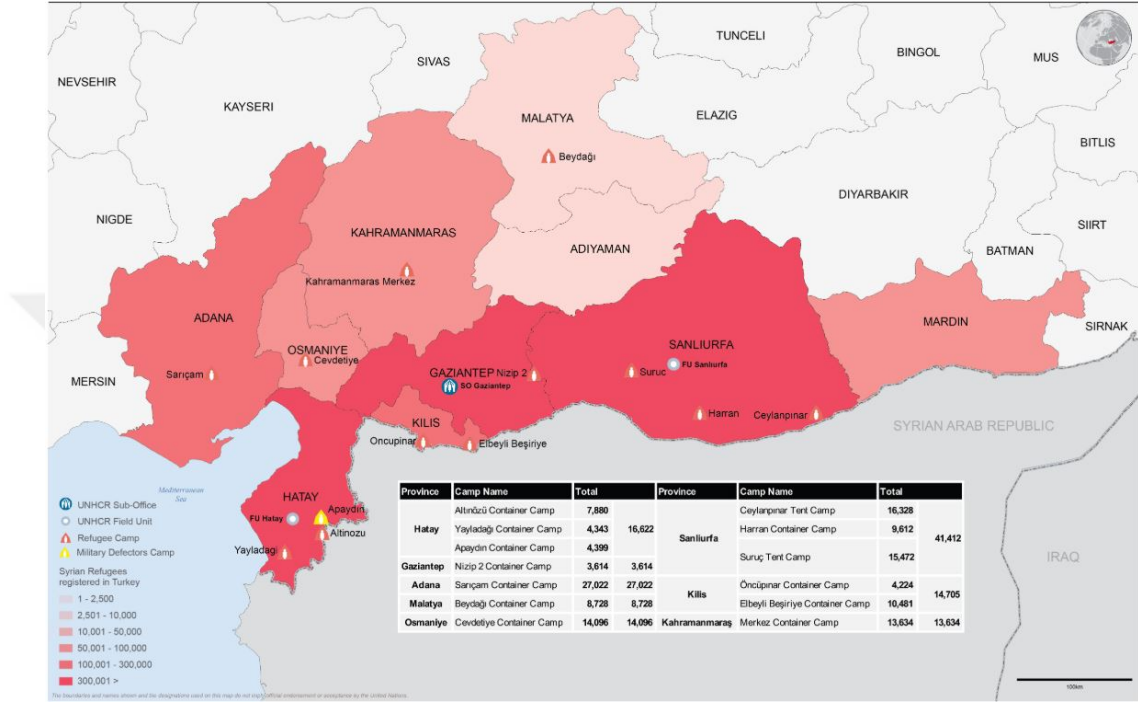


Figure 2.4: Refugee camps in Turkey, March 2019 [4]

Nizip Container Camp and Öncüpınar Container Camp are asylum for refugees from the beginning of the crisis, i.e. for more than 8 years. Since people live in refugee camps for longer time periods, providing the necessary public services is essential to protect health, safety, dignity, etc. of the refugees living in camps. Also, because the authorities can control the refugee camps, they can detect the necessary public services and regularly direct service providers to refugee camps.

In Turkey, certain regular public services are provided to refugee camps as education, environmental health care, safety, etc. For instance, to support self-development of children and youth refugees, Turkish Red Crescent (TRC) in partnership with United Nations International Children's Emergency Fund (UNICEF) conduct a project called Child-Friendly Areas [10]. In the scope of this project, TRC trucks visit the refugee camps regularly and give education to younger refugees. As an example to environmental health services, specialists regularly visit the camps to test the chlorine levels of water and take necessary operations

to regulate it.

When the functioning of the refugee camps in Turkey is analyzed, the authorities are responsible from the following decisions:

- Determining the public services to be provided to refugee camps,
- Choosing appropriate service providers to serve to refugee camps,
- Selecting institutions from which service providers originate and return,
- Deciding travel routes of service providers between camps and institutions.

In addition; along with the listed items authorities actually decide the locations of refugee camps together with their capacity. All these questions form the refugee camp location problem.

These facts show that the crisis is not temporary. It is clear that providing public services to refugee camps is a necessity, and it is believed that the transportation plan of the services should be considered while locating the refugee camps. As Operations Research (OR) is an application oriented discipline, OR tools and methodologies are applied to improve the current system and to ensure efficient use of resources.

# Chapter 3

## Problem Definition

As detailed in the previous chapter, the refugee camp location problem involves the following questions:

- Where to open the refugee camp(s)?
- What should be the capacity of the camp(s)?
- Who should provide the required services from which institutions?
- How to route the service providers?

When the L-LRP is considered, the decisions are as follows:

- Locations of demand nodes,
- Locations of depots,
- Travel routes of vehicles.

If refugee camp location problem and L-LRP is analyzed together, an analogy can be caught within them. Choosing placement of refugee camps corresponds to locating demand nodes. Selecting public services and their responsible institutions correspond to locating depots. Planning travel routes of service

providers within refugee camps and hosting institutions correspond to vehicle routing. Thus, refugee camp location problem is a direct application of L-LRP. In this thesis, L-LRP is the generic problem and refugee camp location problem is an application of it.

For refugee camp location problem, multiple types of services are provided to camps such as health care, education and hygiene. Thus, for L-LRP required services could be of many natures. To satisfy the problem specific requirements, multi-commodity version of the problem is also formulated and explained in Chapter 5.

In the remaining of the study, L-LRP and refugee camp location problem terms are used together to avoid confusion:

- Potential demand nodes are called as candidate refugee camps.
- Potential depots are called as hosting institutions.
- Commodities are called as public services.
- Vehicles are called as service providers.

Strategic decision makers of the host country know the total number of refugees that will be placed to refugee camps. As mentioned in previous chapter, the capacities of refugee camps differ from each other. The authorities should open adequate number of refugee camps with proper capacities such that all refugees are placed to a camp. Also, refugees in all camps should benefit from all pre-determined services.

Service providers are people giving service to refugee camps. A service provider originates from the hosting institution that s/he is connected, visit the camps that are assigned to her/him and returns back to the hosting institution again. There is an upper bound on the daily working hour of the service providers. During the working hours, service providers either spend time for travelling between camps and hosting institutions, or they provide service to refugee camps. At the end of

the working hours, service providers should end their service routes in their hosting institutions. Figure 3.1 shows an example service route of a service provider visiting 4 refugee camps in a day. While determining the travel routes of service providers, the total working hour cannot be exceeded. Also, it is assumed that single service provider serve to a refugee camp from each service type.

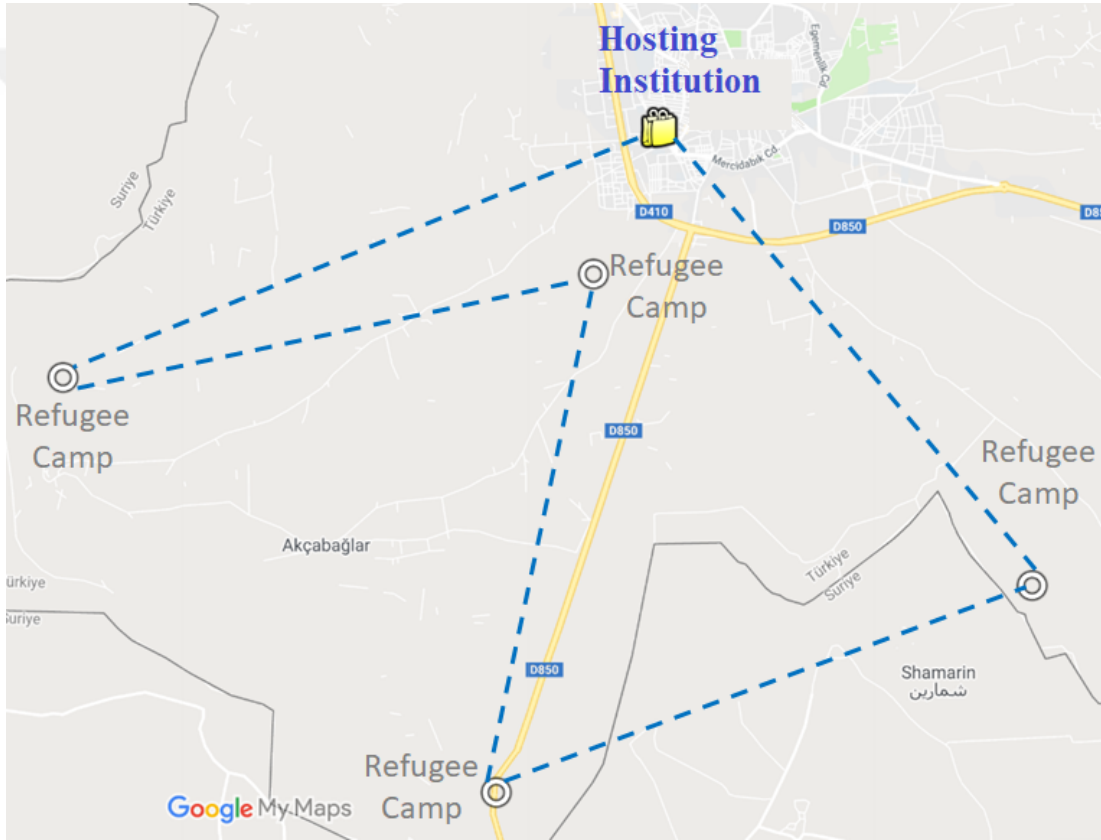


Figure 3.1: Example Service Route of a Service Provider

Hosting institutions are places where service providers originate from and return. Number of service providers in hosting institutions can be limited, which can be a constraint for the optimization problem.

Considering multi-commodity version of the problem is significant since the opened refugee camps are determined according to travel routes from all service types. Assume that there are three types of public services provided to refugee



camps as health care, municipality and safety services. The corresponding service providers are doctors, specialists and police officers, respectively. Let us assume that L-LRP is separately solved for health care, education and safety services and resulting routes for each type of service providers are shown in Figure 3.2. The refugee camps that service providers visit differ from each other. For instance, a refugee camp that is served by a doctor is not served by a specialist or a police officer. Thus, solving L-LRP individually for each service type and aggregating them generally does not provide a feasible solution.

If we assume that the placement of refugee camps are given beforehand, i.e. the locations of demand nodes are known, then LRP can be solved for all service types separately. Combination of individual solutions results in optimal solution since the problem can be decomposed for all service types. However; in L-LRP demand points are not known in advance, thus the problem is not decomposable. Even though considering all service types together complicates the problem, it is a necessity to obtain the global optimum.

Considering the problem specific requirements, the aim of the thesis is to locate refugee camps, select hosting institutions and determine travel routes of service providers so that total tour length of service providers is minimized from all service types.



(a) Routes of the doctor



(b) Route of the specialist



(c) Route of the police officers

Figure 3.2: L-LRP results for different types of services

# Chapter 4

## Literature Review

Location routing problem combines decisions from two different levels of logistics as facility location and vehicle routing. The complexity of the problem increases as these two problems are solved simultaneously; however, Salhi and Rand [11] proved that separate decision making processes result in sub optimal decisions. Consequently, the emphasis on LRP has increased in the last 30 years in OR literature. Nagy and Salhi [12] classify LRP studies and its variants and analyze exact and heuristic solution methodologies with future research directions. Prodhon and Prins [13] extend previous survey by including the recent literature. Simultaneously, Drexel and Schneider [14] conduct a survey on the variants and extensions of LRP. Schneider and Drexel [15] further investigate standard LRP literature after the review of [11].

Humanitarian logistics is one of the major application areas of OR studies. Because there are accumulated studies on this subject, surveys are also available in the literature. One of the most important reviews on humanitarian logistics is conducted by Altay and Green [16]. In this study articles are grouped according to subtitles such as their journal, nationality, publication year, solution methodology, disaster types and phases. Galindo and Batta [17] continue this review by analyzing disaster operations management articles published after the review of [16]. This review concluded that the findings of [16] remained approximately

same. Kovacs and Spens [18], Caunhye et al. [19] and Leiras et al. [20] are also surveys analyzing humanitarian logistics articles and grouping them according to different headings. Çelik et al. [21] reviewed articles between 2007 and 2012 and categorize them according to their disaster cycle phase with also giving case studies. Kara and Savaser [22] extend the study of [21] for research conducted between 2007 and 2012 and they followed similar path for reviewing articles. Relief logistics and development logistics literature are analyzed along with some case studies. As a more focused research, Grass and Fischer [23] conduct a survey related to disaster management as a two-stage stochastic programming.

Since our problem is an extension of the LRP motivated from a humanitarian application, recent and major LRP studies in humanitarian logistics will be analyzed. Altay and Green [16] define four phases in disaster operations management as mitigation, preparedness, response and recovery. The articles are surveyed according to which phase they belong to and how they approach to demand. The review starts with studies related to response phase since it has the majority of the manuscripts related to LRP.

In response phase, the articles generally focuses on locating relief item distribution centers and corresponding routes of relief items. Vahdani et al. [24], Vahdani et al. [25] and Raziei et al. [26] consider routing relief materials under deterministic demand. Vahdani et al. [24] develop a nonlinear multi-objective, multi-period and multi-commodity model with roadway repair and split delivery after an earthquake. As a solution methodology non-dominated sorting genetic algorithm-II (NSGAII) and multi-objective particle swarm optimization (MOPSO) are proposed. Vahdani et al. [25] present a two-stage multi-objective, multi-period location-routing inventory model considering critical and non-critical products. Robust optimization is used to reflect the uncertain nature of the disaster. Similarly, NSGAII and MOPSO are offered as heuristic algorithms. Raziei et al. [26] design network under disruption risk such as capacity of temporary distribution centers, number of vehicles and route capacity after an earthquake. Genetic algorithm (GA) is provided and conditional value at risk (CVar) is considered as a risk measure.

