COVERING VEHICLE ROUTING PROBLEM: APPLICATIONS FOR REFUGEE RELATED SERVICES

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By
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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

COVERING VEHICLE ROUTING PROBLEM: APPLICATIONS FOR REFUGEE RELATED SERVICES

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The world is facing a refugee crisis because of the ongoing war in Syria, and it is important to develop refugees' life conditions and increase their integration to the host communities. There are several services given to refugees to improve humanitarian development. The distribution of cash and e-vouchers to refugees and the routing of trucks which provide Child Friendly Spaces to vulnerable refugee children are addressed in this study. Both problems have similar characteristics as they provide services using mobile vehicles. The distribution of e-vouchers problem is applied for two scenarios, where local distribution centers are opened to cover an area, and a combination of local distribution centers and hand-to-hand delivery is conducted to increase the accessibility. The given problems are categorized as Covering Vehicle Routing Problem and Covering Vehicle Routing Problem with Integrated Tours which are introduced to the literature. The performance of the proposed models is tested and a sensitivity analysis on the problem parameters is given. Three optimization based heuristics are proposed to improve solving times. The proposed solutions are applied to a real life case of city Kilis. In order to apply the models to the routing of Mobile Child Friendly Spaces problem, a bi-objective version of the proposed models is given where the aim is to minimize the unsatisfied demand while minimizing travelled distance. ϵ-constraint method is applied to solve the bi-objective application and all Pareto Optimal solutions are obtained.

Keywords: Humanitarian Logistics, Refugee Services, Covering Vehicle Routing Problem, Integrated Tours, Bi-objective Optimization.

ÖZET

KAPSAYICI ARAÇ ROTALAMA PROBLEMİ: MÜLTECİLERE YÖNELİK UYGULAMALAR

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Suriye'de devam eden savaş sebebiyle dünya bir mülteci kriziyle karşı karşıyadır, ve mültecilerin yaşam koşullarını geliştirmek ve ev sahibi topluluklara entegrasyonlarını arttırmak önemlidir. İnsani gelişmeyi iyileştirmek için mültecilere verilen çeşitli hizmetler bulunmaktadır. Bu çalışmada, mültecilere nakit ve e-kupon dağıtımı ve mülteci çocuklara Çocuk Dostu Alan sağlayan tırların rotalaması problemleri ele alınmıştır. Her iki problem de mobil araçları kullanarak hizmet verdikleri için benzer özelliklere sahiptir. E-kupon dağıtımı problemi iki senaryoya uygulanmıştır; bunlar yerel dağıtım merkezlerinin belirli bir alanı kapsayacak şekilde açılması ve ulaşılabilirliği arttırmak için yerel dağıtım merkezleri ile elden teslimin bir arada kullanılmasıdır. Bu problemler Kapsayıcı Araç Rotalama Problemi ve Entegre Turlar ile Kapsayıcı Araç Rotalama Problemi olarak sınıflandırılmış ve literatüre tanıtılmıştır. Önerilen modellerin performansı test edilmiş ve problem parametreleri üzerine bir duyarlılık analizi yapılmıştır. Çözme sürelerini iyileştirmek için üç optimizasyon tabanlı sezgisel çözüm önerilmiştir. Önerilen çözümler Kilis şehrindeki gerçek bir yaşam durumuna uyarlanmıştır. Modellerin, Mobil Çocuk Dostu Alanların rotalanması problemine uygulanabilmesi için noktaların sahip oldukları taleplerin ve kat edilen mesafelerinin dikkate alındığı iki-amaçlı bir versiyonu verilmiştir. İki-amaçlı model tüm noktaları kapsamayı gerektirmemektedir, ancak kat edilen mesafeyi en aza indirirken karşılanmayan talebi de en aza indirmeyi amaçlamaktadır. İki-amaçlı modeli çözmek için ϵ-kısıt yöntemi uygulanmıştır ve tüm Pareto eniyi sonuçlara ulaşılmıştır.

Anahtar sözcükler: İnsani Yardım Lojistiği, Mülteci Hizmetleri, Kapsayıcı Araç Rotalama Problemi, Bütünleşik Turlar, İki Amaçlı Optimizasyon.

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Chapter 1

Introduction

The Syrian Civil War that started in 2011 resulted in a huge flow of people who migrate to other countries to seek protection, thus created a stress for the hosting countries. The end of the war is still not apparent, hence, the integration of the refugees to the host countries and developing their lifestyles becomes an important aspect from a humanitarian point of view. In this thesis, the challenges refugees face and services related to refugees are investigated through an OR perspective in order to contribute to humanitarian development.

Hence, this thesis focuses on improving the services given to refugees in order to improve their life styles. The main focus is on the mobile services and optimizing the routes of such mobile services. Two new models are introduced to literature, which are Covering Vehicle Routing Problem and Covering Vehicle Routing Problem with Integrated Tours. Then, the bi-objective extension to the proposed models is given.

The remainder of this thesis is organized as follows: in Chapter 2, the Syrian War and the consequences of the war is introduced. The situation of refugee crisis in the world is discussed. The situation of Turkey in terms of refugees is analyzed considering that Turkey became the largest host of refugees in the world. Then, the field study conducted in Önder District, where a considerable

amount of refugees are settled in Ankara, is given in detail in order to have a broader sense of the challenges refugees face.

The problems encountered in the field study and related research are categorized and it was concluded that the economical challenges are one of the main problems which results in other issues such as limited access to education for refugee children. Hence, programmes that provide cash and e-vouchers to refugees are investigated in detail in Chapter 3. A real life example of obtaining a Kızılaykart, an e-voucher programme launched by the collaboration of EU, Turkish Red Crescent, World Food Programme, and Ministry of Family and Social Policies of Turkey is analyzed. Later, the distribution of e-vouchers to the recipients is taken as a problem to be investigated. Then, Child Friendly Spaces programme operated by UNICEF and Turkish Red Crescent is introduced which provides social support and informal education to the children in need. The Mobile Child Friendly Spaces which are operated by large trucks which travel to reach vulnerable children is introduced. The problem of determining the routes of these trucks is also investigated and it was discovered that the e-voucher distribution problem and the routing of the Mobile Child Friendly Spaces problem are very similar. It was concluded that these services which target vulnerable refugees is going to be investigated and the general problem definition for both problems is given in Chapter 3.

In Chapter 4, a literature review on the general humanitarian logistics field is given. Then, related routing literature is analyzed to obtain the similar and distinctive characteristics of our study to the related literature. In Chapter 5, the models developed for the e-voucher distribution problem are given which are categorized as Covering Vehicle Routing Problem and Covering Vehicle Routing Problem with Integrated Tours. In Chapter 6, computational analysis of the introduced models is given and three optimization based heuristics are proposed in order to improve the solution times. The proposed models and heuristics are applied to a real life case with a large data set generated from the city Kilis.

In Chapter 7, the bi-objective extension of the problem is given. The extension is applied on the routing of the Mobile Child Friendly Spaces problem. The

model is solved through ϵ-constraint method and all Pareto optimal solutions are achieved.

Finally, in Chapter 8, the overview of the study and possible directions for future work is given.

Chapter 2

Refugee Situation

This chapter gives an introduction to the Syrian war and the aftermath from the point of refugees. The analysis of the conditions of the Syrian refugees in Turkey and the possible improvements in the processes regarding the analyzed problems are the primary objects in this thesis. Since Turkey became the largest host of the Syrian refugees, it still continues to be an important subject in terms of humanitarian studies. A field work is conducted in Önder District, Ankara where a high number of Syrian refugees are settled in order to determine potential problems for improvement from an OR perspective.

2.1 Syrian War and Refugee Crisis

In 2011, conflict began after the Arab Spring protests started in Syria. The protests were violently suppressed by the government, which resulted in a major conflict between the Syrian military forces and the opposition forces. The protests originally started from the dissatisfaction with the government inspired from the Arab Spring riots of countries such as Yemen, Egypt, Tunisia, Libya and Bahrain. However, the harsh attempt to repress the protests by the Syrian government resulted in an armed conflict between the military and protesters. This caused

Syria to drift into an ongoing civil war. Lots of civilians have been murdered, injured, and/or forced to displace their homes.

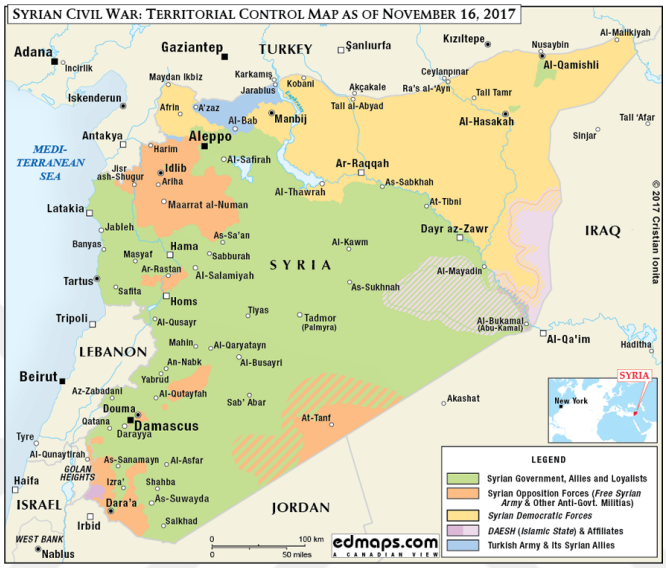


Figure 2.1: Map of the Syrian Civil War [1]

After the Syrian Civil War broke out, a large number of Syrians had to flee their homes for protection. According to UNHCR data, there are over 6 million people who are displaced within Syria and 5.6 million registered refugees outside of Syria. Most of the refugees are in Middle East and North Africa countries, Turkey, Lebanon, Jordan, Iraq, Egypt; and around 10% have migrated to European countries. According to UNHCR data, Turkey has the greatest number of Syrian refugees by over 3.5 million, followed by Lebanon with almost 1 million refugees, and Jordan around 650,000 refugees. The number of Syrian refugees in Iraq is around 250,000 and in Egypt around 120,000. In Europe, Germany is the largest host with approximately 500,000 Syrians applying for asylum. Less than 1% of the displaced Syrians worldwide are outside of Middle East, Africa, or Europe, and they are primarily settled in North America. As of 2017, Syria remains to be the largest source of refugees by contributing to almost one third of the world's refugee population [8].

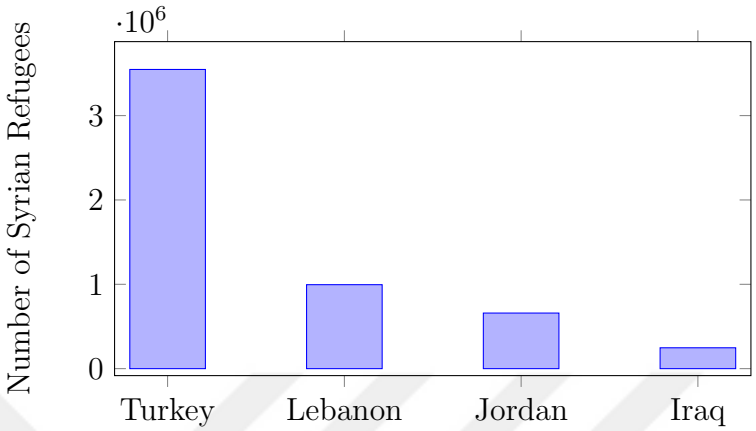


Table 2.1: Total Number of Syrian Refugees by Neighbouring Countries [6]

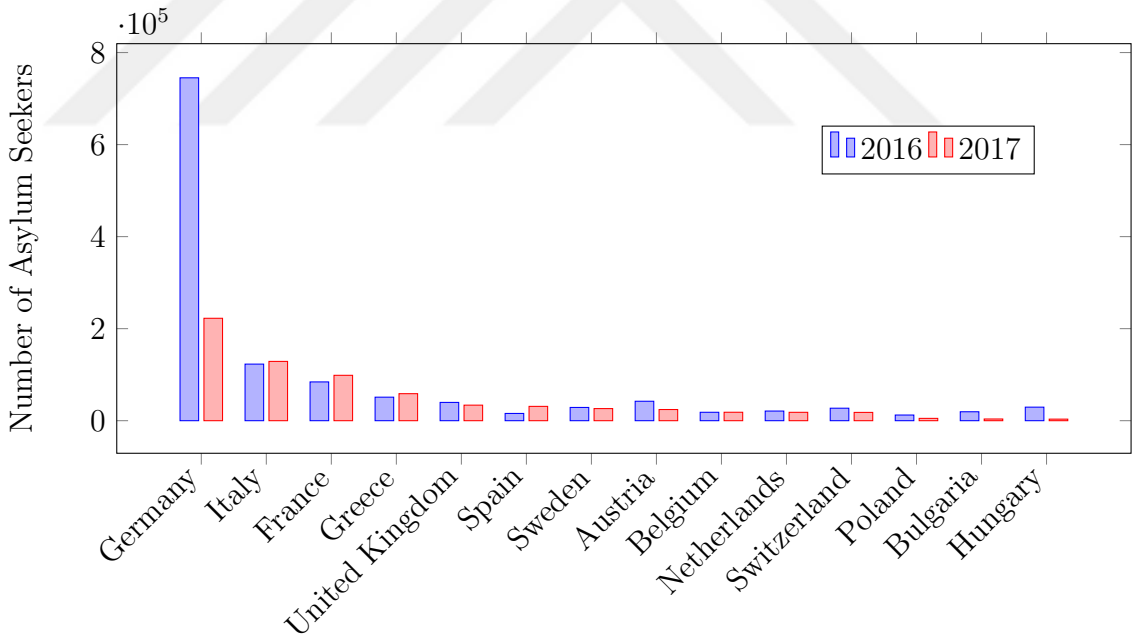
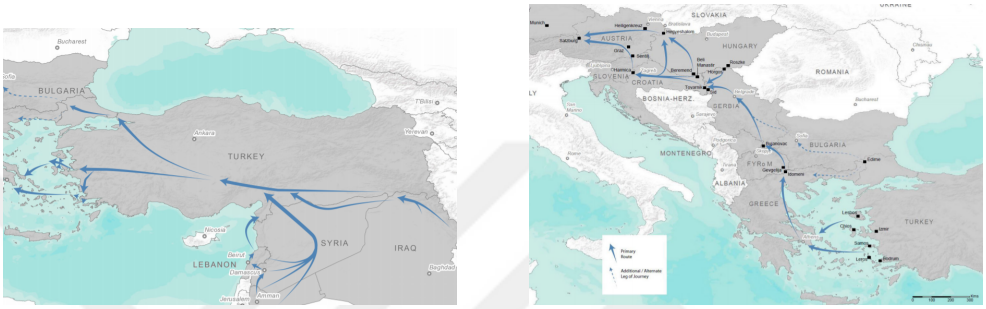


Table 2.2: Total Number of Asylum Seekers in the EU [7]

The Syrians who had to leave their country for protection have suffered from physical and psychological trauma along the way. Most of them lost their homes, families, and their well-beings in the war, thus, had to escape across borders. However, the road to other countries could be dangerous as well. According to

International Organization for Migration, in the year 2015, more than 1 million migrants travelled by sea and around 35,000 by land. Around 3,770 of the refugees were reported to have died trying to cross the Mediterranean because of the over crowded, small boats organized by smugglers [9], [10].



(a) Routes from Syria, Iraq, Lebanon, Jordan, and Turkey

(b) Routes through the Balkan Countries

Figure 2.2: Primary Travel Routes of Syrian Refugees [2]

Most of the refugees who have travelled to other countries are settled in the cities rather than the camps. More than 5 million registered Syrian refugees outside of Syria reside in the urban, peri-urban, or rural areas while only around 460,000 of Syrian refugees are located in the camps [6]. Moreover, there are nearly 3 million registered Syrian refugee children outside of Syria which constitute around half of the Syrian refugees [11]. They face the threat of becoming ill, abused, exploited, and becoming absent from education. Among the registered Syrian refugees, 1.7 million of them are school-aged children. 57% of the registered school-aged Syrian children are enrolled in a formal education, 3% are enrolled in a non-formal education, and 43% remain out of school [12]. Hence, an estimated number of 1.75 million children in Syria and around 40% of Syrian refugee children who are school aged are unable to go to school because of challenges such as funding, resources, capacity of schools, and families' limited sources [11]. They are often faced with early marriage and child labor by their parents in an attempt to meet their basic human needs.

2.2 Syrian Refugees in Turkey

Turkey is the largest host of refugees in the world with over 3.7 million registered refugees according to the estimates of the Ministry of Interior [13]. The refugee population consists of Syrians, Afghans, Iraqis, Iranians, Somalis and other nationalities. However, Syrians constitute approximately 95% of the refugee population in Turkey by a number of 3,547,194 registered refugees according to UNHCR data. Because of the geographical aspects and the open door policy towards the refugees, the number of refugees in Turkey increased drastically after the Syrian Civil War broke out.

