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İSTANBUL KÜLTÜR UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

OPTIMIZING THE FACILITY LOCATION DESIGN OF ORGAN TRANSPLANT CENTERS IN TURKEY

Master of Science Thesis

Amine Zenkhri
2000000481

Department: Industrial Engineering

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June 2023 Amine Zenkhri

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ABBREVIATIONS

RCC	: Regional Coordination Center
NCC	: National Coordination Center
CIT	: Cold Ischemia Time
FLP	: Facility Location Problem
CLP	: Capacitated Facility Location Problem
SFLP	: Single-Facility Location Problem
MFLP	: Multiple Facility Location Problem
CFLP	: Continuous-Facility Location Problem
LSCP	: Location set covering problem
MCP	: Maximal Coverage Problem
MILP	: Mixed-Integer Linear Programming
LR	: Lagrangian Relaxation
GA	: Genetic Algorithm
BWO	: Black Widow Optimization
SA	: Simulated Annealing
TCCA	: Transplantation Centers Coordinators Association

LIST OF SYMBOLS

$\boldsymbol{\mathcal{K}}$: Set of potential RCC locations

$\boldsymbol{\mathcal{M}}$: Set of potential donor cities

$\boldsymbol{\mathcal{N}}$: Set of potential cities with transplantation hospitals

$\boldsymbol{p}$: Total number of RCCs to be located

$\boldsymbol{d_i}$: The number of organs recovered for transplantation in i

$\boldsymbol{p_i}$: Ideal or perfect number of donors for each i as the number of transplants that would have occurred in city i

$\boldsymbol{T}$: Ischemia time

$\boldsymbol{\tau_{ij}}$: Ground travel time between cities $i \in \mathcal{M}$, and $j \in \mathcal{N}$

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Üniversity	**: İstanbul Kültür University**
Enstitü	**: Lisansüstü Eğitim Enstitüsü**
Bölüm	**: Endüstri Mühendisliği**
Programı	**: Mühendislik Yönetimi**
Tez Danışmanı	**: Prof. Dr. Murat Ermiş**
Tez Türü ve Tarihi	: **Yüksek Lisans – Haziran 2023**

ÖZET

TÜRKİYE'DEKİ ORGAN NAKLİ MERKEZLERİNİN TESİS YERİ TASARIMININ OPTİMİZASYONU

Amine Zenkhri

Organ nakli, sağlık hizmetleri sisteminin en hayati bileşenlerinden birisi olup, uygulanamaması durumunda ölümcül olabilecek birçok hastalık için çok önemli bir cerrahi tedavi yöntemidir. Son yirmi yılda sağlık hizmetleri alanında operasyonel ve ulaşım yöntemlerinde kaydedilen tüm ilerlemelere ve sofistike teknolojilere rağmen, organ yetmezliği nedeniyle yaşamanı yitiren hasta sayısında tüm dünyada olduğu gibi Türkiye'de de artış gözlemlenmektedir. Organa duyulan ihtiyacın artması nedeniyle, bağışlanan organların (greft) en uygun alıcı ile sağlıklı ve adil bir şekilde eşleştirmesinin yapılması en önemli süreçlerden birisidir. Bu nedenle, greft tedarik ve dağıtım sürecinin optimize edilmesi ve takibinin yapılmasına duyulan ihtiyaç kaçınılmaz olarak artmıştır.

Bu çalışmanın temel amacı, organ nakli için hiyerarşik bir sistemin kullanıldığı Türkiye'de bölgesel koordinasyon merkezlerinin yeniden bölümlendirilerek sayısını belirleyecek bir matematiksel model geliştirmektir. Bu sorunu ele alırken, küme yapılarının potansiyel organ çiftleri üzerindeki etkileri araştırılacaktır. Matematiksel model, süre ve farklı organ türleri gibi temel kısıtlamaları içerecek şekilde tasarlanmıştır. Optimizasyon modeli, nakil merkezleri ile aynı bölgesel merkeze (RC) atanan donör hastaneler arasındaki toplam seyahat süresini en aza indirmeye çalışır. Önerilen MILP modeli ticari bir çözücü, yani GAMS kullanılarak çözülmüştür.

Anahtar Kelimeler: Organ nakli, Tesis konumu, Karışık tam-sayı programlama, İskemi süresi

University	**: İstanbul Kültür University**
Institute	**: Institute of Graduate Studies**
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ABSTRACT

OPTIMIZING THE FACILITY LOCATION DESIGN OF ORGAN TRANSPLANT CENTERS IN TURKEY

Amine Zenkhri

Organ transplantation is one of the most vital components of healthcare systems and is a very important surgical treatment for many diseases that can be fatal if not applied. Despite all the advances and sophisticated technologies in operational and transportation methods in the field of health services in the last two decades, the number of patients who lost their lives due to organ failure is increasing in Turkey as well as in the rest of the world. Due to the increasing need for organs, matching the donated organs with the most suitable recipient patients in an efficient and fair manner is one of the most important processes. Therefore, the need to optimize and monitor the organ procurement and distribution process has inevitably increased.

The main purpose of this study is to develop a mathematical model that will determine the number of regional coordination centers in Turkey, where a hierarchical system is used for organ transplantation. In addressing this problem, the effects of cluster structures on potential organ pairings will be explored. The mathematical model is designed to include key constraints such as duration and different types of organs. The optimization model tries to minimize the total travel time between the transplant centers and the donor hospitals assigned to the same regional center (RC). The proposed MILP model is solved using a commercial solver, i.e. GAMS.

Keywords: Organ transplant, Facility location, Mixed integer linear programing (MILP), Ischemia time

1. INTRODUCTION

Organ transplantation is the new alternative to cure some sicknesses where the medicament or treatment does not work. Unfortunately, it is hard to procure organs for all the waiting patients. This is a global problem for all nations. Lately in the United States of America (USA), in 2020 they performed over 39,000 organ transplantation, though the waiting list had enlarged to 106, 346 men, women, and children (Health Resources and Services Administration). Consequently, 17 persons die daily waiting for an organ as claimed by Çay (2012). The Figure 1.1 represents the disparity between the organs needed versus those received during 2020 in the USA.

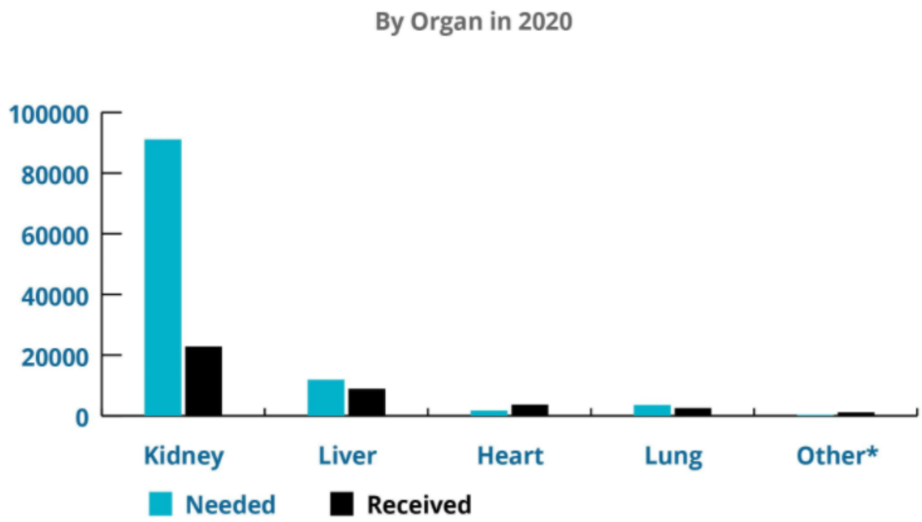

Figure 1.1: Chart represents the variety between organs needed and received in USA (UNOS, 2022).

An organ transplant treatment stands out from others as it involves a surgical procedure that necessitates both donor (either living or deceased, who donates their suitable organ(s) for transplant) and a recipient (a patient who requires the donated organ to survive). This procedure involves surgically removing an organ from the donor and transferring it to a patient who does not have an organ or is incapable of functioning within a medically determined period of cold ischemia. While organ transplantation is a valuable treatment method for organ failure, which can be fatal, it can only be utilized for specific organs (such as the heart, kidney, liver, lung, pancreas, and intestine) and tissues (like the cornea, heart valve, bone marrow, and skin) (TCSB, 2022a). The most frequently performed organ transplant is kidney transplant, followed by liver and heart transplants.

When it comes to the organs processes it is critical and should be performed very wisely. Moreover, the organ has a short lifetime outside the human body. Ischemia time is the appelation of the lifetime of an organ without blood transmission. Knowing that there is a time constraint, the organ transplantat operation should be performed swiftly and carefully. In addition, the patient's donated organ can be recognized in the organ transplantation system using two methods: a centralized procedure and a hierarchical approach. The centralized process, there is only one list for all patients. They matched patient with respect to this list. Where in the hierarchical process, the recipient patient is checked from regional, state, and national stage which means that the the list is divided into areas. By doing that, the search will be more efficient and precise, and each area covers the time bound between donor cities and patient list. Sometimes, it requires airway transportation which is not a permanent option due to the disponibility, and weather conditions. Fairness or rationality is one of the most important problems that is faced in this process, because of the population variety which will make advantages in some cities over others. Therefore, the hierarchical process remains the most important in the organ transplantation system.

In addition, there are other problems to be thought about during this process, such as the equipment of the hospitals. For hospitals to become organ transplant centers, they must specialize in organ-type operations. This means that donors can be all around the country, but hospitals are located in well-known places.

The purpose of this study is to optimize the location-allocation of the organ transplantation centers in Turkey where the hierarchical system is used for the procedure, by respecting the ischemia time. Ischemia time is an important concept in medicine that refers to the amount of time a particular organ or tissue can go without oxygen before it starts to suffer permanent damage.

It is especially important for medical professionals such as cardiologists, neurologists, and surgeons who work with organs like the heart and brain where even brief periods of oxygen deprivation can cause serious harm. The exact amount of ischemia time depends on several factors including the type of tissue involved, its metabolic rate when deprived from oxygen (anaerobic metabolism), and how much residual energy remains after initial cell death has occurred. In general terms however, most tissues have an average period between 5-15 minutes before irreversible damage occurs due to lack of blood flow or inadequate supply levels for essential nutrients like glucose.

Since timely intervention during events such as cardiac arrest is critical in order to minimize long-term consequences from prolonged hypoxia (lack of adequate oxygenation) monitoring patients' vital signs closely throughout treatment helps ensure proper management decisions are taken within this narrow window frame for optimal outcomes.

Question like: "How has the location of health care facilities in Tukey in the last 10 years affected the needs of patients on the waiting list? Are there new methods to have a better statistic?" will be discussed and new hypothesis will be held for future research.

In the literature, there are many studies regarding the organ transplantation system. Broadly, most of the research studies are based on the manegerial problems, and the simulation technique is used to test criteria of blood donors and tissues with those in the waiting list. As far as the researchers' awareness, it has been observed that various papers adopting the analytical models into the organ transplantation system.

1.1. Purpose of Thesis

In this study, the location-allocation problem in the Turkish organ transportation system is discussed, where graft (donor organ) matching is carried out with a hierarchical system. The purpose is to optimize the location of regional centers by minimizing the total transportation time and allocate the cities around them to obtain the best coverage for the country. With this context, there will be a correlation between donors and patients (recipients) allocated into the same zone. A mathematical model is derived and postoptimality analysis is conducted to get the best results. By using the

MILP, an optimal solution is found paying attention to the ischemia time under some assumptions, then applying the sensitivity analysis in order to obtain the maximum equity regarding the population in each city. Knowing that a populated city has a higher number of potential donors than a less populated one, also a higher number in the waiting list. Also, it aims to enhance the hierarchical system for organ transplant by evaluating the impact of clustering methods on coordinating regions. Developing an effective organ logistics network involves strategic decisions considering various factors like cold ischemia time, transportation times, and the location of transplant centers and teams. Due to the complex nature of the transplant network and its interactions, it is crucial to make fair and efficient decisions to maximize the benefits for all stakeholders. To achieve this goal, a mathematical model will be designed, incorporating key constraints such as ischemia and transport times and different organ types.

The outline of the thesis is as follows: Chapter 2 presents facility location and organ transplantation logistics literature. In Chapter 3, the problem definition with the underlying assumptions and notations is formally represented. In addition, a mixed integer linear programming model is proposed. Afterwards, in Chapter 4, computational experiments on the defined problem will be presented. Finally, a general discussion and future research will be given in Chapter 5.

2. LITERATURE REVIEW

The problem dealt with in this thesis can be evaluated in the broader sense of the health management system. The facility location literature is reviewed for the solution methodology. This chapter presents a literature review that considers mathematical modeling and optimization techniques in healthcare systems, location-allocation models, and specific transplant studies.

For many years, various aspects of health services, such as emergency health services, private health services, blood banking, and organ transplantation, have been subjects of research (Savaşer, Kınay, Kara, & Cay, 2019). For instance, Brandeau et al. (2003) studied the optimal distribution of outbreak control resources over multiple non-interacting populations, while Deo et al. (2015) optimized the allocation of HIV diagnostic services to different healthcare facilities. McCoy and Johnson (2014) investigated the optimal allocation of clinical capacity over time. In another study, a cluster coverage model was proposed that finds the locations of roadside clinics in Africa according to efficiency and equity criteria (Ares et al., 2016).

The literature contains numerous studies on blood banking and supply chain, particularly (Katsaliak et al., 2014; Zahiri & Pishvaee, 2017; Pirabán et al., 2019). Heidari-Fathian and Pasandideh (2018) developed a multi-objective mixed integer mathematical programming model to minimize total cost and total environmental impact, addressing sustainability in a blood supply chain network design. Haghjoo et al. (2020) introduced a scenario-based dynamic and robust location-allocation model to design a blood supply chain network under the risks of facility downtime and uncertainty in the event of a disaster.

Although health problems have been discussed for a long time, studies on organ transplantation are relatively new, with varying problem classifications depending on the purpose. Since transplant centers are directly responsible for surgical operations and human life, researchers have emphasized the significance of this issue. Despite improvements in operations and transport methods, location-allocation of transplant centers is inconsistent in some regions (Zahiri et al., 2014a).

Organ transplant is not only limited to a medical surgical procedure but is a form of treatment that concerns all areas surrounding human life such as law, ethics, sociology, economy, and education. In many countries, including Turkey, there are transplant laws on living donor organ transplantations that guarantee the rights of the donor, prevent the abuse of the subject, and prevent organ trade (Law No. 2238, Organ Transplant Centers Directive). In case of not finding enough organs; undesirable results such as an increase in mortality rates and a decrease in the quality of life of patients waiting for organs, having to use non-ideal organs, giving weight to transplants from living donors, increasing treatment costs and creating an environment suitable for illegal organ trade are encountered.

Significant improvements in 10-year survival rates (from 33% to 85%) have been achieved in the last two decades, thanks to advances in the field of health (preoperative optimization, improvement in immunosuppressant agents, ideal intensive care, etc.) (İstan, 2022). However, due to the increasing need for organs, there has also been an increase in the need for healthy and fair matching of donated organs with recipients, optimizing and monitoring the distribution process. For this purpose, it is aimed to ensure the coordination between institutions and organizations working in the field of organ transplantation services all over the world and to ensure that the graft is transferred to the most appropriate patient in the shortest time possible, in accordance with scientific rules and medical ethics (Parker & Williams, 2008).

Because of the limitations and complications mentioned above, a well-functioning sustainable organ transplant system is difficult. Many of these problems cannot be fully controlled. The studies carried out to provide graft supply to more patients have progressed in two different directions.

First is to investigate the question of how the ideal organ transplant system design (listing and matching) should be, that is, organ transplant system policies. In addition, the inclusion of practices such as organ swapping in the system to diversify the donor source was also discussed (Elias, 2017). In particular, the implementation of the organ exchange system through a transfer mechanism from underdeveloped and poor countries to developed countries such as the USA, as suggested by Fox and Swazey (2008), has brought ethical questions about the system.

Second is the improvement of the supply and transport network of the organ transplantation system. Transportation has a vital role as the locations and travel times of patients and hospitals are crucial elements of the organ transplant network. For the improvement of the organ transplantation system and network, many studies have been conducted in countries where different systems are applied such as USA (Stahl et al., 2005; Kong et al., 2010; Demirci et al., 2012; Gentry et al., 2015), Belgium (Beliën et al., 2013), Italy (Bruni et al., 2006; Caruso & Daniele, 2018), Iran (Azizi, 2013; Zahiri et al., 2014a) and Turkey (Çay, 2012; Savaşer et al., 2019).

The time elapsed between the donor's declaration and the delivery of the organ to the recipient facility and the travel times of the relevant parties (transplant team, transplant coordinator, recipient) depend on the responsiveness of the system. Although this problem is not new when considered as a facility location problem, the approach is more complex than the traditional facility location model, as organ transplants have various requirements.

2.1. Facility Location

Facility location decisions are a crucial element in strategic planning and affect many operational and logistical decisions as their results are broadly based. Therefore, the high costs associated with facility construction make facility location a long-term investment. To make such commitments profitable, organizations plan for new facilities to remain in place and operational for an extended period of time. Thus, decision-makers must select sites that will not only perform well relative to the current system state but will continue to be profitable throughout the life of the facility, even as environmental factors, population, and market trends change (Owen & Daskin, 1998).