Some of the literature include covered demand as one of the objective functions or place it into constraints. Yi and Özdamar [27] propose a multi-period, multi-commodity, two-stage procedure by treating vehicles as integer variables with objective of minimizing service delay. Lin et al. [28] present a multi-period, multi-commodity formulation with priority of items and propose a two-phase heuristic approach. The objective function includes the minimization of penalty cost associated with unmet demand. Ahmadi et al. [29] propose a multi-objective, two-stage stochastic program with uncertainty in travel times after an earthquake. They punish unsatisfied demand and select minimizing penalty cost of unsatisfied demand as one of the objectives. For larger instances they use variable neighborhood search(VNS) to handle the problem. Tavana et al. [30] propose a multi-objective, multi-echelon formulation with consideration of perishable products. They allowed cross transportation to reduce unsatisfied demand and they include penalty cost for product shortage. For solution, they compared NSGAII and reference point based non-dominated sorting genetic algorithm.

Rath and Gutjahr [31] and Rath et al. [32] develop multi-objective models with maximizing covered demand as one of their objectives. Rath and Gutjahr [31] consider single commodity LRP with three objectives. The paper propose a math-heuristic based on adaptive epsilon-constraint algorithm and solve multi-trip capacitated team orienteering problem as a subproblem. Rath et al. [32] present two-stage, bi-objective stochastic programming with integrating uncertainty to accessibility of the road network. They provide different formulations and similarly utilize adaptive epsilon-constraint method to solve the problem. Expected value of perfect information(EVPI) and value of stochastic solution(VSS) are used to support the stochastic programming in disaster management. Nolz et al. [33] and Abounacer et al. [34] minimize uncovered demand as one of their objectives. Nolz et al. [33] distribute water after an earthquake and consider multi-modal distribution with different road categories. Non-dominated GA is presented including VNS and path relinking. Abounacer et al. [34] develop a three-objective, multi-commodity model with aggregating demand to demand zones. Epsilon-constraint method and a heuristic algorithm utilizing epsilon-constraint method are proposed to solve smaller and larger-sized instances, respectively. Afshar

and Haghani [35] develop a multi-period, multi-modal formulation in which the objective is minimizing total weighted unsatisfied demand. Also, they include minimum service level for each victim into constraints.

Besides full or partial demand coverage, some LRP studies in humanitarian logistics choose demand as a stochastic element for the problem. Rennemo et al. [36] develop a multi-modal, three-stage stochastic LRP program with uncertainty in number of available vehicles, state of infrastructure and demand of beneficiaries. Also, they consider fairness by giving different utilities to different groups and as the objective they maximize utility by covering demand for different commodities. Bozorgi-Amiri and Khorsi [37] present a multi-objective, dynamic and stochastic program with uncertain demand, cost of procurement and transportation and travel times. They use 2 types of commodities as consumable and non-consumable. Epsilon-constraint method is used as a solution methodology. Caunhye et al. [38] develop a two-stage LRP formulation with recourse and transshipment. They consider demand and state of infrastructure as the sources of uncertainty. The two-stage model is converted to a single-stage program for solution. Moreno et al. [39] consider uncertainty in victim's needs, incoming supply, inventory conditions and road availability. They propose multi-period, multi-commodity multi-modal stochastic program with allowing reuse of vehicles. For solution, they utilize two decomposition based heuristic algorithms as relax-and-fix and fix-and-optimize. Saffarian et al. [40] present a multi-objective, multi-period stochastic program and consider transfer time, demand of regional warehouses and inventory of supply centers as uncertain. For solution, they convert the problem to single-objective by global criterion approach and then apply GA and simulated annealing.

As the disaster phase changes, the facility types to locate and the commodities to route also differ. Alumur and Kara [41], and Mahmoudabadi and Seyedhosseini [42] utilize LRP for mitigation phase. Alumur and Kara [41] develop a multi-objective formulation for hazardous waste LRP with different types of wastes and deterministic generation points. They minimize total cost and transportation risk simultaneously. Similarly, Mahmoudabadi and Seyedhosseini [42] also formulate hazardous material transportation and present an iterative procedure based on

chaos theory on dynamic risk definition.

Chang et al. [43] and Ukkusuri and Yushimito [44] are the LRP studies for preparedness phase. Chang et al. [43] propose a decision-making tool that can be used by government agencies for flood emergency logistics. They consider rescue demand points and amount of demand as uncertain, develop scenarios using geographical information system(GIS) and solve with sample average approximation. Ukkusuri and Yushimito [44] develop a path-based formulation using most reliable path for pre-positioning of supplies with deterministic demand points. They choose the inventory locations such that the probability of the inventory to reach all the demand points is maximized.

For development logistics, Cherkesly et al. [45] design community health care network. They combine location routing problem with covering tour problem and locate supervisors and community health care workers according to deterministic demand points. They propose a set partitioning formulation and reduce the number of variables to solve the problem.

This paper differs from the studies in literature by also locating the demand points. Some studies cover the demand fully, some studies allow partial demand coverage and some of them consider demand as a stochastic element for the problem. However; for none of them, selecting demand points from a set of possible locations is a decision to be made within the problem. To the best of the author's knowledge locating demand points together with classical LRP decisions have not been studied in the literature before. This paper defines this problem and names as L-LRP and gives a solution approach together with a problem specific application.

## Chapter 5

# Mathematical Formulation

In this chapter we introduce a mathematical formulation for the L-LRP which decides on the locations of demand nodes, locations of depots and the required vehicle routes. Specifically, for refugee camp location problem, our aim is to locate refugee camps, to select hosting institutions and to decide travel routes of service providers. For L-LRP, a linear mixed integer mathematical formulation is developed and the details of this formulation is explained in this chapter.

To formally define the problem, consider a graph  $G = (N, A)$  with following sets and parameters.

### Sets:

- |       |                                                                                                                                                                                                            |
|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $R$   | Set of candidate refugee camps.                                                                                                                                                                            |
| $S$   | Set of public services.                                                                                                                                                                                    |
| $H$   | Set of hosting institutions, $H = \bigcup_{s \in S} H_s$ .                                                                                                                                                 |
| $H_s$ | Set of hosting institutions that provide service type $s \in S$ . If a hosting institution can be used for multiple service types, then this hosting institution is duplicated for relevant service types. |
| $N$   | Set of all nodes, $N = R \cup H$ .                                                                                                                                                                         |
| $A$   | Set of all arcs.                                                                                                                                                                                           |



**Parameters:**

- $d_{ij}$  : distance between nodes  $i \in N$  and  $j \in N$ .  
 $Q$  : total number of refugees to be located at the camps.  
 $q_r$  : capacity of refugee camp  $r \in R$ .  
 $SP$  : maximum working time of a service provider (e.g. 8 hours).  
 $c_{sh}$  : number of providers of service  $s \in S$  at hosting institution  $h \in H$ .  
 $m_{ijs}$  : time to traverse arc  $(i, j) \in A$  together with time to serve node  $j \in N$  for service  $s \in S$ .  
 $M$  : a large number (can be equalized to  $SP$ ).

The decisions to be made can be represented by the following sets of variables:

**Decision Variables:**

$$x_r = \begin{cases} 1, & \text{if a refugee camp is built at candidate location } r \in R, \\ 0, & \text{otherwise.} \end{cases}$$

$$y_{ijs} = \begin{cases} 1, & \text{if } (i, j) \in A \text{ is traversed for service } s \in S, \\ 0, & \text{otherwise.} \end{cases}$$

$$z_{ih} = \begin{cases} 1, & \text{if } i \in N \text{ is assigned to hosting institution } h \in H, \\ 0, & \text{otherwise.} \end{cases}$$

$w_{ijs}$  = amount of flow on arc  $(i, j) \in A$  for service type  $s \in S$

The proposed linear integer program is as follows:

$$(L-LRP) \text{ minimize } \sum_{s \in S} \sum_{i \in N} \sum_{j \in N} d_{ij} y_{ijs} \quad (5.1)$$

subject to

$$\sum_{r \in R} q_r x_r \geq Q \quad (5.2)$$

$$\sum_{i \in N} y_{ris} = x_r \quad r \in R, s \in S \quad (5.3)$$

$$\sum_{i \in N} y_{irs} = x_r \quad r \in R, s \in S \quad (5.4)$$

$$\sum_{h \in H_s} z_{rh} = x_r \quad r \in R, s \in S \quad (5.5)$$

$$y_{hrs} \leq z_{rh} \quad r \in R, h \in H, s \in S \quad (5.6)$$

$$y_{rhs} \leq z_{rh} \quad r \in R, h \in H, s \in S \quad (5.7)$$

$$\sum_{r \in R} y_{hrs} \leq c_{sh} \quad h \in H, s \in S \quad (5.8)$$

$$y_{rr's} + z_{rh} + \sum_{\substack{h' \in H_s, \\ h' \neq h}} z_{r'h'} \leq 2 \quad r \in R, r' \in R, r \neq r', h \in H_s, s \in S \quad (5.9)$$

$$\sum_{\substack{i \in R \cup H_s, \\ i \neq r}} w_{ris} - \sum_{\substack{i \in R \cup H_s, \\ i \neq r}} w_{irs} - \sum_{i \in R \cup H_s} m_{ris} y_{ris} = 0 \quad r \in R, s \in S \quad (5.10)$$

$$w_{hrs} = m_{hrs} y_{hrs} \quad r \in R, h \in H_s, s \in S \quad (5.11)$$

$$w_{ijs} \leq M y_{ijs} \quad i \in R \cup H_s, j \in R \cup H_s, s \in S \quad (5.12)$$

$$w_{ris} \geq \sum_{h \in H_s} m_{hrs} y_{hrs} + (m_{ris} + M.SP) y_{ris} - M.SP \quad r \in R, i \in R \cup H_s, s \in S \quad (5.13)$$

$$y_{his} = 0 \quad i \in N, h \in H/H_s, s \in S \quad (5.14)$$

$$x_r \in \{0, 1\} \quad r \in R \quad (5.15)$$

$$z_{ih} \in \{0, 1\} \quad i \in N, h \in H \quad (5.16)$$

$$y_{ijs} \in \{0, 1\}, w_{ijs} \geq 0 \quad i \in N, j \in N, s \in S \quad (5.17)$$

The objective function (5.1) minimizes the total tour length traveled by all service providers from all service types. The total tour length includes the distance covered from hosting institutions to refugee camps, from refugee camps to refugee camps and from refugee camps to hosting institutions.

Constraint (5.2) guarantees that the total capacity of opened refugee camps satisfy the refugee population requirement, i.e., all refugees are placed to a camp. Constraints (5.3) and (5.4) are flow balance constraints for opened refugee camps. These constraints are written for all service types to ensure that all public services are provided to the opened refugee camps. Constraint (5.5) assigns a hosting institution to open refugee camps for all service types.

Constraints (5.6) and (5.7) ensure that the arc between a refugee camp and a hosting institution can be traversed if the refugee camp is assigned to that hosting institution. Constraint (5.8) guarantee that the total number of service providers leaving a hosting institution is less than its capacity.

Constraint (5.9) are taken from Karaoglan et al. [46]. If there is a link between two refugee camps as  $r \in R$  and  $r' \in R$ , then their assigned hosting institutions should be same. If  $y_{rr's} = 1$  and  $z_{rh} = 1$ , then  $r'$  cannot be assigned to another hosting institution different than  $h \in H_s$  for  $s \in S$ . If  $r$  and  $r'$  are assigned to different hosting institutions for service  $s \in S$ , then the arc between two refugee camps cannot be traversed for  $s$ .

Constraints (5.10) to (5.13) are for eliminating sub-tours and ensuring that maximum working hour of a service provider is not exceeded. The constraints are similar to Kara [47] with modification for multiple service types. Constraint (5.10) is flow balance constraint that ensures equal inflow and outflow for a refugee camp. Constraint (5.11) and Constraints (5.12) are boundary constraints. For constraint (5.13),  $M$  could be equalized to  $SP$ . The functioning of constraint (5.13) is as follows:

- If  $y_{hrs} = 0$  and  $y_{ris} = 0$ , then  $w_{ris} \geq 0$  and constraint (5.13) becomes redundant.
- If  $y_{hrs} = 0$  and  $y_{ris} = 1$ , then  $w_{ris} \geq m_{ris}y_{ris}$  and constraint (5.13) becomes redundant because of constraint (5.10).
- If  $y_{hrs} = 1$  and  $y_{ris} = 0$ , then  $w_{ris} \geq 0$  and constraint (5.13) becomes redundant.
- If  $y_{hrs} = 1$  and  $y_{ris} = 1$ , then  $w_{ris} \geq \sum_{h \in H_s} m_{hrs}y_{hrs} + m_{ris}y_{ris}$  and constraint (5.13) becomes restrictive.

Constraint (5.14) is to eliminate usage of an arc between a hosting institution and a refugee camp for incorrect service type. Constraints (5.15) to (5.17) are the domain constraints.

## Chapter 6

# Computational Analysis of the Mathematical Model

In this chapter, the performance of mathematical formulation is tested via series of computational analysis. First, the data sets of different sizes are explained in detail. Next, the optimization model is tested on different size of data and with different parameter selections. Results of parameter selections and effects of the data set size are investigated.