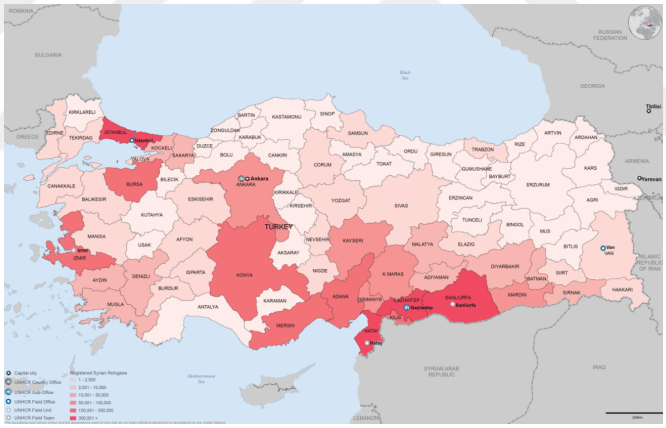


Figure 2.3: Breakdown of Syrian Refugees in Turkey by Province [3]

Some of the Syrian refugees live in camps while a majority of them live in urban or suburban areas. Most of the refugees who live outside of the camps live in the southeast region of Turkey and some major cities such as Istanbul, Ankara, and Izmir. Furthermore, among the Syrian population in Turkey, around 6% of them live in camps. There are 20 camps located in 10 cities, and the total population of the camps is around 230,000. Refugees have access to shelter, health services, food, and education in these camps. However, despite the resources they can reach in the camps, many of the refugees do not prefer to live on the camps due to some restrictions and lack of independence. Therefore, around 94% of the Syrian refugees are living outside of the camps even though the basic resources

can be much more challenging to obtain [13]. They often face various problems due to economical challenges, isolation, exploitation, and language barrier.

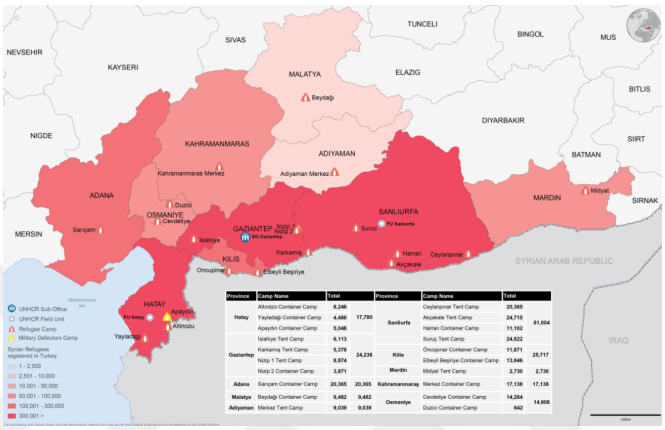


Figure 2.4: Syrian Refugee Camps in Turkey [4]

Moreover, almost half of the Syrian refugees in Turkey are children. Children constitute the 52.5% of the total Syrian population in camps, and 43.3% outside of the camps [14]. The rates for the enrollment to schools is high in camps since education services are provided free of charge with Syrian teachers working voluntarily following the Syrian curriculum, however, the rate of enrollment to schools outside of the camps is very low [15]. Even though there are Turkish schools which provide education to Syrian children, the number of these schools is not enough to meet the demand. There are also private schools supported by some Syrians and NGOs that require a tuition fee which makes harder for Syrian families with economical difficulties to take advantage of these schools [16]. Language difference is also an important factor of the challenges Syrian children face in terms of education. It was considered that the Syrians are in Turkey for a short period of time at the beginning of the crisis, thus, teaching Turkish to Syrian children was not given an importance and the education given was constructed regarding the assumption that the refugees will go back to Syria after the war is over [17]. However, the situation in Syria remains to be complicated, and the education of Syrian children is a matter of high importance because of the risk of generation loss. It is estimated that around 380,000 children remain out of school, which

makes them vulnerable because of the risk of isolation, discrimination, economic and sexual exploitation, and child marriage [11].

2.3 Field Work - Önder District

In order to analyze the conditions of the Syrian refugees through firsthand observations and to determine possible problems for improvement regarding the humanitarian processes, a field work is conducted where a considerable amount of Syrian refugees have been settled.

According to the Ministry of Interior, there are 73,198 registered Syrian refugees in Ankara [18], and it is known by the local community that a large number of these refugees are settled in Önder District. The district is now called 'Little Syria' among locals because of its increasing Syrian population. The field work conducted concerned the people of Önder District and their life situations. The area have been visited many times for a year, and there was a chance to create a connection with people and observe their life situations. Formal and informal interviews have been conducted depending on the situation to gather information. Informal interviews were conducted with the Syrian residents of the district which generally consisted of open ended conversations about everyday life and the backgrounds of the refugees. Formal interviews with pre-prepared questions were generally conducted with officers of official and semi-official organizations such as Ministry of Interior Directorate General of Migration Management, Civil Registry Office, Social Assistance and Solidarity Foundations, Turkish Red Crescent and Temporary Education Centers.

The members of the Syrian community were often interested in conducting conversations and giving information even though the language difference were causing difficulties. Some of them saw this as a chance to raise their voices, some thought they might get some aid and emphasized their economical challenges. Men and children were easier to talk to, while women tend to be more careful,

and often feel more comfortable when their spouses were not near them. Syrian refugees were often disturbed to be seen in photographs and videos since they were worried that the Syrian government can see that they left the country and harm them or their relatives/friends back in Syria. Throughout the study conducted, there were several volunteer key informants to guide us to the Syrian community in terms of knowledge and language. One of them was the Turkish Imam of the local mosque, who was distributing aid delivered to the refugees. Two Syrian cousins who escaped the war together were staying in the mosque and helping the Imam with his duties. They helped through the research since they were inside the community and also have a role in the aid distribution, thus they had knowledge about the situations and acted as translators as well. Over the one year time period we spent in the district, Imam was accused of being unfair in aid distribution by some refugees and suspended to another district, which caused the mosque to turn into a more dull place. Another major informant from the community was Muhammed, a local grocery store owner who used to be a lawyer in Syria. His store was near a local coffee shop where Turkish men often visit to play cards and drink tea, thus making the store a strategical point in terms of interactions of the local Turkish community and the Syrian refugees. Muhammed played a role as a bridge between us and the Syrian community, gathered people for us to talk to, and spending time in his store was always soothing after a long day.

Throughout the field study, it was observed that most of the Syrians complained about unemployment, lack of basic resources, exploitation of work, high rent prices, lack of education for their children, and the reaction of locals. Moreover, a lot of the houses in the area were being demolished because of urban renewal, thus making it harder to find accommodation for Syrians.

Figure 2.5: Demolished Houses Because of the Urban Renewal

Syrians were generally having problems with finding jobs and most of them work in day jobs. Since they do not get insured in these day jobs, it is often the case that the employer pays less than the worth of their labour, or not at all. Because of the difficulties in making money and exploitation of labour, they often rely on the aid distributions since it becomes harder to pay for their basic needs. It is sometimes the case that the skilled workers cannot practice their occupations, such as Muhammed, who was a lawyer in Syria, since his knowledge cannot be applied to Turkish law practices because of the differences in the regulations. Thus, it can be argued that Syrian refugees are often challenged economically. The rent prices in Önder District is low compared to other areas of Ankara, however, it becomes hard to pay the rent without a continuous and dependable work. Thus, families often share houses to decrease the burden.

Schools in the district offers education to Syrian children with Syrian teachers, however, most of them cannot go to school because of the necessity to work to support their households economically or the lack of information and awareness of the parents. It is a common scenery in the district that children are working during school time. It is often the case that there are sick, old or disabled people in the households, which lays a burden on the healthy people of the household, and sometimes children, to earn their livelihood.

Figure 2.6: Refugee Children Working During School Time

Moreover, they sometimes face difficulties because of isolation from the society. Syrians generally live in their own community rather than integrating with the Turkish community. There are Arabic signs in the stores that Syrians are operating, they have an islamic monastery to practice their religious traditions or organize events such as weddings etc., and the local Turkish community are thinking that the Syrians created a 'Little Syria' in the district. Moreover, it is sometimes the case that the locals blame Syrians for general problems. Locals of the neighbourhood think that job market became unreliable because of the cheap labour refugees offer. They accuse Syrians for the theft cases. Furthermore, they often think that Syrians are getting the help from the government even though they need it as much as them. The language barrier is also an issue among Syrians and Turkish. There are some humanitarian organizations which provide free Turkish lessons, however, majority of the Syrians do not speak Turkish. The common thought among them is that they will go back to their homes after the war ends, so they do not see Turkey as their future. However, the situation in Syria remains complicated and the end of the war is not apparent. However, young people are more adaptable to changes and more willing to learn the language and create a future for themselves.

Chapter 3

Problems and Challenges

There are several main problems encountered both in the field work and in the related literature. The general challenges refugees living in the urban or rural areas face can be listed as the access to shelter, health services, basic needs such as food, employment, and education [19], [11], [20]. Syrian refugees in the urban areas generally have a hard time finding shelter especially for the economic reasons. It is often the case that several families gather in one house to share the rent. There are also refugees who are spread to rural areas from camps in order to work in agricultural field and some are living in the unused storehouses or country cottages [19]. The health issues of refugees in the urban areas is also complicated. Even though the Turkish government has made hospitals accessible to refugees, there are still issues such as over crowded population near the borders and limited health services, chronic diseases that require continuous treatment and the shortage of capacity to carry out such treatments, language barrier between the health personnel and the refugees etc. [20] Access to food is also a challenge refugees face which becomes a major threat especially in the development of children. Moreover, most of the Syrian refugees seek informal employment since legal employment is not an option for many which makes them vulnerable against exploitation of labor, thus creating economic challenges and affects the access to basic needs [20]. Education remains to be a major issue since nearly half of the school aged refugee children are out of school.

It can be argued that the main challenge refugees face is poverty, which results in lack of access to other needs such as education. Thus, the programmes which provide services such as cash and e-voucher to those in need is analyzed in this research.

3.1 Cash and e-Voucher Programmes

In order to increase the integration of Syrian refugees into the community and to increase their access to basic needs, cash based e-voucher programmes are implemented where a certain amount of money is given through electronic cards. Cash based interventions have several benefits such as the freedom of choice of what to do with the money that the beneficiaries received and bringing normality and dignity into their lives [21]. Moreover, it is effective in terms of addressing the problem directly, it is cost effective in terms of distributing the aid, it is logistically simpler compared to in-kind donations, it is flexible, and also promotes the local market [22]. Electronic vouchers also reduce the risk of fraud since it operates through specified PIN systems and does not affect the resources of beneficiaries and the funding organizations in the case of lost [23].

There are a number of cash based e-voucher programmes implemented in Turkey. One example is the Emergency Social Safety Net (ESSN), which is the largest humanitarian programme launched by EU with the collaboration of Turkish Red Crescent, World Food Programme (WFP), and Ministry of Family and Social Policies, and it is aimed to reach up to 1.3 million vulnerable refugees [24]. The participants of the programme receive a Kızılaykart, a debit card which gives the recipients a fixed amount of money every month where the money to be received is determined by the number of members of the household. Refugees are able to provide their basic needs such as food, medicine, clothing etc. through this card. The priority to receive the card is given to women, number of elderly, number of children, and number of disabled persons in the household.

Even though the ESSN program works well in the urban areas, there might

be issues in rural areas where access to cash points is not easy or there are security concerns. Thus, it is reasonable to study other means of distribution of such cards. Welthungerhilfe implemented several cash based e-voucher systems mainly in the southeast region of Turkey where the refugee population is high [22]. The distribution of the cards is categorized into four main categories which are centralized distribution, localized distribution, mobile distribution, and house-to-house distribution. In centralized distribution, all of the beneficiaries are gathered into one place and all of the cards are distributed in several days. The downside of this distribution system is the issues with crowd, security, finding a suitable space for the distribution place, and accessibility. Localized distribution is similar in terms of the beneficiaries going to a place to collect their cards, however, in spite of a central distribution point, each district has their own distribution conducted by the mukhtar of the district. This system has higher accessibility, however, redistribution of the cards for the families who did not pick up on the scheduled time is necessary. Another way of distribution introduced is mobile distribution, where a vehicle is used as a base for distribution. This system also has high accessibility, however, security can be an issue. The last way of distributing the cards is house-to-house distribution, where families get their cards delivered into their houses. This system is beneficial for the beneficiaries especially if there are old, disabled persons in the household since the need for going to a place to gather the cards is eliminated. The inspection of the situations of the households can also be made on point which is another advantage. However, it is more time consuming and only a low number of people can be reached at a given time.

In order to have a broader sense of such services, the distribution process of Kızılaykart is investigated and a flowchart is generated during the field study conducted in Ankara. Thus, the flowchart given in Figure 3.1 illustrates the journey that a refugee has to take in order to obtain a Kızılaykart.

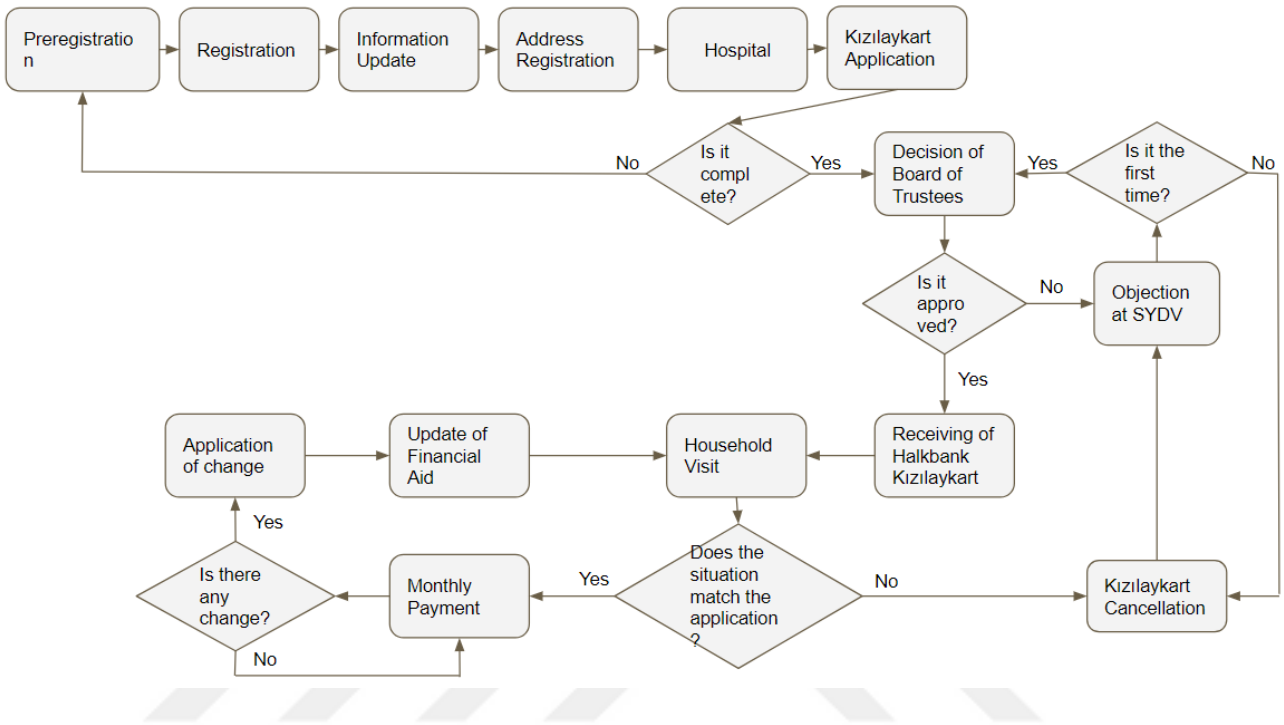


Figure 3.1: Flowchart of Obtaining a Kızılaykart

Each step of the Kızılaykart obtaining process illustrated in the flowchart in Figure 3.1 is analyzed in detail by interviewing the officers of the related sections considering the city Ankara. Through this investigation, it was possible to understand in depth what a refugee has to go through when they enter a new city in terms of diplomatic processes, and also how the process of receiving an e-voucher works in a real, observable case. The detailed study of the Kızılaykart obtaining process is as follows:

- **Preregistration:** This is the first step of registration when a refugee enters into a new city which is processed in Civil Registry offices. Refugees receive a pre-registration document to prove they have entered the city and they are only able to receive emergency services with this document.
- **Registration - Information Update**: This process is conducted in the Ministry of Interior - Directorate General of Migration Management where

refugees get their identity cards by presenting their documents such as identity cards from their hometown, passports etc. The identity cards they receive start with the number 99 which indicates it is new, safer than the older versions and hard to copy. If a person does not have any documents to present, he/she must apply to the Embassy. Then, the refugees update their information such as education, address, occupation, military service, diseases, where they lived in their hometown etc. Their identity cards are sealed only after the information update.