The facility location problem (FLP) is a classic optimization problem that occurs in many real-world scenarios, such as the optimal location of warehouses, factories, or hospitals. The main purpose of FLP is to determine the optimal location of facilities to minimize costs while meeting customer demand. The problem is complex and involves the balance between the cost of setting up a new facility, the cost of transporting goods to customers, and the demand for the goods. Basic facility location problem formulations can be characterized as static and deterministic. These problems take constant, known quantities as input and produce a single solution. The solution is chosen by the decision maker based on one of many possible criteria.

In some cases, facilities may have capacity constraints, leading to capacitated facility location problems (CLP). In these problems, Shipping costs are frequently conceived to be connected to the quantity provided as well as the distance between the facilities and the recipient. An important way to measure the effectiveness of a facility location is to determine the average distance traveled by those who visit it (Church & ReVelle, 1976). Because, as the average travel distance increases, the accessibility of the facility and therefore the efficiency of the location decreases. This relationship applies to facilities where proximity is desired, such as libraries, schools, and emergency centers. Laporte, Nickel, and Saldanha-da-Gama (2020) describes the roots of Location Science and some disciplines with strong ties to this research field and presents examples of successful applications.

In general, FLP can be classified into three main types: single-facility location problem (SFLP), multiple facility location problem (MFLP), and continuous-facility location problem (CFLP). SFLP involves determining the optimal location of a single facility to serve customers. MFLP involves finding the optimal location of multiple facilities to serve customers and CFLP involves determining the optimal location of facilities in a continuous space. When facility locations must be selected from a given set of candidate locations, the corresponding location allocation problem becomes a discrete optimization problem (Wesolowsky, 1993).

In 1964, Hakimi introduced the more general problem of locating multiple facilities such that the total weighted distance between customers and the nearest facility is minimized (Hakimi, 1964) and this problem is called as *p*-median. In this problem, the objective can be regarded as an efficiency as opposed to the equity goal of minimizing the maximum distance. The model was formulated as integer programming (Toregas et al., 1971), and can be solved in polynomial time when *p* is fixed (Owen & Daskin, 1998). There are various variations of this problem as 1-median, *p*-median with different distant metrics, and dynamic *p*-median problem. It should be noted that additional constraints may be required over basic *p*-median model in some real-life problems.

Sometimes minimizing total cost or considering travel time is not enough to address some real-life problems. If there is a time limit on travel time for a facility, then the problem cannot be defined using the *p*-median formulation. Facilities should be located to cover a minimum distance or time to demand nodes. This can be addressed with another location problem known as the covering problem (Church & ReVelle, 1976).

In the simplest type of covering problem, it is tried to find the locations of the minimum number of facilities that will cover all demand points within a given distance/time limit and named as location set covering problem (LSCP) (Toregas et al., 1971). If the demand weights differ between customers, another type of coverage problem can be used, i.e., the Maximal Coverage Problem (MCP) (Church & ReVelle, 1974). This model includes the weight of demand points and it tries to maximize the number of customers covered by positioning *p* number of facilities. The number facilities to be located is fixed as *p*, and the problem is called as *p*-center problem. These models are generally used in the determination of the location of urban facilities (Church & ReVelle, 1976).

Current et al. (2001) has classified basic facility location models into eight types based on their consideration of distance: set covering, maximal covering, *p*-center, *p*-dispersion, *p*-median, fixed charge, hub, and maxisum. In this classification, the first four are based on maximum distance, and the second four are based on total/average distance.

It is very challenging to find the best solution for location models. The main obstacle to formulating and using these models was the complexity of computation until fast digital computers emerged. There are algorithms that solve the problem of finding the optimal location of a single facility according to the maximum cost criterion in full polynomial time. However, due to the complexity of the classical *p*-median and *p*-center problems, algorithms that give exact solutions are limited by the size of the solution space, and there are several approximation algorithms in the literature (Charikar et al., 2002; Dyer & Frieze, 1985). For example, while there is a

2-approximation algorithm for *p*-center problems in metric space (Dyer & Frieze, 1985), no such algorithm is known for minimax facility location problems in flow networks. Additionally, location models are unique to each application, meaning that the objectives, variables, and constraints depend on the specific location problem being addressed. Therefore, there is no universal location model that can be applied to all current or future situations (Current et al., 2001).

Many studies on FLP have been done in the literature and various approaches have been proposed to solve the problem (Campbell, & O'Kelly, 2012). Some of the commonly used approaches include exact algorithms (Sherali et al., 2002; Das et al., 2020; Tedeschi & Andretta, 2021), heuristics (Cooper, 1964; Galvao & ReVelle, 1996), and metaheuristics (Rolland et al., 1997; Basu et al., 2015; Alidaee & Wang, 2022). Exact algorithms aim to find the optimal solution to the FLP, while heuristic and metaheuristic algorithms aim to find a near-optimal solution within a reasonable time.

It has also been argued that implementing a supply chain management approach to organ transplants with the goal of increasing the number of available organs may worsen inequalities in access to treatment. This is a pressing issue because there are far more people in need of transplants than there are organs available, which is partly due to the uneven distribution of transplant centers, donors, and recipients. To address this problem, the healthcare industry is developing systems that use standardized data and logistics to speed up organ procurement and distribution. However, these practices must be implemented in a fair and unbiased manner that does not favor more privileged patients (Cole, 2021).

2.2. Organ Transplant Network

Numerous investigations have examined the positioning of healthcare facilities, with some approaching healthcare issues as a location problem, as seen in studies by Farahani et al. (2010), Rais & Viana (2011), Syam & Côté (2012), Shariff et al. (2012), and Sha & Huang (2012). Healthcare facility location is critical because it shares several characteristics with other facilities, such as a dispersed customer base, accessibility and speed of access, low settlement density, and transportation, among others (Pierskalla & Brailer, 1994). According to a thorough evaluation by Daskin and

Dean (2005), studies on health facility location include factors such as accessibility, adaptability, and usability, such as those by Khodaparasti et al. (2018), Abodey et al. (2020), Kouvelis & Yu (2013), Ji et al. (2020), and Burger and Christian (2020).

The locations of the transplant centers have a significant impact on the total distance that must be traveled between the graft and the recipient. Because it directly affects the time elapsed between the removal of an organ from the donor's body and its subsequent transplant operation. Therefore, designing an efficient supply chain for transplant facilities is a complex task that requires careful management of the location-allocation system to maximize the network's benefits and minimize its overall costs. Decisions regarding the placement of facilities are very important as it is a long-term decision. These decisions also have a significant impact on performance in terms of responsiveness and costs (Azizi, 2013).

Previous studies have proposed several location-allocation models for organ transplant facilities based on accessibility criteria, including integer programming (IP) and mixed-integer linear programming models (MILP). Stahl et al. (2005) proposed an integer programming model that determines regions to maximize geographic parity weighted by transport allocation efficiency. Bruni et al. (2006) proposed a mixed-integer linear programming model that optimally organizes high-throughput transport systems in Italy to equalize waiting lists if special centers play critical roles in organ management and supply.

Other studies have focused on maximizing the efficiency of intraregional transplants of liver allocation systems in the USA using a branch-and-bound approach (Kong et al., 2010), designing a regional network for allocating cadaveric livers (Demirci et al., 2012), and proposing a MILP model that determines the optimal location of transplant centers for five different organs while minimizing the total weighted time under a budget constraint in Belgium (Belien et al., 2013). Moreover, Zahiri et al. (2014a, 2014b) developed multi-period optimization models for organ transplant network design that consider uncertainty, with the goal of minimizing the overall cost and total supply chain cost and time. These studies aimed to minimize either the total organ transplant process time or the travel distance between the donor and the recipients.

Ahmadi-Javi, Seyedi, and Syam (2017) classified different types of healthcare facility location and presents comprehensive review identifing research gaps and possible future directions. They also analyzed according to various descriptive dimensions as decision variable, uncertainty, objective function, etc. They concluded that there is still a need to examine more realistic healthcare facility location problems in order to develop both new optimization models and solution methodologies.

Another study conducted by Rouhani and Amin (2022) developed a new two-objective hierarchical location-allocation model to design a transplant network while considering the uncertain parameters. The proposed approach uses robust convex optimization to minimize the total time and costs in the network and maximize geographic parity, which is crucial under supply and demand uncertainty. The study also considers different transportation modes, and the optimal mode is selected through the model solution. Meanwhile, Salimian and Mousavi (2022) proposed a three-objective robust optimization model to design transport networks that are adaptable to disruption scenarios. Their research introduced a mixed integer nonlinear programming (MINLP) model for building a scenario-based organ transplant supply chain, and two metaheuristic optimization algorithms, namely genetic algorithm (GA) and black widow optimization (BWO), were utilized as solution methods.

Current distribution policies have resulted in geographical disparities in access to donated organs across the country for transplant waiting list candidates. In order to eliminate this inequality and create an efficient system, a new continuous distribution model has been proposed by using mathematical optimization and simulation techniques (Bertsimas et al., 2020). According to results of the simulations, the concept of continuous distribution provided both the largest reduction in patient deaths and the most equitable geographic distribution across comparable organ payload.

Another recent simulation-optimization study aimed to improve the way organ transplant offers is made to potential recipients. This proposed policy is likely to be applicable to any type of organ and is flexible in offering the organ to more than one patient at a time. It has been shown that the proposed policy enables the use of more organs than the current one-at-a-time policy and shortens the time required for the allocation of organs (Erozo, 2022).

Ensuring fairness in the organ supply and transplant network is a crucial objective. Numerous attempts have been made in recent decades to tackle the unequal distribution of organs for transplantation, resulting in significant progress in various domains. However, significant efforts are still necessary to suggest and design policy adjustments that can promote equity in the liver transplantation system, given the considerable imbalance that currently exists (Wahid, et al., 2021).

The literature review about mathematical modeling and optimization techniques in organ transplantation network systems is summarized and compared in Table 2.1.

2.3. Literature Synthesis

If we want to relate the studies to be done within the scope of the thesis with the literature, although there are many studies in the literature on organ transplantation, it has been observed that there are very limited studies dealing with Turkey's unique dynamics as seen from Table 2.1.

While studies were conducted on the liver, which initially aimed to minimize the total cost or total time, in addition to these, in recent years, Location-Allocation models that maximize total earning or responsiveness (efficiency) and include multiple organs and modes of transport have been proposed. Another point is that though there is a high demand for organs, the number of possible donors can vary greatly depending on factors such as population density and demographics. As a result, some regions and provinces may have higher concentrations of possible donors, resulting in a more biased transplant waiting list. This highlights the fact that for those living in less populated or rural areas, there may be limited access to donor organs and longer waiting times. In addition, socioeconomic considerations, such as access to healthcare resources or the cost of transportation to a transplant facility, can affect a patient's chances of getting an organ transplant. This situation ultimately raises the question of how justice (equity) can be achieved in patients' access to organ transplantation.

Another important issue in organ transplantation is the total time between the removal of the organ from the donor and its transplantation to the recipient. This period is defined as the ischemia period and differs for each organ that can be transplanted. For this reason, the locations of different types of facilities and the efficiency of the organ transportation logistics in the whole process are also very important in terms of transplanting the organ to the patient in a healthy way. In addition, due to these time constraints, it is possible to use different transportation modes such as air transportation by ambulance plane, or helicopter, as well as land transportation in the organ transplant network. However, this kind of transportation may not accessible in every region, and their availability may be affected by some factors such as weather and emergency situations. For example, in rural or isolated areas where ground transportation may be problematic, using airplanes and helicopters for timely organ transplants can be critical.

By using the mathematical optimization model, a solution can be found paying attention to the ischemia time under some assumptions, and by applying the sensitivity analysis in order to obtain the maximum equity regarding the population in each city.

Table 2.1: Related studies in the literature

Study	Modeling Approach	Decisions	Objective Functions	Type of Organ	Allocation Method	Transp. Mode	Multi Obj.
Stahl et al. (2005)	Set partitioning (INLP)	Defining regions	Max transplant efficiency	Liver	–	–	Yes
Bruni et al. (2006)	Location-allocation (MILP)	Defining regions & selecting hospitals	Min waiting list, Min travelled distance	Liver	–	–	No
Kong et al. (2010)	Set partitioning (MILP)	Defining regions	Max transplant efficiency	Liver	Hierarchical	–	No
Demirci et al. (2012)	Set partitioning (ILP)	Defining regions	Max transplant efficiency	Liver	Hierarchical	–	Yes
Beliën et al. (2013)	p-median (MILP)	Locating transplant centers	Min total time	Multiple	Centralized	–	No
Zahiri et al. (2014a)	Mixed period LA (MILP, FP)	Locating transplant centers	Min total time, Min total cost	Multiple	Centralized	Multi	Yes
Zahiri et al. (2014b)	Mixed period LA (MILP, MINLP, FP, RP)	Locating transplant centers	Min total cost	Multiple	Centralized	Multi	No
Gentry et al. (2015)	LA (ILP)	Defining regions & locating centers	Min misdirected organs	Liver	Hierarchical	Multi	No
Savaser et al (2019)	LA (MINLP)	Defining regions & locating centers	Max responsiveness	Multiple	Hierarchical	Multi	No
Rouhani et al. (2022)	LA (MILP, RP)	Defining regions, Locat. transp. centers	Min total cost, Min total time	Multiple	Hierarchical	Multi	Yes
Erozo et al. (2022)	Simulation-optimization	Batch-offering	Max earnings	Multiple	Hierarchical	–	No
Proposed study	Location-allocation (MILP)	Defining regions, Locat. transp. centers	Min travelled distance	Multiple	Hierarchical	Multi	No

3. PROBLEM DEFINITION AND FORMULATION

3.1. Organ Transplant System Design

An organ is described as “a differentiated structure (such as a heart, kidney, leaf, or stem) consisting of cells and tissues and performing some specific function in an organism” (Merriam-Webster, 2023). Organ failure is a relentless disease that anyone can get, without discrimination. Hundreds of thousands of people die from organ failure every year around the world. Organ transplantation from a cadaver or a living donor to a patient has been an important therapy in the treatment of this potentially fatal diseases (Roth et al. 2005).

With the advent of advanced medicines, anti-rejection treatments, and sophisticated surgical techniques, more and more people have been able to benefit from this basic surgical operation. The distinguishing characteristic of this treatment is the need for a donor, who can be living or dead and donates their proper organ(s) for transplant, as well as a recipient, who is the patient who is dependent on the received organ for survival. An organ transplant procedure is the surgical removal of an organ from the donor and its transfer to a patient who does not have an organ or is unable to function, within a medically determined period of cold ischemia. Although this treatment method is useful in the treatment of organ failure, which can ultimately be fatal, it can only be applied to some organs (heart, kidney, liver, lung, pancreas, intestine) and tissues (cornea, heart valve, bone marrow, skin) (TCSB, 2022a). The most common and highly demande organ transplants are kidney, followed by liver and heart (Cleveland Clinic, 2022).

There are two different parties as decision-makers in the allocation of organs. The first group of decision makers is the individual patient and his or her doctor. Naturally, the objective of this side is to maximize a measure of the patient's benefit, typically life expectancy. The second party can be defined as the community and its purpose is to design an organ allocation system that will maximize some criteria like total clinical benefit and some measure of equity. Equality is a critical issue in the societal perspective on organ transplantation (Alagoz et al., 2009).

The majority of research in the organ transplant and donation field concentrates on developing systems that equitably distribute organs to those in need (Dominguez-Gil, et al., 2021). Since kidneys and livers are the most commonly transplanted organs, they receive the most attention and research within this area. Transplantation is the preferred treatment for patients with end-stage liver or renal disease because it enhances both survival and quality of life. It is a prevalent practice to perform simultaneous kidney and pancreas transplants on diabetic patients with end-stage renal disease. Although the number of liver and kidney transplants has risen over time, this increase has not kept pace with the growing number of patients requiring these transplants (Smith, et al., 2012).

Despite the potential of organ transplantation treatment to greatly enhance patient survival rates and improve quality of life, its inherent characteristics introduce numerous constraints. The most important problem is the imbalance between the demand and supply of organs, and organ transplants face long waiting lists. For example, In the United States, on average, 68 individuals lose their lives daily due to the unavailability of a timely organ transplant, and it's estimated that about 45,000 patients are added to the waiting lists annually (UNOS, 2022). In 2018, a total of 9,548 organ transplants were conducted in Turkey. However, as of June 2022, there remain 29,228 individuals on the waiting list for a compatible organ (TCSB, 2022b). Out of a population of approximately 84 million, the projected number of potential donors reaches up to 586,456.

Another important limitation is the compatibility of the graft with the patient to be transplanted. There are many factors such as blood type, tissue compatibility, and immune status that must be met in determining the potential recipient for the organ found. In addition, factors such as age and psychological state are also important limitations. Despite the biocompatibility of the organ with the patient and the immunosuppressant agents used, rejection by the body is a serious problem and requires immediate removal of this organ from the body.

Donated organs have a limited lifespan until they are transplanted into another compatible body. Thus, the duration from when a donor is identified to the point of transplantation is crucial in the organ donation process. As the length of time an organ stays outside the donor's body increases, the quality of the donor organ correspondingly decreases (Vroemen et al., 1984). The interval of time an organ can survive without receiving blood is known as the cold ischemia time. This represents the maximum length of time that the organ can stay outside the donor's body. (as shown in Table 3.1). This underscores the significance of the recipient’s proximity and the location of the graft.