### 6.1 Data Sets

To perform computational analysis, a real life data set from Southern part of Turkey is used since the refugee camps in Turkey are placed in this region. Refugees are assumed to take three types of public services as health care, education and municipality services. The corresponding hosting institutions are assumed to be hospitals, high schools and municipality buildings, respectively. Current refugee camps and nonresidential large areas are selected as candidate refugee camps. Candidate refugee camps together with hospitals, high schools and municipality buildings constitute the set of all nodes.

There are 10 cities in the region of interest which are Adana, Adiyaman, Gaziantep, Hatay, Kahramanmaraş, Kilis, Malatya, Mardin, Osmaniye and Şanlıurfa. There are currently 13 refugee camps. Together with empty areas, we have 74 candidate refugee camp locations. In these cities there are 60 hospitals, 77 high schools and 33 municipality buildings, which makes 244 nodes of concern in total. Locations of these 244 nodes are shown in Appendix A. The breakdowns of nodes according to cities are detailed in Table 6.1. All nodes are mapped using the ArcGIS program and required distance matrix is attained [48]. When the distance values are checked, they failed to satisfy the triangular inequality. In order to ensure triangular inequality and obtain shortest paths between nodes, Dijkstra's algorithm is applied and necessary updates are performed in the distance matrix.

| City          | Nb. of<br>Candidate<br>Refugee<br>Camps | Nb. of<br>Hospitals | Nb. of<br>High<br>Schools | Nb. of<br>Municipality<br>Buildings | <b>TOTAL</b> |
|---------------|-----------------------------------------|---------------------|---------------------------|-------------------------------------|--------------|
| Adana         | 6                                       | 10                  | 10                        | 6                                   | <b>32</b>    |
| Adiyaman      | 6                                       | 6                   | 5                         | 1                                   | <b>18</b>    |
| Gaziantep     | 8                                       | 8                   | 16                        | 4                                   | <b>36</b>    |
| Hatay         | 9                                       | 5                   | 8                         | 5                                   | <b>27</b>    |
| Kahramanmaraş | 6                                       | 5                   | 8                         | 2                                   | <b>21</b>    |
| Kilis         | 12                                      | 2                   | 4                         | 2                                   | <b>20</b>    |
| Malatya       | 6                                       | 5                   | 9                         | 2                                   | <b>22</b>    |
| Mardin        | 6                                       | 4                   | 3                         | 3                                   | <b>16</b>    |
| Osmaniye      | 6                                       | 6                   | 6                         | 1                                   | <b>19</b>    |
| Şanlıurfa     | 9                                       | 9                   | 8                         | 7                                   | <b>33</b>    |
| <b>TOTAL</b>  | <b>74</b>                               | <b>60</b>           | <b>77</b>                 | <b>33</b>                           | <b>244</b>   |

Table 6.1: Large Data Set

The data set that is compromised of 244 nodes is called large data set which will be used for the case study of refugee camp location problem. Medium- and small-size data sets are constructed from this large data set via restricting the number

of cities. Medium data set includes 5 cities as Gaziantep, Hatay, Kahramanmaraş, Kilis and Osmaniye. Small data set consists of two cities as Gaziantep and Kilis. Number of nodes, candidate refugee camps and hosting institutions are presented in Table 6.2. Locations of corresponding nodes in medium and small data set are presented in Appendix B and Appendix C, respectively.

| Data Set        | Number of<br>Nodes | Number of<br>Candidate<br>Refugee Camps | Number of<br>Hosting<br>Institutions |
|-----------------|--------------------|-----------------------------------------|--------------------------------------|
| Small Data Set  | 56                 | 20                                      | 36                                   |
| Medium Data Set | 123                | 41                                      | 82                                   |
| Large Data Set  | 244                | 74                                      | 170                                  |

Table 6.2: Specifications of the Data Sets

Recall that, the following parameters are required in the optimization problem. The parameter selections will be explained one by one.

- $d_{ij}$ , distance between nodes  $i \in N$  and  $j \in N$ .
- $Q$ , number of refugees to be located at the camps.
- $q_r$ , capacity of refugee camp  $r \in R$ .
- $SP$ , maximum working time of a service provider.
- $c_{sh}$ , number of providers of service  $s \in S$  at hosting institution  $h \in H$ .
- $m_{ijs}$ , time to traverse arc  $(i, j) \in A$  together with time to serve node  $j \in N$  for service  $s \in S$ .

For parameter analysis different number of refugees ( $Q$ ) are considered to be placed to camps. For the capacity of refugee camps, the parameters are selected in three different ways. First, capacities are assigned with uniform distribution probability within range  $[3000, 25000]$ . The range is determined according to observation from current camp capacities. Second, a fixed capacity setting is used, which assigns capacity as 15000 for all candidate refugee camps. Third, a discrete capacity is designated according to the size of the area that the candidate refugee camp is placed. We believe this discrete setting is more realistic, since it utilizes the area information and thus discrete capacity setting is used for the case study. Let  $a_r$  be the size of the area that the refugee camp  $r \in R$  is placed, then the capacity of the camp is found by the following function:

$$q_r = \begin{cases} 5000, & \text{if } a_r < 333,333 \text{ m}^2, \\ 15000, & \text{if } a_r \geq 333,333 \text{ m}^2 \text{ and } a_r < 666,666 \text{ m}^2, \\ 25000, & \text{if } a_r \geq 666,666 \text{ m}^2. \end{cases}$$

We remark here that, thanks to ArcGIS data, the area values of all 74 nodes are available [48]. Table 6.3 shows the number of candidate refugee camps with different capacities and total capacity of the corresponding city. For instance, in Adana the 6 candidate refugee camps are actually at locations with large surface areas. For the large data set, total capacity obtained from all cities equals to 950,000. Table 6.4 shows real capacities of current 13 refugee camps that serve in the Southern part of Turkey and discrete capacities calculated according to their actual area. The discrete capacities generally does not match with the real capacities. We observe that some of the refugee camps are overcrowded, whereas some of them are empty compared to their surface area. However using area information could provide better utilization of the surface.



| City          | Nb. of<br>Camps with<br>$q_r = 5,000$ | Nb. of<br>Camps with<br>$q_r = 15,000$ | Nb. of<br>Camps with<br>$q_r = 25,000$ | Total<br>Capacity |
|---------------|---------------------------------------|----------------------------------------|----------------------------------------|-------------------|
| Adana         | -                                     | -                                      | 6                                      | 150,000           |
| Adıyaman      | -                                     | 3                                      | 3                                      | 120,000           |
| Gaziantep     | 6                                     | -                                      | 2                                      | 80,000            |
| Hatay         | 9                                     | -                                      | -                                      | 45,000            |
| Kahramanmaraş | -                                     | 3                                      | 3                                      | 120,000           |
| Kilis         | 2                                     | 10                                     | -                                      | 160,000           |
| Malatya       | 6                                     | -                                      | -                                      | 30,000            |
| Mardin        | 1                                     | 5                                      | -                                      | 80,000            |
| Osmaniye      | 6                                     | -                                      | -                                      | 30,000            |
| Şanlıurfa     | 3                                     | 3                                      | 3                                      | 135,000           |
| <b>TOTAL</b>  | <b>33</b>                             | <b>24</b>                              | <b>17</b>                              | <b>950,000</b>    |

Table 6.3: Discrete Capacities of Candidate Refugee Camps According to Cities

| Refugee Camp                    | Real<br>Capacity | Calculated Discrete<br>Capacity Based on<br>Actual Area |
|---------------------------------|------------------|---------------------------------------------------------|
| Altınözü Container Camp         | 7,880            | 5,000                                                   |
| Yayladağı Container Camp        | 4,343            | 5,000                                                   |
| Apaydın Container Camp          | 4,399            | 5,000                                                   |
| Nizip 2 Container Camp          | 3,614            | 25,000                                                  |
| Sarıçam Container Camp          | 27,022           | 25,000                                                  |
| Beydağı Container Camp          | 8,728            | 5,000                                                   |
| Cevdetiye Container Camp        | 14,096           | 5,000                                                   |
| Ceylanpınar Tent Camp           | 16,328           | 25,000                                                  |
| Harran Container Camp           | 9,612            | 15,000                                                  |
| Suruç Tent Camp                 | 15,472           | 5,000                                                   |
| Öncüpınar Container Camp        | 4,224            | 15,000                                                  |
| Elbeyli Beşiriye Container Camp | 10,481           | 15,000                                                  |
| Merkez Container Camp           | 13,364           | 25,000                                                  |

Table 6.4: Real and Calculated Discrete Capacities of Current Refugee Camps

Recall that  $m_{ijs}$  refer to time to traverse arc  $(i, j) \in A$  with time to serve node  $j \in N$  for service  $s \in S$ . Let  $m'_{rs}$  show the time to serve refugee camp  $r \in R$  for service  $s \in S$ .  $m'_{rs}$  values are calculated according to following function for both random, fixed and discrete capacities. For  $s \in \{Health\ care, Education\}$  and  $r \in R$ , i.e. for doctors and teachers,

$$m_{rs} = \begin{cases} 2 \text{ hours,} & \text{if } q_r \leq 5000, \\ 3 \text{ hours,} & \text{if } q_r > 5000 \text{ and } q_r \leq 15000, \\ 4 \text{ hours,} & \text{if } q_r > 15000. \end{cases}$$

As an example to municipality services, chlorination of waters in camps can be given. Since the duration of this process is shorter compared to health care and education services, for  $s \in \{Municipality\ Services\}$  and  $r \in R$ , the corresponding function for service time is calculated as below:

$$m'_{rs} = \begin{cases} 1 \text{ hour,} & \text{if } q_r \leq 15000, \\ 2 \text{ hours,} & \text{if } q_r > 15000. \end{cases}$$

After determination of  $m'_{rs}$  values, for  $s \in S$ ,  $m_{ijs}$  values are calculated with  $d_{ij}$  values. Speed of vehicles that transport service providers is assumed to be 90 km/h. Then, corresponding  $m_{ijs}$  are calculated as follows:

- If  $i \in N$  and  $j \in R$ , then  $m_{ijs} = m'_{js} + d_{ij}/90$ .
- If  $i \in R$  and  $j \in H$ , then  $m_{ijs} = d_{ij}/90$ .

Maximum working hour of service providers are considered as 8 hours. Numbers of service providers in hosting institutions are taken as 30, which does not constitute any restriction for the problem. Since authorities can direct adequate number of service providers to refugee camps, for this application of L-LRP,  $c_{sh}$  values do not affect the feasible region. However; in another application in which service providers are limited,  $c_{sh}$  could be one of the restrictions for the problem.

Table 6.5 shows that totally 60 instances are tested with different data sets and parameter selections.

|                                                                             | Small Data<br>Set | Medium Data<br>Set | Large Data<br>Set |
|-----------------------------------------------------------------------------|-------------------|--------------------|-------------------|
| Random Capacity                                                             | ✓                 | ✓                  | ✓                 |
| Fixed Capacity                                                              | ✓                 | ✓                  | ✓                 |
| Discrete Capacity                                                           | ✓                 | ✓                  | ✓                 |
| $Q$ (in thousands) = 50, 75,<br>100, 125, 150, 175                          | ✓                 | ✓                  | ✓                 |
| $Q$ (in thousands) = 200,<br>225, 250, 275, 300, 325<br>(Discrete Capacity) | -                 | -                  | ✓                 |
| Total Nb. of Instances                                                      | 18                | 18                 | 24                |

Table 6.5: Breakdowns of Test Instances

## 6.2 Computational Analysis of the Mathematical Model

Mathematical model is coded in JAVA with solver library of IBM CPLEX 12.8.1. The instances for mathematical model are tested on a Linux OS with Dual Intel Xeon E5-2690 v4 14 Core 2.6GHz processors with 128 GB of RAM. The results of the mathematical model are presented below according to small data set, medium data set and large data set for the case study. For each type of data set, a time limit of 6 hours is forced on CPLEX. Different values of  $Q$  (*nb. of refugees*) are used to test the performance of the optimization model.

### 6.2.1 Small Data Set

Tables 6.6, 6.7 and 6.8 show computational performance of small data set with random, fixed and discrete capacities, respectively. The number of refugees to be placed to camps ( $Q$ ) range between 50,000 and 175,000. As  $Q$  value increases, solution times also increases for all camp capacity types since more routing decisions are necessary. There is a significant difference when  $Q = 50,000$  and  $Q = 175,000$ . Thus,  $Q$  is a significant parameter for L-LRP which sharply affects the solution time. As expected, with the increasing value of  $Q$ , number of opened refugee camps also increases to place all refugees to camps.