When the crisis began, the registration was done in a hurry in order to cope with the huge amount of people applying to the registration offices, hence there were a lot mistakes during the information gathering process. This information update process is a project conducted with UN to eliminate the mistakes in the information of all Syrians in 81 cities and keep track of the registrations. Moreover, the identity cards are only valid in the city that they received the card. If they change their cities, they must get an approval from the Directorate General of Migration Management in the city that they are coming from and update the residence in their identity card from the city that come to.

Figure 3.2: Refugees Waiting in the Line of Ministry of Interior - Directorate General of Migration Management

- **Address Registration:** Refugees who are settled apply to Civil Registry Offices in order to get a Residence Document. To get the residence document, they must provide their identity card and a document to prove their address such as contract of lease, receipt etc. There are often problems

with communication among the refugees and the officers of the Civil Registry Office because of the language differences and lack of translators. In these offices, addresses are documented and address changes are made.

- **Hospital:** Refugees need to document if there are any disabled or pregnant person in their households if they are declaring there are in the application of Kızılaykart.

- **Kızılaykart Application:** The application for Kızılaykart is conducted in the Social Assistance and Solidarity Foundations. Financial and other aid are given to both Turkish citizens and refugees who are in need in these foundations. There are officers from Turkish Red Crescent who speak Arabic to assist Syrian refugees. In order for a Kızılaykart application to be completed, identity card and residence document are needed. If there are any disabled people and pregnant women in the household, they need to document their situation. Next, the application is examined by a Decision Board which consists of members from Turkish Red Crescent, WFP, Ministry of Family and Social Policies and EU. There are criteria that the applicants should satisfy such as there must be at least two disabled people in the household or at least two elders or at least four kids, there should be no social security etc. in order for the application to pass the committee. In some rare occasions, if the applicant does not satisfy the criteria but the officer of the Red Crescent who took the application think they are really in need, s/he can take initiative. The applicant is then notified via text message that their application is approved or not.

- **Receiving of Kızılaykart:** Kızılaykarts are distributed to offices of Halkbank. Recipient of Kızılaykart goes to the office assigned to him/her which is informed via text and s/he is able to receive the Kızılaykart with his/hers identity card.

- **Household Visits:** Household visits are conducted in order to compare the information given by the recipient of Kızılaykart and the actual conditions. If the information given is not correct, the card is cancelled. Moreover, the situation of the recipients of the Kızılaykart is investigated in order

to assess the success of the e-voucher program. Household visits are conducted 1-2 months after the Kızılaykarts are distributed without notifying the household by a team constituted of members from The Red Crescent, WFP, Ministry of Family and Social Policies and EU.

- **Update of Financial Aid:** If there is any change, such as birth of a new child etc., the recipient of the card applies to the Social Assistance and Solidarity Foundation and his/hers financial aid is updated.
- **Cancellation/Objection:** In case of disapproval of the application or cancellation of the financial aid, the applicant has a chance to object to the decision for one time. If the application is not approved, applicants generally object to the decision. Even though the officer who takes the application thinks it will not change the situation since the applicant does not satisfy the criteria, s/he still takes the objection and sends it to Board of Trustees. If the objection is not approved, applicant cannot object anymore.

After the analysis of Kızılaykart and other e-voucher programmes such as the programme introduced by Welthungerhilfe, it was concluded that a distribution mechanism of e-vouchers which combines stable and mobile service providers is going to be investigated in order to provide an effective service for various conditions. Thus, the implementation of e-vouchers in order to enhance the access to basic needs is studied and several OR approaches are used to optimize the processes regarding the e-voucher distributions. It was also discovered that the model created for the e-voucher problem can be developed and implemented into the problem of optimizing the routes of Mobile Child Friendly Spaces in order to enhance the access of refugee children to education, which will be introduced in the next section.

3.2 Mobile Child Friendly Spaces

Even though the enrollment rates to schools among Syrian refugee children increases, more than 40% of the Syrian refugee children in Turkey are out of

school [25]. Thus, the issue of education has high importance considering the fact that Turkey is the largest host of Syrian refugees in the world and almost half of the Syrian population in Turkey consists of children. There are many Turkish schools where Syrian children can go to, however, it is often the case that these schools are overcrowded and students take shifts attending to classes. Generally, school time is divided between Syrian and Turkish children, and there are Syrian teachers working in these schools to overcome the language barrier. Isolation can also be another challenge, most of the Syrian children carry a lot of psychological burden which makes it harder to socialize with other children. Most Syrian children have missed some years of school because of the ongoing conflict in Syria, thus it can be a challenge for them to fill the gaps. Moreover, as mentioned before, lots of families cannot afford to send their children to school. Even though public schools provide free education service, these families rely on their childrens income from child labor.

There are other services to support children in terms of formal and non-formal education, mainly operated by the Turkish Red Crescent and UNICEF. There are temporary education centers (TEC) and child friendly spaces (CFS) constructed to support children. The temporary education centers are recognized by Ministry of National Education to give Arabic education for Syrian children. There are also support for early childhood education (ECE) to give pre-primary education to young children in order to increase their adaptability to a different social environment and decrease the barriers caused by language. There are lots of aid in terms of school supplies or cash aid for education. For non-formal education, child friendly spaces are used as a response to childrens needs such as psycho-social well-being. CFSs are also used as structures to provide early recovery and long-term support for vulnerable children. The objectives of CFS are to assure the protection and well-being of the children, to provide opportunities for children to play, acquire skills, receive social support, and to make children aware of their rights [26]. As of 2017, there have been 28 Child Friendly Spaces all around Turkey, moreover, there are 2 mobile CFS (MCFS) that are used to reach vulnerable children [27]. These mobile CFSs are large trucks which provide safe spaces for children to play, learn, and receive support. These 2 trucks operate

mainly in two cities of Turkey, İzmir and Şanlıurfa where the refugee population is high.

Figure 3.3: A Mobile Child Friendly Space Truck [5]

The mobile child friendly spaces are travelling to reach vulnerable refugee children especially on areas where the refugee population is high and other ways of psychological and social help is less reachable. The trucks generally park near Turkish schools where there are large numbers of Syrian students. It is estimated that around 400 students attend these mobile CFS in a month [27]. Both Turkish and non-Turkish children are able to attend these mobile CFS in order to increase the integration of refugee children to local life. The selection of schools where the truck will be located is done by the collaboration of UNICEF, Turkish Red Crescent, Provincial Directorate of National Education, and local authorities. Since these spaces serve a purpose of psychological support to the refugee children, the main aim is to reach a lot of children and be able to talk to them at least one time rather than having continuous support. Thus, they stay about 1 or 2 month in one place, and then travel to another location.

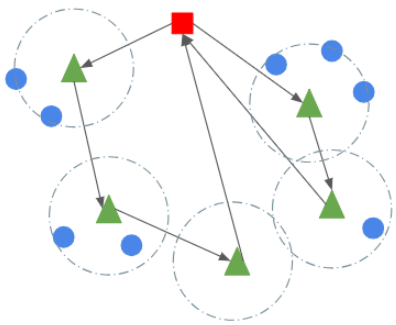
The problem of mobile CFS is determining the routes of the trucks to travel while minimizing the total distance travelled and maximizing the areas covered in order to reach the maximum number of children and provide them an effective service. The problem is similar to the distribution of e-vouchers where service providers are travelling along a route to demand points in order to provide a service to improve the living conditions of people in need.

3.3 The General Problem Definition

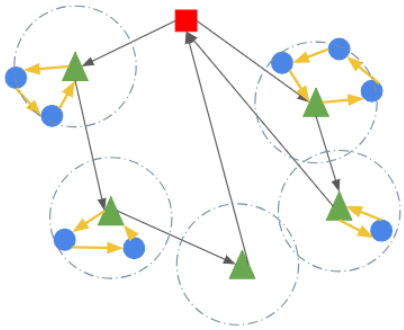
During the problem analysis phase, it was discovered that the e-voucher problem and mobile CFS problem are very similar. Both problems use vehicles to provide a service to the demand points. In the e-voucher problem, service provided is the cash aid through e-vouchers and the demand points are the households of refugees; where in mobile child friendly spaces, service is the space for children and the demand point is the local schools. The general problem is providing the distribution of the service from main centers to local centers and covering the demand points by either visiting them or visiting a nearby point.

Considering the e-voucher distribution, the first scenario is to conduct the distribution through opening stable local centers. The demand points which are close to these stable local distribution centers will be considered to be covered by this center. In the second scenario, both stable local centers and mobile service providers are considered. An officer will travel to the demand points that are close to the local centers to provide the distribution. In this case, any problems which may arise due to accessibility are aimed to be minimized.

(a) Geographically scattered points



(b) First scenario



(c) Second scenario

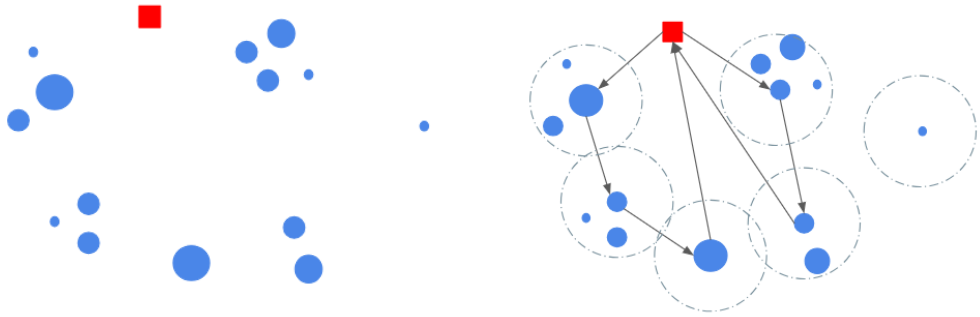
Figure 3.4: Illustration of the E-voucher Distribution Problem

As illustrated in Figure 3.4, vehicles travel through a geographically scattered set of points and the points that the vehicles visit become the local distribution centers for the e-vouchers. In the first scenario, the points which are close to these local distribution centers is assumed to be covered, i.e., people who reside close to the local distribution centers are expected to travel to those centers to collect their e-vouchers. In the second scenario, considering people might not be able to collect their e-vouchers themselves because of reasons such as disabled or elder people in the households, lack of easy accessibility of the region or lack of security, an officer travels to the points which are close enough to the local distribution centers to deliver the e-vouchers.

The objective of the e-voucher distribution problem is to minimize the total distance travelled. In the first scenario, the only aspect to consider is the total

distance travelled by the vehicles. However, in the second scenario, the distance travelled by the officer in the small tours is also taken into account along with the distance travelled by the vehicles. In this case, the primary objective is to minimize the distance travelled in the main tour while the secondary objective is to minimize the distance travelled in the smaller tours. These objectives are transformed into a weighted sum single objective. A higher weight is given to the primary objective and a significantly smaller weight is given to the secondary objective in order to minimize the distances of the smaller tours by not affecting the main tour significantly.

The mobile CFS problem is similar to the e-voucher problem, there are several vehicles travelling a geographical area, and some demand points are visited while some are covered. The trucks provide child friendly spaces for the refugee children, and they stay at a certain point regarding the demands of the points, and the children that are close to the location of the truck is considered to be covered by the mobile CFS. It is assumed that the trucks leave a depot, travel along the route, stay at some points for some time, and return to the depot for maintenance. The difference between the e-voucher distribution problem and the mobile CFS problem is that all of the points are covered in the e-voucher distribution since equity is an important aspect considering all of the recipients who are entitled to receive an e-voucher must get an e-voucher, whereas in mobile CFS problem maximizing the number of children to attend these child friendly spaces is important, but covering all of the points is not a necessity. Thus, the decision maker decides on the tour of the mobile CFS by taking two different objectives into consideration, which are minimizing the total distance travelled and maximizing the number of children to attend the mobile CFS, i.e, minimizing the unmet demand.



(a) Geographically scattered points illustrated according to their demand

(b) Possible route of the trucks

Figure 3.5: Illustration of the Mobile CFS Problem

The illustration of the mobile CFS problem can be seen on Figure 3.5. In this problem, since the number of children residing in the demand points is important, the points are illustrated according to their demands; the points where the demand for a CFS is low is illustrated to be small and the points where the demand for a CFS is higher is shown to be bigger. The vehicles travel through the demand points and stop at some points to create child friendly spaces, and the demand points that are close to these stops of the trucks are considered to be covered, i.e., children who are close to the location of the truck are expected to travel to the truck themselves. However, some points might be eliminated from the tour considering the demand of the point and the distance of the point to the tour, i.e., if a point is far from the tour and the demand for the child friendly space is low, the decision maker can choose not to travel to that point in order to reduce the total distance travelled. It can be argued that the e-voucher distribution problem focuses on equality by covering each demand point, however, the multi objective extension takes other aspects into consideration, and experiments with different objectives.

Chapter 4

Literature Review

Humanitarian logistics is receiving increasing interest from academics and practitioners and it will expand its market as it is forecasted that both man-made and natural disasters will increase five fold over the next 50 years [28]. Moreover, Van Wassenhove [29] states that logistics is the most important part of disaster relief since it makes the difference between successful and failed operation; and also taking 80% of the disaster relief operations. Considering the increasing demand for humanitarian relief operations and importance of logistics in such cases, and the dire consequences of both natural and man-made disasters, it can be argued that studying humanitarian logistics has upmost importance.

There are fundamental differences between humanitarian relief chains and commercial supply chains in terms of goals, customer and demand characteristics, and environmental conditions; and the characteristics of humanitarian relief chains can be listed as unpredictability of demand in terms of timing, location, and size, suddenness of demand occurring in large amounts with short lead times, importance of adequate and on-time delivery, and lack of resources such as supply, people, technology, transportation, capacity, money [30]. Van Wassenhove [29] defines humanitarian logistics as the processes and systems to mobilize people, resources, skills, and knowledge in order to help vulnerable people affected by both natural and man-made disasters.

4.1 Humanitarian Logistics Literature

The literature on humanitarian logistics generally defines four phases of the disaster management cycle which are mitigation, preparation, response, and reconstruction [31]. Altay and Green [32] defines mitigation phase as the application of measures that would prevent the onset of a disaster or reduce the impacts if it occurs, and defines preparation phase as the preparation of activities of the community to respond when a disaster occurs. Cozzolino [31] argues that mitigation phase relates to the responsibilities of governments while in preparation phase strategies to implement a successful operational response are incorporated and physical network design, information and communication technology systems are developed. Moreover, Altay and Green [32] defines response phase as the employment of resources and emergency procedures to preserve life, property, environment, and the political, social, and economic structure of the community; and defines reconstruction phase as the long term actions to stabilize the community after the immediate impact of the disaster has passed.

There are various literature reviews conducted on humanitarian logistics and disaster management. Altan and Green [32] categorized articles in terms of their stance on the disaster management cycle, the type of the disaster, and also the research methodology and contribution to the literature. They suggested research questions to be prioritized in disaster operations management research. Kovacs and Spens [28] distinguished humanitarian logistics into two main branches, continuous aid work and disaster relief; and mainly focused on disaster relief by analyzing literature in terms of disaster management cycle and the characteristics of the supply network of humanitarian aid. Caunhye et al. [33] categorized the literature of emergency logistics into facility location and relief distribution, and analyzed the optimization models according to model types, objectives, constraints, and decisions. Galindo and Batta [34] extended the review of Altay and Green [32] and resulted in similar conclusions. Ozdamar and Ertem [35] focused on the response and recovery phases of the disaster management cycle and categorized the related mathematical models in terms of their structure, objectives, constraints, and solution methodology. Habib et al. [36] categorized

their research on facility location, network design and relief distribution, and mass evacuation; and compared the models according to their objective functions, constraints, and problem types. Goldschmidt and Kumar [37] categorized related literature according to disaster management cycle, and argued that researches have been primarily focused on establishing supply chain methodologies to improve disaster response rather than humanitarian development. Bayram [38] conducted literature review on emergency evacuation and analyzed static, dynamic, deterministic, stochastic, and robust evacuation models in the related literature. Kara and Savaşer [39] categorized humanitarian logistics as relief logistics and development logistics, and gave the characteristics, application areas, and challenges of the related literature. They argued that development logistics include providing healthcare and sustainable energy for developed countries, and providing access to basic resources such as food, clean water, shelter, education, hygiene etc. for third-world countries. Behl and Dutta [40] classified humanitarian supply chain management literature according to scope of research and content of the research such as resilience based, disaster phases, technology related etc. Bealt and Mansouri [41] reviewed the humanitarian logistics literature according to community participation arguing communities are able to meet the disaster management needs by forming ad hoc networks. They defined local respondents as members of the disaster-affected community who take action on the first phase of the relief efforts within the disaster affected community; and categorized the related studies into activities such as reconstruction, procurement, transportation, distribution, information sharing, livelihood recovery, community empowerment, and relief. Gutjahr and Nolz [42] reviewed literature on the application of multi-criteria optimization in humanitarian aid and categorized deterministic and stochastic multi-criteria optimization studies according to pre-disaster and post-disaster phases. They gave optimization criteria in humanitarian aid as response time, travel distance, coverage, reliability, security, equity, and psychological or social costs.