Table 3.1: Cold ischemia time for heart, liver, and kidney (P. çay. 2012)

Organ	**Ischemia time (hr)**	**Organ removal surgery time (min)**	**Organ implantation surgery time (min)**	**Average transportation time (min)**
Heart	5	10	70	220
Liver	12	45	270	405
Kidney	18	60	450	570

As discussed earlier, countries typically use one of two primary methods to locate the most suitable match for organ transplantation, taking into account certain matching criteria: the centralized approach and the hierarchical approach. The centralized method operates off a single waiting list that spans the entire region or country. Once an organ becomes available for donation, potential recipients are prioritized based on a matching score that considers various factors. These include blood and tissue type, organ size, age of the recipient, urgency of need, duration spent on the waiting list, and geographical distance between the donor and the recipient (OPTN, 2016). The organ is then transplanted to the recipient with the highest score who meets the eligibility criteria. In the event of a mismatch, the recipient with the next best score is evaluated until a successful pairing occurs. Under this system, it's not guaranteed that a patient in the same hospital will receive the organ, despite their need and waiting status. The Eurotransplant is an example of the centralized approach, which coordinates organ allocation between seven countries including Austria, Belgium, Croatia, Germany, Luxembourg, the Netherlands, and Slovenia (Beliën et al., 2013).

In contrast, in the hierarchical approach, multiple waiting lists at the city or regional level within a country are considered for evaluation of graft transplant. As a compatible organ is identified, candidates within the first level, typically those in the donor's hospital, are reviewed. If a fitting match doesn't emerge, attention shifts to the second level, often encompassing candidates within the donor's city. This hierarchical process of evaluation proceeds through all the subsequent tiers until an appropriate recipient is located. Many countries, such as the USA, Italy, and Turkey, use this method, although it varies based on the healthcare policies in practice (Stahl et al., 2005; Alagoz et al., 2009; Kong et al., 2010; Bruni et al., 2006; Savaşer et al., 2019). The hierarchical method differs between countries according to the healthcare policies in practice. For example, In the context of Italy, the donated organ is initially transported to the organ donation center before reaching the hospital of the recipient. However, in Turkey and the United States, the organ is directly delivered to the hospital where the recipient is located.

While the centralized method is fairer, ensuring that the organ goes to the most suitable recipient, the hierarchical approach increases the likelihood of keeping the organ functional by transplanting it to the closest suitable recipient.

3.2. National Transplant System in Turkey

In Turkey, efforts have been made to increase the availability of donor organs for transplantation. In 1979, Law No. 2238 was passed to provide a legal framework for organ donation and prevent illegal organ trafficking. The Transplantation Centers Coordinators Association (TCCA) was subsequently established in 1994 with 41 founding members from 14 of the 16 transplantation centers in Turkey. This organization set up advisory boards for kidney, liver, heart, and immunology and established principles for organ transplant and distribution. The Ministry of Health established the National Organ and Tissue Transplant Coordination System in 2001 to manage organ allocation at the national level, and a web-based database system called TODS was implemented. The Organ and Tissue Transplant Services Regulation and National Organ and Tissue Transplant Coordination System (Directive No. 19735) are among the legal documents that guide the transplantation process in Turkey.

According to TDIS records, as of June 2022, while 23,610 kidneys, 173 lungs, 1321 heart, and 2439 liver patients were waiting for organ transplantation, 3930 organ transplants could be performed in Turkey (TCSBb, 2022). Although the number of organ transplants has increased over the years, there has been a remarkable increase in the number of patients waiting for organs (Figure 1.1). In addition, with the advances in surgical techniques and treatment methods in the field of health sciences, an increase of approximately 20% (from 66% to 85%) has been achieved in the survival rate of patients awaiting organs in the last ten years. As a result, since the increase in the number of patients waiting for an organ is larger than the increase in the number of transplanted patients, this network requires better management of the logistics system to maximize the benefits to those involved.

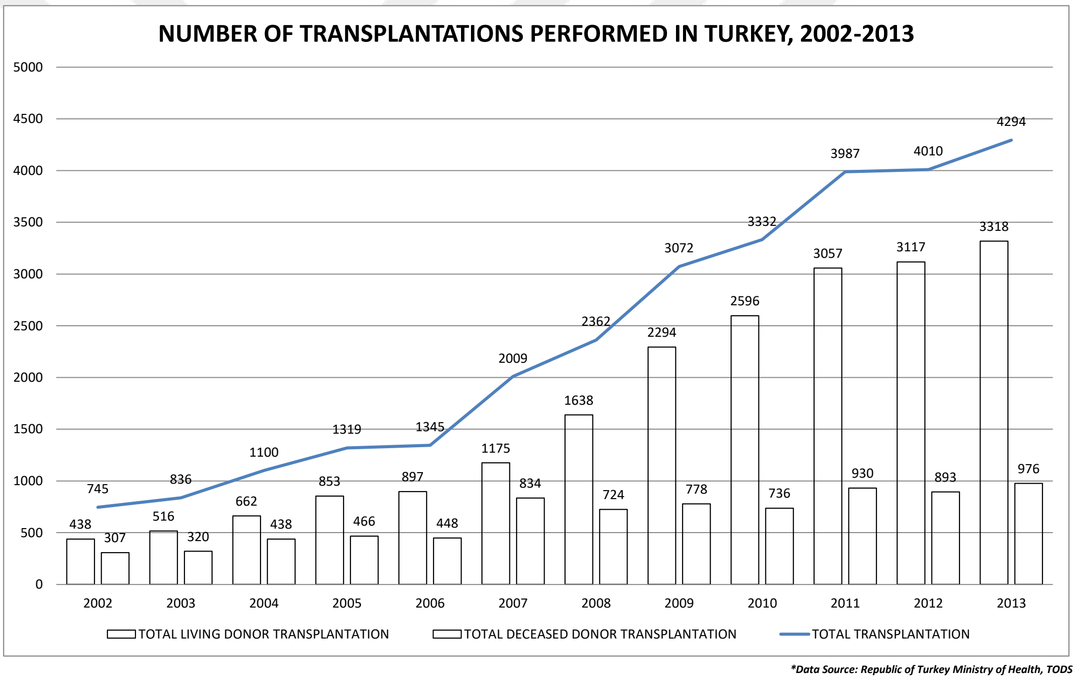

Figure 3.1: Number of transplantations performed in Turkey.

In Turkey, where the hierarchical system is implemented, organ allocations are coordinated by the National Coordination Center (NCC) and nine Regional Coordination Centers (RCC). The organizational chart of the national tissue and organ transplant coordination system in Turkey is represented in Figure 3.2.

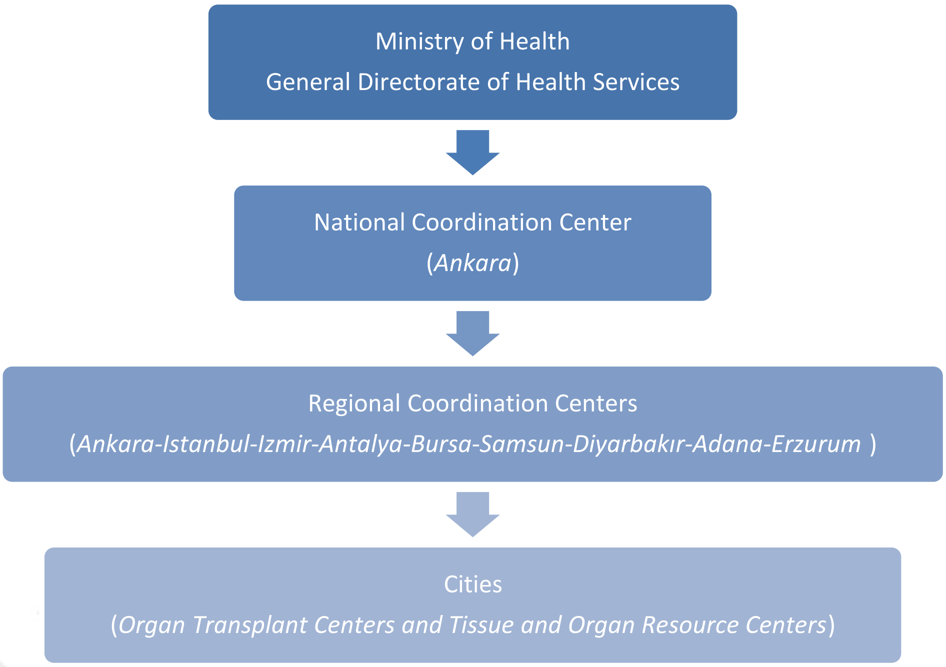

Figure 3.2: National tissue and organ transplant coordination system.

Within this organizational framework, the NCC bears the responsibility for managerial and strategic decisions within the organization, whereas the RCCs orchestrate organ transplant activities across the cities within their respective regions. Therefore, while RCCs manage calls specific to their region, the NCC oversees the communication between different RCCs. Each city is allotted exactly one RCC to guarantee effective coordination, as depicted in Figure 3.2.

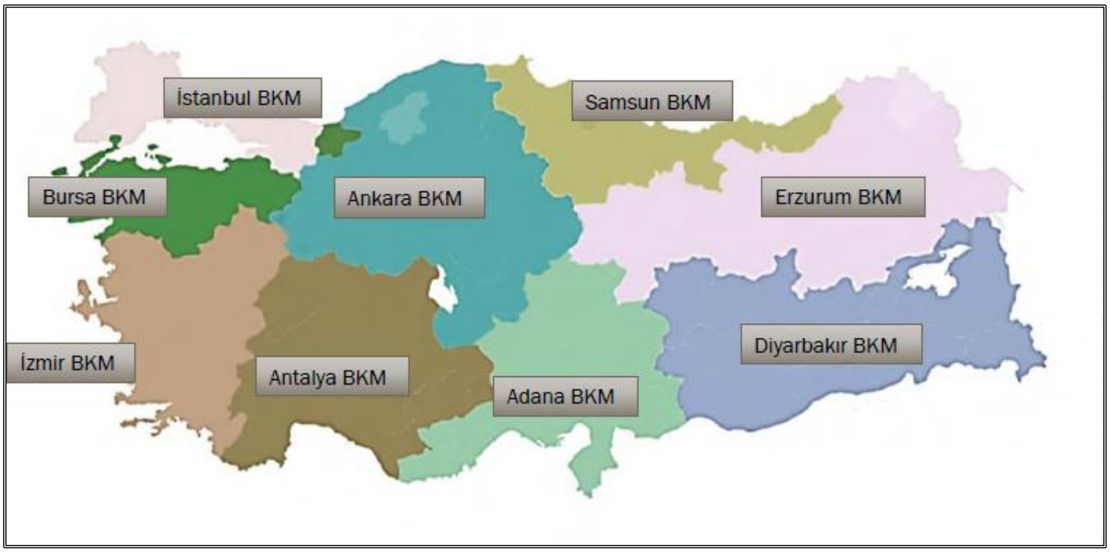

Figure 3.3: Current RCC locations in Turkey.

In some cities, it may happen that there is a higher number of potential donors compared to other cities. Not every city in the country has a hospital capable of performing organ transplants, and each suitable hospital usually specializes in only one organ type. Even if a donor exists in any province, potential recipients must only be in cities with transplantable hospitals. Therefore, each patient is registered in the system through a suitable hospital and has a separate waiting list for each organ type.

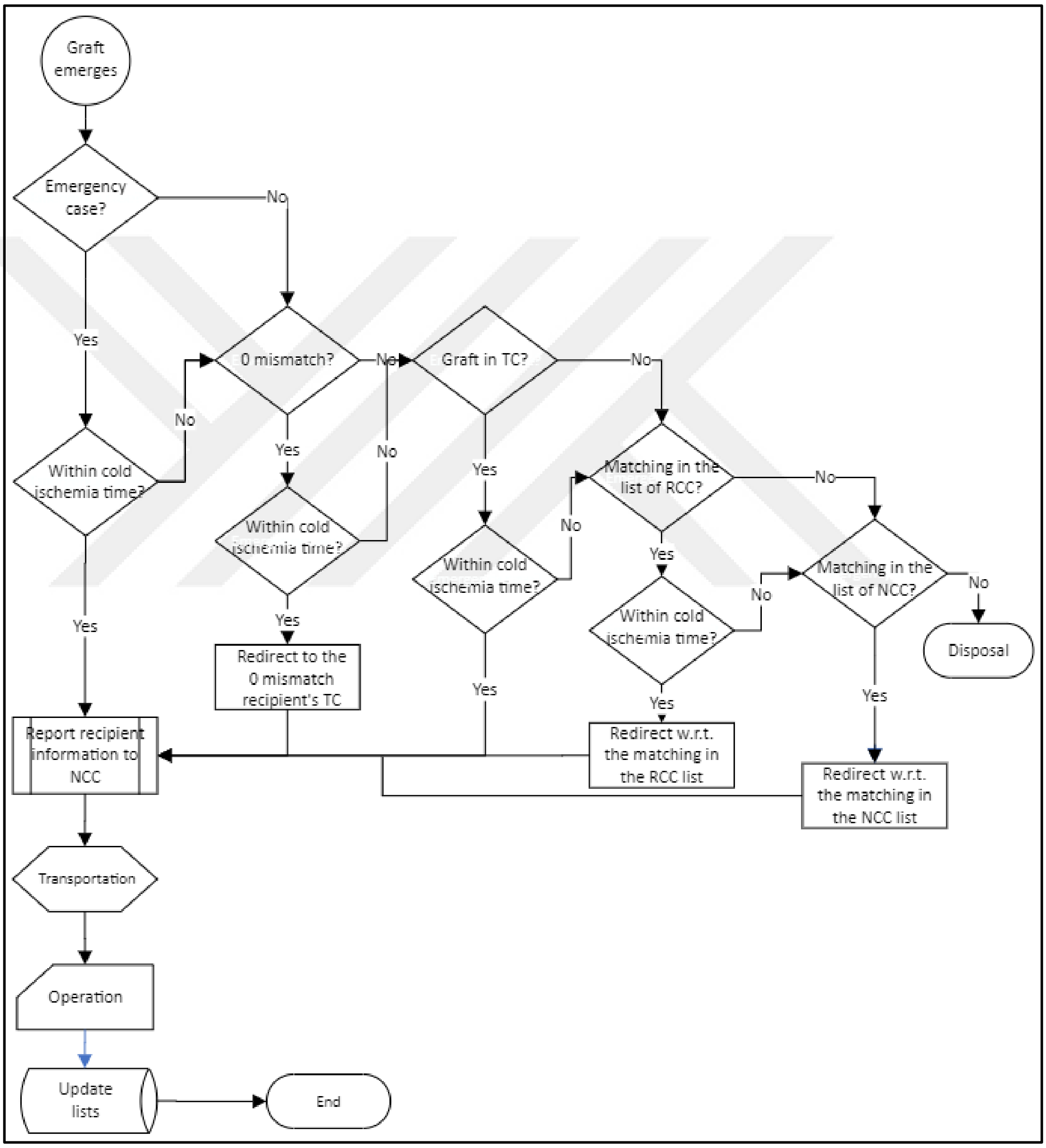

Figure 3.4: Organ transplantation process in Turkey.

The organ transplantation process in Turkey takes place according to the workflow given in Figure 3.4. The matching process starts when an organ is available.

A nationwide investigation starts at the same time to find any emergency cases. If a patient who matches the organ is found within the limits of the cold ischemia time, the organ is dispatched straight to the patient's hospital, bypassing the RCC assignment hierarchies. If no appropriate emergency patient can be found, a search is conducted for a patient who perfectly matches the organ (0 mismatch). If there is no perfect match, the NCC's waiting list comes into consideration. After every successful transfer, the waiting lists of both the RCCs and the NCC are updated dynamically.

Table 3.2: Provinces connected to regional coordination centers (UODNKSY, 2022).

Kidney Transplantation Centers		**Liver Transplantation Centers**	
City	Number of Centers	City	Number of Centers
Adana	3	Adana	3
Ankara	8	Ankara	7
Antalya	3	Antalya	3
Bursa	4	Aydin	1
Çanakkale	1	Bursa	3
Denizli	1	Diyarbakir	1
Diyarbakir	1	Elazig	1
Elazig	1	Eskisehir	1
Erzurum	1	Erzurum	1
Eskisehir	1	Gaziantep	1
Gaziantep	2	Istanbul	19
Mersin	1	Izmir	6
Istanbul	32	Kayseri	1
Izmir	6	Konya	1
Kayseri	2	Malatya	1
Konya	2	Samsun	1
Malatya	1	Sivas	1
Kahramanmaras	1	**Heart Transplantation Centers**	
Mugla	1	City	Number of Centers
Sakarya	1	Ankara	4
Samsun	1	Antalya	1
Sivas	1	Bursa	1
Lung Transplantation Centers		Istanbul	7
City	Number of Centers	Izmir	2
Istanbul	2		

In subsequent stages of the hierarchical system, a compatible donor-recipient pair might be identified, but the transit time may exceed the permissible cold ischemia duration. Consequently, the organ can't be transported. While apt matching criteria significantly enhance the chances of a successful transplant, the overall system might falter if the organizational architecture of the transplant system isn't optimally designed. Therefore, the supply and transport network of the system greatly influences the overall success. The Air Ambulance system, which is currently operating with thousands of land ambulances, airplanes, and helicopters under the responsibility of the Ministry of Health, is used to support the transportation of organs and transplant teams in addition to its main duties.

Kidney extraction from cadaver donors originating in organ and tissue resource centers is performed by transplant centers in provinces affiliated to RCC (Table 2.1) and sequentially according to Appendix A.