Time limit does not constitute restriction for any of the instances. Within different types of refugee camp capacities, the instances with fixed capacity seem to be solved in longer durations. Also, the data set with random capacities is solved fastest except for  $Q = 175,000$ .

| <b>Q</b> | <b>CPU<br/>(seconds)</b> | <b>Number of<br/>Used Refugee<br/>Camps</b> | <b>Total<br/>Distance</b> |
|----------|--------------------------|---------------------------------------------|---------------------------|
| 50,000   | 2.75                     | 3                                           | 92.44                     |
| 75,000   | 3.5                      | 4                                           | 194.56                    |
| 100,000  | 8.79                     | 6                                           | 318.34                    |
| 125,000  | 23.70                    | 7                                           | 432.01                    |
| 150,000  | 32.81                    | 8                                           | 552.40                    |
| 175,000  | 2938.03                  | 10                                          | 744.82                    |

Table 6.6: Results of small data set with random capacities

| <b>Q</b> | <b>CPU<br/>(seconds)</b> | <b>Number of<br/>Used Refugee<br/>Camps</b> | <b>Total<br/>Distance</b> |
|----------|--------------------------|---------------------------------------------|---------------------------|
| 50,000   | 3.33                     | 4                                           | 137.50                    |
| 75,000   | 8.21                     | 5                                           | 205.32                    |
| 100,000  | 29.52                    | 7                                           | 319.35                    |
| 125,000  | 574.42                   | 9                                           | 510.59                    |
| 150,000  | 609.66                   | 10                                          | 607.48                    |
| 175,000  | 11757.18                 | 12                                          | 836.00                    |

Table 6.7: Results of small data set with fixed capacities

| <b>Q</b> | <b>CPU<br/>(seconds)</b> | <b>Number of<br/>Used Refugee<br/>Camps</b> | <b>Total<br/>Distance</b> |
|----------|--------------------------|---------------------------------------------|---------------------------|
| 50,000   | 4.14                     | 4                                           | 137.50                    |
| 75,000   | 7.14                     | 5                                           | 243.41                    |
| 100,000  | 252.6                    | 8                                           | 405.87                    |
| 125,000  | 351.72                   | 9                                           | 567.57                    |
| 150,000  | 1303.77                  | 10                                          | 786.35                    |
| 175,000  | 2477.80                  | 11                                          | 1014.00                   |

Table 6.8: Results of small data set with discrete capacities

Figure 6.1 shows an example output of L-LRP when  $Q = 50,000$  in small data set with discrete capacity. Red, green and blue lines show the travel routes of health care, education and municipality services, respectively. As it is one of the requirements of the problem, all public services are provided to all opened refugee camps. Also note that, for education and health care services, travel routes are combined of 2 refugee camps. However; for municipality services 4 refugee camps can be visited in a single tour. The difference occurs because of the varied service times of different services.

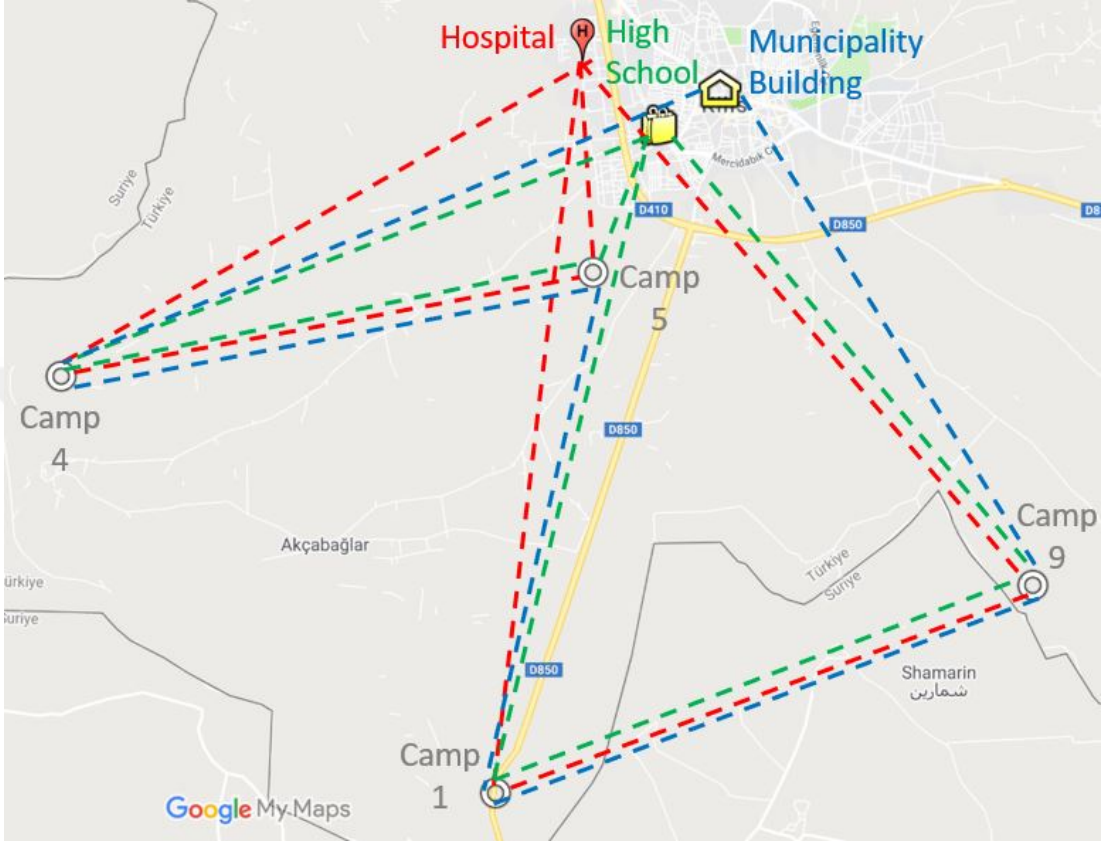


Figure 6.1: Example Service Routes for L-LRP

As an example, for discrete capacity setting of small data set, opened candidate refugee camps for different values of  $Q$  are listed in Table 6.9. Candidate refugee camps 1, 4 and 5 are used for all values of  $Q$  and each of them have capacity of 15,000. When  $Q$  increases from 125,000 to 150,000, only a single camp is added to current opened refugee camps. However; in the increase of  $Q$  from 100,000 to 125,000, we observe that some of the current camps are closed and new refugee camps are selected instead of them. Camps 1, 2, 9, 10 and 11 are among current refugee camps that are serving in Turkey.

|                             | Candidate Refugee Camp |          |          |          |          |           |           |          |          |           |          |          |           |
|-----------------------------|------------------------|----------|----------|----------|----------|-----------|-----------|----------|----------|-----------|----------|----------|-----------|
| <b>Q</b>                    | <b>1</b>               | <b>4</b> | <b>5</b> | <b>2</b> | <b>9</b> | <b>10</b> | <b>11</b> | <b>3</b> | <b>7</b> | <b>13</b> | <b>6</b> | <b>8</b> | <b>14</b> |
| 50,000                      | *                      | *        | *        |          | *        |           |           |          |          |           |          |          |           |
| 75,000                      | *                      | *        | *        | *        |          |           | *         |          |          |           |          |          |           |
| 100,000                     | *                      | *        | *        | *        | *        | *         | *         |          |          |           |          |          | *         |
| 125,000                     | *                      | *        | *        | *        | *        | *         |           | *        | *        | *         |          |          |           |
| 150,000                     | *                      | *        | *        | *        | *        | *         | *         | *        | *        | *         |          |          |           |
| 175,000                     | *                      | *        | *        | *        |          | *         | *         | *        | *        | *         | *        | *        |           |
| <b>Occurrence Ratio (%)</b> | 100                    | 100      | 100      | 83.33    | 66.67    | 66.67     | 66.67     | 50       | 50       | 50        | 16.67    | 16.67    | 16.67     |

Table 6.9: Opened Camps in Small Data Set with Discrete Capacities

## 6.2.2 Medium Data Set

Tables 6.10, 6.11 and 6.12 show computational performance of medium data set with random, fixed and discrete capacities, respectively. As in the small data set, the value of  $Q$  directly affects the solution time.

As in small data set, medium data set has also difference between the solution times of different types of refugee camp capacities. For random-capacitated instances, all tests are performed within less than 106 seconds. The instances with fixed capacities are solved in longer duration compared to random capacity setting. However; all instances are solved to optimality within the time limit. On the other hand, for discrete capacities, the instance with  $Q = 175,000$  cannot be solved in 21600 seconds.

In the small data set, the main distinctive factor that determines the solution times is  $Q$  values. However; for medium data set, type of refugee camp capacities has a significant effect on the solution duration together with  $Q$  values.

| <b>Q</b> | <b>CPU<br/>(seconds)</b> | <b>Number of<br/>Used Refugee<br/>Camps</b> | <b>Total<br/>Distance</b> |
|----------|--------------------------|---------------------------------------------|---------------------------|
| 50,000   | 22.43                    | 3                                           | 80.12                     |
| 75,000   | 42.41                    | 4                                           | 194.57                    |
| 100,000  | 55.49                    | 6                                           | 304.68                    |
| 125,000  | 90.92                    | 8                                           | 413.97                    |
| 150,000  | 105.10                   | 9                                           | 528.40                    |
| 175,000  | 103.10                   | 10                                          | 641.57                    |

Table 6.10: Results of medium data set with random capacities

| <b>Q</b> | <b>CPU<br/>(seconds)</b> | <b>Number of<br/>Used Refugee<br/>Camps</b> | <b>Total<br/>Distance</b> |
|----------|--------------------------|---------------------------------------------|---------------------------|
| 50,000   | 49.81                    | 4                                           | 121.15                    |
| 75,000   | 59.24                    | 5                                           | 166.46                    |
| 100,000  | 61.33                    | 7                                           | 281.82                    |
| 125,000  | 127.73                   | 9                                           | 395.84                    |
| 150,000  | 584.72                   | 10                                          | 490.87                    |
| 175,000  | 3290.53                  | 12                                          | 649.40                    |

Table 6.11: Results of medium data set with fixed capacities



| <b>Q</b> | <b>CPU<br/>(seconds)</b> | <b>Gap (%)</b> | <b>Number of<br/>Used Refugee<br/>Camps</b> | <b>Total<br/>Distance</b> |
|----------|--------------------------|----------------|---------------------------------------------|---------------------------|
| 50,000   | 44.17                    | -              | 3                                           | 83.65                     |
| 75,000   | 61.35                    | -              | 5                                           | 166.46                    |
| 100,000  | 53.52                    | -              | 6                                           | 272.37                    |
| 125,000  | 692.96                   | -              | 9                                           | 434.83                    |
| 150,000  | 1821.07                  | -              | 10                                          | 596.53                    |
| 175,000  | 21600.00                 | 2.64           | 13                                          | 800.12                    |

Table 6.12: Results of medium data set with discrete capacities

For medium data set with discrete capacities, refugee camps for different values of  $Q$  are listed in Table 6.13. Candidate refugee camps 1, 5 and 36 are used for all  $Q$  values. The capacities of these camps are 15,000, 15,000 and 25,000 respectively. Generally, an increase in  $Q$  by 25,000 results in addition of new refugee camps to the current ones. However; we can observe that in some cases current camps are closed and new camps are added instead of them, as in increase of  $Q$  from 75,000 to 100,000. Camps 1, 2, 30 and 36 are among current refugee camps that are serving in Turkey.

| <b>Q</b>                        | <b>Candidate Refugee Camp</b> |          |           |          |          |           |          |           |           |          |          |          |           |
|---------------------------------|-------------------------------|----------|-----------|----------|----------|-----------|----------|-----------|-----------|----------|----------|----------|-----------|
|                                 | <b>1</b>                      | <b>5</b> | <b>36</b> | <b>4</b> | <b>2</b> | <b>11</b> | <b>9</b> | <b>10</b> | <b>17</b> | <b>3</b> | <b>7</b> | <b>6</b> | <b>30</b> |
| 50,000                          | *                             | *        | *         |          |          |           |          |           |           |          |          |          |           |
| 75,000                          | *                             | *        | *         | *        |          |           | *        |           |           |          |          |          |           |
| 100,000                         | *                             | *        | *         | *        | *        | *         |          |           |           |          |          |          |           |
| 125,000                         | *                             | *        | *         | *        | *        | *         | *        | *         | *         |          |          |          |           |
| 150,000                         | *                             | *        | *         | *        | *        | *         |          | *         | *         | *        | *        |          |           |
| 175,000                         | *                             | *        | *         | *        | *        | *         | *        | *         | *         | *        | *        | *        | *         |
| <b>Occurrence<br/>Ratio (%)</b> | 100                           | 100      | 100       | 83.33    | 66.67    | 66.67     | 50       | 50        | 50        | 33.33    | 33.33    | 16.67    | 16.67     |

Table 6.13: Opened Camps in Medium Data Set with Discrete Capacities

### 6.3 Large Data Set

Tables 6.14 and 6.15 show computational performance of large data set with random and fixed capacities, respectively. As in the small and medium data set, the value of  $Q$  directly affects the solution time for both capacity types. In large data set, instances with random capacities solved faster compared to instances with fixed capacities. Random-capacitated instances are solved within 577 seconds, whereas fixed-capacitated instances could be solved in 1764 seconds.

| <b>Q</b> | <b>CPU<br/>(seconds)</b> | <b>Number of<br/>Used Refugee<br/>Camps</b> | <b>Total<br/>Distance</b> |
|----------|--------------------------|---------------------------------------------|---------------------------|
| 50,000   | 267.30                   | 3                                           | 80.12                     |
| 75,000   | 317.38                   | 4                                           | 162.27                    |
| 100,000  | 313.89                   | 5                                           | 270.66                    |
| 125,000  | 351.32                   | 7                                           | 379.07                    |
| 150,000  | 484.92                   | 9                                           | 495.34                    |
| 175,000  | 576.24                   | 10                                          | 610.80                    |

Table 6.14: Results of large data set with random capacities

| <b>Q</b> | <b>CPU<br/>(seconds)</b> | <b>Number of<br/>Used Refugee<br/>Camps</b> | <b>Total<br/>Distance</b> |
|----------|--------------------------|---------------------------------------------|---------------------------|
| 50,000   | 338.56                   | 4                                           | 121.15                    |
| 75,000   | 532.75                   | 5                                           | 166.46                    |
| 100,000  | 455.57                   | 7                                           | 281.82                    |
| 125,000  | 661.07                   | 9                                           | 395.84                    |
| 150,000  | 983.96                   | 10                                          | 465.68                    |
| 175,000  | 1763.11                  | 12                                          | 620.12                    |

Table 6.15: Results of large data set with fixed capacities

## 6.4 Case Study for the Southern Part of Turkey

The large data set with discrete capacities is proposed as the case study for the refugee camp location problem applied to the Southern part of Turkey. The computational results are shown in Table 6.16 for different values of  $Q$ . The tests show that L-LRP has difficulty in solving instances with  $Q \geq 225,000$  in 21600 seconds.