Seifert et al. [43] analyzed literature on humanitarian supply chain management responding to refugees. The related literature was categorized as quantitative and qualitative content analysis; where quantitative content analysis consisted of focus of the research, type of operation such as disaster relief and developmental aid, and type of research approach, and qualitative content analysis consisted of supply chain management categories which are performance measurement and logistics, and refugee categories which are public health and human rights. It was concluded that there are more theoretical works than empirical ones, and recent studies focus more on disaster relief than development aid operations. Thus, it can be observed that even though there are many studies on humanitarian logistics, many of them focus on disaster preparedness and relief rather than humanitarian development.

4.2 Related Routing Problems

Travelling Salesman Problem (TSP) is a well known problem where an optimal route is selected among the geographically scattered customers or demand points. Vehicle Routing Problem (VRP) is the generalization of TSP, where the routes of the several vehicles are determined while minimizing travelling costs. In TSP and VRP, all of the demand points in a network is visited. However, there are some variations of the problem where not all of the points in the network are visited, but most profitable ones are selected to visit. Feillet et al. [44] classified such problems as Travelling Salesman Problem with Profits (TSPs with Profits). Feileet et al. defined three classes of problems under TSPs with Profits, which are Selective Travelling Salesman Problem (STSP), Quota Travelling Salesman Problem (Quota TSP), and Profitable Tour Problem (PTP). The objective of STSP is to find a route that maximizes collected profit while travel costs do not exceed a pre-specified value, and the objective of Quota TSP is to find a route that minimizes travel costs while collected profit is not smaller than a pre-specified value. PTP combines the two objectives.

Another variant of TSPs with Profits is the Prize Collecting Travelling Salesman Problem (PCTSP) which was introduced by Balas [45], where a prize is given at every point the salesman visits and a penalty is charged for every point salesman fails to visit. The problem can be seen as a generalized version of Quota TSP where penalties for unvisited vertices are also added to the objective function. Thus, the objective of PCTSP is to minimize the travelling costs and penalties while a pre-specified amount of prize must be collected. Maximum Benefit Travelling Salesman Problem (MBTSP) is another prize collecting TSP introduced by Malandraki and Daskin [46], where the objective is to maximize the net benefit of the tour rather than minimizing its cost.

Erdoğan et al. [47] introduced Attractive Travelling Salesman Problem (ATSP), where there is a set of vertices for facilities and another set of vertices for customers, and each facility vertex generates a profit derived from the customer vertices which is measured by an attraction function. Similar to TSPs with Profits, not every vertices are compulsory to visit and the objective is to generate a tour to maximize profit. Erdoğan et al. [47] illustrated the application of ATSP by mentioning the planning of the tour of a mobile entertainment facility such as a circus, where visiting a facility vertex generates a profit, however, facilities with extra services or closer to larger population areas are assumed to be more attractive, thus generates more profit for the customers. The ATSP can be classified as a STSP considering the objective is to maximize the profit while not exceeding the travelling cost limitations.

Another variant of TSP with Profits where the objective is to maximize the profit is the Orienteering Problem (OP). OP is introduced by Tsiligirides [48] and Golden et al. [49], where competitors are travelling through a geographical region and visit points where each point is associated with a score. The objective is to find a route to maximize the score with time, capacity, or cost limitations. The multi competitor extension of the OP is the Team Orienteering Problem (TOP), where a team consisting of several competitors starts at the same point, travels along a route to visit as many point as possible to increase their score, and end at the same point [50]. Each point brings a score only for the first visit of any member of the team, and the objective is to maximize the total score by not

exceeding the time limitations. Archetti et al. [51] investigated the capacitated versions of team orienteering (CTOP) and profitable tour problems (CPTP). They proposed tabu search and variable neighbourhood search algorithms for the CTOP and CPTP which were found to be effective.

The classification of routing problems with profits and their properties are summarized in Table 4.1:

Problem	**Introduced By**	**Objective**	**Vehicle**	**Dynamics**
Selective Travelling Salesman Problem (STSP)	Laporte and Martello [52]	maximize profit	single	Length do not exceed a preset value
Quota Travelling Salesman Problem (Quota TSP)	Awerbuch et al. [53]	minimize cost	single	Profit not smaller than a preset value
Profitable Tour Problem (PTP)	Dell'Amico et al. [54]	minimize cost+penalties	single	Profit not smaller than a preset value
Prize Collecting Travelling Salesman Problem (PCTSP)	Balas [45]	minimize cost	single	Profit not smaller than a preset value Penalties for unvisited nodes
Maximum Benefit Travelling Salesman Problem (MBTSP)	Malandraki and Daskin [46]	minimize cost-profit	single	Multiple visits to nodes
Attractive Travelling Salesman Problem (ATSP)	Erdoğan et al. [47]	maximize profit	single	Attraction function for profit
Orienteering Problem (OP)	Tsiligirides [48]	maximize profit	single	Time limitations
Team Orienteering Problem (TOP)	Chao et al. [50]	maximize profit	multi	Time limitations Specified start and end points
Capacitated Team Orienteering Problem (CTOP)	Archetti et al. [51]	maximize profit	multi	Time limitations Capacity restrictions
Capacitated Profitable Tour Problem (CPTP)	Archetti et al. [51]	maximize profit-cost	multi	Capacity restrictions

Table 4.1: Routing Problems with Profits

Another related problem is the Covering Salesman Problem (CSP) where a minimum cost tour is identified such that any node not included in the tour is within some predetermined covering distance of a node in the tour [56]. In CSP, every node must be covered and the decision of which nodes to cover and which nodes to visit is considered by minimizing the travel costs. Golden et al. [57] proposed a Generalized Covering Salesman Problem (GCSP) where each node needs to be covered at least a predetermined time and there is a cost associated with visiting each node. Three cases of GCSP is proposed, where each node can be visited at most once, where a node can be visited more than once but

overnight stays are not allowed, and where a node can be visited more than once consecutively. Arkin and Hassin [58] introduced a Geometric version of CSP, where each customer specifies a neighbourhood that they are willing to travel to meet the salesman, and a minimum length tour is determined by intersecting all of the customers' neighbourhoods.

Another well known problem is the Covering Tour Problem (CTP) which can be considered as a generalization of CSP. In CTP, a set of vertices V that can be visited, a set of vertices $T \subseteq V$ that must be visited, and a set of vertices W that must be covered are defined, and a minimum length tour over a subset of V such that it contains all vertices of T, and that it lies within a pre-specified distance from every vertex of W is aimed to be found [59]. Hachicha et al. [60] proposed a multi-vehicle version CTP. An example for the application of CTP is health care teams travelling in rural areas of developing countries to deliver medical care, where they visit a subset of villages and the residents of unvisited villages travel to nearest node on the tour to obtain medical care [61]. Furthermore, Hodgson et al. [62] implemented CTP for planning mobile health care facilities in Ghana, where the mobile facilities are expected to increase the accessibility to equipped, staffed, and supplied health care facilities. In the study, mobile facilities' travelled distance is minimized by covering all population centers within the range of a feasible amount, and a trade-off between the facility driving distance and patron walking distance is observed. Another CTP application in humanitarian aid is the location of satellite distribution centers to deliver aid to affected people of a disaster area studied by Naji-Azimi et al. [63]. People who are in the disaster affected region are expected to go to these distribution centers which are close to their homes to supply their needs, and the distribution centers are supplied from a central depot through capacitated vehicles. The model is constructed as a generalization of CTP and a heuristic approach is proposed to solve large instances.

In Maximal Covering Tour Problem (MCTP) and Median Tour Problem (MTP), the tour must visit only p nodes of the n nodes in the network while minimizing tour length and maximizing access to the tour for the nodes that are not included in the tour [61]. In MCTP, the access objective is defined as to

maximize the total demand within a predetermined distance from a tour stop, and in MTP, the access objective is defined as minimizing the travel distance from an unvisited node to reach the nearest stop in the tour.

Another similar problem is the Ring Star Problem (RSP), where an allocation of a cycle through a subset of vertices of a graph is determined and the objective is to minimize the sum of the cycle cost and the assignment cost of the vertices not in the cycle to their closest vertex in the cycle [64]. The Capacitated m-Ring Star Problem (CmRSP) is the multi tour version of RSP where each tour has a capacity of visiting nodes [65]. Both problems are proposed to be applied into telecommunications network design.

Other related routing problems are the Generalized Travelling Salesman Problem (GTSP) and Generalized Vehicle Routing Problem (GVRP). Baldacci et al. [55] defines GVRP as an extension of VRP where each set of vertices are partitioned into clusters, and the routes of the vehicles are determined considering minimizing the total cost. In GVRP, exactly one vertex of any cluster should be visited and each route should not exceed the pre-specified upper limits of demand and duration. Bektaş et al. [68] introduced new integer linear programming models for GVRP, proposed branch-and-cut algorithms, and gave some application areas such as health care logistics, where each district consists of several municipalities and the medical distribution team delivers pharmaceutical products into one municipality within each district. Another application area of GVRP is also given as the urban waste collection problem, where the routes of the vehicles to collect the urban waste and deliver it to the dump, incinerator, or a recycling plant is determined considering minimum transportation costs [68], [69].

Other variants of these problems are the Close Enough TSP (CETSP) and Close Enough VRP (CEVRP). CETSP was introduced by Gulczynski [66] for the radio frequency identification system where utility companies read meters from a distance and a heuristic approach is proposed to solve the problem. CEVRP is the extension of CETSP where the formulation is proposed by Mennel [67], and it is given that if a vehicle is within a specified distance of the node, than the node is considered to be covered. The difference of CETSP and CEVRP between

other covering problems is that the vehicle do not need to visit any node to cover other nodes within the region of a specified distance, however, if the vehicle visits the intersection of coverage areas of some nodes, it is assumed that it covers those nodes.

The summary of the properties of several covering problems can be seen in Table 4.2:

Problem	**Introduced By**	**Objective**	**Vehicle**	**Dynamics**
Covering Salesman Problem (CSP)	Current and Schilling [56]	minimize cost	single	Each node can be covered or visited
Generalized Covering Salesman Problem (GCSP)	Golden et al. [57]	minimize cost	single	Cost of visiting each node Nodes can be visited more than once
Geometric Covering Salesman Problem (geometric CSP)	Arkin and Hassin [58]	minimize cost	single	Covering intersection of the neighbourhoods
Covering Tour Problem (CTP)	Gendreau et al. [59]	minimize cost	single	Set of vertices to cover and set of vertices to visit
Multi-vehicle Covering Tour Problem (mCTP)	Hachicha et al. [60]	minimize cost	multi	Set of vertices to cover and set of vertices to visit
Maximal Covering Tour Problem (MCTP)	Current and Schilling [61]	minimize length maximize access	single	Visit only p nodes of the network Access - maximize demand
Median Tour Problem (MTP)	Current and Schilling [61]	minimize length maximize access	single	Visit only p nodes of the network Access - minimize access distance
Ring Star Problem (RSP)	Labbé et al. [64]	minimize cost	single	Assignment costs are included
Capacitated m-Ring Star Problem (cmRSP)	Baldacci et al. [65]	minimize cost	multi	Capacity restrictions
Generalized Travelling Salesman Problem (GTSP)	Henrylab [70]	minimize cost	single	Vertices are partitioned to clusters
Generalized Vehicle Routing Problem (GVRP)	Ghiani and Improta [71]	minimize cost	multi	Vertices are partitioned to clusters
Close Enough Travelling Salesman Problem (CETSP)	Gulczynski et al. [66]	minimize length	single	Visiting the intersection of coverage areas
Close Enough Vehicle Routing Problem (CEVRP)	Mennel [67]	minimize length	multi	Visiting the intersection of coverage areas

Table 4.2: Covering-Routing Problems

There are various implementations of selective travelling salesman/vehicle routing and covering tour applications to humanitarian problems in the literature. Veenstra et al. [72] introduced a facility location and vehicle routing problem for the delivery of medication to the patients in Netherlands. It is given that the medication can be delivered from a local pharmacy through lockers where patients

who are close to the lockers can obtain the medication, or it can be delivered to the homes of the patients. The problem consists of three decisions, whether to open a lock or not, determining the routes of vehicles that visit the patients who are not assigned to any locker, and determining the routes of vehicles that visit the opened lockers. The objective is to minimize the costs of opening lockers and travel costs. The problem is solved by a branch-and-bound algorithm, and a hybrid heuristic is introduced which was found to be more effective in achieving solutions within a time limit compared to the branch-and-bound algorithm.

Balcik [73] studied post-disaster assessment performed by relief agencies to determine the scope of the required response and to investigate the needs of the disaster affected communities. Since the post-disaster assessment needs to be quick, it was argued that not all disaster affected sites are needed to be covered, rather, a limited number of sites must be selected for the assessment which would cover different community groups with distinct characteristics. Balcik introduced a Selective Assessment Routing Problem (SARP) to determine which sites to visit and how the routes of the vehicles should be while ensuring that the different characteristics of the communities are covered in a balanced way. SARP is argued to be a variant of team orienteering problem with a coverage objective, which maximizes the minimum coverage ratio across the critical characteristics, such as characteristics related to geographical aspects or amount of disaster impact. A tabu search heuristic is proposed to solve the problem and a case study is conducted based on the data from 2011 Van earthquake in Turkey.

Sahinyazan et al. [74] introduced a mobile blood collection system where bloodmobiles perform tours to collect blood and return to the depot to prevent the blood spoilage, and shuttles are operating to visit the bloodmobiles to transfer the collected blood to the depot so that bloodmobiles can continue their tours without the need to return to the depot. The proposed problem is defined as Selective Vehicle Routing Problem with Integrated Tours (SVRPwIT) and the objectives are maximizing the amount of collected blood and minimizing the transportation costs of the vehicles. A mathematical model and a heuristic is given to solve the problem, and computational analysis on a real and a constructed data set is conducted. The proposed problem in Sahinyazan et al. [74] is similar to

our approach in terms of interdependent tours which are conducted with several vehicles.

Jia et al. [75] proposed a maximal covering problem with quantity-of-coverage and quality-of-coverage requirements to determine the location of medical supply facilities for large scale emergencies. Similarly, Abounacer et al. [76] proposed a three-objective location transportation problem to determine the number, the position, and the mission of humanitarian aid distribution centers in the disaster affected region. The first objective is given as determining the minimum total transportation duration of the aid from the distribution centers to the demand points, second objective is minimizing the number of first aiders needed to operate the distribution centers, and the third objective is minimizing the non-covered demand. They proposed an epsilon-constraint method that generated the exact Pareto front.

Even though there are similar problems to our problem in the literature, there is not any exact approach that meet our requirements. TSPs with Profits decide on which route to select depending on the profits attached to nodes. The multi-objective extension of our problem takes demand of the nodes into consideration and maximizes the covered demand which is close to TSPs with Profits, however, our original problem does not deal with the profits of the nodes while selecting which nodes to visit. Moreover, the difference of our problem to CTP is that which nodes to cover or which nodes to visit is not pre-determined in our problem. Similarly, in GVRP the set of nodes are clustered and a route among the clusters is selected minimizing the travel costs, and the model decides on the route among the given clusters rather than creating a cluster, which is the case in our problem. CSP is the closest problem that fits our needs since it selects which nodes to include in the tour and which nodes to cover. Since several vehicles are used in our problem, a multi-vehicle version of the CSP will be introduced. Moreover, to the best of our knowledge, there is not a problem defined on CSP which conducts integrated tours from the nodes in the tour to the nodes that are covered but not included in the tour. The comparison of our problems to the most related literature can be seen on Table 4.3.