3.3. Proposed Mathematical Model

In this portion, we define the problem and construct an optimization model to identify the best clusters for the organ transplantation system. The model aims to reduce the potential-weighted transportation cost or time within a single cluster.

3.3.1. Problem Description

Given that this study aims to examine the impact of clustering on potential matches, the primary objective of the mathematical model is to cultivate clusters that maximize the potential for timely transportation in the first layer. Consequently, the mathematical models do not account for the hierarchical matching process. As the number of donated organs is significantly fewer than the number of recipients, there's a high likelihood that an available organ will find a match with a patient within the same region. Moreover, the unpredictability of certain aspects of the process, including emergency situations, matching probabilities, and supply and demand dynamics, are challenging to encapsulate in a MILP (Mixed Integer Linear Programming) formulation, thereby necessitating approaches like robust optimization.

In this research, the devised model takes into account a realistic and comparatively intricate transplant network that includes donors, recipients, hospitals, Transplant Centers (TCs), and RCCs. Two elements are particularly crucial: i) dividing countries into distinct regions; and ii) orchestrating the organ supply chain within these regions and the interplay between different regions. The focus is on the first element. For model simplification, the transplant network is established at the regional hierarchy level and model its interrelation with other districts within the county. The mathematical model should provide answers to the ensuing questions: 1) Where are the TCs and RCCs situated? 2) Which cities are assigned to these RCCs? 3) Which TCs and hospitals undertake organ extraction operations for which donors? 4) Where are transplant surgeries carried out for regional recipients? 5) What's the volume of organ flow from facilities to recipient TCs? 6) What transport methods are employed for shipping?

3.3.2. Formulation of the Basic Model

In this segment, the mixed-integer linear programming (MILP) model is presented, operating under the presumption of deterministic supply and demand. The fundamental assumptions, collections, parameters, and decision variables are delineated as follows.

- The positions of extraction hospitals and transplant centers are established.
- Each city is assigned precisely to one RCC.
- The total count of RCCs is admited.
- The total transportation time between a donor hospital and the TC should not exceed the cold ischemia time.
- After extraction, the organs are transferred to the transplant centers as soon as possible.

3.3.2.1. Formulation of the location – allocation model (M1)

In this section, we formulate the organ transplant system design problem as a 0-1 Integer Programming (IP) model, assuming the deterministic number of organ donors and patients. The main assumptions, sets, parameters, and decision variables are defined below.

- The location of removal hospitals and transplant centers are known.
- Each city is allocated to exactly one RCC.
- Total number of RCCs is known.
- The total transportation time between a donor hospital and the TC should not exceed the cold ischemia time.
- After extraction, the organs are transferred to the transplant centers as soon as possible.

• Sets	
• $\mathcal{M}$	• Set of locations for donor cities, $m = \{1,2,\dots,\mathcal{M}\}$
• $\mathcal{N}$	• Set of locations for cities having TCs, $n = \{1,2,\dots,\mathcal{N}\}$
• $\mathcal{K}$	• Set of potential locations for RCCs, $k = \{1,2,\dots,\mathcal{K}\}$

• Parameters	
• p	• Total number of RCCs to be located
• T	• Ischemia time
• $\tau_{m,n}$	• Terrestrial travel time between cities $m \in \mathcal{M}$, and $n \in \mathcal{N}$
• d_m	• The number of organs donated for transplantation in city $m \in \mathcal{M}$
• r_n	• The number of organ recipients for each city $n \in \mathcal{N}$
• pr_n	• Weight (priority) of city n having TC(s) $n \in \mathcal{N}$

• Decision Variables	
• $x_{m,k}$	• 1 if m is assigned to RCC at k, 0 otherwise
• $z_{m,n,k}$	• 1 if city m served by the same RCC at k donates the organ to recipient n, 0 otherwise
• y_k	• 1 if RCC is located at k, 0 otherwise
•	•

Using the defined notations, the objective function and constraints can be formulated as follows:

The objective of the organ transplant network problem here is to choose RCC locations and allocated cities to make the total delivery time (cost) within the same cluster as low as possible. So, the objective function that we wish to minimize:

$$Min \quad \sum_{m\in\mathcal{M}} \sum_{n\in\mathcal{N}} \sum_{k\in\mathcal{K}} pr_n \cdot z_{m,n,k} \cdot \tau_{m,n}$$

The donor intending to donate a particular organ in city m is served by only one RCC which it has coordinate organ transplants between cities in their regions.

$$\sum_{k\in\mathcal{K}} x_{m,k} = 1 \qquad \forall m \in \mathcal{M}$$

The number of RCCs is set to p.

$$\sum_{k\in\mathcal{K}} y_k = p$$

A recipient of a regional cluster can be transferred to a TC only if the TC has been allocated to that region already, i.e., a recipient should not be assigned to a non-existing RCC.

$$x_{m,k} \leq y_k \qquad \forall m \in \mathcal{M}, \forall k \in \mathcal{K}$$

If the city is an RCC, then it should be assigned to itself.

$$y_k \leq x_{k,k} \qquad \forall k \in \mathcal{K}$$

A particular organ is only transferred to a specific TC for transplantation from a facility equipped to remove the organ to a recipient within the ischemia time.

$$z_{m,n,k} \cdot \tau_{m,n} \leq T \qquad \forall m \in \mathcal{M}, \forall n \in \mathcal{N}, \forall k \in \mathcal{K}$$

Possible donor-recipient matches must be ensured between cities assigned to the same RCC.

$$z_{m,n,k} = x_{m,k} \cdot x_{n,k} \qquad \forall m \in \mathcal{M}, \forall n \in \mathcal{N}, \forall k \in \mathcal{K}$$

However, this constraint set is nonlinear and must be linearized. When the following constraints are added instead of the nonlinear constraint set, the final mixed integer linear programming formulation is obtained.

$$z_{m,n,k} \leq \frac{x_{m,k} + x_{n,k}}{2}, \qquad \forall m \in \mathcal{M}, \forall n \in \mathcal{N}, \forall k \in \mathcal{K}$$

$$z_{m,n,k} \geq x_{m,k} + x_{n,k} - 1, \qquad \forall m \in \mathcal{M}, \forall n \in \mathcal{N}, \forall k \in \mathcal{K}$$

Finally, the domain of decision variables can be defined as follows.

$$x_{m,k}; y_k; z_{m,n,k} \in \{0,1\} \text{ and } w_{m,n,k} \geq 0$$

In short, the basic 0-1 integer programming model is built as follows:

$$Min \quad \sum_{m\in\mathcal{M}}\sum_{n\in\mathcal{N}}\sum_{k\in\mathcal{K}} pr_n \cdot z_{m,n,k} \cdot \tau_{m,n} \tag{3.1}$$

subject to

$$\sum_{k\in\mathcal{K}} x_{m,k} = 1 \qquad \forall m \in \mathcal{M} \tag{3.2}$$

$$\sum_{k\in\mathcal{K}} y_k = p \tag{3.3}$$

$$x_{m,k} \le y_k \qquad \forall m \in \mathcal{M}, \forall k \in \mathcal{K} \tag{3.4}$$

$$y_k \le x_{k,k} \qquad \forall k \in \mathcal{K} \tag{3.5}$$

$$z_{m,n,k} \cdot \tau_{m,n} \le T \qquad \forall m \in \mathcal{M}, \forall n \in \mathcal{N}, \forall k \in \mathcal{K} \tag{3.6}$$

$$z_{m,n,k} \le \frac{x_{m,k} + x_{n,k}}{2} \qquad \forall m \in \mathcal{M}, \forall n \in \mathcal{N}, \forall k \in \mathcal{K} \tag{3.7}$$

$$z_{m,n,k} \ge x_{m,k} + x_{n,k} - 1 \quad \forall m \in \mathcal{M}, \forall n \in \mathcal{N}, \forall k \in \mathcal{K} \tag{3.8}$$

$$x_{m,k}; y_k; z_{m,n,k} \in \{0,1\} \quad \forall m \in \mathcal{M}, \forall n \in \mathcal{N}, \forall k \in \mathcal{K} \tag{3.9}$$

3.3.2.2. Network flows formulation (M2)

This model adds the flows between donor and recipient cities to the M1. New parameters and one additional decision variable are defined as follows.

Decision Variables	
$w_{m,n,k}$	Total number of potential organs matches between cities $m \in \mathcal{M}$ and $n \in \mathcal{N}$ in the region of RCC $k \in \mathcal{K}$

Organ flow between two cities can be defined by taking the minimum of potential organ donations and recipients.

$$w_{m,n,k} \le d_m \cdot z_{m,n,k} \qquad \forall m \in \mathcal{M}, \forall n \in \mathcal{N}, \forall k \in \mathcal{K} \tag{3.10}$$

$$w_{m,n,k} \le r_n \cdot z_{m,n,k} \qquad \forall m \in \mathcal{M}, \forall n \in \mathcal{N}, \forall k \in \mathcal{K} \tag{3.11}$$

Total number of organs transported to a TC from donor cities mustn't be less than total number of transplantations in this TC.

$$\sum_{m \in \mathcal{M}} \sum_{k \in \mathcal{K}} w_{m,n,k} \geq r_n \qquad \forall n \in \mathcal{N} \tag{3.12}$$

4. COMPUTATIONAL RESULTS AND SENSITIVITY ANALYSIS

The use of the General Algebraic Modeling System (GAMS) is investigated in this study to improve the distribution of Regional Coordination Centers (RCCs) for organ transplants throughout a network of possible donor cities. To reflect the operational dynamics of organ transplantation operations, a mathematical model is built, and its solution is obtained utilizing GAMS' computational capabilities.

The effective allocation of Regional Coordination Centers (RCCs) is critical in the time-sensitive process of organ transportation and has a significant impact on the success rate of transplant surgeries. Possible solutions for placing RCCs can be examined using mathematical modeling and optimization tools, with the goal of lowering weighted trip time while complying to the system's restrictions.

The mathematical model's primary goal is to discover the most ideal RCC locations that reduce overall weighted travel time from donor cities to RCCs. The model includes binary indicators for city selection as an RCC and city assignment to RCCs, as well as variables denoting the significance (referred to as *weight*) of each city-transplant center pair. This weight reflects the priority given to cities when they are allocated to the same RCC, and it is factored into the objective function. Multiple constraints apply to the concept, including the necessity that each city be allocated to precisely one RCC, limits on the overall number of RCCs, and the ability for a city to serve as its own RCC.

The model is executed for several organs, each with its own set of parameters such as the required number of RCCs to be located and the ischemia time. The model returns results for each iteration, including the selected RCCs and the cities assigned to each RCC. GAMS's robustness allows for the quick resolution of this complicated model, providing vital insights into the best distribution of RCCs across the network.

To find near optimal solution for the large-scale problem instances in reasonable CPU times, the model is devised in 2 steps. Also, knowing that it’s a complex model it is suggested to use a high performancecomputer.

This chapter is dedicated to conducting computational studies aimed at evaluating the mathematical models proposed in earlier sections of the thesis. The implementation of these models involved utilizing GAMS as the programming language, while the computational experiments were carried out on a computer system equipped with an Aspire Nitro5 Intel(R) Core (TM) i5-9300H CPU running at 2.40MHz and 16.0 GB of RAM.

To solve the mathematical model, the CPLEX solver was employed due to its well-established reputation for efficiently handling mixed-integer linear programming problems. The selection of this hardware configuration and solver reflects a deliberate effort to strike a balance between computational efficiency and solution accuracy.

These computational experiments play a crucial role in assessing the performance and robustness of the proposed mathematical models. By providing valuable insights into their effectiveness and practical applicability within real-world contexts, these studies contribute to a comprehensive evaluation of the models' capabilities.

4.1. Data Analysis

The organ transplantation data used in this thesis were obtained from Bilkent University's database, which may be accessed at the following website https://ie.bilkent.edu.tr/bkara/dataset.php. This dataset is an essential resource for researching many aspects of organ transplantation, such as the variables that impact transplant success and post-operative outcomes. We have updated the populations of the cities, the TC list, etc. in this dataset according to the most recent values. In this part, an overview of the data gathered, describes its structure, and explain its significance to this study.

The dataset comprises information on organ transplantation centers, donors, and recipient waiting lists. The dataset contains information on the distribution of organ transplantation centers in major Turkish cities. With 32 transplantation centers, Istanbul, the most populated city, has the most transplantation centers, mainly for kidney transplants. Ankara and Izmir are two more large cities having significant transplantation centers. Ankara, the capital city, has 8 kidney, 7 liver, and 4 heart transplantation centers, while Izmir has 6 kidney, 6 liver, and 2 heart transplantation centers. Smaller cities including Adana, Antalya, and Bursa are also involved in organ transplantation, with centers for kidney, liver, and, in certain circumstances, heart transplants. The research also suggests that lung transplantation centers are limited, with just two in Istanbul. The geographic dispersion of these centers emphasizes the significance of extending access to organ transplantation services and ensuring that patients from all areas have access to life-saving transplants in a timely way.

Next, the given statistic depicts the possible number of organ suppliers in various cities. These values may illustrate the possible availability of organs for transplantation in each city, considering factors such as population, demography, and organ donation rates. The data shows that prospective organ supplies vary greatly among cities, with some cities having much larger potential organ supplies than others.

Istanbul, for example, has the largest potential organ supply (43,678), followed by İzmir (34,697) and Konya (19,706). Some cities, on the other hand, have far lower prospective organ supply, with scores below 100, such as Tunceli, Bayburt, and Ardahan. This gap in prospective organ supply emphasizes the significance of efficient organ allocation and transportation networks to guarantee that organs are successfully delivered to patients in need, regardless of where they are located.

Understanding prospective organ supply in various locations can assist in influence efforts for increasing organ donation rates, promoting equal access to transplantation services, and optimizing the organ allocation process. Healthcare practitioners and politicians may work together to ensure that all patients have an equitable opportunity to receive life-saving transplants by addressing inequities in organ supply and enhancing organ distribution networks.

In the end, the dataset shown in the Excel file contains statistics on the number of patients on organ transplant waiting lists in various cities. This data demonstrates the increasing demand for organ transplantation as well as the discrepancies in the number of people waiting for organs in various places.

The latest data of 2022 have shown that overall, the potential donors increased to 586,456 people, while they saved only 3,854 donors. This disparity reveals a significant unmet potential for organ donation and underscores the importance of intensified efforts to close this gap.

The data reveals that there is a large pool of people who are medically qualified to be organ donors, but the number of actual donors remains low (see Appendix B). This might be due to several circumstances, including a lack of awareness and understanding of organ donation, cultural or religious attitudes, and practical difficulties in the organ procurement procedure. Efforts should be undertaken to educate the public about the necessity of organ donation and to debunk myths regarding the procedure.

Furthermore, it is critical to enhance infrastructure and speed uporgan donation procedures in order to maximize the use of potential donors. Improving coordination across healthcare institutions, transplant centers, and organ procurement organizations can contribute to a more efficient and coordinated strategy to locating and acquiring organs from suitable donors.

Furthermore, the data can aid in the identification of possible mismatches between organ availability and demand in various locations, supporting efforts to improve organ allocation and transportation to guarantee that available organs are successfully delivered to patients in need, regardless of their location.

The organ transplantation data gathered from the Bilkent University database is critical for our research since it’s allowing the researcher to assess the factors that determine the success and failure of organ transplantation surgeries. By analyzing this data, patterns, and trends that might assist in improving patient outcomes and optimizing the allocation of available organs can be found.

4.2. Computational Experiments

The mathematical model implemented in the experiment aimed to optimize the assignment of cities to RCCs based on an objective function. This function sought to balance a variety of critical factors including the importance or weight of connecting different cities to RCCs, the time of transportation between the cities and the RCCs, among other considerations.

As shown in Figure 4.1, the first selected list of RCCs is as below Ankara, Balikesir, Trabzon, Diyarbakir, Samsun, Sakarya, Adana, Isparta, and Van for the organ kidney.

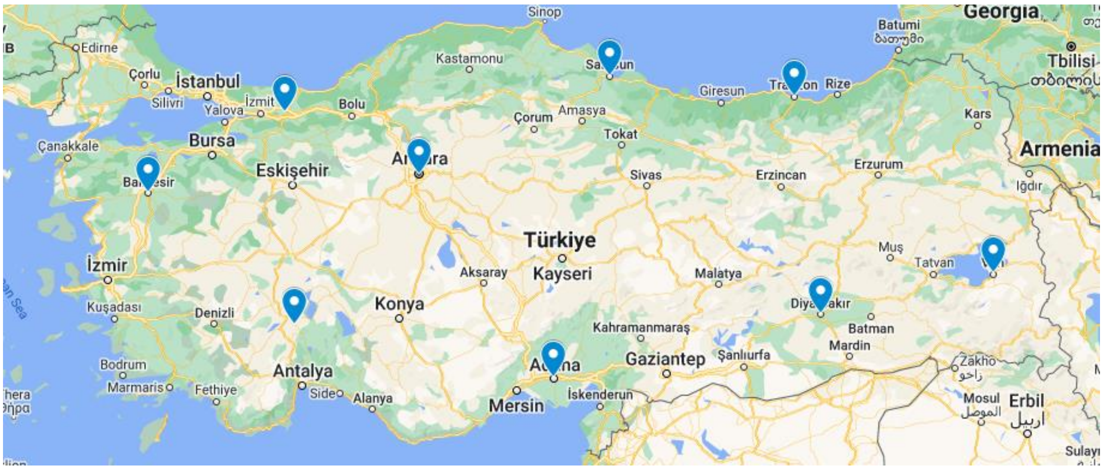

Figure 4.1: The primary result of the mathematical model.