As detailed in Chapter 2, currently 140,000 Syrians populate inside the 13 refugee camps in the Southern part of Turkey [9]. When 13 refugee camps are placed with L-LRP formulation, up to 225,000 refugees can be placed to refugee camps. Also, as it is close to 140,000, when  $Q = 150,000$  for the optimization problem, 8 refugee camps become adequate to provide asylum for all refugees.

| $Q$     | CPU<br>(seconds) | Gap (%) | Number of<br>Used Refugee<br>Camps | Total<br>Distance |
|---------|------------------|---------|------------------------------------|-------------------|
| 50,000  | 540.84           | -       | 3                                  | 83.65             |
| 75,000  | 549.44           | -       | 5                                  | 166.46            |
| 100,000 | 530.50           | -       | 6                                  | 252.18            |
| 125,000 | 627.85           | -       | 7                                  | 358.09            |
| 150,000 | 2711.25          | -       | 8                                  | 510.51            |
| 175,000 | 18440.46         | -       | 11                                 | 668.99            |
| 200,000 | 15883.93         | -       | 12                                 | 821.42            |
| 225,000 | 21600.00         | 4.48    | 13                                 | 994.81            |
| 250,000 | 21600.00         | 6.76    | 16                                 | 1170.67           |
| 275,000 | 21600.00         | 4.97    | 17                                 | 1354.87           |
| 300,000 | 21600.00         | 5.08    | 18                                 | 1565.42           |
| 325,000 | 21600.00         | 5.61    | 19                                 | 1784.55           |

Table 6.16: Results of large data set with discrete capacities

Table 6.17 shows opened refugee camps according to different  $Q$  values with discrete capacities in large data set. As it is in case in small and medium data set, when the  $Q$  value is increased by 25,000, generally new camps are added to current camps. However; there are cases where some of the current camps are closed and new refugee camps are opened instead of them. Refugee camps 1,4 and 69 are opened for all  $Q$  values with capacities 15,000, 15,000 and 25,000, respectively. Camps 1, 2, 13, 30, 37, 51, 57 and 69 are among current refugee camps that are serving in Turkey.

|                             | Candidate Refugee Camp |          |           |          |           |          |           |          |          |           |
|-----------------------------|------------------------|----------|-----------|----------|-----------|----------|-----------|----------|----------|-----------|
| <b>Q</b>                    | <b>1</b>               | <b>4</b> | <b>69</b> | <b>5</b> | <b>51</b> | <b>2</b> | <b>11</b> | <b>9</b> | <b>3</b> | <b>30</b> |
| 50,000                      | *                      | *        | *         |          |           |          |           |          |          |           |
| 75,000                      | *                      | *        | *         | *        |           |          |           | *        |          |           |
| 100,000                     | *                      | *        | *         | *        | *         |          |           | *        |          |           |
| 125,000                     | *                      | *        | *         | *        | *         | *        | *         |          |          |           |
| 150,000                     | *                      | *        | *         | *        | *         | *        | *         |          |          |           |
| 175,000                     | *                      | *        | *         | *        | *         | *        | *         | *        | *        | *         |
| 200,000                     | *                      | *        | *         | *        | *         | *        | *         | *        | *        | *         |
| 225,000                     | *                      | *        | *         | *        | *         | *        | *         |          | *        | *         |
| 250,000                     | *                      | *        | *         | *        | *         | *        | *         | *        | *        | *         |
| 275,000                     | *                      | *        | *         | *        | *         | *        | *         | *        | *        | *         |
| 300,000                     | *                      | *        | *         | *        | *         | *        | *         | *        | *        | *         |
| 325,000                     | *                      | *        | *         | *        | *         | *        | *         | *        | *        | *         |
| <b>Occurrence Ratio (%)</b> | 100                    | 100      | 100       | 91.67    | 83.33     | 75       | 75        | 66.67    | 58.33    | 58.33     |

Table 6.17: Opened Camps in Large Data Set with Discrete Capacities

|                             | Candidate Refugee Camp |           |          |           |           |           |          |           |           |           |
|-----------------------------|------------------------|-----------|----------|-----------|-----------|-----------|----------|-----------|-----------|-----------|
| <b>Q</b>                    | <b>53</b>              | <b>62</b> | <b>7</b> | <b>10</b> | <b>17</b> | <b>37</b> | <b>6</b> | <b>36</b> | <b>57</b> | <b>13</b> |
| 50,000                      |                        |           |          |           |           |           |          |           |           |           |
| 75,000                      |                        |           |          |           |           |           |          |           |           |           |
| 100,000                     |                        |           |          |           |           |           |          |           |           |           |
| 125,000                     |                        |           |          |           |           |           |          |           |           |           |
| 150,000                     |                        | *         |          |           |           |           |          |           |           |           |
| 175,000                     | *                      |           |          |           |           |           |          |           |           |           |
| 200,000                     | *                      | *         |          |           |           |           |          |           |           |           |
| 225,000                     | *                      | *         | *        | *         |           |           |          |           |           |           |
| 250,000                     | *                      | *         | *        | *         | *         |           | *        |           |           |           |
| 275,000                     | *                      | *         | *        | *         | *         | *         |          | *         |           |           |
| 300,000                     | *                      | *         | *        | *         | *         | *         |          | *         | *         |           |
| 325,000                     | *                      | *         | *        | *         | *         | *         | *        |           | *         | *         |
| <b>Occurrence Ratio (%)</b> | 58.33                  | 58.33     | 41.67    | 41.67     | 33.33     | 25        | 16.67    | 16.67     | 16.67     | 8.33      |

Table 6.17: (Cont.) Opened Camps in Large Data Set with Discrete Capacities

## 6.5 Comparison of Data Sets from Different Sizes

Small, medium and large data sets are all solved for random, fixed and discrete capacities with different  $Q$  values. Tables 6.18, 6.19 and 6.20 summarize the results of computational tests according to solution times and objective function values. For a fixed  $Q$  value, as the size of the data set increases, objective function value decreases because of the enlarged feasible region. Also, for all data sets and capacity types, increasing  $Q$  value results in higher solution times. Among the capacity types, generally random-capacitated instances are solved in shorter duration, whereas discrete-capacitated instances are solved in longer duration.

Increasing the size of the data generally increases the solution times. However; it can be also inferred that the solution time is not directly related to the size of the data set. For instance, for large data set with discrete capacities, the optimization problem finds optimal solutions for all  $Q$  values within 18441 seconds. On the other hand, for medium data set optimal solution for  $Q = 175,000$  could not be found in 21600 seconds.

| Q       | Small Data Set     |                | Medium Data Set    |                | Large Data Set     |                |
|---------|--------------------|----------------|--------------------|----------------|--------------------|----------------|
|         | Solution Time(sec) | Total Distance | Solution Time(sec) | Total Distance | Solution Time(sec) | Total Distance |
| 50,000  | 2.75               | 92.44          | 22.43              | 80.12          | 267.30             | 80.12          |
| 75,000  | 3.50               | 194.56         | 42.41              | 194.57         | 317.38             | 162.27         |
| 100,000 | 8.79               | 318.34         | 55.49              | 304.68         | 313.89             | 270.66         |
| 125,000 | 23.70              | 432.01         | 90.92              | 413.97         | 351.32             | 379.07         |
| 150,000 | 32.81              | 552.40         | 105.10             | 528.40         | 484.92             | 495.34         |
| 175,000 | 2938.03            | 744.82         | 103.10             | 641.57         | 576.24             | 610.80         |

Table 6.18: Comparison of Different-sized Data Sets with Random Capacities

| Q       | Small Data Set     |                | Medium Data Set    |                | Large Data Set     |                |
|---------|--------------------|----------------|--------------------|----------------|--------------------|----------------|
|         | Solution Time(sec) | Total Distance | Solution Time(sec) | Total Distance | Solution Time(sec) | Total Distance |
| 50,000  | 3.33               | 137.50         | 49.81              | 121.15         | 338.56             | 121.15         |
| 75,000  | 8.21               | 205.32         | 59.24              | 166.46         | 532.75             | 166.46         |
| 100,000 | 29.52              | 319.35         | 61.33              | 281.82         | 455.57             | 281.82         |
| 125,000 | 574.42             | 510.59         | 127.73             | 395.84         | 661.07             | 395.84         |
| 150,000 | 609.66             | 607.48         | 584.72             | 490.87         | 983.96             | 465.68         |
| 175,000 | 11757.18           | 836.00         | 3290.53            | 649.40         | 1763.11            | 620.12         |

Table 6.19: Comparison of Different-sized Data Sets with Fixed Capacities

| Q       | Small Data Set     |                | Medium Data Set    |                | Large Data Set     |                |
|---------|--------------------|----------------|--------------------|----------------|--------------------|----------------|
|         | Solution Time(sec) | Total Distance | Solution Time(sec) | Total Distance | Solution Time(sec) | Total Distance |
| 50,000  | 4.14               | 137.50         | 44.17              | 83.65          | 540.84             | 83.65          |
| 75,000  | 7.14               | 243.41         | 61.35              | 166.56         | 549.44             | 166.46         |
| 100,000 | 252.68             | 405.87         | 53.52              | 272.37         | 530.50             | 252.18         |
| 125,000 | 351.72             | 567.57         | 692.96             | 434.83         | 627.85             | 358.09         |
| 150,000 | 1303.77            | 768.35         | 1821.07            | 596.53         | 2711.25            | 510.51         |
| 175,000 | 2477.80            | 1014.00        | >21600.00          | 800.12         | 18440.46           | 668.99         |

Table 6.20: Comparison of Different-sized Data Sets with Discrete Capacities

## Chapter 7

# A Two Stage Math-Heuristic for L-LRP

Computational analysis of mathematical formulation reveals that for small number of  $Q$  values, the optimization problem are solved in short times. However; as more refugees are required to be placed to camps, solution times get longer. Especially, for some of the instances of medium and large data set with discrete capacities, 21600 seconds become inadequate to obtain the optimal solution. Thus, a heuristic algorithm is essential to find good solutions in shorter times. In this section, we propose a two-stage math-heuristic algorithm and explain it in detail.

The proposed heuristic algorithm consists of two stages. First stage uses the complete data set and downsizes it (mainly the alternative locations of candidate refugee camps and hosting institutions) by solving an assignment problem. The second stage uses the obtained smaller data set to solve L-LRP model provided in Chapter 5.

### **First stage:**

Using sets and parameters defined in Chapter 5, a coefficient called  $\beta$  is defined, which determines to which extent that the data set will be downsized. Additionally, the following decision variables are used:

$$x_r = \begin{cases} 1, & \text{if candidate refugee camp } r \in R \text{ is opened} \\ 0, & \text{otherwise.} \end{cases}$$

$$t_{rhs} = \begin{cases} 1, & \text{if } r \in R \text{ is assigned to hosting institution } h \in H \text{ for} \\ & \text{service type } s \in S, \\ 0, & \text{otherwise.} \end{cases}$$

Then, following assignment model is solved:

$$\text{(FS) minimize } \sum_{s \in S} \sum_{r \in R} \sum_{h \in H} d_{rh} t_{rhs} \quad (7.1)$$

subject to

$$\sum_{r \in R} q_r x_r \geq \beta \cdot Q \quad (7.2)$$

$$\sum_{h \in H_s} t_{rhs} = x_r \quad r \in R, s \in S \quad (7.3)$$

$$x_r \in \{0, 1\} \quad r \in R \quad (7.4)$$

$$t_{rhs} \in \{0, 1\} \quad r \in R, h \in H, s \in S \quad (7.5)$$

The objective function (7.1) minimizes the distance between refugee camps and their assigned hosting institutions. Constraint (7.2) opens refugee camps with adequate capacity which can be asylum for  $\beta \cdot Q$  refugees. The coefficient  $\beta$  is used to not downsize the data set too much and restrict the solution space of the original problem. If  $\beta \cdot Q$  exceeds the total capacity of data set, then the constraint is changed as  $\sum_{r \in R} q_r x_r \geq \sum_{r \in R} q_r$ . Constraint (7.3) assigns a hosting institution from all service types to all opened refugee camps. Constraints (7.4) and (7.5) are the domain constraints.

After solving (FS), if  $x_r = 0$ , then  $r \in R$  is subtracted from set  $R$ . Also, if  $\sum_{s \in S} \sum_{r \in R} t_{rhs} = 0$ , i.e. hosting institution  $h \in H$  is never used, then it is deleted from set  $H$ . With the remaining nodes, sets  $R'$ ,  $H'$  and  $N' = R' \cup H'$  are formed to be processed in second stage.



## Second stage:

In the second stage of the algorithm, the exact L-LRP formulation, explained in Chapter 5, is solved with the downsized data set obtained from the first stage. Time limit of 300 seconds are put to obtain the solutions faster.