Problem	Introduced By	Objective	Vehicle	Dynamics
Routing Problems with Profits	various	various	various	Most profitable nodes are selected to visit
Generalized Vehicle Routing Problem (GVRP)	Ghiani and Improta [71]	minimize cost	multi	Set of clusters to visit
Multi-vehicle Covering Tour Problem (mCTP)	Hachicha et al. [60]	minimize cost	multi	Set of vertices to cover and set of vertices to visit
Covering Salesman Problem (CSP)	Current and Schilling [56]	minimize cost	single	Each node can be covered or visited
Covering Vehicle Routing Problem (CoveringVRP)	Buluç and Kara	minimize cost	multi	Each node can be covered or visited
Covering Vehicle Routing Problem with Integrated Tours (CoveringVRPwIT)	Buluç and Kara	minimize cost	multi	Integrated tours from the visited nodes to the covered nodes

Table 4.3: Comparison of the Proposed Problems to the Related Literature

Chapter 5

Model Development

In this chapter, two models which are constructed for the e-voucher distribution problem are going to be introduced. The bi-objective extension of the problem which is constructed for the Mobile Child Friendly Spaces application is going to be introduced in Chapter 7.

The first model can be classified as a multi vehicle version of the Covering Salesman Problem where several vehicles are travelling through a region and the selection of which nodes to cover and which nodes to visit is determined by the tour. The nodes that the vehicles visit becomes local distribution centers and the points which are close to those local distribution centers is considered to be covered. Since the problem introduced is the multi-vehicle version of the CSP, we will refer our problem as Covering Vehicle Routing Problem (CoveringVRP). The objective of CoveringVRP is to minimize the total distance travelled by the vehicles. The second model is the extension of the first model with interdependent tours conducted from the visits of the vehicles, i.e., local distribution centers, to the nodes that the local distribution center is assumed to cover. In this case, an officer is travelling to the nodes that are close to the distribution center to deliver the e-voucher by hand to the residence of households, and by this approach any issues with accessibility is aimed to be minimized. The second case is classified as a Covering Vehicle Routing Problem with Integrated Tours (CoveringVRPwIT).

The objective for the CoveringVRPwIT is to minimize the total distance travelled by the vehicles and also by the officers in the smaller tours. To the best of our knowledge, problems CoveringVRP and CoveringVRPwIT are not defined in the literature.

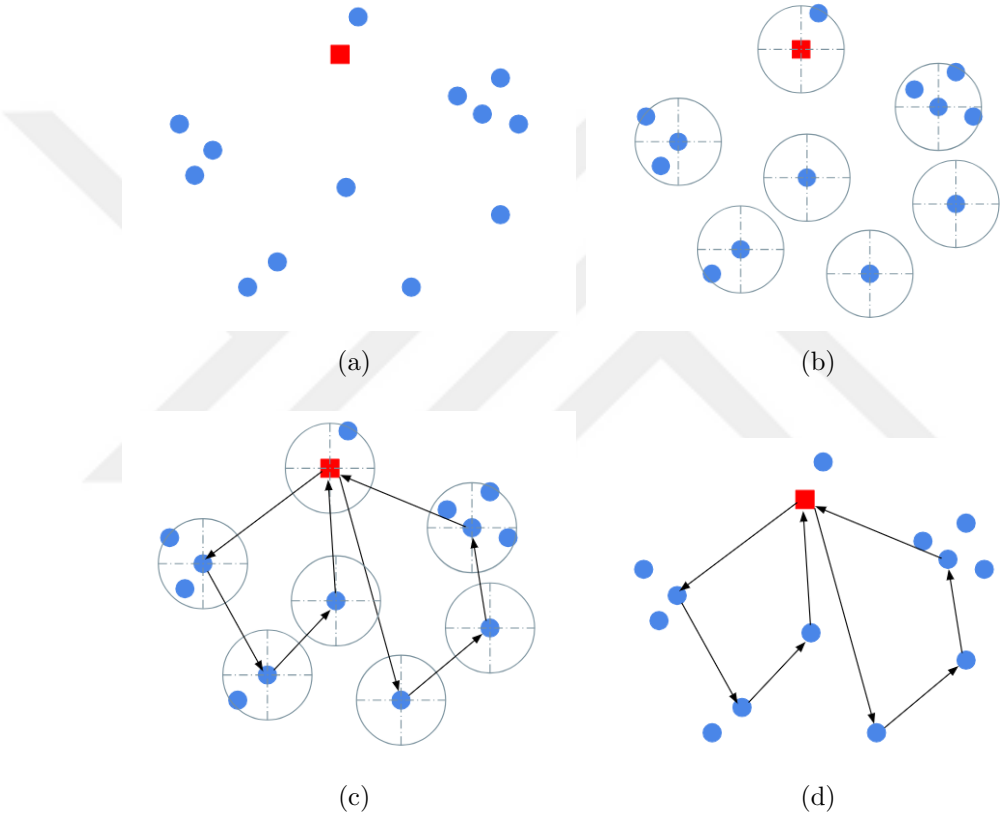
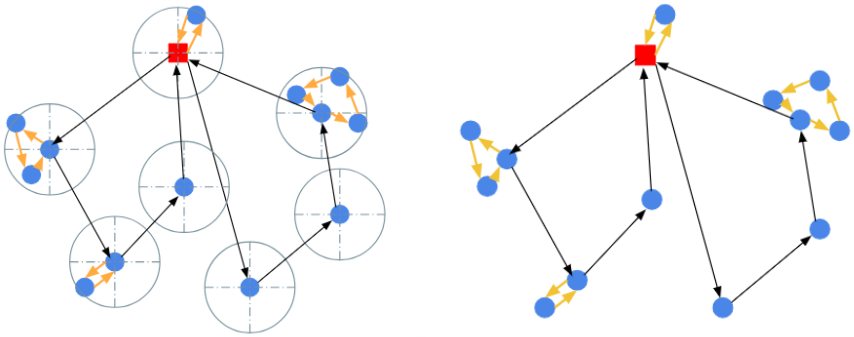


Figure 5.1: An Example of a Possible Tour for CoveringVRP



(a) (b)

Figure 5.2: An Example of a Possible Tour for CoveringVRPwIT

Figure 5.1 illustrates a possible tour for CoveringVRP where vehicles travel along geographically scattered nodes. The nodes that are within the coverage range of the visited nodes are assumed to be covered. Figure 5.2 illustrates the CoveringVRPwIT version of the problem, where smaller tours from the visited nodes to the covered nodes are conducted along with the main tour.

There are several assumptions for the problem which are as follows:

1. Each node is assumed to be covered if there is a visited node within a range, i.e., the nodes that have a distance less than γ between a visited node is considered to be covered.
2. Each node must be covered.
3. Each node can be visited at most once only by one vehicle.
4. Each main tour starts and ends at the depot.
5. Each smaller tour starts and ends at the hosting node.

Let $G = (V, A)$ be a graph such that $V = \{0, 1, ..., n\}$ is the set of nodes where n is the number of nodes, and $A = \{(i, j) : i, j \in V\}$ is the set of arcs. Node 0 denotes the depot. There is a distance matrix $D = \{d_{ij} : (i, j) \in A\}$ associated

with each arc in the set A, and the distance matrix is symmetric. It is assumed that $d_{ii} = 0$ for any i. N_i is defined as the set of nodes that the distance between them and node i is less than or equal to a pre-specified value, γ, for any i. Thus, N_i can be defined as the set nodes such that $N_i = \{j : d_{ij} \leq \gamma\}$. The number of vehicles is denoted by m, and the maximum distance a vehicle can travel is denoted by C. In CoveringVRPwIT, where both the distance travelled in main tours and in smaller tours are included in the objective function, α denotes the weight of the primary objective which is minimizing the total distance travelled in the main tour; and β denotes the weight of the secondary objective which is minimizing the total distance travelled in the smaller tours.

The decision variables used in the models are given below:

$$x_{ij} = \begin{cases} 1, & \text{if } j \text{ is visited right after } i \\ 0, & \text{otherwise} \end{cases}$$

$$z_i = \begin{cases} 1, & \text{if node } i \text{ is visited} \\ 0, & \text{otherwise} \end{cases}$$

In CoveringVRPwIT, where smaller tours are conducted as well, two more decision variables are defined which are as follows:

$$y_k^i = \begin{cases} 1, & \text{if } k \text{ is visited with the route starting from } i \\ 0, & \text{otherwise} \end{cases}$$

$$w_{jl}^i = \begin{cases} 1, & \text{if } j \text{ is visited right after } l \text{ and hosted at } i \\ 0, & \text{otherwise} \end{cases}$$

Covering Vehicle Routing Problem

$$\min \quad \sum_i \sum_j d_{ij} x_{ij} \tag{5.1}$$

$$\text{s.t.} \quad \sum_j x_{0j} = m \tag{5.2}$$

$$\sum_i x_{i0} = m \tag{5.3}$$

$$\sum_j x_{ij} = z_i \qquad \forall i \quad i \neq 0 \tag{5.4}$$

$$\sum_j x_{ji} = z_i \qquad \forall i \quad i \neq 0 \tag{5.5}$$

$$(1 - z_i) \leq \sum_{k \in N_i} z_k \qquad \forall i \tag{5.6}$$

$$\sum_i x_{ii} = 0 \tag{5.7}$$

$$u_i - u_j + C\, x_{ij} \leq C - d_{ij} x_{ij} \qquad \forall i \quad \forall j \neq 0 \tag{5.8}$$

$$u_i \leq C - d_{i0} x_{i0} \qquad \forall i \tag{5.9}$$

$$x_{ij} = \{0, 1\} \qquad \forall i \quad \forall j \tag{5.10}$$

$$z_i = \{0, 1\} \qquad \forall i \tag{5.11}$$

(5.1) denotes the objective function, which minimizes the total distance travelled. Constraints (5.2) and (5.3) ensures that the tour starts and ends at the depot and m vehicles are conducting the tour. Constraints (5.4) and (5.5) restricts a node to be visited at most once. Constraint (5.6) ensures that if a node is not visited, then another one which is in a pre-determined range of the node must be visited. Constraint (5.7) ensures that a visit from a node to itself is eliminated from the tour. Constraints (5.8) and (5.9) are Miller-Tucker-Zemlin subtour elimination constraints and constraints (5.10) and (5.11) are domain constraints.

Covering Vehicle Routing Problem with Integrated Tours

$$\min \quad \sum_i \sum_j \left(\alpha \, d_{ij} x_{ij} + \sum_l \beta \, d_{jl} w^i_{jl} \right) \tag{5.12}$$

$$\text{s.t.} \qquad (5.2) - (5.11)$$

$$y^i_k \leq z_i \qquad \forall i \quad \forall k \tag{5.13}$$

$$\sum_{\substack{i \in N_k \\ i \neq k}} y^i_k = (1 - z_k) \qquad \forall k \tag{5.14}$$

$$\sum_{\substack{j \in N_i \\ j \neq k}} w^i_{kj} = y^i_k \qquad \forall i \quad \forall k \in N_i \quad k \neq i \tag{5.15}$$

$$\sum_{\substack{j \in N_i \\ j \neq k}} w^i_{jk} = y^i_k \qquad \forall i \quad \forall k \in N_i \quad k \neq i \tag{5.16}$$

$$v^i_j - v^i_l + n \, w^i_{jl} \leq n - 1 \qquad \forall i \quad \forall j \in N_i \quad \forall l \in N_i \quad l \neq i \tag{5.17}$$

$$y^i_k = \{0, 1\} \qquad \forall i \quad \forall k \tag{5.18}$$

$$w^i_{jl} = \{0, 1\} \qquad \forall i \quad \forall j \quad \forall l \tag{5.19}$$

Objective function (5.12) is the weighted sum of the distance travelled with the main vehicles, and the distance travelled in the small tours. Constraints (5.2) - (5.11) are the same with the first model and determines the main tour. Constraints (5.13) - (5.19) are to determine the routes of the small tours. Constraint (5.13) prevents any small route to start from a node that is not visited. Constraint (5.14) ensures that a node that is not visited is going to be included in exactly one small tour, and a node that is visited is not going to be included to any small tours. Constraints (5.15) and (5.16) restrict a node in a small tour to be visited at most once. Constraint (5.17) is a Miller-Tucker-Zemlin subtour elimination constraint, and constraints (5.18)-(5.19) are domain constraints.

Chapter 6

Computational Analysis

In this chapter, the test runs to determine the performance of the mathematical models and their solutions are discussed. Three heuristics are proposed for solving larger instances and their computational analysis is given. The data set used to analyze the mathematical models and heuristics consists of 45 nodes which are constructed from the real data of the city Burdur in Turkey, which was collected and used in the literature by Kara and Savaşer [77].

6.1 Computational Results

6.1.1 Base Case Analysis

First of all, a single instance is used in the preliminary analysis. For CoveringVRPwIT where the objective function is a weighted sum of the total distances travelled in the main tour and the smaller tours, the weights are fixed to $\alpha = 1$ and $\beta = 10^{-2}$ respectively, since the distance travelled in the main tour is considered to have higher importance. The weights are determined considering that the aim is to minimize the distance travelled in the main tours and minimize the distance travelled in the smaller tours without affecting the main tour significantly.

Number of vehicles is considered to be $m = 2$, and the maximum distance a vehicle can travel is given as $C = 1500$. The maximum distance between a visited node and another which provides the node to be covered, i.e., the covering range, is fixed to $\gamma = 90$. The results obtained from the preliminary analysis can be seen in the table below:

	α	β	m	C	Distance of Main Tours	Distance of Smaller Tours	Objective Value	Solution Time (sec)
CoveringVRP	-	-	2	1500	1866.38	-	1866.38	1041.25
CoveringVRPwIT	1	10^{-2}	2	1500	1866.38	2403.09	1890.41	2550.23

Table 6.1: Solutions on a Single Instance

The solution times for both of the models is determined to be high, thus, an improvement on subtour elimination constraints in terms of solution times is applied which will be introduced in the next section.

6.1.2 Arc Based Subtour Elimination

In order to reduce the solving time of the models, Miller-Tucker-Zemlin (MTZ) constraints were updated and developed into arc based versions. The update was done only in the main tour's subtour elimination constraints since the smaller tours were relatively easier.

In Toyoglu et al. [78], five linear programming formulations for distance constraint vehicle routing problems are compared according to their solution times. Among these five formulations three of them are node based representations and the remaining two are arc based representations. The comparison yields the solution that Kara [79], which uses an arc based formulation gives the best results in terms of solution times and optimality gap. Hence, the subtour elimination formulation proposed in Kara [79] is integrated into our models to reduce the

solving times. u_{ij} is defined as the total distance a vehicle travels up to node j when the vehicle goes from node i to node j. Thus, the constraints (5.8) and (5.9) in models CoveringVRP and CoveringVRPwIT were updated in the following way:

$$\sum_{\substack{j \\ j \neq i}} u_{ij} - \sum_{\substack{j \\ j \neq i}} u_{ji} - \sum_{j} d_{ij} x_{ij} = 0 \qquad \forall i \quad i \neq 0 \tag{6.1}$$

$$u_{0i} = d_{0i} x_{0i} \qquad \forall i \quad i \neq 0 \tag{6.2}$$

$$u_{ij} \leq (C - d_{j0}) x_{ij} \qquad \forall i \quad \forall j \quad j \neq 0 \tag{6.3}$$

$$u_{i0} \leq C x_{i0} \qquad \forall i \quad i \neq 0 \tag{6.4}$$

$$u_{ij} \geq (d_{0i} + d_{ij}) x_{ij} \qquad \forall i \quad i \neq 0 \quad \forall j \tag{6.5}$$

An analysis is made on the updated version of CoveringVRP to observe any improvements since the changes on the subtour elimination constraints are conducted only on the main tour. Hence, any improvement in CoveringVRP would yield similar results in CoveringVRPwIT. The updated version of CoveringVRP is tested using the same data set and a time limitation of 6 hours (21600 seconds) is set. Instances using various values of m and C are included to have a better analysis. The new results of the model with the arc based MTZ constraints are shown in the table below.

m	C	CoveringVRP			CoveringVRP with updated MTZ		
		Objective Value	Gap (%)	Solution Time (sec.)	Objective Value	Gap (%)	Solution Time (sec.)
2	1200	2089.58	21.98	21600	2089.58	0	227.18
	1500	1866.38	0	1041.25	1866.38	0	27.76
	2000	1811.42	0	136.33	1811.42	0	24.15
3	1000	-	-	21600	2532.66	0	177.29
	1200	2166.86	10.17	21600	2166.86	0	130.97
	1500	1943.66	0	582.83	1943.66	0	26.51
4	1000	2609.93	28.82	21600	2609.93	0	168.84
	1200	2251.95	9.53	21600	2251.95	0	301.07
	1500	2028.75	0	248.06	2028.75	0	23.01

Table 6.2: Comparison of Arc Based MTZ

It can be observed from Table 6.2 that the model with the updated MTZ constraints yields far better solutions than the original model in terms of solution times. On several instances the original model did not manage to finish the branch-and-cut algorithm and for the instance with values $m = 3, C = 1000$, the original model did not manage to find a feasible solution during the time limit. The updated model with arc based MTZ constraints as subtour elimination constraints manage to find optimum solutions on very short times, such that the largest solution time did not exceed 5 minutes. Hence, the updated version of subtour elimination constraints are going to be used for the models CoveringVRP and CoveringVRPwIT for the rest of this work.