The computational experiment results of M1 displayed the distribution of cities to each selected RCC, showing which cities were assigned to which RCCs. This assignment was based on the model's objective function and the constraints introduced to ensure a feasible and practical solution. The objective value obtained in the experiment was 58843.94, indicating the minimum travel time multiplied per the total potential number of kidney matches found by the model.

Following an assessment, the RCC of Ankara was awarded the most cities, suggesting that it serves as a hub for kidney transplantation. The model included aspects such as proximity, organ availability, and demand in the allotted cities, resulting in an apparent concentrated solution.

Yet, it is important to highlight that the interpretation of these results is dependent on the specific description of the variables in the objective function. Due to the lack of precise definitions in the experiment, this interpretation is somewhat generic and should be confirmed using explicit definitions.

Certain cities, such as Hakkari, did not appear in the ultimate output of a computer experiment involving the allocation of cities to different Regional Coordination Centers (RCC). This phenomenon might be traced to the model's limitations and parameters. For example, unique logistical, topographical, or resource constraints may have limited the practicality of immediately assigning an RCC to Hakkari. Other considerations might be the size, population, or amount of need for the RCC's services in Hakkari.

Despite not showing up in the computational output, these cities are not overlooked in the actual implementation. In fact, a common practice in such models is to automatically assign cities like Hakkari to the closest available RCC. This approach helps ensure that all areas receive the necessary coverage and resources, despite the logistical and practical challenges that may arise. The process of automatic assignment also underscores the flexibility and adaptability of the model, as it strives to optimize resource allocation while ensuring comprehensive coverage across all areas. It demonstrates how computational models can work alongside real-world judgment and decision-making to provide the best possible outcomes.

While the model chose Balikesir as the best RCC site, Izmir, a larger city with numerous transplant clinics, might be a more effective hub. Izmir is Turkey's third most populated city, and it is home to a large number of modern healthcare facilities, including multiple transplant centers. As a result, Izmir already has a large proportion of both donors and receivers. The city's significant healthcare infrastructure, along with its transportation networks, allows it to serve a larger geographical and logistical catchment area. As a result, choosing Izmir over Balikesir may better serve a bigger population and give more fast access to organ transplant treatments, thereby shortening ischemia periods and enhancing transplant success rates.

The similar argument may be applied to Sakarya's selection as an RCC over Istanbul. Istanbul, Turkey's largest city and a worldwide metropolis, is home to several of the country's most renowned and advanced healthcare facilities, including a substantial number of transplant clinics. It is one of the top cities for organ transplantation, having a huge donor base and a significant number of potential recipients. Its better transportation infrastructure, which includes an international airport, also gives a significant advantage in terms of organ accessibility and speed of delivery, both of which are critical variables in successful transplant results. In the heavily populated Marmara area, replacing Sakarya with Istanbul as an RCC might potentially maximize the utilization of existing healthcare and logistical facilities and provide greater coverage.

While the present model has established a good foundation for prospective RCC allocation across Turkey, it is crucial to note that these results are not final and might be adjusted further. The model must be continuously evaluated and improved due to the complexity of organ transplant logistics. Several factors, including demographic changes, advances in medical technology, improvements in transportation infrastructure, and alterations in healthcare policy, can all have a substantial impact on the best placement of RCCs. Furthermore, the model might be improved by taking into account more precise data, such as particular organ transplantation rates, success rates associated with ischemia periods, and shifting priorities of various organ transplants. This iterative technique will not only increase the model's accuracy but also its effectiveness in real-world applications., ensuring a more efficient and fair organ transplantation network across Turkey.

Next, in order to cope with the complexity of the researcher divide the model into small, medium and full-sized model by reducing the number of RCC to the minimum.

4.2.1. Small – Size Problem Instance

This mixed-integer programming model provides a sophisticated mechanism for allocating Regional Collection Centers (RCCs) for organ transplantation among different Turkish cities. Adana, Hatay, Mersin, Ankara, Nigde, and Cankiri are among the cities under consideration in this concept. The parameters established by the model represent the important characteristics of each city as well as their potential involvement in organ transplantation logistics. The essential restrictions of the model are dictated by parameters such as pp, which represents the total number of RCCs to be found, and TT, which defines the maximum permissible ischemia duration. Other factors, such as TC, which indicates the presence of a Transplant Center in a city, $ratio$, which explains the organ transplantation ratio, and t and h, which enumerate terrestrial trip time and transit distance between cities, offer more comprehensive data of the transplantation process.

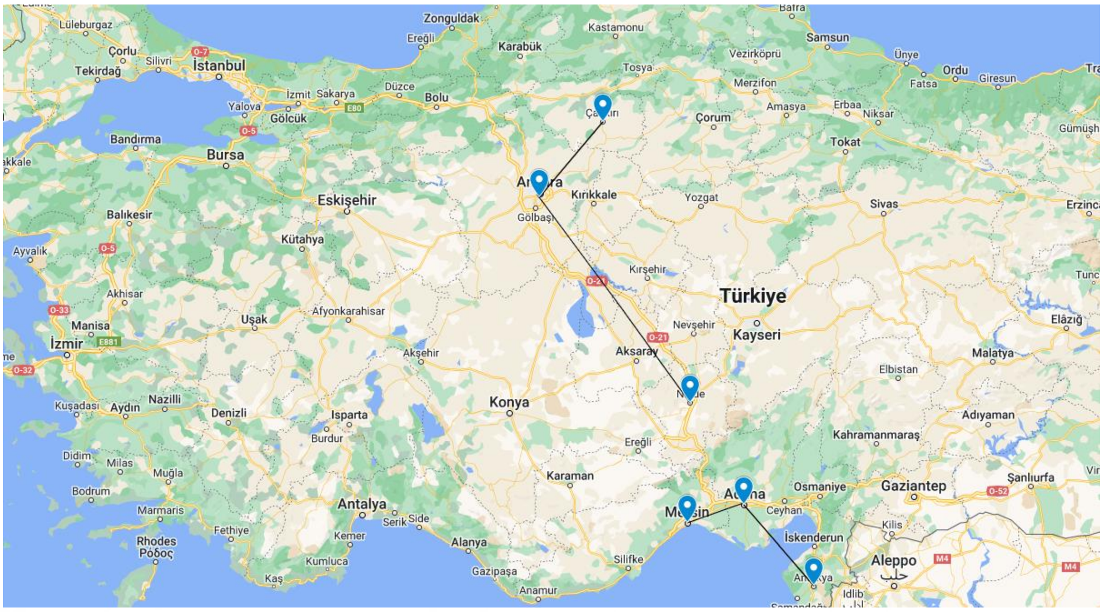

Figure 4.2: Small – size model result

The presented approach was effective in optimizing the placement of Regional Collection Centers (RCCs) for organ transplantation, with an objective value of 88.01. This implies that the total organ delivery time throughout the cities analyzed has been significantly reduced. The model's results identify two cities, Adana and Ankara, as the best places to develop RCCs.

When it comes to allocating cities to these RCCs, Adana has been chosen as an RCC and will also function as the major center for organ collecting and distribution for two additional cities, Hatay and Mersin. This indicates that organs obtained from these places would be routed through the RCC in Adana, taking into account the model's limits and parameters.

Similarly, Ankara has been designated as another RCC. Ankara has been recognized as the principal organ collection and distribution location for two more cities, Nigde and Cankiri, in addition to being a donor city. This choice is consistent with the model's goal of providing a streamlined and efficient organ transport procedure while adhering to crucial medical limitations like maximum permissible ischemia duration.

In summary, our optimization model has effectively mapped an organ transportation network that reduces overall organ delivery time in the locations under consideration.

4.2.2. Medium – Size Problem Instance

The ideal solution was obtained with an objective value of 782.66 in the optimization analysis for the allocation of kidney transplantation services in Turkey. This suggests that our improved model will result in a much shorter distance traveled by renal patients to the nearest Renal Care Center (RCC).

The best solution has identified Adana, Bursa, Istanbul, and Van as RCCs, suggesting that these cities are most suited to serve as principal centers for kidney transplantation based on existing demand distribution and the requirement to decrease travel distances.

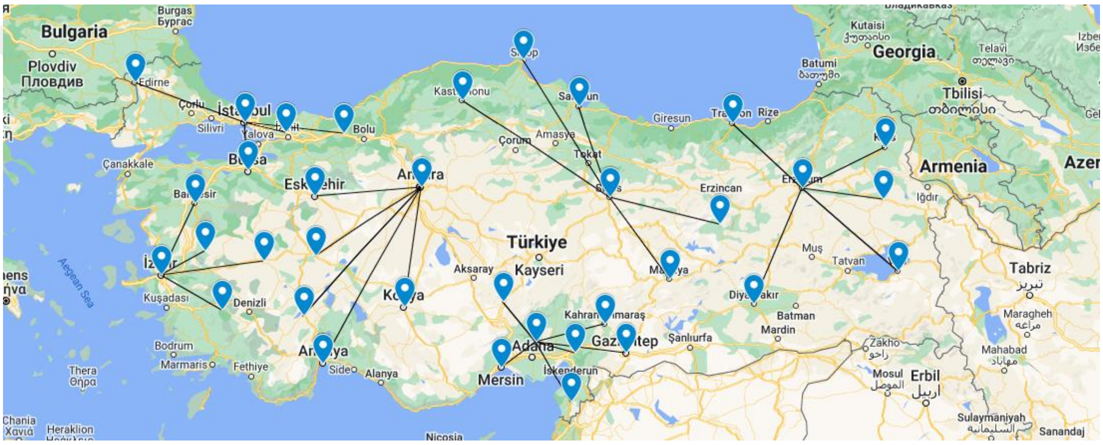

Figure 4.3: Medium – size model result

The allotment implies a smart distribution around the country, easing access for patients from surrounding cities. It should be highlighted that this optimal approach assumes medical service and facility homogeneity among RCCs. Real-world implementation should take into account aspects such as RCC capacity, medical competence, and local infrastructure to ensure that the allocation does not overburden RCC resources. In addition, future versions should take into account changes in demand patterns, demographic shifts, and healthcare advances for periodic reallocation and optimization.

4.2.3. Large – Size Problem Instance

While the current model's optimization analysis was effective in delivering an optimal solution for the allocation of kidney transplantation services in Turkey, it encountered difficulties when applied to a bigger issue size. The greater model's complexity exceeded the processing capabilities of the present system, prohibiting it from providing results. However, based on the initial results, we can forecast the probable consequences and ramifications of implementing the model on a bigger scale.

Scaling up the methodology to tackle greater issue sizes holds the prospect of improving kidney transplantation service allocation even more. The enhanced approach may better respond to the demands of a broader population and further minimize travel distances for patients seeking kidney transplants with a larger dataset comprising a higher number of cities and RCCs. However, to overcome the increasing complexity, such an endeavour needs advanced computational resources and procedures.

To overcome the processing power limits of the existing system, parallel computing or cloud computing is highly recommended. Parallel computing is dividing large computational workloads into smaller, more manageable subtasks that may be executed concurrently across numerous processors or computer nodes. By dispersing the effort and leveraging the power of parallel computing, this strategy may dramatically expedite the optimization process.

Cloud computing resources, on the other hand, can provide scalable and on-demand computational capacity, enabling for the efficient execution of larger-scale optimization models. Cloud-based systems provide the dynamic allocation of computing resources depending on the individual demands of the optimization issue, allowing for the study of larger datasets in an acceptable period.The optimization approach may be modified to meet larger-scale difficulties by employing parallel computing or cloud computing capabilities, accommodating a greater number of cities, RCCs, and other important elements. This will improve the precision and efficiency with which kidney transplantation services are allocated, resulting in better healthcare outcomes and more access to treatment for patients across the country. Furthermore, as technology advances and computational resources become more widely available, the use of parallel computing and cloud computing in healthcare optimization models will become more common, allowing for more efficient allocation of healthcare resources and improved decision-making processes.

5. CONCLUSION

The research represents a significant leap in the use of mathematical optimization, notably mixed integer programming models, to address difficult real-world issues like organ transplantation logistics. The study shows the application of abstract mathematical methods to actual, country-specific problems with substantial health effects by concentrating on Turkey's geographical environment.

The model provides insights on the best location of RCCs across Turkey's unique and broad geography. It employs a rigorous mathematical technique to propose a prospective RCC architecture that tries to reduce overall organ delivery time. This primary goal emphasizes the importance of speed in organ transplantation, as every minute can literally mean the difference between life and death.

The model considers a wide variety of variables, exhibiting its comprehensive and multifaceted character. It takes into account the ischemia time, which is the time when an organ is still viable for transplantation. This element adds a biological restriction to the model, tying it to the reality of organ transplantation science.

A recent study bears some conceptual parallels with the current study (Savaser et al., 2018). Both research focus on the important issue of effective organ transplantation logistics, stressing the potentially life-saving benefits of greater operational efficiency. Each research makes use of mathematical optimization approaches to provide insights into this complicated system, demonstrating the ability of modern computational models in tackling challenging real-world issues. Both studies, albeit diverse in their particular, highlight the need of taking into account several aspects in organ transplantation, such as ischemia duration, recipient priority, and transit logistics.

Both acknowledge the importance of RCCs in the network and attempt to provide an ideal distribution that minimizes total delivery times. As a result, Çay's work may be viewed as a forerunner to the current study, establishing the framework for the use of mixed-integer programming models in the domain of organ donation logistics. This academic lineage highlights the significance of iterative research and the continual pursuit of greater operational efficiency in the organ transplantation network.

5.1. Main Contributions

With this study, Turkey's organ transplantation system was modeled, and the regional sharing and coordination structure was tried to be rearranged. The main contributions of this research are listed below:

- One of the main contributions of this study is to highlight logistics issues in organ transplantation and guide decision-makers when optimizing these systems.
- We tried to find the most suitable clusters for hierarchical systems. Our method improves system performance by minimizing the potential weighted transport distance and highlighting critical cities that define the average travel time limits in a cluster.
- Also, by shortening the transportation time from the donor city to the recipient city, we increase the time allotted for the surgery, which indirectly improves the performance of the surgery and thus increases the probability of a successful transplant.
- We hope that this study can be extended to other countries using a similar hierarchical organ transplant system.

5.2. Limitations and Recommendations

Despite the tremendous advances achieved by this work, several limitations must be acknowledged. To begin, the intricacy of the optimization model, together with the quantity of the data collection, offers significant computing hurdles. Given the enormity of the problem and the sophisticated network of organ donation logistics that spans a whole country like Turkey, putting the concept into action can be time-consuming. This can be a significant constraint, particularly in the context of organ transplantation, where time is of the essence. It's also worth mentioning that the model's execution is strongly reliant on the computational capabilities of the local hardware, which may limit researchers without access to high-performance computer resources.

Given these constraints, future research should investigate the use of modern computing techniques such as parallel computing and cloud-based solutions to increase computational efficiency. Parallel computing, which divides the issue into smaller portions that can be addressed concurrently, has the potential to greatly reduce the time necessary to execute the optimization model. Cloud computing, on the other hand, may give researchers with access to strong computational resources without requiring a significant initial investment in hardware. Furthermore, cloud systems frequently provide built-in parallel computing capability, as a result, they are an appealing alternative for executing complicated and data-intensive models. Using these technologies might enable more frequent and dynamic optimization, allowing the organ transplantation network to respond to changes in organ availability, demand, and other important parameters more quickly.

Furthermore, the accuracy and applicability of the optimization outcomes are heavily influenced by the quality and timeliness of the data used. This study employs a static data collection, which may overlook temporal fluctuations in parameters such as organ availability, demand, and transportation network circumstances. While this data is a good place to start when modeling and improving the organ transplantation network, using outdated or erroneous data might result in unsatisfactory or misleading outcomes.

As a result, future research should try to add real-time or near real-time data into the model. This would offer a more accurate view of the present condition of the organ transplantation network and allow for the development of solutions more suited to the system's immediate requirements. Utilizing technical improvements in data gathering and transmission, such as the Internet of Things (IoT) and advanced data analytics platforms, might make real-time data integration easier. These would enable the model to react to changes and provide more accurate and timely responses by allowing for continuous monitoring and updating of important parameters.

However, it's crucial to remember that employing real-time data comes with its own set of obstacles, such as the need for a solid data infrastructure, strong data privacy and security safeguards, and efficient algorithms capable of managing continuous streams of data. Nonetheless, addressing these obstacles has the potential to dramatically increase the performance of the organ transplantation logistics model, resulting in better patient outcomes and a more efficient healthcare system.