The algorithmic representation of the proposed heuristic is as below:

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**Algorithm 1** Two-Stage Heuristic for L-LRP

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**Require:** Define  $N' = \emptyset$ ,  $R' = \emptyset$ ,  $H' = \emptyset$ ,  $H'_s = \emptyset$ , and  $A' = \emptyset$ .

- 1: **Stage 1:** Solve (FS) with sets  $N, A, R, S, H$  and  $H_s$  and coefficient  $\beta$ .
  - 2: **for all**  $r \in R$  **do**
  - 3:   **if**  $x_r = 1$  **then**
  - 4:     Add  $r$  to  $R'$ .
  - 5:   **end if**
  - 6:   **for all**  $s \in S$  **do**
  - 7:     **for all**  $h \in H$  **do**
  - 8:       **if**  $t_{rhs} = 1$  &  $h \notin H_s$  **then**
  - 9:         Add  $h$  to  $H_s$
  - 10:       **end if**
  - 11:     **end for**
  - 12:   **end for**
  - 13: **end for**
  - 14: Update  $H' = \bigcup_{s \in S} H'_s$ .
  - 15: Update  $N' = R' \cup H'$
  - 16: Update  $A'$  and  $G' = (N', A')$
  - 17: **Stage 2:** Solve (L-LRP) with sets  $N', A', R', S, H'$  and  $H'_s$  with time limit of 300 seconds
  - 18: Report the results
-

## Chapter 8

# Computational Analysis of the Heuristic

In this chapter, computational analysis of the heuristic algorithm is presented. First, medium data set is selected as the test instance to determine the value of coefficient  $\beta$ . Then, with the determined  $\beta$  value, heuristic algorithm is run on instances from large data sets and results are discussed.

The heuristic algorithm are coded in JAVA using IBM CPLEX 12.8.1. The test instances are performed on a computer having Windows 10 with Intel Core i7-7700HQ 2.8 GHz processor with 16 GB of RAM.

### 8.1 Sensitivity Analysis on $\beta$

For the proposed heuristic algorithm, the first stage determines the extent to which the data set will be downsized. The size of the obtained smaller data set is significant since it affects the second stage in two ways. First, if the value of  $\beta$  is small, then the obtained data set becomes small and the feasible region for the second stage may be very restrictive. Second, if the value of  $\beta$  is large, then the

second stage problem may have feasible region that is larger than desired. The large feasible region may negatively affect the time to find a good solution in 300 seconds.

To determine the value of coefficient  $\beta$ , medium data set is used. Heuristic algorithm is performed on instances from both random, fixed and discrete capacities. Four values for  $\beta$  are experimented as 1.5, 2, 2.5 and 3. Different number of refugees are placed to camps, i.e.,  $Q$  values are altered as 50,000, 75,000, 100,000, 125,000, 150,000 and 175,000. Totally, 72 instances are analyzed and the convenient values for  $\beta$  are detected. Tables 8.1, 8.2, and 8.3 show the results for discrete, fixed and random capacities, respectively. Solution gap of heuristic algorithm is calculated as below using the best solution found in 21600 seconds with L-LRP formulation:

$$\text{Gap}(\%) = \frac{\text{Heuristic Obj. Fn. Value} - \text{L-LRP Obj. Fn. Value (in 21600 sec)}}{\text{L-LRP Obj. Fn. Value (in 21600 sec)}}$$

| Q       | Mathematical<br>Model Obj.<br>Value | $\beta=1.5$       |            | $\beta=2$         |            | $\beta=2.5$       |            | $\beta=3$         |            |
|---------|-------------------------------------|-------------------|------------|-------------------|------------|-------------------|------------|-------------------|------------|
|         |                                     | Total<br>Distance | Gap<br>(%) | Total<br>Distance | Gap<br>(%) | Total<br>Distance | Gap<br>(%) | Total<br>Distance | Gap<br>(%) |
| 50,000  | 80.12                               | 92.44             | 15.38      | 80.12             | -          | 80.17             | 0.06       | 80.12             | -          |
| 75,000  | 194.57                              | 194.57            | -          | 194.57            | -          | 194.57            | -          | 194.57            | -          |
| 100,000 | 304.68                              | 304.68            | -          | 304.68            | -          | 304.68            | -          | 304.68            | -          |
| 125,000 | 413.97                              | 425.51            | 2.79       | 419.07            | 1.23       | 419.07            | 1.23       | 419.07            | 1.23       |
| 150,000 | 528.40                              | 590.94            | 11.84      | 549.29            | 3.95       | 543.77            | 2.91       | 528.40            | -          |
| 175,000 | 641.57                              | 759.58            | 18.39      | 704.27            | 9.77       | 641.57            | -          | 641.57            | -          |

Table 8.1: Heuristic results of medium data set with random capacities

| Q       | Mathematical<br>Model Obj.<br>Value | $\beta=1.5$       |            | $\beta=2$         |            | $\beta=2.5$       |            | $\beta=3$         |            |
|---------|-------------------------------------|-------------------|------------|-------------------|------------|-------------------|------------|-------------------|------------|
|         |                                     | Total<br>Distance | Gap<br>(%) | Total<br>Distance | Gap<br>(%) | Total<br>Distance | Gap<br>(%) | Total<br>Distance | Gap<br>(%) |
| 50,000  | 121.15                              | 121.15            | -          | 121.15            | -          | 121.15            | -          | 121.15            | -          |
| 75,000  | 166.46                              | 166.46            | -          | 166.46            | -          | 166.46            | -          | 166.46            | -          |
| 100,000 | 281.82                              | 281.82            | -          | 281.82            | -          | 281.82            | -          | 281.82            | -          |
| 125,000 | 395.84                              | 436.26            | 10.21      | 395.84            | -          | 395.84            | -          | 395.84            | -          |
| 150,000 | 490.87                              | 490.87            | -          | 490.87            | -          | 490.87            | -          | 490.87            | -          |
| 175,000 | 649.40                              | 649.40            | -          | 649.40            | -          | 649.40            | -          | 649.40            | -          |

Table 8.2: Heuristic results of medium data set with fixed capacities

| Q       | Mathematical<br>Model Obj.<br>Value | $\beta=1.5$       |            | $\beta=2$         |            | $\beta=2.5$       |            | $\beta=3$         |            |
|---------|-------------------------------------|-------------------|------------|-------------------|------------|-------------------|------------|-------------------|------------|
|         |                                     | Total<br>Distance | Gap<br>(%) | Total<br>Distance | Gap<br>(%) | Total<br>Distance | Gap<br>(%) | Total<br>Distance | Gap<br>(%) |
| 50,000  | 83.65                               | 83.65             | -          | 83.65             | -          | 83.65             | -          | 83.65             | -          |
| 75,000  | 166.46                              | 216.04            | 29.70      | 166.46            | -          | 166.46            | -          | 166.46            | -          |
| 100,000 | 272.37                              | 272.37            | -          | 272.37            | -          | 272.36            | -          | 272.36            | -          |
| 125,000 | 434.83                              | 462.03            | 6.26       | 434.83            | -          | 434.83            | -          | 434.83            | -          |
| 150,000 | 596.53                              | 596.53            | -          | 596.53            | -          | 596.53            | -          | 569.75            | 0.04       |
| 175,000 | 800.12                              | 815.31            | 1.90       | 800.12            | -          | 800.35            | 0.03       | 800.35            | 0.03       |

Table 8.3: Heuristic results of medium data set with discrete capacities

The results show that except  $\beta = 1.5$ , for fixed capacities all  $n$  values provide the optimal solution. However; for random and discrete capacities value of  $\beta$  affects the quality of the solution. For random capacity  $\beta = 3$  seems to be the best option with maximum 1.23 % of solution gap. For discrete capacity,  $\beta = 2$  seems to be the best option. However; for both discrete and random-capacitated instances  $\beta = 2.5$  also provides good solutions with maximum solution gap of 2.91%.

As a result, computational results support that  $\beta = 2$ ,  $\beta = 2.5$  and  $\beta = 3$  are all acceptable coefficients. With these three values for  $\beta$ , computational studies are conducted for large data set and they are summarized in Tables 8.4, 8.5 and 8.6.

| Q       | Mathematical<br>Model Obj.<br>Value | $\beta=2$         |         | $\beta=2.5$       |         | $\beta=3$         |         |
|---------|-------------------------------------|-------------------|---------|-------------------|---------|-------------------|---------|
|         |                                     | Total<br>Distance | Gap (%) | Total<br>Distance | Gap (%) | Total<br>Distance | Gap (%) |
| 50,000  | 80.12                               | 98.71             | 23.20   | 80.12             | -       | 92.44             | 15.37   |
| 75,000  | 162.27                              | 162.27            | -       | 162.27            | -       | 162.27            | -       |
| 100,000 | 270.66                              | 270.66            | -       | 270.66            | -       | 270.66            | -       |
| 125,000 | 379.07                              | 379.07            | -       | 379.07            | -       | 379.07            | -       |
| 150,000 | 495.34                              | 495.34            | -       | 507.77            | 2.51    | 495.34            | -       |
| 175,000 | 610.80                              | 650.23            | 6.46    | 615.43            | -       | 615.43            | -       |

Table 8.4: Heuristic results of large data set with random capacities

| Q       | Mathematical<br>Model Obj.<br>Value | $\beta=2$         |         | $\beta=2.5$       |         | $\beta=3$         |         |
|---------|-------------------------------------|-------------------|---------|-------------------|---------|-------------------|---------|
|         |                                     | Total<br>Distance | Gap (%) | Total<br>Distance | Gap (%) | Total<br>Distance | Gap (%) |
| 50,000  | 121.15                              | 121.15            | -       | 121.15            | -       | 121.15            | -       |
| 75,000  | 166.46                              | 166.46            | -       | 166.46            | -       | 166.46            | -       |
| 100,000 | 281.82                              | 281.82            | -       | 281.82            | -       | 281.82            | -       |
| 125,000 | 395.84                              | 395.85            | -       | 395.85            | -       | 395.85            | -       |
| 150,000 | 465.68                              | 465.68            | -       | 465.68            | -       | 465.68            | -       |
| 175,000 | 620.12                              | 620.12            | -       | 620.12            | -       | 620.12            | -       |

Table 8.5: Heuristic results of large data set with fixed capacities

| Q       | Mathematical<br>Model Obj.<br>Value | $\beta=2$         |         | $\beta=2.5$       |         | $\beta=3$         |         |
|---------|-------------------------------------|-------------------|---------|-------------------|---------|-------------------|---------|
|         |                                     | Total<br>Distance | Gap (%) | Total<br>Distance | Gap (%) | Total<br>Distance | Gap (%) |
| 50,000  | 83.65                               | 83.65             | -       | 83.65             | -       | 83.65             | -       |
| 75,000  | 166.46                              | 169.38            | 1.75    | 169.38            | 1.75    | 169.38            | 1.75    |
| 100,000 | 252.18                              | 301.76            | 19.66   | 252.18            | -       | 252.18            | -       |
| 125,000 | 358.09                              | 358.09            | -       | 358.09            | -       | 358.09            | -       |
| 150,000 | 510.51                              | 510.51            | -       | 510.51            | -       | 510.51            | -       |
| 175,000 | 668.99                              | 668.99            | -       | 668.99            | -       | 668.99            | -       |
| 200,000 | 821.42                              | 821.42            | -       | 821.42            | -       | 821.42            | -       |
| 225,000 | 994.81                              | 994.81            | -       | 994.81            | -       | 994.81            | -       |
| 250,000 | 1170.67                             | 1183.15           | 1.07    | 1077.67           | -       | 1170.90           | 0.02    |
| 275,000 | 1354.87                             | 1385.14           | 2.23    | 1354.87           | -       | 1358.96           | 0.30    |
| 300,000 | 1565.42                             | 1582.50           | 1.09    | 1597.71           | 2.06    | 1596.34           | 1.98    |
| 325,000 | 1784.55                             | 1793.27           | 0.49    | 1819.20           | 1.94    | N/A               | N/A     |

Table 8.6: Heuristic results of large data set with discrete capacities

Similar to medium data set, for large data set with fixed capacities all  $\beta$  values provide the optimal solution. For random and discrete-capacitated instances  $\beta = 2.5$  provides better solutions compared to  $\beta = 2$  and  $\beta = 3$  within 300 seconds. For random capacities,  $\beta = 2$  and  $\beta = 3$  have solution gap when  $Q = 50,000$  whereas  $\beta = 2.5$  finds the optimum. For discrete-capacitated instances, when  $Q = 100,000$ ,  $\beta = 2.5$  and  $\beta = 3$  finds the optimal solution whereas  $\beta = 2$  ends up with gap of 19.66%. When  $\beta = 2.5$  and  $\beta = 3$  are compared, even if for

$Q = 300,000$   $\beta = 3$  ends with lower gap, it fails to find a feasible solution for  $Q = 325,000$  in 300 seconds. For both medium and large data sets, if  $\beta = 2.5$  is selected, the heuristic algorithm performs with at most 2.91% solution gap in 300 seconds.

Note that for some instances  $\beta = 2.5$  gives better solution than  $\beta = 3$  with a smaller feasible region. The reason of this is the time limit for some instances. Since we put a time limit of 300 seconds to second stage of the heuristic algorithm, some of the instances could not be solved to optimality. We can observe this situation in medium data set with discrete capacity when  $Q = 150,000$ . The solution of  $\beta = 3$  ends with 0.04% gap, whereas  $\beta = 2.5$  gives the optimum. However; for some instances, the reason of this case is the quality of the feasible region. For instance, when  $Q = 50,000$ ,  $\beta = 2.5$  provides a better feasible region compared to  $\beta = 3$  so that it could reach to optimum whereas  $\beta = 3$  end up with 15.37% gap.