6.1.3 Sensitivity Analysis on Problem Parameters

Sensitivity analysis is applied on several parameters of the models such as the number of vehicles m and distance capacity of vehicles C. The analysis is conducted for 2, 3, and 4 vehicles. The maximum distance that each vehicle can travel was decided considering the number of vehicles and the average total distances of the tours, and experiments were conducted with the values of 1200, 1500, and 2000 for 2 vehicles and 1000, 1200, and 1500 for 3 and 4 vehicles. The

results of the sensitivity analysis on parameters can be seen on the table below:

	m	C	Distance of Main Tours	Distance of Small Tours	Objective Value	Gap (%)	Solution Time (sec.)
CoveringVRP	2	1200	2089.58	-	2089.58	0	227.18
		1500	1866.38	-	1866.38	0	27.76
		2000	1811.42	-	1811.42	0	24.15
	3	1000	2532.66	-	2532.66	0	177.29
		1200	2166.86	-	2166.86	0	130.97
		1500	1943.66	-	1943.66	0	26.51
	4	1000	2609.93	-	2609.93	0	168.84
		1200	2251.95	-	2251.95	0	301.07
		1500	2028.75	-	2028.75	0	23.01
CoveringVRPwIT	2	1200	2090.65	2101.96	2111.67	0	1345.45
		1500	1866.38	2403.09	1890.41	0	53.86
		2000	1811.42	2366.77	1835.09	0	42.8
	3	1000	2532.66	2354.96	2556.21	0	956.8
		1200	2167.93	2065.64	2188.59	0	2239.54
		1500	1943.66	2366.77	1967.33	0	69.93
	4	1000	2609.93	2325.22	2633.18	0.86	21600
		1200	2253.02	2004.77	2273.07	0	11587.83
		1500	2028.75	2305.9	2051.81	0	72.89

Table 6.3: Solutions of the Sensitivity Analysis on Parameters

The model CoveringVRPwIT yield a solution with a gap within the time limit on instance with values $m = 4, C = 1000$. Other than that, an optimum solution is found for both models on each instance. It can be observed that the distance of the main tours increases as number of vehicles m increases and the maximum distance each vehicle can travel C decreases. This result indicates that the more a vehicle's capacity to travel increases, the less distance is travelled to cover all the nodes.

6.2 Heuristics

The model for CoveringVRP reached optimum values in very short times, however, some instances took a lot of time to solve and some did not manage to find the optimum solution within the time limit for the model proposed for CoveringVRPwIT. Thus, three optimization based heuristics are proposed to solve the problem in a shorter time with small optimality gaps for CoveringVRPwIT.

6.2.1 Optimization Based Nearest Neighbour Heuristic

In the first heuristic proposed to solve CoveringVRPwIT, a combination of an optimization model and nearest neighbour approach is used. First, model CoveringVRP is solved to find the main tour since the model managed to find optimal solutions in short times. Then, to find the smaller tours conducted from the visited nodes in the main tour, a clustering method is conducted using the lexicographic order of the nodes. A cluster is created for each node in the main tour and nodes that are not visited are assigned to the clusters. Then, among the clusters, nearest neighbour approach is used to obtain the small tours.

Since generally a larger value is given to minimizing the distance travelled in the main tour, obtaining the exact optimum solution to finding the main tour can be considered to be important while the solution to find the routes of the small tours can be relaxed without damaging the value of the objective function drastically. Therefore, the proposed heuristic uses the optimization model for finding the main tour, and uses the given algorithm to cluster the neighbours and find the small tours.

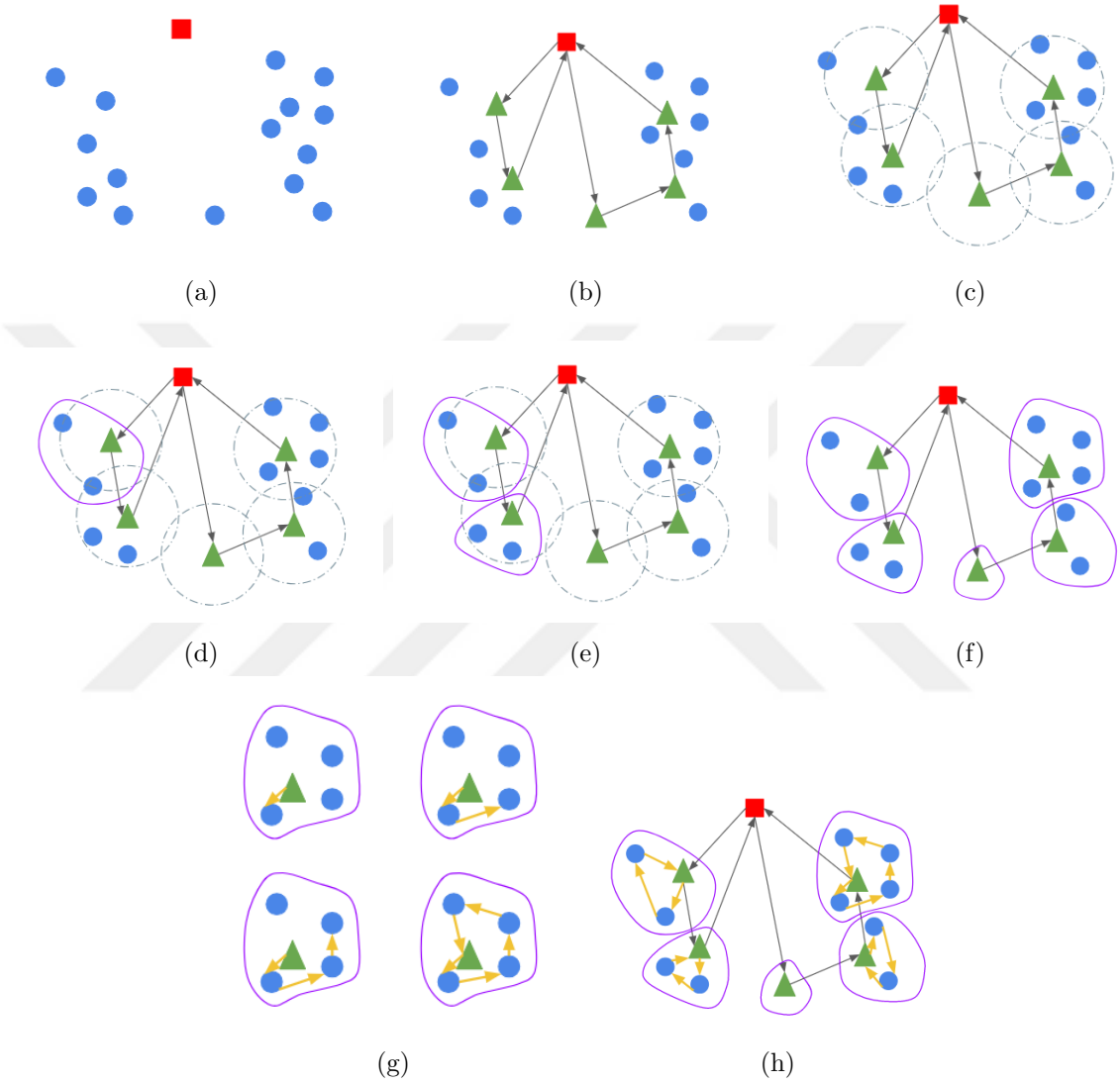


Figure 6.1: Illustration of the Optimization Based Nearest Neighbour Heuristic

Figure 6.1 illustrates the Optimization Based Nearest Neighbour Heuristic. First, model CoveringVRP is solved to find the main tour. Then, clusters are determined for each visited node using the lexicographic order of the nodes, and if an unvisited node appears on the coverage range of several visited nodes, it was made sure that the unvisited node appears only in one cluster hosted by a visited node. Then, nearest neighbour algorithm is used for each cluster to find the small tours, which was illustrated in part (g) for one cluster. Small tours

start from the host node, and the officers travel to the nearest node from where they stand until there are no unvisited nodes remain in the clusters. The pseudo code of the heuristic can be seen below:

Algorithm 1 Optimization Based Nearest Neighbour Heuristic

Step 1: Solve CoveringVRP. Then, if $z_i = 1$, add i to Z.
Step 2: Cluster the neighbouring nodes:
  for all $i \in Z$ **do**
    for all j st. $j \notin Z$ & $j \notin Z_k$ for any $k \in Z$ **do**
      if $d_{ij} \leq \alpha$ & $i \neq j$ **then**
        Add j into Z_i
      end if
    end for
  end for
Step 3: Find the tours for each cluster using nearest neighbour method:
  for all $i \in Z$ **do**
    if $|Z_i| > 0$ **then**
      for all $k, l \in Z_i$ **do**
        Take $\min\{d_{ik}\}$, set $w^i_{ik} = 1$ & $Z_i = Z_i - \{k\}$
        Take $\min\{d_{kl}\}$, set $w^i_{kl} = 1$ & $Z_i = Z_i - \{l\}$
        If $|Z_i| = 0$, set $w^i_{li} = 1$
      end for
    end if
  end for

Step 1 of the heuristic is to solve CoveringVRP since it is relatively easier to solve, and finding the main tour. Next, it takes the values obtained from the model, and creates a set for the nodes that are visited. In step 2, the neighbours of the visited nodes are clustered. It was made sure that a node appears only in one cluster even if it is neighbours with several visited nodes. In Step 3, among these clusters, nearest neighbour method is used. Starting from the node that is visited, nearest node in the cluster of the visited node is visited until there is no

node left unvisited in the cluster.

6.2.2 Two Stage Optimization Based Heuristic

In the second heuristic, CoveringVRP is solved similar to the first heuristic and the neighboring nodes are clustered according to the lexicographic order of the nodes. However, rather than applying nearest neighbour method, a basic travelling salesman model is applied to determine each of the small routes starting from the visited nodes. Through this approach, reducing the optimality gaps is aimed without increasing the solution times drastically. The pseudo code of the heuristic can be seen below:

Algorithm 2 Two Stage Optimization Based Heuristic

Step 1: Solve CoveringVRP. Then, if $z_i = 1$, add i to Z.
Step 2: Cluster the neighbouring nodes:
  for all $i \in Z$ **do**
    for all j st. $j \notin Z$ & $j \notin Z_k$ for any $k \in Z$ **do**
      if $d_{ij} \leq \alpha$ & $i \neq j$ **then**
        Add j into Z_i
      end if
    end for
  end for
Step 3: Find the tours for each cluster by solving the following model:

$$\min \quad \sum_{i \in Z} \sum_{j \in Z_i} \sum_{l \in Z_i} d_{jl}\, w^i_{jl} \tag{6.6}$$

$$\text{s.t.} \quad \sum_{l \in Z_i} w^i_{jl} = 1 \qquad \forall i \in Z \quad \forall j \in Z_i \quad j \neq i \tag{6.7}$$

$$\sum_{l \in Z_i} w^i_{lj} = 1 \qquad \forall i \in Z \quad \forall j \in Z_i \quad j \neq i \tag{6.8}$$

$$v^i_j - v^i_l + |Z|\, w^i_{jl} \leq |Z| - 1 \qquad \forall i \in Z \quad \forall j \in Z_i \quad \forall l \in Z_i \quad l \neq i \tag{6.9}$$

$$w^i_{jl} = \{0, 1\} \qquad \forall i \in Z \quad \forall j \in Z_i \quad \forall l \in Z_i \tag{6.10}$$

Step 1 and Step 2 are same with the first heuristic, it solves CoveringVRP to find the main tour and clusters the neighbouring nodes for each visited node in the tour. Step 3 of the heuristic solves a basic optimization model for each cluster and finds the small tours starting from the hosting nodes to visit the unvisited nodes.

6.2.3 Three Stage Optimization Based Heuristic

In the third heuristic, CoveringVRP is solved to find the main tours. Moreover, an assignment model is used to cluster the neighbouring nodes rather than applying lexicographic approach. Unvisited nodes are clustered according to the neighbouring visited nodes by minimizing the distance of the unvisited nodes to their hosting node. Then, the travelling salesman model is applied to find the small tours within the clusters. In order to introduce the assignment model for the clusters, we need to define a new decision variable q_{ij} which equals to 1 if j is assigned to the cluster of i, and 0 otherwise.

Algorithm 3 Three Stage Optimization Based Heuristic

1: **Step 1:** Solve CoveringVRP. Then, if $z_i = 1$, add i to Z.

2: **Step 2:** Cluster the neighbouring nodes by solving the following model, if $q_{ij} = 1$, add j to Z_i.

$$\min \quad \sum_{i \in Z} \sum_{j \in N_i} d_{ij}\, q_{ij} \tag{6.11}$$

$$\text{s.t.} \quad \sum_{i \in (Z \cap N_j)} q_{ij} = 1 \qquad \forall j \notin Z \tag{6.12}$$

$$q_{ij} = \{0, 1\} \qquad \forall i \in Z \quad \forall j \in N_i \tag{6.13}$$

3: **Step 3:** Find the tours for each Z_i by solving the following model:

$$\min \quad (6.6)$$

$$\text{s.t.} \quad (6.7) - (6.10)$$

Step 1 is the same with the first 2 heuristics, CoveringVRP is solved to find the main tours and the visited nodes are determined. Then, in Step 2, an assignment model is solved in order to determine the clusters. An unvisited node is assigned to a cluster by minimizing the distance of the node to the hosting node of the cluster. Thus, the clusters hosted by each visited node is determined. Step 3 is the same with the second heuristic, where a travelling salesman model is solved to find the tours within each cluster.

6.2.4 Comparisons of the Heuristics

In order to test the heuristics and compare their results, a computational analysis is conducted using the Burdur data which was used earlier to test the optimization models as well. Optimization Based Nearest Neighbour Heuristic is represented as Heuristic 1, Two Stage Optimization Based Heuristic is represented as Heuristic 2, and Three Stage Optimization Based Heuristic is represented as Heuristic 3. The results can be seen on Table 6.4.

	m	C	Distance of Main Tours	Distance of Small Tours	Objective Value	Gap (%)	Solution Time (sec.)
CoveringVRPwIT	2	1200	2090.65	2101.96	2111.67	0	1345.45
		1500	1866.38	2403.09	1890.41	0	53.86
		2000	1811.42	2366.77	1835.09	0	42.8
	3	1000	2532.66	2354.96	2556.21	0	956.8
		1200	2167.93	2065.64	2188.59	0	2239.54
		1500	1943.66	2366.77	1967.33	0	69.96
	4	1000	2609.93	2325.22	2633.18	0.86	21600
		1200	2253.02	2004.77	2273.07	0	11587.83
		1500	2028.75	2305.9	2051.81	0	72.89
Heuristic 1	2	1200	2089.58	2735.61	2116.94	0.25	226.18
		1500	1866.38	2767.71	1894.06	0.19	28.16
		2000	1811.42	2738.38	1838.8	0.2	24.42
	3	1000	2532.66	2570.38	2558.36	0.08	179.59
		1200	2166.86	2713.68	2193.99	0.25	130.06
		1500	1943.66	2722.96	1970.89	0.18	26.82
	4	1000	2609.93	2525.63	2635.19	0.08	165.96
		1200	2251.95	2790.54	2279.86	0.3	299.95
		1500	2028.75	2799.82	2056.75	0.24	23.33
Heuristic 2	2	1200	2089.58	2605.14	2115.63	0.19	227.43
		1500	1866.38	2629.84	1892.68	0.12	28.48
		2000	1811.42	2658.88	1838.01	0.16	24.63
	3	1000	2532.66	2417.71	2556.84	0.03	179.32
		1200	2166.86	2634.17	2193.2	0.21	131.92
		1500	1943.66	2658.88	1970.25	0.15	27.02
	4	1000	2609.93	2446.75	2634.4	0.05	167.63
		1200	2251.95	2724.88	2279.2	0.27	300.65
		1500	2028.75	2749.58	2056.25	0.22	23.85
Heuristic 3	2	1200	2089.58	2427.6	2113.86	0.1	226.91
		1500	1866.38	2403.09	1890.41	0	28.57
		2000	1811.42	2421.6	1835.64	0.03	24.75
	3	1000	2532.66	2355.47	2556.22	0	178.8
		1200	2166.86	2391.28	2190.77	0.1	131.29
		1500	1943.66	2366.77	1967.33	0	27.13
	4	1000	2609.93	2319.16	2633.12	0	166.39
		1200	2251.95	2330.41	2275.25	0.1	302.9
		1500	2028.75	2305.9	2051.81	0	25.1

Table 6.4: Comparison of the Heuristics

The optimality gaps are calculated considering the objective values. For the instance $m = 4, C = 1000$ where the optimization model found the solution with a gap during the time limit, the gap for the heuristics were calculated assuming the solution of the model is an exact solution.