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APPENDICES

APPENDIX A – ORDER OF ORGAN AND TISSUE INTAKE/EXTRACTION

No	Cities	Centers	Date (1)	Date (2)	Date (3)	Date (4)	Date (5)
1	ADANA	Çukurova Üniversitesi Tıp Fakültesi Hastanesi					
2	ANKARA	Ankara Üniversitesi Tıp Fakültesi Hastanesi					
3		Başkent Üniversitesi Tıp Fakültesi Hastanesi					
4		Gazi Üniversitesi Tıp Fakültesi Hastanesi					
5		G.A.T.A. Hastanesi					
6		Hacettepe Üniversitesi Tıp Fakültesi Hastanesi					
7		Türkiye Yüksek İhtisas Eğitim ve Araştırma Hastanesi					
8		Ankara Etlik İhtisas Hastanesi					
9		Ankara Numune Eğitim ve Araştırma Hastanesi					
10	ESKİŞEHİR	Osmangazi Üniversitesi Tıp Fakültesi Hastanesi					
11	ANTALYA	Akdeniz Üniversitesi Tıp Fakültesi Hastanesi					
12	İSTANBUL	İstanbul Üniversitesi İstanbul Tıp Fakültesi Hastanesi					
13		İstanbul Üniversitesi Cerrahpaşa Tıp Fakültesi Hastanesi					
14		Marmara Üniversitesi Tıp Fakültesi Hastanesi					
15		Özel Memorial Hastanesi					
16		Özel Florence Nightingale Hastanesi					
17		Yeditepe Üniversitesi Tıp Fakültesi Hastanesi					
18		Haydarpaşa Numune Eğitim ve Araştırma Hastanesi					
19		Dr. Lütfi Kırdar Kartal Eğitim ve Araştırma Hastanesi					
20		Özel Medicana Hastanesi					
21		Özel Hizmet Hastanesi					
22		Özel Gaziosmanpaşa Hastanesi					

No	Cities	Centers	Date (1)	Date (2)	Date (3)	Date (4)	Date (5)
23	BURSA	Uludağ Üniversitesi Tıp Fakültesi Hastanesi					
24	İZMİR	Dokuz Eylül Üniversitesi Tıp Fakültesi Hastanesi.					
25		Ege Üniversitesi Tıp Fakültesi Hastanesi					
26		İzmir Eğitim ve Araştırma Hastanesi					
27		İzmir Tepecik Eğitim ve Araştırma Hastanesi					
28		Özel Şifa Hastanesi					
29		Özel Kent Hastanesi					
30		İzmir Atatürk Eğitim ve Araştırma Hastanesi					
31	KONYA	Selçuk Üniversitesi Tıp Fakültesi Hastanesi					
32	SAMSUN	Ondokuz Mayıs Üniversitesi Tıp Fakültesi Hastanesi					
33	MALATYA	İnönü Üniversitesi Tıp Fakültesi Hastanesi					
34	KAYSERİ	Erciyes Üniversitesi Tıp Fakültesi Hastanesi.					
35	MERSİN	Mersin Üniversitesi Tıp Fakültesi Hastanesi					
36	ERZURUM	Atatürk Üniversitesi Tıp Fakültesi Hastanesi					
37	DENİZLİ	Pamukkale Üniversitesi Tıp Fakültesi Hastanesi					

APPENDIX B – DONOR ACTIVITY IN TURKEY

DONOR ACTIVITY IN TURKEY, 2002-2013

PERIOD	BRAIN DEATH	FAMILY CONSENT	FAMILY CONSENT %	FAMILY REFUSAL	FAMILY REFUSAL %	USED	USED %	UNUSED	UNUSED %
2002	148	111	75%	37	25%	102	92%	9	8%
2003	163	117	72%	46	28%	105	90%	12	10%
2004	220	147	67%	73	33%	136	93%	11	7%
2005	229	174	76%	55	24%	153	88%	21	12%
2006	270	165	61%	105	39%	143	87%	22	13%
2007	594	245	41%	349	59%	223	91%	22	9%
2008	720	262	36%	458	64%	242	92%	20	8%
2009	952	298	31%	654	69%	262	88%	36	12%
2010	1036	272	26%	764	74%	246	90%	26	10%
2011	1292	334	26%	958	74%	311	93%	23	7%
2012	1477	345	23%	1132	77%	343	99%	2	1%
2013	1703	379	22%	1324	78%	377	99%	2	1%

**Data Source: Turkey Organ and Tissue Information System, Republic of Turkey Ministry of Health*

NUMBER OF TRANSPLANTS PERFORMED IN TURKEY, 2002-2013

PERIOD	KIDNEY	LIVER	HEART	LUNG	HEART LUNG	PANCREAS	SMALL INTESTINE	CARDIAC VALVE	CORNEA	TOTAL
2002	550	159	20	0	0	0	1	15	-	745
2003	605	174	23	0	0	9	1	24	-	836
2004	775	245	33	2	0	37	1	7	-	1100
2005	926	324	36	1	0	13	0	19	-	1319
2006	949	319	45	0	0	7	0	25	-	1345
2007	1302	473	61	1	1	9	3	159	-	2009
2008	1665	602	50	0	3	10	3	29	-	2362
2009	2362	592	54	7	0	18	1	38	-	3072
2010	2495	697	87	3	0	29	3	18	-	3332
2011	2953	905	95	5	0	26	2	1	2	3989
2012	2905	1001	61	25	2	6	5	5	1833	5843
2013	2944	1248	63	32	0	4	2	1	2894	7188

**Data Source: Turkey Organ and Tissue Information System, Republic of Turkey Ministry of Health*

NUMBER OF LIVING/DECEASED DONOR TRANSPLANTS PERFORMED IN TURKEY, 2002-2013

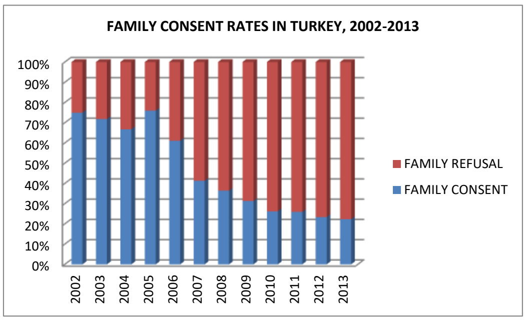
PERIOD	LIVING DONOR KIDNEY TRANSPLANT	DECEASED DONOR KIDNEY TRANSPLANT	LIVING DONOR LIVER TRANSPLANT	DECEASED DONOR LIVER TRANSPLANT	TOTAL LIVING DONOR TRANSPLANT	TOTAL DECEASED DONOR TRANSPLANT	TOTAL
2002	361	189	77	82	438	307	745
2003	428	177	88	86	516	320	836
2004	529	246	133	112	662	438	1100
2005	653	273	200	124	853	466	1319
2006	692	257	205	114	897	448	1345
2007	911	391	264	209	1175	834	2009
2008	1248	417	390	212	1638	724	2362
2009	1931	431	363	229	2294	778	3072
2010	2107	388	489	208	2596	736	3332
2011	2433	520	624	281	3057	930	3987
2012	2381	524	736	265	3117	893	4010
2013	2359	585	959	289	3318	976	4294
TOTAL	16033	4398	4528	2211	20561	7850	28411

**Data Source: Turkey Organ and Tissue Information System, Republic of Turkey Ministry of Health*

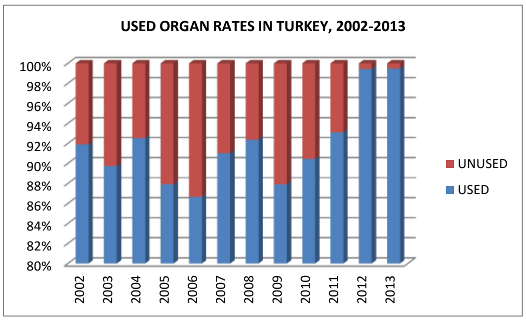
ORGAN DONATION AND TRANSPLANT RATES PER MILLION POPULATION IN TURKEY, 2002-2013

PERIOD	ORGAN DONATION	LIVING DONOR KIDNEY TRANSPLANT	DECEASED DONOR KIDNEY TRANSPLANT	LIVING DONOR LIVER TRANSPLANT	DECEASED DONOR LIVER TRANSPLANT
2002	1,6	5,2	2,7	1,1	1,2
2003	1,7	6,1	2,5	1,3	1,2
2004	2,1	7,5	3,5	1,9	1,6
2005	2,4	9,1	3,8	2,8	1,7
2006	2,3	9,6	3,5	2,8	1,6
2007	3,3	12,4	5,3	3,6	2,9
2008	3,5	16,8	5,6	5,3	2,9
2009	4,0	25,8	5,7	4,8	3,1
2010	3,6	27,8	5,1	6,5	2,7
2011	4,4	31,8	6,8	8,2	3,7
2012	4,5	30,8	6,8	9,5	3,4
2013	4,9	30,2	7,5	12,3	3,7

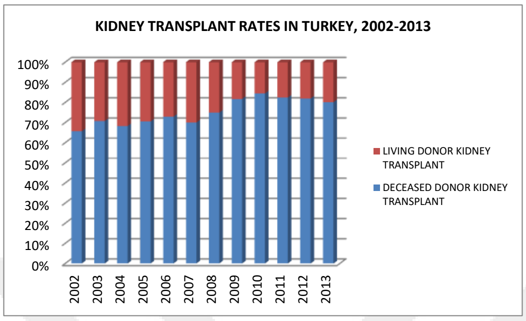
** Required population data for calculations were taken from **Turkish Statistical Institute, Address Based Population Registration System.** Population data for missing years, 2002-2006 were estimated by Turkish Transplant Foundation. Donation and transplantation data were obtained from **Republic of Turkey Ministry of Health, Turkey Organ and Tissue Information System.***



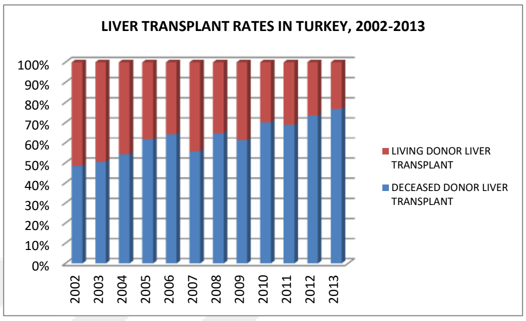
Data Source: Republic of Turkey Ministry of Health, TODS



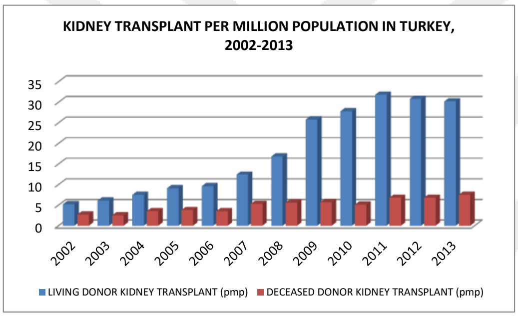
Data Source: Republic of Turkey Ministry of Health, TODS



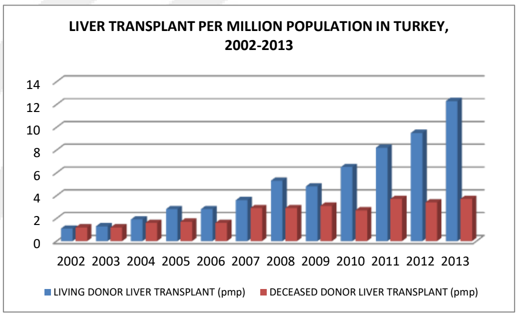
Data Source: Republic of Turkey Ministry of Health, TODS



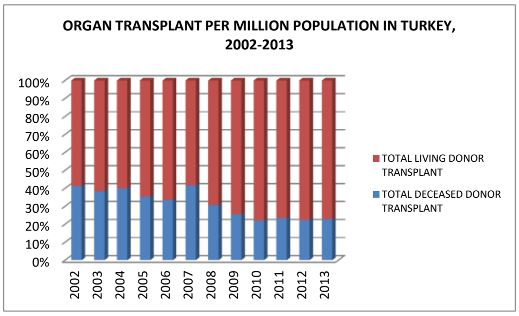
Data Source: Republic of Turkey Ministry of Health, TODS



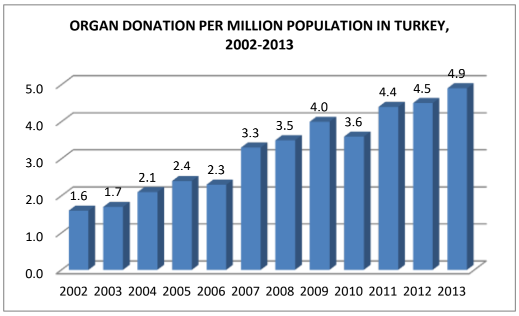
Data Source: Republic of Turkey Ministry of Health, TurkStat



Data Source: Republic of Turkey Ministry of Health, TurkStat



Data Source: Republic of Turkey Ministry of Health, TurkStat



Data Source: Republic of Turkey Ministry of Health, TurkStat

APPENDIX C – DISTANCE TABLE

	Burdur	Bursa	Canakkale	Cankiri	Corum	Denisli	Diyarbakir	Edirne
36	659.36	855.02	1124.32	559.84	551.68	741.53	522.17	1162.96
37	956.26	1115.33	1388.34	760.1	694.3	1057.97	207.77	1426.99
38	163.9	276.56	549.58	389.17	491.81	234.94	1082.47	643.55
39	1386.11	1437.05	1691.14	1004.85	844.59	1487.82	440.74	1641.52
40	764.12	702.05	956.14	269.85	109.59	835.16	690.45	906.52
41	420.76	384.75	730.91	133.26	235.13	491.8	874.95	681.29
42	124.54	544.47	693.23	667.33	730.5	220.45	1063.11	911.46
43	1376.39	1314.32	1568.41	882.12	721.86	1447.43	516.94	1518.79
44	287.24	418.52	423.25	741.65	844.29	128.16	1370.67	659.57
45	393.84	147.86	197.42	623.92	782.39	308.76	1404.13	516.42
46	350.42	94.47	368.93	419.66	547.28	373.56	1191.58	434.52
47	1148.73	1270.71	1543.73	915.48	730.87	1250.44	144.8	1582.37
48	1352.75	1461.67	1673.82	987.53	827.27	1454.46	206.68	1624.2
49	561.41	291.44	545.53	202.09	360.56	584.55	1081.24	495.91
50	0	421.29	629.89	537.5	640.14	167.86	1149.33	788.27
51	421.29	0	272.98	495.73	654.2	449.5	1262.83	388.23
52	629.89	272.98	0	750.29	908.76	475.79	1537.85	238.14
53	537.5	495.73	750.29	0	156.83	623.05	909.73	699.73
54	640.14	654.2	908.76	156.83	0	725.95	779.57	857.39
55	167.86	449.5	475.79	623.05	725.95	0	1251.1	817.58
56	1149.33	1262.83	1537.85	909.73	779.57	1251.1	0	1576.56
57	788.27	388.23	238.14	699.73	857.39	817.58	1576.56	0
58	1011.08	1131.87	1406.89	778.76	648.61	1112.84	155.56	1444.92
59	1018.39	1069.09	1323.65	635.77	474.43	1120.15	348.4	1272.48
60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1461
61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	520.82
62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1343.33
63	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1161.65
64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1319.55
65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1308.94
66	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	795.38
67	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1167.32
68	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	234.6
69	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	554.86
70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1660.86
71	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	744.27
72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1015.79
73	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	66.46
74	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	863.26
75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	335.85
76	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	937.89
77	243.55	181.77	456.78	442.5	545.4	265.9	1181.97	551.73
78	911.34	1032.14	1307.15	679.03	548.88	1013.11	231.7	1345.18
79	362.3	294.49	320.78	692.19	795.09	208.4	1387.22	665.86
80	822	951.51	1226.52	598.4	532.46	923.76	383.92	1264.55
81	1178.29	1361.12	1636.14	1008.02	873.18	1280.06	93.61	1674.17
82	245.23	519.11	528.56	769.83	872.73	147.99	1376.94	754.68
83	1260.09	1380.89	1594.77	906.9	745.55	1361.86	212.17	1543.6
84	555.34	625.11	900.12	272	283.86	657.1	655.36	938.15
85	539.2	706.42	981.44	388.9	381.17	640.96	698.46	1019.47
86	959.75	913.68	1168.24	480.36	319.02	1044.32	644.26	1117.07
87	1213.9	1167.84	1422.4	734.52	573.18	1298.48	577.25	1371.23
88	486.77	217.48	472.04	303.59	461.25	509.12	1180.42	420.87
89	808.63	762.56	1017.12	329.24	167.9	893.2	763.47	965.95
90	1328.01	1443.16	1718.17	1090.05	959.89	1429.78	180.32	1756.2
91	827.56	724.15	978.71	290.66	266.75	912.14	963.46	927.54
92	773.97	818.37	1169.08	399.09	308.46	875.73	474.26	1117.91
93	690.07	290.03	200.07	603.42	761.08	719.38	1480.24	142.88
94	838.12	817.94	1072.5	384.63	182.38	864.9	577.8	1021.33
95	1136.91	1090.84	1345.4	657.52	496.18	1221.48	576.04	1294.23
96	1146.85	1194.82	1449.38	761.5	600.16	1248.62	223.03	1398.21
97	989.16	1171.99	1447.01	818.88	752.94	1090.92	173.42	1485.03
98	169.28	320.93	462.44	499.17	602.07	154.7	1194.2	690.89
99	1473.1	1593.9	1807.79	1119.91	958.57	1574.87	390.59	1756.62
100	615.84	594.24	944.95	170.51	107.96	700.42	696	893.78
101	634.34	365.06	619.62	278.5	436.16	656.69	1167.5	555.69
102	429.43	589.97	864.99	321.9	319.62	531.19	717.23	903.01
103	1124.93	1175.63	1430.19	742.32	580.98	1226.7	439.89	1379.02
104	403.1	601.13	876.14	465.58	529.37	504.87	801.9	1046.73
105	477.01	455.4	806.11	106.78	166.01	561.58	805.69	754.94
106	1244.18	1359.32	1634.34	1006.21	876.06	1345.95	96.49	1672.37
107	1352.24	1535.07	1810.09	1181.97	1116.02	1454.01	276.86	1848.12
108	668.52	470.35	724.91	246.97	380.16	761.98	1185.6	673.74
109	1427.14	1426.31	1680.87	992.99	831.65	1528.91	549.49	1629.7
110	1493.88	1544.58	1799.14	1111.26	949.92	1595.64	562.19	1747.97
111	476.17	71.61	326.17	446.08	603.74	500.96	1322.91	341.08
112	597.08	428.8	683.36	162.67	320.32	681.63	1060.01	632.19
113	881.84	1092.51	1367.53	739.41	673.46	683.6	363.11	1405.56
114	716.73	914.76	1189.77	644.66	636.92	818.49	437.49	1242.64
115	519.89	250.6	505.16	253.38	411.04	542.24	1130.21	453.99