The heuristic algorithm finds solutions of good quality in short duration even if the mathematical formulation could not reach to optimality in some medium-sized instances and for all larger-sized and discrete-capacitated instances with  $Q \geq 225,000$  in 21600 seconds.

## Chapter 9

### Conclusions

In the classical LRP, the customers are at fixed and known demand locations. With the known customer nodes, depots are located and corresponding vehicle routes are planned. However; especially for some public applications, locations of demand nodes could also be decision variables for the problem. In this thesis, we formulate the problem of locating demand nodes together with classical LRP decisions. The problem is called as Location-Location Routing Problem (L-LRP) and to the best of the authors knowledge, this is the first time such a problem is defined to literature.

As an application area to L-LRP, refugee camp location problem is detailed. As data supports, Refugee Crisis is a growing problem. Especially after Syrian Civil War, the number of refugees have drastically increased throughout the whole world, especially in neighbor countries to Syria. Turkey is the host country being asylum to more than three and a half million Syrians, which makes Turkey as the country having the largest number of refugees in its borders.

In this study, refugees in Turkey are analyzed with focus on refugee camps. Even though the majority of the refugees are outside of the camps, there is still a huge number of people living inside the refugee camps even eight years have passed from the beginning of the war. Also, refugee camps are places where refugees are

placed when they first come to host country by the authorities. From authorities' point of view, refugee camps are places where they can take control and serve to refugees systematically via providing necessary public services.

When L-LRP and refugee camp location problem are analyzed together, similarities between them could be captured. Locating refugee camps correspond to locating demand nodes. Determining the institutions to serve to refugee camps correspond to locating depots. Arranging the travel routes of service providers giving service to refugee camps correspond to vehicle routing. Thus, refugee camp location problem is a direct application of L-LRP. Since, there are multiple public services provided to refugee camps, multi-commodity version of the L-LRP is presented in the thesis.

In Chapter 4, LRP studies with focus on humanitarian logistics are reviewed since the refugee camp location problem is a humanitarian application of L-LRP. In Chapter 5, a linear integer mathematical model is proposed for the L-LRP with refugee camp location terms. However; the proposed formulation is a generic formulation and it can be used in any application where demand nodes needs to be located along with LRP decisions. The aim of the optimization problem is to minimize travel length of service providers from all types and satisfy problem specific requirements.

In Chapter 6, the performance of mathematical model is analyzed via series of computational tests. A real data set is obtained from the southern part of Turkey where 13 refugee camps for Syrians are placed. From real data set, small, medium and large data sets are constructed to experiment the optimization problem's performance according to the size of the data. Also, three types of capacities for refugee camps are used as random, fixed and discrete. The results of the computational studies of mathematical model reveals that the number of refugees to be distributed to camps and the capacity type of refugee camps have major impacts on solution times. Interestingly, the solution time of the formulation is not directly related to the size of the data set. Another observation obtained from the analysis is that mathematical model fails to find optimal solution within reasonable solution times for some of the medium and larger-sized instances,



which motivates us to develop a heuristic algorithm.

In order to obtain solutions of high quality in shorter duration, in Chapter 7 a heuristic algorithm is proposed which is a math-heuristic based on two stages. First stage decreases the size of the data set by solving an assignment problem. Second stage solves L-LRP model proposed in Chapter 5 with the downsized data set. In Chapter 8, performance of heuristic algorithm is tested and sensitivity analysis are conducted for parameter selection. The computational results show that the heuristic algorithm performs well in quite short solution times.

The main contribution of this thesis is to define L-LRP, which is not defined in the location literature before. The L-LRP is a generic problem that locates demand nodes in addition to classical LRP decision. In the thesis, refugee camp location problem is chosen as the application area of L-LRP and it is analyzed in detail. However; the proposed mathematical formulation and heuristic algorithm could be used in any L-LRP application.

In this study, minimizing total tour length of all service providers is selected as the objective function. However; different objectives could be used for fairness such as minimizing the maximum tour length within the service providers. As multi-commodity models are common in OR studies with humanitarian applications, multiple objectives could be considered simultaneously. As a future research direction, multi-objective L-LRP could be formulated. Another future research could be developing periodic L-LRP to provide dedicated service providers to increase service quality in refugee camps.