Solution times for the heuristics is very satisfactory since the highest solution time for all of the heuristics did not exceed 5 minutes. Moreover, Heuristic 2 find

lower gaps in each instance compared to Heuristic 1 since it uses an optimization model to find the tours of each cluster while Heuristic 1 uses a nearest neighbour approach, and Heuristic 3 find lower gaps compared to the first two heuristic since it uses an optimization model to find both the clusters and the tours within these clusters. For half of the instances, Heuristic 3 managed to find the exact optimum solution with short solution times and for other instances, it managed to find solutions with low optimality gaps. The solution times for each heuristic are very similar to each other, hence, it can be argued that Heuristic 3 did a better job in terms of finding solutions with lower gaps in short solution times. The maximum, minimum, and average gap values for each heuristic can be seen on the table below:

Heuristic 1			**Heuristic 2**			**Heuristic 3**		
Minimum Gap (%)	Maximum Gap (%)	Average Gap (%)	Minimum Gap (%)	Maximum Gap (%)	Average Gap (%)	Minimum Gap (%)	Maximum Gap (%)	Average Gap (%)
0.08	0.25	0.2	0.03	0.27	0.16	0	0.1	0.04

Table 6.5: Comparison of the Heuristics in terms of Optimality Gap

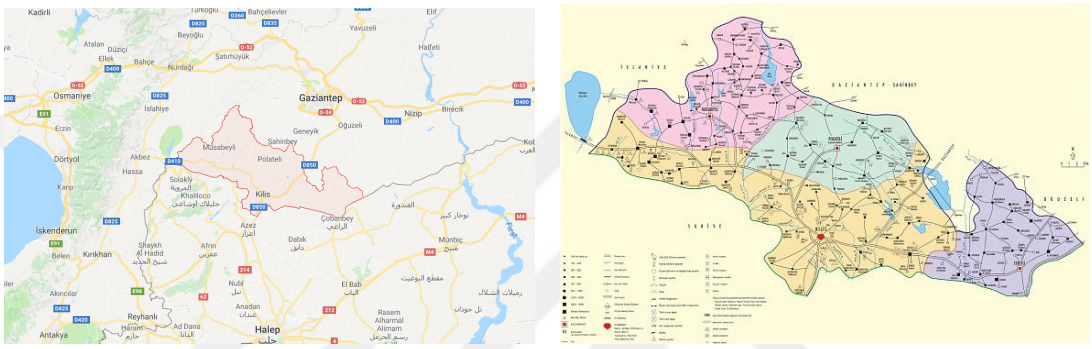
Therefore, it can be concluded that all of the heuristics achieved solutions in short solution times, however, Heuristic 3 which uses a three-stage optimization approach did better than Heuristic 1 and Heuristic 2 in terms of optimality gap.

6.3 A Real Life Scenario: Kilis

In this section, the computational results on a real life scenario is given. The large data set generated from the city Kilis in Turkey is introduced and the performance of the models and the heuristics are tested with this large data set.

Kilis is a small city near the Turkish-Syrian border, and because of its critical location, it has inhabited a large number of refugees who fled Syria. According to

the Ministry of Interior Directorate General of Migration Management, 95.15% of the population of Kilis consists of Syrians [18]. Thus, Kilis is chosen as a pilot area to test our problem considering the large proportion of Syrian refugees to the population of Kilis.


Gaziantep
Kilis
Halep
Osmaniye
İskenderun
Antakya
Nizip
Musabeyli
Şahinbey
Oğuzeli
Polateli
Çobanbey
Dabık
Münbiç
El Bab
Rasem Alharmal Alimam
Reyhanlı
Kırıkhan
Afrin
Azez
Nubl
Anadan
Ad Dana
Sheykh Al Hadid
Halfeti
Birecik
Yavuzeli
Şahinbey
Polateli
Akbez
Hassa
Karsı
Dörtyol
Erzin
Islahiye
Nurdağı
Beyreğu
Atalan
Düziçi
Ellek
Bahçe
Akıncılar
Belen
Geneyik
Solaklı
Khalloco

It is aimed to find multiple vehicle tours to cover all of the nodes of Kilis and find smaller tours from the visited nodes to the neighbouring covered nodes. The number of vehicles is determined to be $m = 2$, the capacity of each vehicle is given as $C = 500000$, and the coverage radius of vehicles is determined to be $\gamma = 1000$. The weight of the primary objective function which is minimizing the total distance travelled in the main tours is determined to be $\alpha = 1$ and the secondary objective function which is minimizing the total distance travelled in the smaller tours is determined to be $\beta = 0.01$. A time limit is set to 6 hours (21600 seconds). The results obtained from the models and the heuristics can be seen on the tables below:

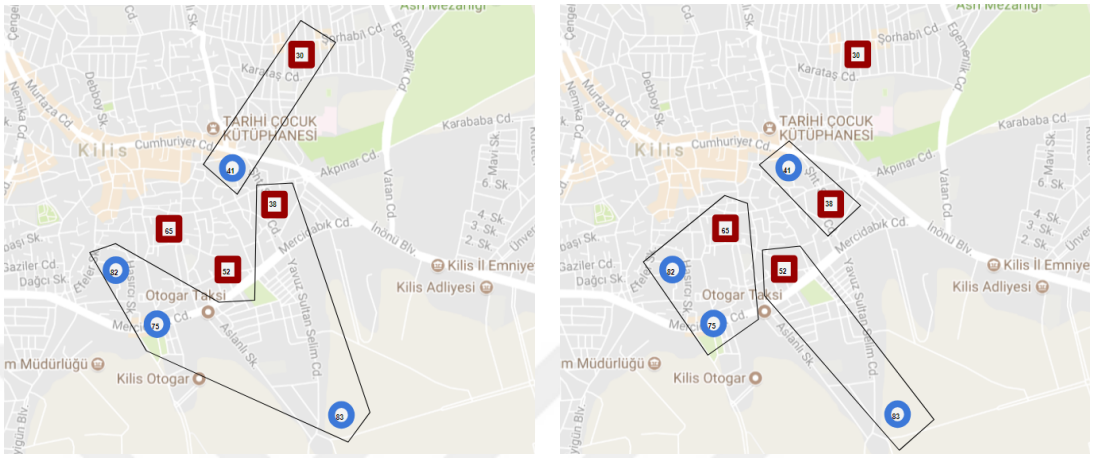
	Distance of Main Tours	Distance of Small Tours	Gap (%)	Solution Time (sec.)
CoveringVRP	730398.38	-	29.96	21600
CoveringVRPwIT	-	-	-	21600

Table 6.6: Solutions of Models Obtained from the Dataset Kilis

	Distance of Main Tours	Distance of Small Tours	Objective Value	Solution Time (sec.)
Heuristic 1	730398.4	47057.77	730868.95	21600
Heuristic 2	730398.4	44438.06	730842.76	21600
Heuristic 3	730398.4	33910	730737.48	21600

Table 6.7: Solutions of Heuristics Obtained from the Dataset Kilis

Model CoveringVRPwIT failed to achieve a solution within the time limit, however, the heuristics which are constructed for the model CoveringVRPwIT managed to find results. Heuristic 3 achieved the best solution compared to other two heuristics in finding the small tours. In order to have an understanding of the differences in heuristics, an example of a clustering and the routing of a smaller tour from a visited node to the neighbouring unvisited nodes is illustrated below:

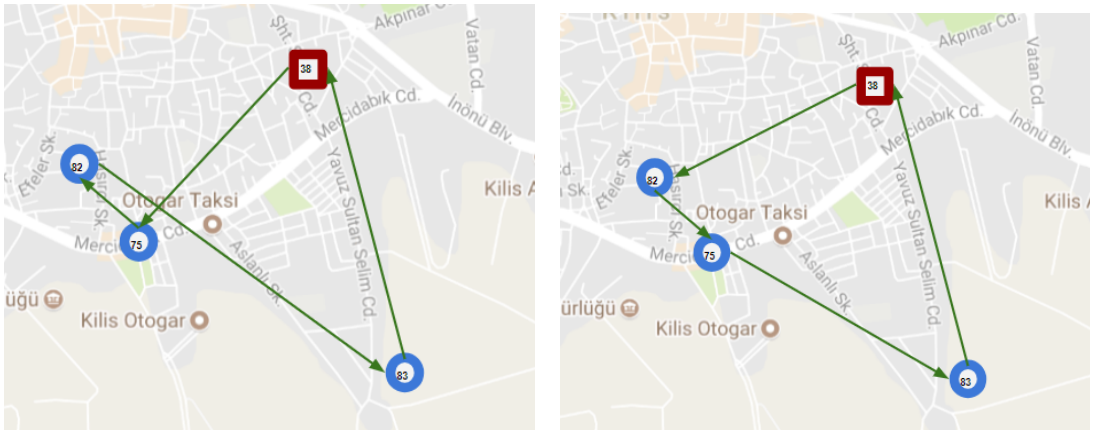


(a) Heuristic 1 and Heuristic 2

(b) Heuristic 3

Figure 6.4: An Example of Clusters Constructed by the Heuristics

Figure 6.4 represents a section of the main tour where square shaped nodes represent the visited nodes and round shaped nodes represent the unvisited but covered nodes. Main tours are same for each heuristic since it is optimized by solving CoveringVRP. Part (a) of Figure 6.4 shows the clustering obtained by the lexicographic approach in Heuristics 1 and 2, and part (b) represents the clustering obtained by Heuristic 3 which uses an assignment model.



(a) Heuristic 1

(b) Heuristic 2

Figure 6.5: An Example of a Small Tour Determined by the Heuristics

Figure 6.5 illustrates an example of a small tour for Heuristics 1 and 2 for one cluster. The difference between the heuristics is that Heuristic 1 uses the Nearest Neighbour Approach where Heuristic 2 uses the Travelling Salesman Problem to find the smaller tours.

To conclude, the models and the heuristics are applied to a real life scenario considering the city Kilis which is near the Turkish-Syrian border and a large amount of Syrian refugees reside. The data set generated was large and it was possible to test the performances of the models and heuristics. CoveringVRP managed to find a solution with an optimality gap within the time limit with the large data set whereas CoveringVRPwIT failed to achieve a solution. However, heuristics which was constructed to solve CoveringVRPwIT managed to find solutions and it was observed that Heuristic 2 which uses a 2-stage optimization process achieved slightly better solutions than Heuristic 1 which uses a combination of optimization and nearest neighbour approach, and Heuristic 3 which uses a 3-stage optimization process achieved the best results in terms of minimizing total travelled distances of the smaller tours.

Chapter 7

Extension: Mobile Child Friendly Spaces

In this chapter, the multi objective version of the cash and e-voucher problem, which is adapted to the problem of routing mobile child friendly spaces is introduced. The mobile CFS are trucks operated by the collaboration of Turkish Red Crescent and UNICEF, which creates an area for psychological and educational support to the refugee children in places it visits. The detailed introduction to this service is given in Chapter 3.

The main distinction of this problem to the e-voucher problem is that it considers the demand of the points in the selection of which points to visit. Thus, not every demand point is needed to be visited or covered, but a selection of points to visit is made considering total travelling distances and the demand. There is also a lower capacity defined for trucks to eliminate any node with very low demand to be included in the main tour, however, they can still be covered. The objectives of the problem is to minimize the total distance travelled by the trucks and to minimize the total unmet demand. Since the two objectives of this problem are different kinds in contrast to e-voucher distribution problem, we used an epsilon constraint method for the mobile CFS application rather than a weighted sum approach.

7.1 The Bi-Objective Model

The bi-objective model can be represented as follows:

$$\begin{aligned} \text{minimize} \quad & (f_1, f_2) \\ \text{subject to} \quad & x \in S \end{aligned}$$

where f_1 and f_2 represents the two objective functions and S represents the feasibility space. In multi objective problems, the term optimality is replaced with Pareto optimality or efficiency, and the Pareto optimal solutions are the solutions that cannot be improved in one objective without deteriorating the performance of other objectives [80]. Therefore, there is not one optimum solution in multi objective problems, but a set of Pareto optimal solutions and the decision depends on the preference of the decision maker. For our problem, we will apply the ϵ-constraint method to obtain the Pareto optimum solutions.

In the ϵ-constraint method, one objective function is optimized using the others as constraints, which can be represented as follows for the bi-objective model [80]:

$$\begin{aligned} \text{minimize} \quad & f_1 \\ \text{subject to} \quad & f_2 \leq \epsilon_2 \\ & x \in S \end{aligned}$$

The represented model will be solved iteratively and the ϵ value will be changed in each iteration to obtain the non-dominated solutions.

To introduce the constraints that define the feasible space S, we need to define a new decision variable D_i, which equals to the total demand covered by visiting node i, and 0 for the unvisited nodes. Moreover, the decision variable y_k^i which was defined to determine if k is visited in a small tour hosted by i is used only to define the clusters hosted by visited nodes, i.e., it will not serve the purpose of determining the small routes but rather determine if node k is in the range of i. The number of demand for each node i is represented by a_i. $MinCover$ represents the minimum amount of demand a visited node must cover, and D is the total demand of all demand points. Thus, the bi-objective model which is reduced to a single objective one can be represented as follows:

$$\min \quad \sum_i \sum_j d_{ij} x_{ij} \tag{7.1}$$

$$\text{s.t.} \quad (5.2)-(5.5), (5.7), (5.13), (6.1)-(6.5)$$

$$\sum_{\substack{i \in N_k \\ i \neq k}} y_k^i \leq (1 - z_k) \qquad \forall k \tag{7.2}$$

$$D_i = \sum_{\substack{k \in N_i \\ k \neq i}} y_k^i a_k + z_i a_i \qquad \forall i \tag{7.3}$$

$$D_i \geq MinCover\ z_i \qquad \forall i \tag{7.4}$$

$$\sum_i (D - D_i) \leq \epsilon \tag{7.5}$$

$$x_{ij} = \{0, 1\} \qquad \forall i \quad \forall j \tag{7.6}$$

$$z_i = \{0, 1\} \qquad \forall i \tag{7.7}$$

$$y_k^i = \{0, 1\} \qquad \forall i \quad \forall k \tag{7.8}$$

(7.1) represents the first objective function, f_1, which is minimizing the total distance travelled. Constraint (7.2) is the relaxed version of constraint (5.14), and it restricts any visited node to be included in any cluster hosted by another visited node. Constraint (7.3) determines the demand satisfied by each visited node, such that a node satisfies its own demand and the demand of the nodes that it covers. Constraint (7.4) gives a lower bound to the unmet demand of each visited node. The constraint eliminates any node with very low demand to be visited, however, it does not restrict these nodes with very low demands to be covered. Constraint (7.5) is the adaptation of the second objective function which represents the total unmet demand, f_2, to a constraint using an ϵ value as an upper limit, which will be reduced iteratively to obtain Pareto optimum solutions.

The ϵ-constraint method applied to find the Pareto optimum solutions in our bi-objective model first starts by setting ϵ to a large value. Then, the bi-objective model is solved. Assuming that the solution of the bi-objective model is (f_1^*, f_2^*), ϵ is set to $f_2^* - k$ where f_2^* is the value of the second objective function and k is

the stepsize which is a small enough number. Then, the model is solved again and the ϵ value is decremented accordingly to move to the next Pareto optimal solution. This iteration continues until the model is feasible. By this approach, the non-dominated solutions are achieved.

7.2 Pareto Optimum Analysis

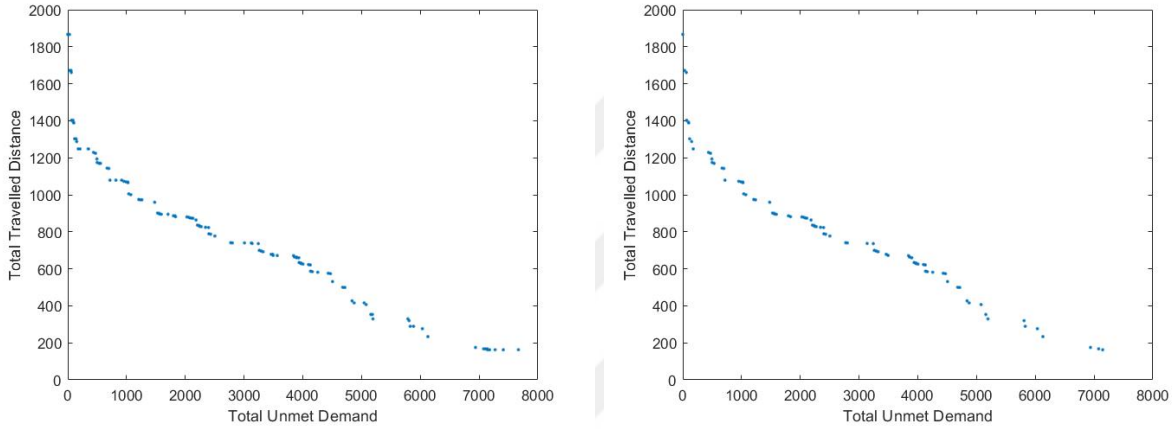
The bi-objective model takes two objective functions into consideration; which are minimizing the total distance and minimizing the total unmet demand. Hence, an analysis of the interaction of two objectives is presented to give an explicit view to the decision maker.