	Elazig	Erzincan	Erzurum	Eskisehir	Gaziantep	Giresun	Gumushane
36	486.78	671.03	803.32	700.98	221.38	720.45	780.83
37	203.19	464.34	519.73	965	149.07	563.93	549.65
38	944.21	951.52	1140.04	134.13	782.31	855.99	1013.9
39	496.95	369.09	182.1	1281.92	746.12	539.73	381.39
40	559.49	369.27	557.79	577.79	578.02	322.13	429.06
41	743.99	680.9	869.42	234.42	642.4	599.32	757.22
42	1028.35	1050.57	1239.09	439.5	762.95	1094.68	1160.37
43	514.64	377.5	148.85	1190.06	822.33	356.83	320.8
44	1232.41	1239.72	1428.24	458.23	1070.51	1208.47	1349.52
45	1280.52	1197.28	1385.8	295.51	1103.98	1086.45	1244.35
46	1060.62	993.02	1181.54	79.6	959.03	882.19	1040.09
47	141.59	255.37	183.83	1120.38	450.19	537.44	379.1
48	332.54	351.77	287.49	1311.34	512.07	641.09	482.76
49	950.28	775.45	963.97	290.59	848.69	664.62	822.53
50	1011.08	1018.39	1206.91	316.31	849.18	1004.32	1128.18
51	1131.87	1069.09	1257.61	150.86	1030.28	958.26	1116.16
52	1406.89	1323.65	1512.17	425.88	1305.3	1212.82	1370.72
53	778.76	635.77	824.29	365.68	677.18	524.94	682.85
54	648.61	474.43	662.95	468.58	611.23	363.6	521.5
55	1112.84	1120.15	1308.67	338.66	950.94	1088.9	1229.95
56	155.56	348.4	323.45	1114.57	310.02	635.73	477.39
57	1444.92	1272.48	1461	520.82	1343.33	1161.65	1319.55
58	0	265.37	320.76	983.11	340.1	442.04	394.36
59	265.37	0	190.15	914.55	601.07	289.05	130.72
60	320.76	190.15	0	1103.02	628.8	360.83	202.49
61	983.11	914.55	1103.02	0	879.55	831.98	989.89
62	340.1	601.07	628.8	879.55	0	695.62	683.1
63	442.04	289.05	360.83	831.98	695.62	0	157.53
64	394.36	130.72	202.49	989.89	683.1	157.53	0
65	467.19	738.19	783.98	830.33	203.53	787.1	847.18
66	983.18	990.47	1178.93	296.02	821.93	988.39	1099.46
67	550.43	750.69	867.21	688.7	286.77	799.6	859.68
68	1210.2	1039.26	1227.73	280.65	1146.14	929.84	1086.5
69	1273.9	1281.19	1469.65	416.15	1112.65	1283.66	1443.32
70	522.56	390.02	202.69	1301.95	829.87	554.93	402.23
71	806.48	615.02	803.48	471.95	784.12	483.14	642.8
72	431.09	440.33	628.8	552.02	330.21	489.24	549.32
73	1419.12	1248.18	1436.64	491.48	1355.06	1135.76	1295.42
74	565.22	570.03	758.49	423.63	464.34	586.24	679.01
75	1132.92	961.98	1150.44	239.37	1068.86	849.56	1009.22
76	734.54	741.83	930.29	341.76	561.46	784.96	850.82
77	1059.94	991.38	1179.84	77.69	881.49	909.82	1069.49
78	100.24	361.21	417.03	881.41	240.9	473.43	490.4
79	1247.98	1255.27	1443.73	390.23	1086.73	1232.87	1392.53
80	321.01	567	637.8	800.78	80.64	615.91	675.99
81	248.48	443.17	419.14	1210.39	338.47	729.02	572.36
82	1259.95	1267.24	1455.7	487.51	1076.45	1237.15	1376.22
83	253.23	272.76	208.62	1230.15	516.79	560.16	403.5
84	523.9	528.71	717.17	474.38	423.02	577.62	637.7
85	562.97	570.26	758.75	555.69	397.98	619.17	679.25
86	490.08	305.11	406.41	787.41	657.02	45.36	205.02
87	530	255.76	261.02	1041.56	866.41	209.2	173.09
88	1048.96	878.02	1066.49	215.96	984.9	765.6	925.26
89	609.3	424.33	555.08	636.29	705.11	194.02	353.69
90	335.19	447.27	383.13	1292.42	488.19	734.67	578.01
91	777.31	592.34	712.36	655.22	851.58	351.3	510.97
92	342.81	247.55	436.02	667.64	401.77	296.46	356.54
93	1348.79	1177.85	1366.31	419.26	1284.73	1065.43	1225.09
94	446.35	305.54	494.01	607.99	465.92	236.53	364.99
95	493.01	229.37	261.83	964.57	817.15	132.2	99.75
96	139.99	127.36	242.31	1039.3	476.41	413.21	256.55
97	312.77	507.45	492.2	1021.26	149.34	719.94	636.64
98	1054.96	1062.25	1250.71	216.85	893.71	966.49	1126.16
99	466.25	485.77	377.3	1443.17	695.21	733.51	576.84
100	564.54	470.94	659.4	443.5	528.44	472.38	579.93
101	1036.05	852.94	1041.4	363.54	971.99	696.29	855.95
102	585.77	593.06	781.53	439.24	478.63	641.97	702.05
103	392.64	127.46	123.67	1020.12	729.05	236.08	79.42
104	747.18	754.46	942.93	450.4	501.41	803.37	863.45
105	674.23	611.98	800.45	304.67	573.35	530.43	690.09
106	251.36	446.04	375.52	1208.59	404.36	731.89	575.23
107	431.73	543.81	479.67	1384.34	512.42	831.21	674.55
108	1054.15	796.93	985.4	468.83	990.09	665.18	824.85
109	546.79	410.39	226.96	1322.33	854.11	467.67	422.61
110	637.84	477.12	289.8	1389.06	866.81	646	489.34
111	1191.45	1020.51	1208.98	205.36	1127.39	908.09	1067.75
112	928.56	737.1	925.56	424.72	918.62	594.61	754.27
113	402.33	663.3	681.89	941.78	61.73	756.91	744.21
114	400.67	674.08	717.45	764.02	137.01	722.98	783.06
115	998.76	827.82	1016.28	249.08	934.7	715.39	875.06

	Hatay	Isparta	Mersin	Istanbul	Izmir	Kars	Kastamonu	Kayseri
36	155.24	603.85	69.81	928.06	894.58	1005.12	666.64	304.56
37	309.58	927.98	392.82	1192.09	1218.7	721.53	866.89	412.97
38	716.16	167.64	574.53	406.73	329.99	1339.9	495.96	515.09
39	940.12	1357.83	1023.36	1406.63	1648.55	167.21	982.38	807.7
40	670.43	733.17	594.95	671.62	1028.44	757.66	247.38	317.05
41	632.95	391.18	491.32	446.39	586.85	1069.29	240.05	314.87
42	696.8	128.84	463.25	674.64	451.92	1438.96	774.12	614.14
43	977.51	1345.44	1060.75	1283.89	1640.71	206.76	840.19	816.1

	Kirklareli	Kirsehir	Kocaeli	Konya	Kutahya	Malatya	Manisa
36	1136.98	343.75	850.78	343.38	663.41	387.05	387.05
37	1401	547.1	1114.81	667.51	987.54	103.8	1192.78
38	617.56	447.64	365.46	227.59	98.83	844.47	304.07
39	1615.54	937.39	1329.34	1109.19	1358.74	592.88	1622.63
40	880.54	331.03	594.34	529.74	654.61	459.75	977.65
41	655.31	180.32	369.11	262.13	311.25	644.26	560.93
42	885.47	589.26	633.37	304.72	366.74	928.61	426.01
43	1492.81	945.8	1206.61	1117.6	1266.88	610.57	1589.92

Kahramanmaras	Mardin	Mugla	Mus	Nevsehir	Nigde	Ordu	Rize	Sakarya	Samsun	Siirt	Sinop	Sivas	Tekirdag	Tokat	Trabzon
194.21	550.5	846.45	735.79	310.79	179.9	681.85	918.98	766.82	720.16	700.22	849.9	426.61	1066.65	490.76	841.99
163.4	298.42	1182.5	452.21	505.79	504.03	561.14	728.97	1030.85	678.36	386.45	824.83	335.64	1330.68	439.18	648.3
755.13	1111.42	381.71	1193.22	488.47	472.33	811.42	1065.57	342.05	660.3	1261.15	679.23	707.1	545.34	632	988.58
820.02	516.64	1634.6	248.97	896.07	937.62	585.31	439.92	1245.39	733.98	329.81	891.26	614.92	1545.21	672.9	440.73
499.24	784.06	981.94	640.4	317.21	414.52	277.55	531.71	510.38	126.43	814.91	272.9	219.34	810.21	115.02	454.71
563.63	973.24	638.57	993	237.23	343.47	554.74	808.9	285.15	403.62	1055.27	423.31	434.97	584.98	375.32	731.9
735.77	1092.06	314.5	1277.36	587.52	540.07	1050.11	1304.27	609.96	898.99	1241.79	957.38	806.15	813.25	870.3	1227.27
831.33	612.68	1594.21	402.16	904.48	946.03	402.41	149.67	1122.65	551.08	576.67	708.36	623.33	1422.48	593.58	225.84
1043.33	1399.62	99.87	1481.42	776.67	760.53	1163.89	1418.05	616.33	1012.77	1549.35	1123	995.3	688.88	984.47	1341.05
1100.16	1433.09	378.38	1468.41	773.76	794	1041.87	1296.03	345.67	890.75	1582.81	852.34	1042.72	418.22	946.13	1219.03
880.25	1289.87	520.33	1309.63	553.85	635.17	837.61	1091.77	141.41	686.49	1371.9	648.08	747.12	336.32	741.88	1014.77
458.28	240.53	1397.22	116.31	661.17	700.24	558.75	437.63	1186.23	677.97	290.82	845.98	480.08	1486.06	583.62	438.44
585.97	282.58	1578.99	84.56	852.12	900.51	686.68	541.29	1228.06	774.37	95.76	942.38	597.59	1527.89	655.58	542.09
769.91	1179.53	791.66	1046.58	443.51	524.83	620.04	874.2	99.77	468.92	1261.56	430.51	623.28	399.6	524.31	797.2
822	1178.29	245.23	1260.09	555.34	539.2	959.75	1213.9	486.77	808.63	1328.01	827.56	773.97	690.07	838.12	1136.91
951.51	1361.12	519.11	1380.89	625.11	706.42	913.68	1167.84	217.48	762.56	1443.16	724.15	818.37	290.03	817.94	1090.84
1226.52	1636.14	528.56	1594.77	900.12	981.44	1168.24	1422.4	472.04	1017.12	1718.17	978.71	1169.08	200.07	1072.5	1345.4
598.4	1008.02	769.83	906.9	272	388.9	480.36	734.52	303.59	329.24	1090.05	290.66	399.09	603.42	384.63	657.52
532.46	873.18	872.73	745.55	283.86	381.17	319.02	573.18	461.25	167.9	959.89	266.75	308.46	761.08	182.38	496.18
923.76	1280.06	147.99	1361.86	657.1	640.96	1044.32	1298.48	509.12	893.2	1429.78	912.14	875.73	719.38	864.9	1221.48
383.92	93.61	1376.94	212.17	655.36	698.46	644.26	577.25	1180.42	763.47	180.32	963.46	474.26	1480.24	577.8	576.04
1264.55	1674.17	754.68	1543.6	938.15	1019.47	1117.07	1371.23	420.87	965.95	1756.2	927.54	1117.91	142.88	1021.33	1294.23
321.01	248.48	1259.95	253.23	523.9	562.97	490.08	530	1048.96	609.3	335.19	777.31	342.81	1348.79	446.35	493.01
567	443.17	1267.24	272.76	528.71	570.26	305.11	255.76	878.02	424.33	447.27	592.34	247.55	1177.85	305.54	229.37
637.8	419.14	1455.7	208.62	717.17	758.75	406.41	261.02	1066.49	555.08	383.13	712.36	436.02	1366.31	494.01	261.83
800.78	1210.39	487.51	1230.15	474.38	555.69	787.41	1041.56	215.96	636.29	1292.42	655.22	667.64	419.26	607.99	964.57
80.64	338.47	1076.45	516.79	423.02	397.98	657.02	866.41	984.9	705.11	488.19	851.58	401.77	1284.73	465.92	817.15
615.91	729.02	1237.15	560.16	577.62	619.17	45.36	209.2	765.6	194.02	734.67	351.3	296.46	1065.43	236.53	132.2
675.99	572.36	1376.22	403.5	637.7	679.25	205.02	173.09	925.26	353.69	578.01	510.97	356.54	1225.09	364.99	99.75
172.73	532.98	1009.73	718.28	462.14	331.25	749.13	986.25	918.17	797.22	682.71	943.69	493.88	1218	558.03	909.26
794	1150.29	275.24	1232.09	527.34	511.2	944.66	1198.82	490.44	793.54	1300.01	8811.5	745.97	693.73	810.12	1121.82
262.9	619.19	776.3	804.49	320.87	189.98	761.9	999.02	776.9	730.25	768.91	859.98	506.65	1076.73	570.8	922.03
1031.32	1440.93	651.83	1310.37	704.92	786.23	883.83	1137.99	187.63	732.71	1522.96	694.3	884.68	138.91	788.1	1060.99
1083.56	1439.86	205.43	1521.66	816.9	800.76	1139.94	1394.1	542.56	988.82	1589.58	1049.22	1035.53	615.1	960.52	1317.1
839.58	620.92	1655.52	331.92	916.99	958.54	600.48	347.74	1266.3	749.15	496.74	906.43	635.84	1566.13	693.82	423.92
704.22	1113.83	875.64	884.84	377.82	494.72	438.09	692.25	347.11	290.03	1059.35	184.26	466.89	646.94	362.57	615.25
252.63	662.24	828.86	682	92.81	131.89	453.01	690.14	617.88	449.81	744.27	547.68	197.76	917.7	261.91	613.14
1238.88	1648.49	864.8	1517.93	912.48	993.79	1091.39	1345.55	395.19	940.27	1730.52	901.86	1092.24	118	995.66	1268.55
384.48	794.09	770.47	813.85	58.08	174.98	541.2	795.35	465.01	390.08	876.12	505.05	325.64	764.83	350.02	718.36
952.44	1362.05	638.16	1231.49	626.04	707.35	804.96	1059.11	108.76	653.84	1444.09	615.43	805.8	238.6	709.22	982.12
533.18	889.47	543.97	983.24	278.49	236.66	741.07	995.23	549.59	589.95	1039.2	948.35	497.12	761.61	561.27	918.23
852.52	1208.81	412.78	1305.96	550.19	569.72	863.22	1117.37	247.16	712.1	1358.53	753.83	743.45	450.46	683.8	1040.38
221.43	324.73	1160.37	349.17	242.33	463.4	468.74	625.93	949.39	585.96	411.44	732.43	243.23	1249.21	346.77	588.94
1058.08	1414.37	234.63	1496.17	791.42	775.28	1114.46	1368.62	499.54	963.34	1564.1	1006.21	1010.05	572.09	935.04	1291.62
0	410.31	1047.25	569.5	346.78	368.78	580.78	817.9	871.84	628.87	560.03	775.34	325.53	1171.67	389.68	740.91
410.31	0	1404.52	307.75	753.88	726.04	737.7	672.83	1312.96	856.92	188.6	1056.9	567.71	1612.79	671.24	669.48
1047.25	1404.52	0	1508.33	803.57	787.43	1190.79	1444.95	715.8	1039.67	1555.96	1058.61	1022.2	788.34	1011.37	1367.95
569.5	307.75	1508.33	0	773.22	812.3	607.78	462.39	1149.16	695.47	180.05	863.48	518.69	1448.99	576.68	463.19
346.78	753.88	803.57	773.22	0	139.65	511.8	777.19	542.35	452.23	835.3	561.65	284.82	842.18	320.71	700.19
368.78	726.04	787.43	812.3	139.65	0	580.92	818.05	597.19	549.27	874.59	680.27	325.68	897.02	389.83	741.05
580.78	737.7	1190.79	607.78	511.8	580.92	0	254.99	721.48	149.9	780.47	307.19	294.08	1021.31	192.41	178
817.9	672.83	1444.95	462.39	777.19	818.05	254.99	0	975.11	403.54	637.26	560.82	495.62	1274.94	446.04	78.3
871.84	1312.96	715.8	1149.16	542.35	597.19	721.48	975.11	0	580.05	1370.3	541.64	732.02	299.83	635.44	908.33
628.87	856.92	1039.67	695.47	452.23	549.27	149.9	403.54	580.05	0	887.92	158.72	346.02	869.32	241.7	326.7
560.03	188.6	1555.96	180.05	835.3	874.59	780.47	637.26	1370.3	887.92	0	1146.82	657.63	1663.61	761.17	711.05
775.34	1056.9	1058.61	863.48	561.65	680.27	307.19	560.82	541.64	158.72	1146.82	0	491.81	831.13	387.49	484.36
325.53	567.71	1022.2	518.69	284.82	325.68	294.08	495.62	732.02	346.02	657.63	491.81	0	1019.45	106.66	418.45
1171.67	1612.79	788.34	1448.99	842.18	897.02	1021.31	1274.94	299.83	869.32	1663.61	831.13	1019.45	0	927.4	1200.29
389.68	671.24	1011.37	576.68	320.71	389.83	192.41	446.04	635.44	241.7	761.17	387.49	106.66	927.4	0	369.04
740.91	669.48	1367.95	463.19	700.19	741.05	178	78.3	908.33	326.7	711.05	484.36	418.45	1200.29	369.04	0
456.26	316.47	1395.09	242.05	659.79	698.56	430.86	394.29	1012.31	568.02	406.39	713.81	373.22	1304.27	431.35	355.83
221.17	197.63	1217.11	381	564.14	535.73	717.55	746.33	1099.14	846.41	351.92	922.2	489.62	1391.1	606.73	735.93
864.51	1221.78	301.17	1304.29	598	568.57	922.37	1176.01	365.08	770.39	1372.7	789.17	817.35	591.4	742.49	1098.48
782.52	466.44	1721.34	218.55	986.04	1024.81	779.3	636.09	1370.72	928	279.05	1085.66	731.63	1662.68	789.76	686.97
452.2	789.44	846.89	742.08	132.47	289.97	428.26	681.9	507.88	276.28	879.37	374.23	224.85	799.84	235.55	604.37
858.93	1300.05	863.37	1124.08	529.44	584.28	652.17	905.8	171.39	503.7	1350.87	397.59	706.71	461.76	600.59	828.27
408.65	806.69	677.66	835.1	128.81	118.35	604.78	841.13	517.12	487.93	957.61	611.9	348.16	809.08	412.3	763.6
676.5	535.47	1373.17	325.03	635.78	676.65	281.87	138.67	993.13	430.57	572.89	588.23	354.04	1285.09	412.17	139.54
472.21	829.48	651.34	996.5	323.86	176.27	766.18	1002.53	660.83	697.69	980.4	755.59	509.56	871.59	573.71	925
497.11	904.21	708.05	923.55	167.62	286.23	486.31	739.94	363.04	334.33	989.05	396.78	365.9	661	306.43	662.42
476.2	108.8	1472.13	219.29	751.47	790.75	740.51	629.65	1286.47	877.66	86.82	1023.45	570.29	1578.43	673.94	630.52
584.25	200.07	1580.19	276.59	927.22	898.81	877.01	733.8	1462.22	984.47	98.82	1130.26	750.67	1754.18	854.31	734.68
877.03	1318.15	968.66	1068.07	547.53	602.38	621.07	874.7	287.84	472.59	1368.97	366.49	648.7	579.8	544.59	797.17
863.06	645.06	1675.38	388.45	937.99	978.86	513.47	260.06	1243.8	662.17	597.24	819.83	656.25	1535.76	714.38	337.71
954.11	638.04	1742.11	390.15	1004.73	1045.59	691.8	479.43	1362.07	840.5	450.64	998.16	722.98	1654.03	781.11	557.09
1014.33	1455.45	569.92	1291.65	684.84	739.68	863.97	1117.6	123.68	711.99	1506.27	673.79	862.11	241.59	768.17	1040.08
805.56	1246.68	927.11	1008.24	476.07	530.91	550.49	804.12	246.29	402.02	1243.38	295.92	588.87	538.25	484.75	726.6
141.69	390.69	1109.79	570.69	484.66	428.41	719.73	930.23	1019.66	766.93	541.61	912.72	463.1	1311.62	527.25	878.54
107.81	465.07	944.68	649.99	395.41	263.3	685.79	922.14	856.74	733	615.99	878.79	429.17	1148.7	493.32	844.61
821.63	1262.76	748.92	1098.96	492.14	546.99	671.27	924.91	68.1	519.29	1313.58	481.09	669.41	360.06	575.47	847.38