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# Appendix A

## Maps of Large Data Set

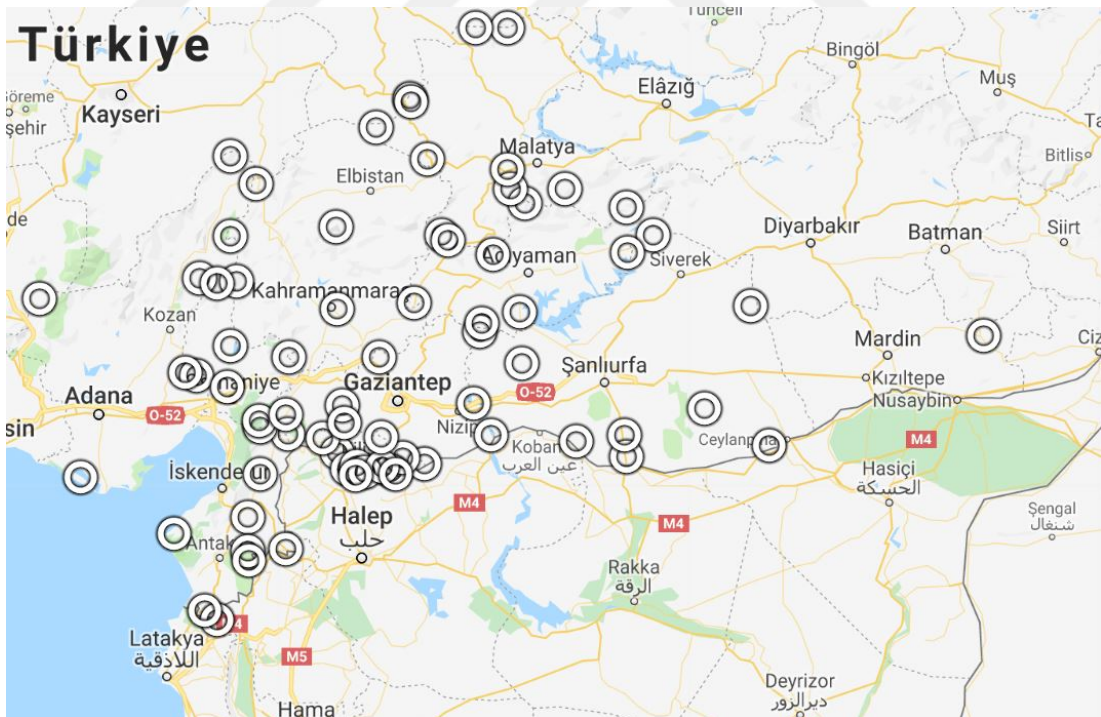


Figure A.1: Candidate Refugee Camps in Large Data Set



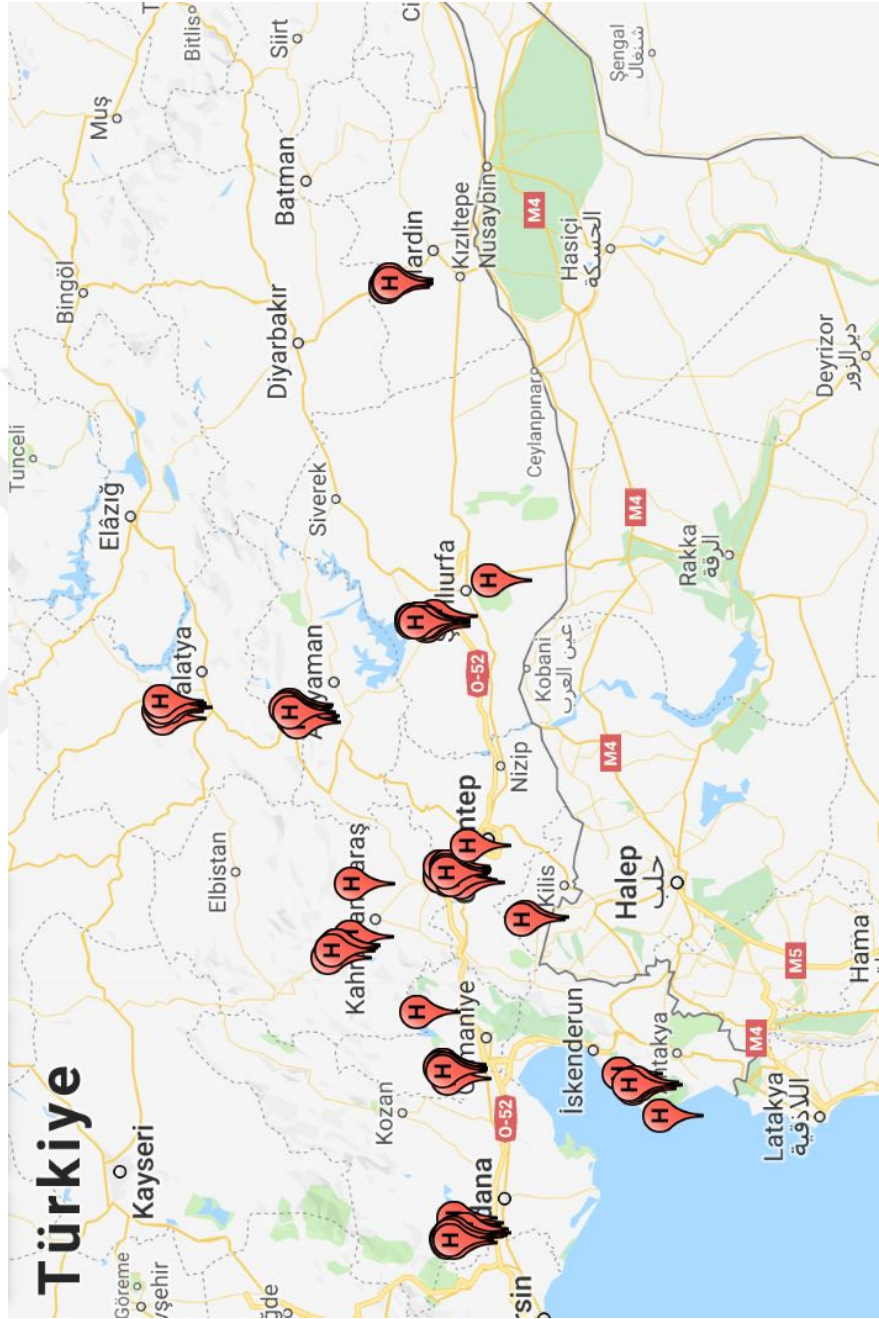


Figure A.2: Hospitals in Large Data Set

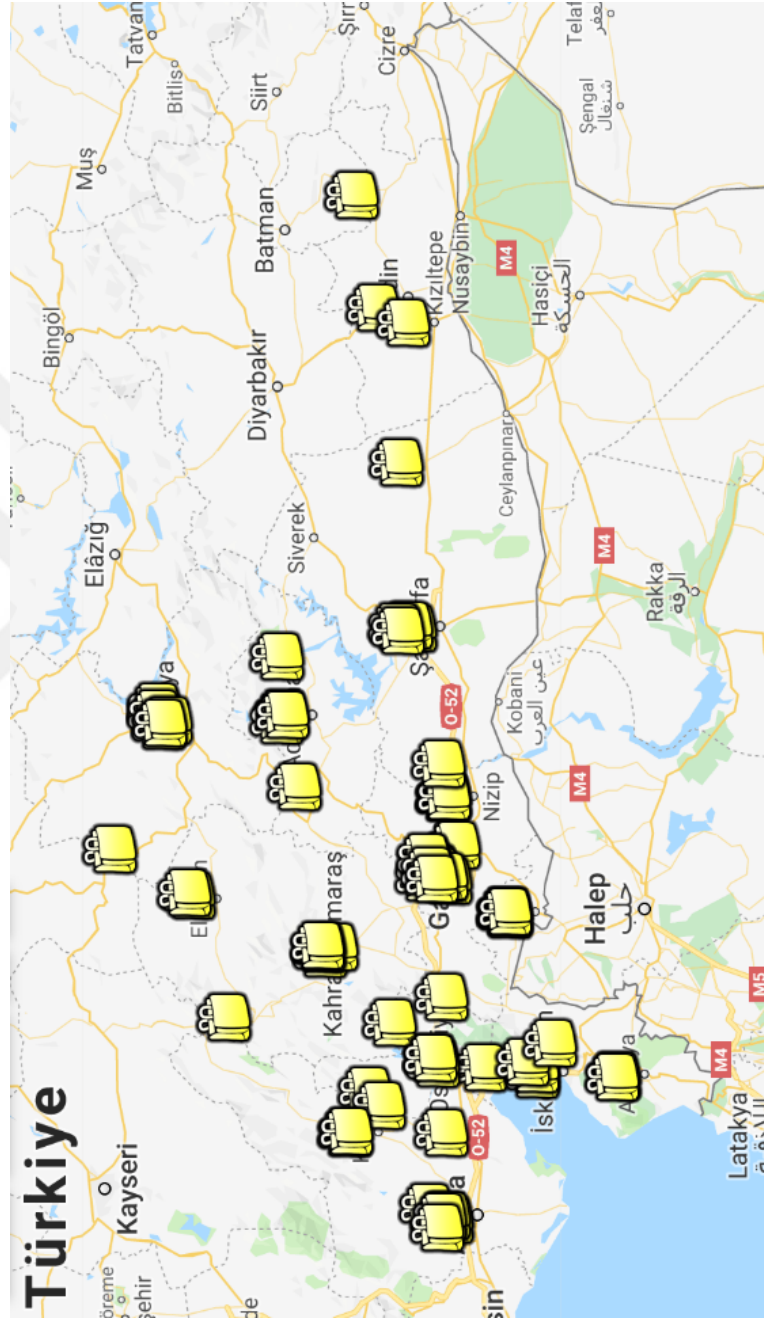


Figure A.3: High Schools in Large Data Set

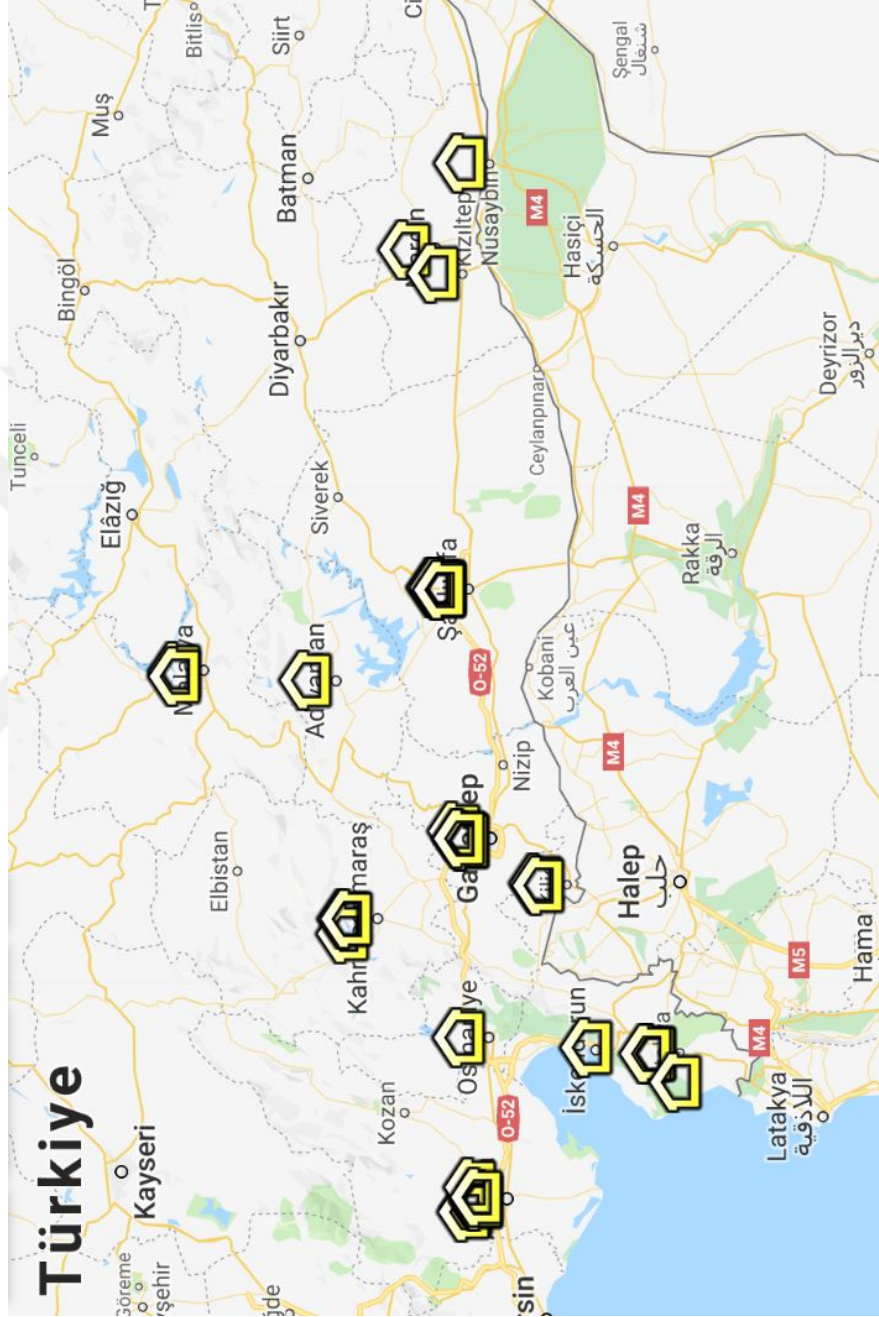


Figure A.4: Municipality Buildings in Large Data Set

# Maps of Medium Data Set







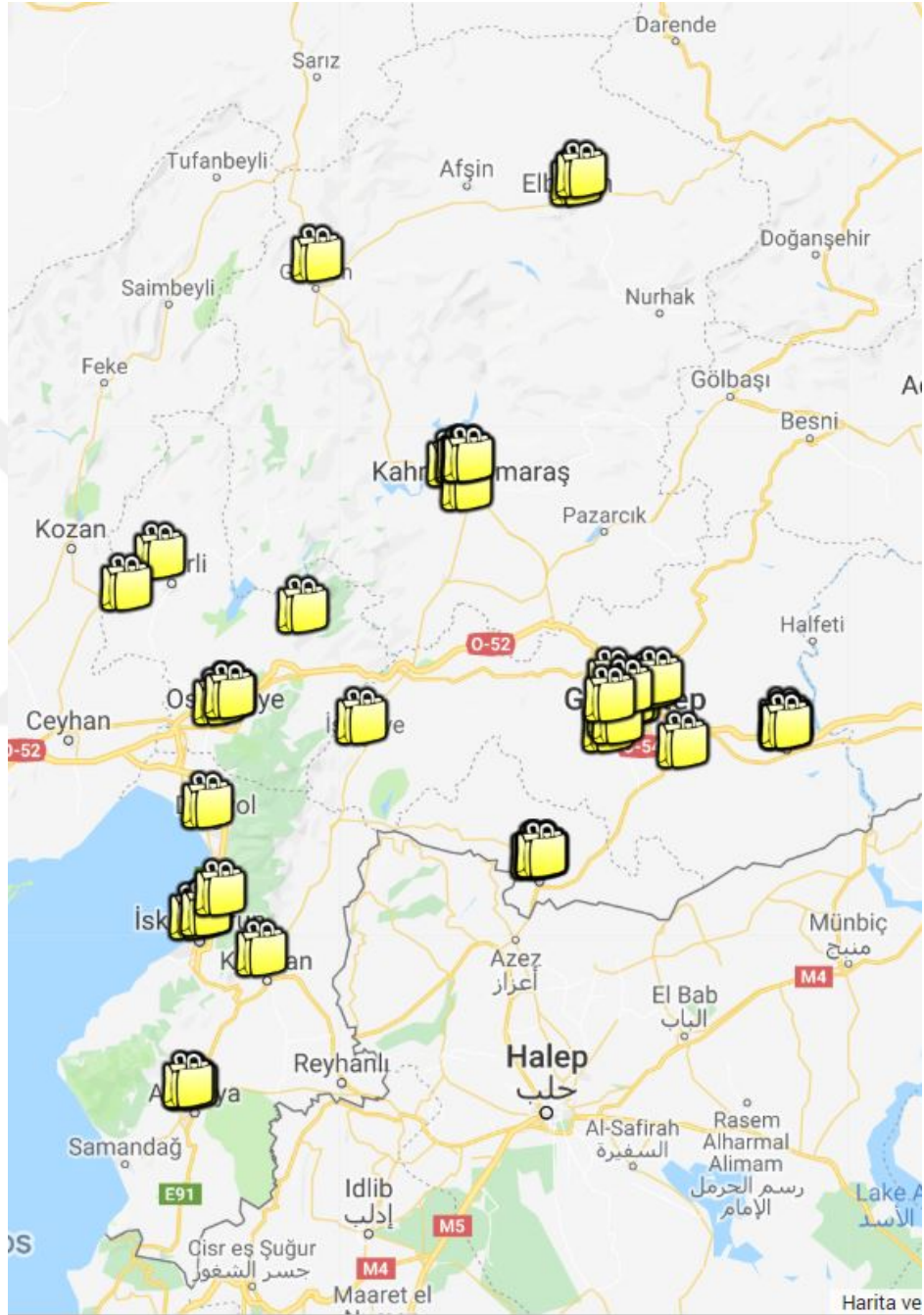


Figure B.3: High Schools in Medium Data Set





## Appendix C

### Maps of Small Data Set



Figure C.1: Candidate Refugee Camps in Small Data Set



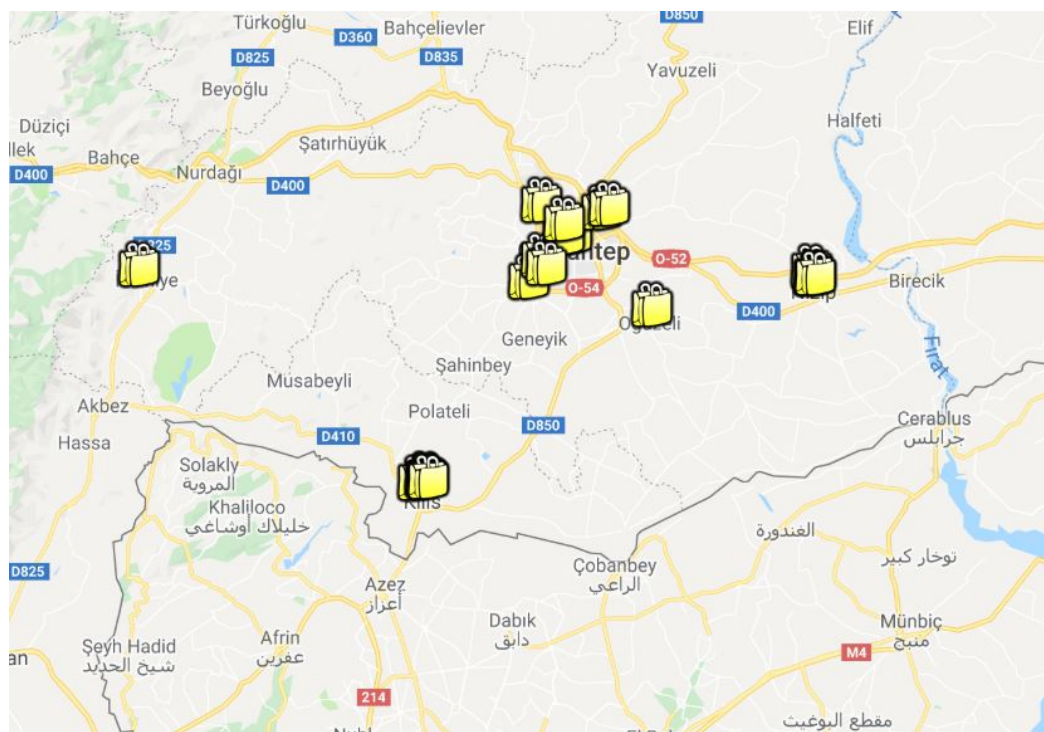
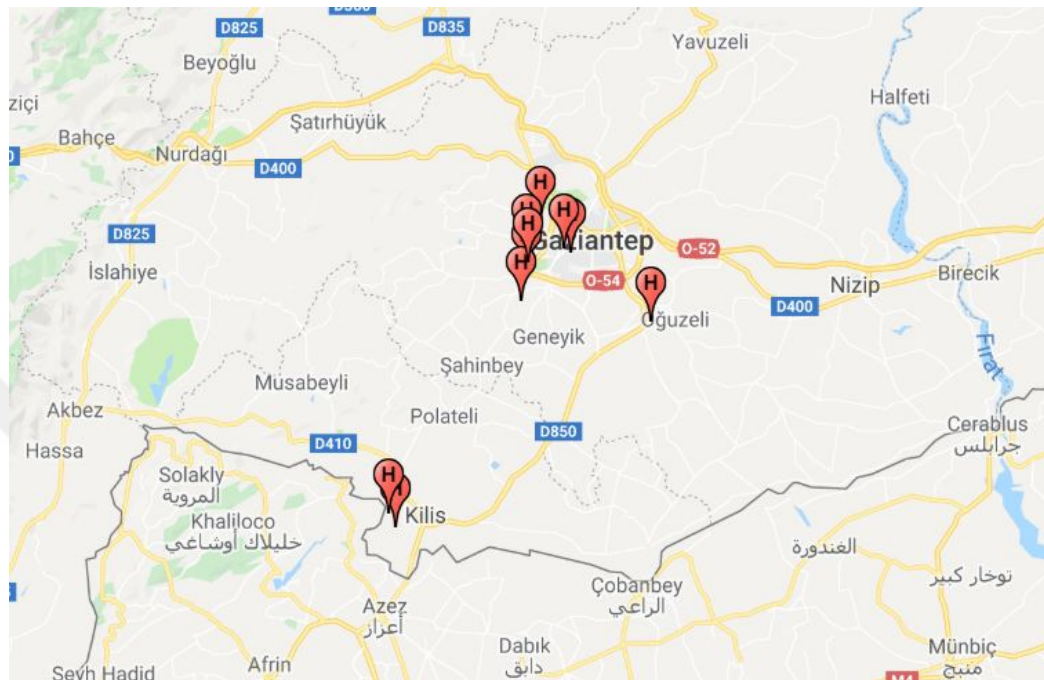




Figure C.4: Municipality Buildings in Small Data Set