For the analysis, the Burdur data set which consists of 45 demand points is used. The 35.2% of the Syrian population in Turkey consists of children aged between 4-17, who are at the age for preschool, elementary, and secondary education [81]. Since the mobile CFS targets these children, the demand of the nodes is calculated as an estimated child population by multiplying the population of the nodes by 0.352.

The described ϵ-constraint method is applied to obtain the efficient solutions and the ϵ value is decremented by 1 for each iteration, i.e., the stepsize is specified as $k = 1$ in order to obtain all the Pareto optimal solutions. The efficient solutions are found for the base case, which is the instance $m = 2, C = 1500$. It took 124 iterations to find all the non-dominated solutions. The Pareto frontier is represented in part (a) in Figure 7.1.

A point x^* is said to be a weakly Pareto optimal if there is no other x such that $f_i(x) < f_i(x^*)$ for any i and a strictly Pareto optimal if there is no other x $(x \neq x^*)$ such that $f_i(x) \leq f_i(x^*)$ for any i [82]. Thus, part (a) in Figure 7.1 represents both weakly Pareto optimal and strictly Pareto optimal solutions. In order to analyze only the strictly Pareto optimal solutions, we eliminate the weakly non-dominated solutions from the set and represent the Pareto Optimum

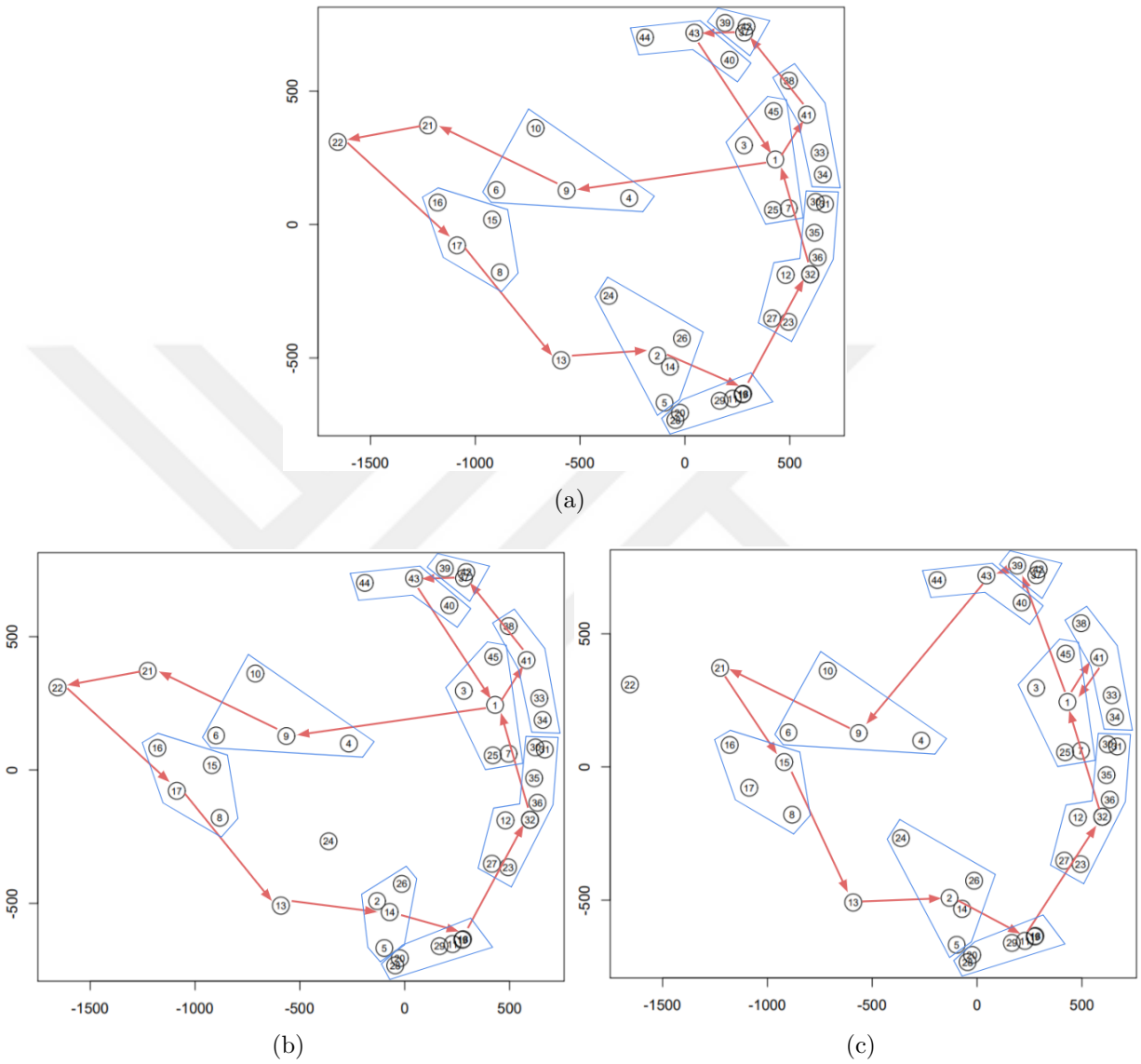
Curve of only the strictly non-dominated solutions in part (b) in Figure 7.1. The number of strictly non-dominated solutions is found to be 85. Therefore, it can be argued that the solution set represented in part (b) strongly dominates any other solution.



(a) Non-Dominated Solutions (b) Strictly Non-Dominated Solutions

Figure 7.1: Pareto Optimum Curves

The strict drop on the left-hand-side of the Pareto Optimum Curve shows that if the decision maker settles to cover 2% less of the total demand, she manages to drop the total travelling distance by 33%. The figure does not show any other strict drops, but the Pareto frontier fluctuates among the two objectives, and the decision to which objective to prioritize is upto the preference of the decision maker. Some examples of possible tours are given on the Figure 7.2.



(a)

(b)

(c)

Figure 7.2: Possible Tours for Mobile CFS

Tour (a) represented in Figure 7.2 is the tour where all demand is satisfied and the total travelled distance is 1866.38. There is a slight difference in the tour (b), where node 14 is visited instead of node 2, thus node 24 became out of the coverage range. Through this difference, travelled distance is reduced to 1856.13 and unsatisfied demand became 30. In tour (c), node 24 stays in the tour, but node 22 is eliminated from the tour to decrease the travelled distance. Thus, the travelled distance is reduced to 1671.43 and unsatisfied demand became 31. The

reduce in the travelled distance is more significant in tour (c) compare to tour (b). The total unsatisfied demand of tour (b) is slighter lower than tour (c), however, this difference can be neglected in order to reduce the travelled distance. The decision to which route to take is upto the preferences of the decision maker since each decision results in different outcomes.

Chapter 8

Conclusion

The ongoing Syrian Civil War caused a huge number of people to displace their homes to seek protection. This caused a refugee crisis throughout the world, and taking action from a humanitarian point of view became a necessity. Turkey became the largest host of refugees in the world with over 3.7 million registered refugees. Even though there are refugee camps in Turkey which provide shelter, food, health services, and education; around 94% of the Syrian population live outside of the camps because of the restrictions and lack of independence in the camps. Moreover, children constitute almost half of the Syrian population in Turkey, and more than 40% of them are out of school. Therefore, it can be argued that increasing the integration of Syrians to the community and improving their living conditions especially for the development of children to prevent a loss generation is highly important. Thus, this thesis focused on investigating the problems refugees face in Turkey and improving the services provided to them from an OR perspective.

A field study is conducted in Ankara in order to analyze the living conditions of the refugees and observe the challenges they face as explained in detail in Chapter 2. As a result of the field study and related research on the subject, the general problems and challenges refugees face is determined. It was concluded that economic challenges is the main problem refugees face which results in other

issues such as children's limited access to education. Then, several OR related problems are investigated and the programmes which provide cash and e-vouchers to refugees is analyzed in detail. It was concluded to study the distribution problem of e-voucher services in detail, which provides cash aid through electronic cards, in order to improve the access to such services. A covering vehicle routing model is developed to approach the issue, which was later discovered to able to adapt to the Mobile Child Friendly Space services in order to increase the access of refugee children to psychological support and informal education. Thus, a bi-objective extension of the proposed model is introduced in order to adapt to the Mobile CFS problem.

During the literature review conducted, it was discovered that most of the literature on humanitarian services focuses on disaster relief and preparedness operations, and there are not much study on humanitarian development. Moreover, a study that covers all the aspects of the introduced problems could not be found, thus, a new model is introduced. To distribute the e-vouchers to the recipients, two cases is taken into account, which are opening local distribution centers, and a combination of opening local distribution centers and hand-to-hand delivery. The model proposed for only using the local distribution centers is classified as a Covering Vehicle Routing Problem, and the model for the combination of local distribution centers and hand-to-hand delivery is classified as a Covering Vehicle Routing Problem with Integrated Tours.

Computational analysis is conducted on the models with the data set generated from the city Burdur in Turkey. Subtour elimination constraints of the models are updated to achieve shorter solution times. A sensitivity analysis is conducted on the problem parameters, and the changes of the objective values and solution times are investigated by changing the values of the number of vehicles and the distance capacities of the vehicles. Later, three heuristics are proposed to solve CoveringVRPwIT in shorter times and the heuristics are constructed to give good results only if a higher importance is given to minimizing the travelled distance of the main tours rather than minimizing the travelled distance of the integrated tours. First heuristic first solved CoveringVRP, then clustered the covered but unvisited nodes according to the lexicographic order of the visited nodes, and used

nearest neighbour approach to find the integrated tours. Second heuristic also solved CoveringVRP to find the main tours and clustered the neighbouring nodes using the lexicographic order, but then used a basic application of Travelling Salesman Problem for each cluster to find the integrated tours. Third heuristic again solved CoveringVRP to find the main tours, but solved an assignment model to find clusters for each visited node. Then, it used a Travelling Salesman Problem to find the small tours. During the computational analysis, it was observed that the third heuristic reached better solutions than the first two heuristics with minor changes in the solution times. Then, the proposed models and heuristics are applied to a real life scenario of the city Kilis which is near the Turkish-Syrian border and a huge amount of Syrian refugees are residing in order to test the performances in a large data set and a practical case. CoveringVRP managed to find a solution with an optimality gap and the heuristics are used to solve CoveringVRPwIT.

Then, the extension of the proposed models is given as an application of Mobile CFS problem. Two objectives of different kinds are used and the model is updated to a bi-objective version. The problem is given as determining the routes of the trucks which serves a purpose of creating child friendly spaces to the places they visit. The child population of the nodes is taken into account, and the objectives are determined as minimizing the total distance that the vehicles travel, and minimizing the total unmet demand. The model is solved using ϵ-constraint method and all of the Pareto optimum solutions are obtained.

For our study, we approached the distribution of e-voucher problem from both sides, such that CoveringVRP delivers to only the local distribution centers and do not visit the covered nodes, and CoveringVRPwIT delivers to local distribution centers and delivers by hand to the unvisited nodes. As a future research, one may combine the two problem into one, so that the solution includes delivering to local distribution centers, not visiting covered nodes, and hand delivering to nodes where access to local distribution centers is lower because of geographical or security reasons. This kind of problem can be constructed as a variation of covering tour problem where the nodes which are needed to be visited are determined beforehand.

Moreover, as a future research, one may develop the multi-objective version of the problem by taking other kinds of objectives into account. To illustrate, balanced coverage according to the demand of the nodes might be added as an objective, i.e., each coverage cluster can have an approximately equal demand to obtain a more balanced service. In addition, in our study, covering or visiting a node is not related to its demand. As a future research, the demand of the nodes can be taken into account in the decision of whether visiting or covering a node is more preferable, such that a node with higher demand would be visited rather than covered while nodes with lower demands are covered rather than visited. The service times of the mobile CFS trucks can also be determined according to the demand it covers at a visit, i.e., the truck can stay at a point longer if the demand is higher.

To conclude, the problems of CoveringVRP and CoveringVRPwIT are introduced and a bi-objective extension is presented in this work, and such problems are applied to practical humanitarian development problems. The possible directions available for future work is also proposed for anyone who wishes to study these problems.

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Appendix A

Data

Table A.1: Estimated School Aged Refugee Population of Dataset Burdur

Villages	Population	Estimated Child Population	Villages	Population	Estimated Child Population
i1	1236	436	i24	84	30
i2	845	298	i25	73	26
i3	1779	627	i26	943	332
i4	585	206	i27	2589	912
i5	769	271	i28	697	246
i6	990	349	i29	241	85
i7	730	257	i30	267	94
i8	564	199	i31	965	340
i9	679	240	i32	495	175
i10	664	234	i33	286	101
i11	986	348	i34	64	23
i12	393	139	i35	98	35
i13	147	52	i36	483	171
i14	79	28	i37	237	84
i15	1992	702	i38	907	320
i16	555	196	i39	299	106
i17	268	95	i40	93	33
i18	197	70	i41	587	207
i19	252	89	i42	175	62
i20	288	102	i43	91	33
i21	95	34	i44	895	316
i22	88	31	i45	1480	521
i23	67	24			

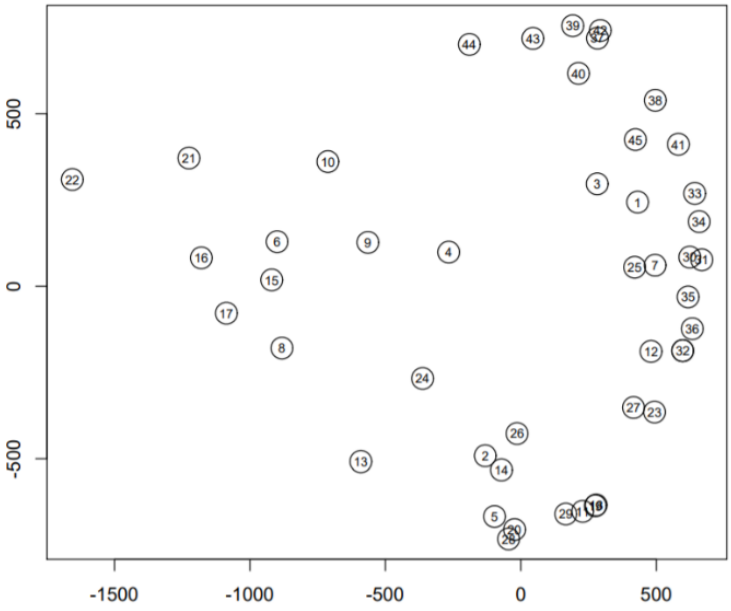

Figure A.1: Distribution of Villages of Burdur Dataset According to Their Distances

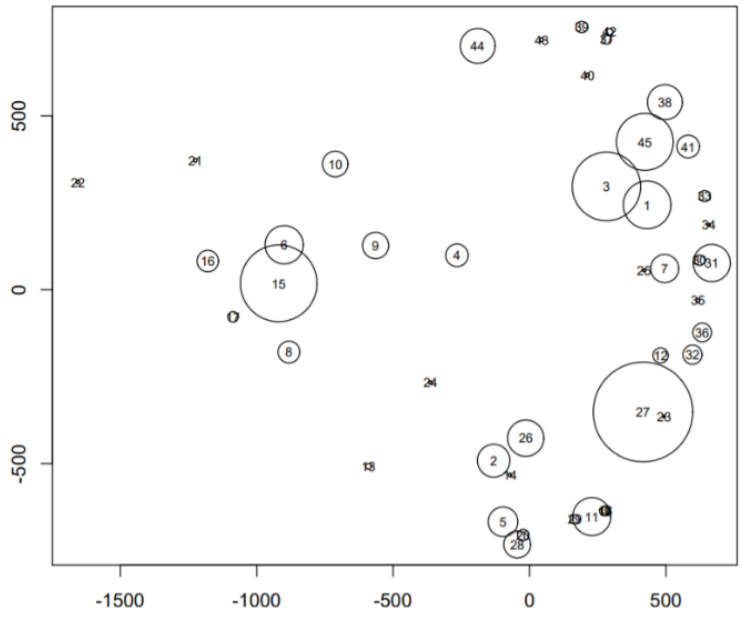

Figure A.2: Distribution of Villages of Burdur Dataset According to Their Distances and Populations