Yozgat	Zonguldak	Aksaray	Bayburt	Karaman	Kirikkale	Batman	Sirnak	Bartin	Ardahan	Igdir	Yalova	Karabuk	Kilis	Osmaniye	Duzce
459.61	753.91	260.55	777.58	283.34	455.86	616.39	724.45	772.01	1029.35	1120.4	909.31	700.54	254.04	88.02	716.62
611.21	1017.94	584.68	591.61	607.46	656.12	302.62	427.37	1036.03	745.76	765.06	1173.34	964.57	207.91	243.06	980.64
467.51	489.62	362.56	1058.07	336.23	328.68	1177.31	1285.37	520.15	1360.28	1427.01	331.44	448.73	814.97	649.86	375.17
838.3	1220.3	960.43	302.56	697.07	979.34	369.05	426.35	1164.3	244.34	144.64	1387.88	1104.46	799.22	873.6	1195.18
217.17	485.3	402.92	475.82	638.57	275.21	786.94	911.45	429.29	778.03	844.76	652.87	369.46	640.25	606.32	460.18
210.84	272.24	227.02	787.45	370.96	72	971.44	1147.19	290.34	1089.66	1156.39	427.64	218.87	704.63	566.64	234.94
706.21	757.53	461.61	1157.12	327.29	563.35	1157.96	1266.01	743.61	1456.33	1526.06	599.36	672.14	795.61	630.5	643.08
829.44	1053.34	968.83	286.21	1130.23	887.49	569.06	678.21	1022.24	119.5	338.88	1265.14	951.66	875.42	910.99	1072.45
819.99	763.91	650.76	1346.27	624.44	681.15	1465.52	1573.57	869.2	1648.48	1715.21	470.46	827.65	1103.17	938.06	649.45
818.58	493.25	684.23	1303.83	657.9	679.74	1498.98	1607.04	598.54	1554.5	1672.77	199.8	556.99	1136.64	971.53	378.8
522.98	288.99	518.71	1099.57	529.87	384.14	1288.07	1463.82	394.28	1350.24	1468.51	118.22	352.73	1021.26	843.5	174.54
701.81	1173.32	723.04	300.28	864.44	811.5	196.92	387.36	1050.57	409.87	500.92	1328.72	990.74	503.28	537.94	1136.02
820.98	1202.97	914	403.93	1003.95	1002.45	135	192.3	1146.97	478.33	331.74	1370.55	1087.14	565.16	639.54	1177.86
399.14	158.61	408.38	882	552.09	260.3	1177.73	1358.48	176.71	1132.67	1250.94	242.26	135.16	910.92	748	49.56
615.84	634.34	429.43	1124.93	403.1	477.01	1244.18	1352.24	668.52	1427.14	1493.88	476.17	597.08	881.84	716.73	519.89
594.24	365.06	589.97	1175.63	601.13	455.4	1359.32	1535.07	470.35	1426.31	1544.58	71.61	428.8	1092.51	914.76	250.6
944.95	619.62	864.99	1430.19	876.14	806.11	1634.34	1810.09	724.91	1680.87	1799.14	326.17	683.36	1367.53	1189.77	505.16
170.51	278.5	321.9	742.32	465.58	106.78	1006.21	1181.97	246.97	992.99	1111.26	446.08	162.67	739.41	644.66	253.38
107.96	436.16	319.62	580.98	529.37	166.01	876.06	1116.02	380.16	831.65	949.92	603.74	320.32	673.46	636.92	411.04
700.42	656.69	531.19	1226.7	504.87	561.58	1345.95	1454.01	761.98	1528.91	1595.64	500.96	681.63	983.6	818.49	542.24
696	1167.5	717.23	439.89	801.9	805.69	96.49	276.86	1185.6	549.49	562.19	1322.91	1060.01	363.11	437.49	1130.21
893.78	555.69	903.01	1379.02	1046.73	754.94	1672.37	1848.12	673.74	1629.7	1747.97	341.08	632.19	1405.56	1242.64	453.99
564.54	1036.05	585.77	392.64	747.18	674.23	251.36	431.73	1054.15	546.79	637.84	1191.45	928.56	402.33	400.67	998.76
470.94	852.94	593.06	127.46	754.46	611.98	446.04	543.81	796.93	410.39	477.12	1020.51	737.1	663.3	674.08	827.82
659.4	1041.4	781.53	123.67	942.93	800.45	375.52	479.67	985.4	226.96	289.8	1208.98	925.56	681.89	717.45	1016.28
443.5	363.54	439.24	1020.12	450.4	304.67	1208.59	1384.34	468.83	1322.33	1389.06	205.36	424.72	941.78	764.02	249.08
528.44	971.99	478.63	729.05	501.41	573.35	404.36	512.42	990.09	854.11	866.81	1127.39	918.62	61.73	137.01	934.7
472.38	696.29	641.97	236.08	803.37	530.43	731.89	831.21	665.18	467.67	646	908.09	594.61	756.91	722.98	715.39
579.93	855.95	702.05	79.42	863.45	690.09	575.23	674.55	824.85	422.61	489.34	1067.75	754.27	744.21	783.06	875.06
610.96	905.26	411.9	844.85	434.69	607.21	598.88	706.93	923.36	1011.84	1102.89	1060.66	851.59	141.3	95.04	867.97
600.76	638.01	401.43	1096.93	375.1	475.9	1216.18	1324.24	652.46	1399.15	1465.88	479.84	581	853.84	688.73	523.56
469.69	763.99	270.63	857.62	229.22	465.94	685.08	793.14	782.09	1098.04	1189.1	919.39	710.62	322.74	155.36	155.36
660.54	316.7	669.78	1145.79	732.44	521.7	1439.13	1614.88	440.5	1396.46	1514.73	102.44	390.95	1172.32	1009.4	220.76
796.04	690.14	690.99	1386.5	664.67	657.2	1505.75	1613.8	795.42	1688.71	1755.44	396.68	753.88	1143.4	978.29	575.68
859.22	1241.22	981.34	323.48	1142.74	1000.26	535.98	593.28	1185.22	90.44	138.1	1408.79	1125.38	883.67	919.23	1216.1
276.33	213.21	427.71	719.13	571.4	212.59	1034.49	1287.78	182.11	950.72	676.8	489.6	111.53	845.22	750.47	296.9
198.23	604.96	154.69	548.73	316.09	243.15	660.44	836.19	623.06	850.94	917.67	760.37	551.6	393.63	359.7	567.67
868.1	530.02	877.34	1353.35	1021.05	729.26	1646.69	1822.44	648.06	1604.02	1722.29	315.41	606.51	1379.88	1216.96	428.32
114.76	452.09	96.79	676.61	318.36	111.01	792.29	968.04	470.19	978.82	1045.55	607.5	377.06	525.48	430.73	414.8
581.66	222.01	590.9	1066.91	734.61	442.83	1360.25	1536	310.41	1317.59	1435.86	88.77	320.08	1093.44	930.53	141.88
397.17	536.68	152.58	848.08	109.06	254.31	955.37	1063.42	554.78	1150.29	1217.03	547.71	483.31	593.02	427.91	499.38
519.31	394.74	459.95	1095.93	433.62	380.48	1274.7	1382.76	500.03	1398.14	1464.87	236.56	458.48	912.36	747.25	280.28
464.97	936.48	486.2	488.58	647.6	574.66	327.61	507.98	954.57	642.73	733.78	1091.88	828.98	302.76	301.09	899.18
770.56	647.12	665.51	1361.02	639.18	631.72	1480.26	1588.32	752.41	1663.23	1729.96	353.67	710.86	1117.92	952.81	532.66
452.2	858.93	408.65	676.5	472.21	497.11	476.2	584.25	877.03	863.06	954.11	1014.33	805.56	141.69	107.81	821.63
789.44	1300.05	806.69	535.47	829.48	904.21	108.8	200.07	1318.15	645.06	638.04	1455.45	1246.68	390.69	465.07	1262.76
846.89	863.37	677.66	1373.17	651.34	708.05	1472.13	1580.19	968.66	1675.38	1742.11	569.92	927.11	1109.79	944.68	748.92
742.08	1124.08	835.1	325.03	996.5	923.55	219.29	276.59	1068.07	388.45	390.15	1291.65	1008.24	570.69	649.99	1098.96
132.47	529.44	128.81	635.78	323.86	167.62	751.47	927.22	547.53	937.99	1004.73	684.84	476.07	484.66	395.41	492.14
289.97	584.28	118.35	676.65	176.27	286.23	790.75	898.81	602.38	978.86	1045.59	739.68	530.91	428.41	263.3	546.99
428.26	652.17	604.78	281.87	766.18	486.31	740.51	877.01	621.07	513.47	691.8	863.97	550.49	719.73	685.79	671.27
681.9	905.8	841.13	138.67	1002.53	739.94	629.65	733.8	874.7	260.06	479.43	1117.6	804.12	930.23	922.14	924.91
507.88	171.39	517.12	993.13	660.83	363.04	1286.47	1462.22	287.84	1243.8	1362.07	123.68	246.29	1019.66	856.74	68.1
276.28	503.7	487.93	430.57	697.69	334.33	877.66	984.47	472.59	662.17	840.5	711.99	402.02	766.93	733	519.29
879.37	1350.87	957.61	572.89	980.4	989.05	86.82	98.82	1368.97	597.24	450.64	1506.27	1243.38	541.61	615.99	1313.58
374.23	397.59	611.9	588.23	755.59	396.78	1023.45	1130.26	366.49	819.83	998.16	673.79	295.92	912.72	878.79	481.09
224.85	706.71	348.16	354.04	509.56	365.9	570.29	750.67	648.7	656.25	722.98	862.11	588.87	463.1	429.17	669.41
799.84	461.76	809.08	1285.09	871.59	661	1578.43	1754.18	579.8	1535.76	1654.03	241.59	538.25	1311.62	1148.7	360.06
235.55	600.59	412.3	412.17	573.71	306.43	673.94	854.31	544.59	714.38	781.11	768.17	484.75	527.25	493.32	575.47
604.37	828.27	763.6	139.54	925	662.42	630.52	734.68	797.17	337.71	557.09	1040.08	726.6	878.54	844.61	847.38
596.93	978.93	721.57	254.99	882.98	737.97	320.87	528.73	922.92	461.01	527.74	1146.5	863.09	538.13	536.47	953.81
670.29	1111.04	617.68	608.68	640.47	715.2	268.52	370.71	1129.14	718.27	730.97	1266.45	1057.68	201.68	276.06	1078.75
577.3	533.58	472.25	1167.76	445.93	438.47	1287.01	1395.06	638.86	1469.97	1536.7	375.4	558.51	924.66	759.55	419.12
954.99	1336.99	1048.01	498.46	1163.95	1136.47	295	352.3	1280.99	445.46	224.13	1504.57	1221.15	725.16	799.54	1311.87
0	481.85	211.66	577.45	481.89	141.04	792.58	1032.54	499.95	879.66	946.4	637.25	333.65	589.98	553.44	444.56
481.85	0	495.05	958.21	638.76	346.98	1264.4	1440.15	88.4	1164.02	1327.15	315.09	102.53	997.59	834.68	115.94
211.66	495.05	0	698.99	215.48	217.58	812.58	980.97	513.12	1001.2	1067.94	650.42	441.65	510.57	345.46	457.72
577.45	958.21	698.99	0	859.76	717.28	491.86	596.01	903.24	344.07	410.8	1125.81	832.67	792.43	779.38	933.12
481.89	638.76	215.48	859.76	0	362.16	895.6	1003.66	662.63	1164.63	1231.36	655.39	591.16	533.26	368.15	607.24
141.04	346.98	217.58	717.28	362.16	0	902.1	1077.85	361.77	1020.21	1086.94	499.08	268.64	635.29	540.54	306.38
792.58	1264.4	812.58	491.86	895.6	902.1	0	183.52	1279.48	598.89	490.32	1416.79	1153.89	455.81	530.19	1224.09
1032.54	1440.15	980.97	596.01	1003.66	1077.85	183.52	0	1492.05	694.36	547.76	1629.35	1420.58	564.59	638.97	1436.66
499.95	88.4	513.12	903.24	662.63	361.77	1279.48	1492.05	0	1133	1272.36	420.31	85	1015.7	852.79	204.23
879.66	1164.02	1001.2	344.07	1164.63	1020.21	598.89	694.36	1133	0	222.38	1376.17	1062.69	908.06	943.62	1183.47
946.4	1327.15	1067.94	410.8	1231.36	1086.94	490.32	547.76	1272.36	222.38	0	1495.89	1212.48	896.63	971.01	1303.19
637.25	315.09	650.42	1125.81	655.39	499.08	1416.79	1629.35	420.31	1376.17	1495.89	0	377.53	1150.9	989.99	199.34
333.65	102.53	441.65	832.67	591.16	268.64	1153.89	1420.58	85	1062.69	1212.48	377.53	0	901.28	782.67	185.54
589.98	997.59	510.57	792.43	533.26	635.29	455.81	564.59	1015.7	908.06	896.63	1150.9	901.28	0	145.16	965.49
553.44	834.68	345.46	779.38	368.15	540.54	530.19	638.97	852.79	943.62	971.01	989.99	782.67	145.16	0	800.64
444.56	115.94	457.72	933.12	607.24	306.38	1224.09	1436.66	204.23	1183.47	1303.19	199.34	185.54	965.49	800.64	0