Logistic Design and Facility Location for Organ Transplantation Centers

Mohammad Taghi Valipour Azizi

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the Degree of

Master of Science
in
Industrial Engineering

Eastern Mediterranean University
June 2013
Gazimagusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Elvan Yılmaz
Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Industrial Engineering.

Asst. Prof. Dr. Gokhan Izbirak
Chair, Department of Industrial Engineering

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

Prof. Dr. Bela Vizvari
Supervisor

Examining Committee

---

1. Prof. Dr. Bela Vizvari ____________________
2. Asst. Prof. Dr. Emine Atasöylu ____________________
3. Asst. Prof. Dr. Sahand Daneshvar ____________________

ABSTRACT

In recent years, it has seen a significant discussion and attention about importance of organ transplantation and in order to secure the shortage of organ donor, people are encouraged to donate their organs after their death. Location of organ transplantation center is considerably important in healthcare facility location problems like hospital, blood banking and emergency medical services (EMS). In this research four different provinces of Iran are considered to analyze and investigate for occupy different locations for organ transplantation centers. The purpose of this research is to design and analysis the logistic of organ transplantation in terms of minimization of three different types of transportation between hospital, patient and center, models are formulated based on minimize the maximum acceptable service distance, maximize the total demand assigned to the centres and maximize the percentage of covered demand and at last develop and compare them to each other. Various mixed integer programming models are formulated to determine the number and locations of these centers. These models are applied practically for 20 hospitals among these regions. Computational and experimental results which are obtained by simulation and xpress optimizer as a powerful tool in optimization indicate an interesting concept for using this research as basic data for development and improvement for logistic of organ transplantation.

Keywords: Organ Transplantation; Logistic; Hospital; Transportation; Healthcare Modeling

ÖZ

Geçmiş yıllarda organ naklinin önemi hakkında ciddi tartışmalar yaşanmış ve konuya dikkat çekilmiştir. Organ bağışında sıkıntı yaşanmaması için, insanlar ölümden sonra organlarını bağışlamaları için cesaretlendirilmeye başlanmıştır. Düşük miktarda organ arzı bulunduğu için, nakil ihtiyacı bulunan kişiler bekleme listesinde uzun süre beklemek zorunda kalmışlardır. Hastahane, kan bankası ve acil tıbbi hizmetler gibi organ nakil merkezlerinin de yer tespiti, sağlık tesisi yer problemleri arasında önem bulmaktadır. Bu çalışmada organ nakil merkezi yerleşimi için İran'da 4 ayrı vilayet incelenmiş ve araştırılmıştır. Bu çalışmanın amacı organ nakli lojistiği için hastahane, hasta ve merkez arasındaki üç farklı ulaşım şeklini ve kabul edilebilir hizmet mesafesini en aza indirgemek, merkezlere atanmış talep oranını ve karşılanmış talep oranını azamileştirmek, ve son olarak bunları geliştirip kıyaslayarak analiz edip araştırmaktır. Bu merkezlerin sayısı ve yerlerini belirlemek için çeşitli karma tamsayılı doğrusal program modelleri oluşturulmuştur. Bu modeller belirtilen bölgelerdeki 20 hastahane üzerinde uygulanmıştır. Simülasyon ve xpress eniyileyici kullanılarak elde edilen temel hesapsal ve deneysel verilerin organ nakli lojistiğinin geliştirilmesi ve iyileştirilmesi için yapılacak eniyilemede güçlü birer araç olduğu bu araştırmada ortaya çıkan ilginç kavramlar arasında yer almaktadır.

Anahtar Kelimeler: Organ Nakli, Lojistik, Hastahane, Ulaşım, Sağlık Sistemleri Modellemesi

ACKNOWLEDGMENTS

Apart from the efforts which I have done, the success of any project depends largely on the encouragement and guidelines of many others. I take this opportunity to express my gratitude to the people who have been instrumental in the successful completion of this thesis. First of all, thank god for the wisdom and perseverance that he has been bestowed upon me during this research project and indeed throughout my life. I would like to express my greatest appreciation to Prof. Béla Vizvári. I can’t say thank you enough for his tremendous support and help. I feel motivated and encouraged every time I attended his meeting and certainly without his encouragement and guidelines this thesis would not have materialized. Furthermore, I would like to thanks Dr. Behnam Mirzapour for introducing me to the topic as well for the support on the way. I warmly thank to the chair of department, Assist. Prof. Dr Gökhan İzbırak, for providing excellent facilities and healthy environment for research. I would like to thank, Assist. Prof. Dr. Orhan korhan for the Turkish translation of my thesis abstract. I wish to thank my parents for their undivided support and interest who inspired me and encouraged me to go on my own way, without whom I would be unable to complete my project.

Finally, I would like to express my appreciation to all faculty members and my friends who have helped and motivated me in several ways. To particular mentioning them, I have put the names of them as to be: Dr. Adham Machieh, Dr. Emine Atasoylu, Dr. Sahand Daneshvar, Sadegh, Arman, Hood, Maziyar, Mahdi, Sam, Farhood and Mahmud.

Dedicated to my dear family who are the only reason of my life

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

There has been a remarkable growth and discussion about organ transplantation (OT) in last decades and it has become widespread. Many diseases can be treated by transplantation such as heart and liver failure, terminal lung illnesses and etc. On the other hand, brain death (BD) patient can gift a life to at least five persons who are needed an organ to be alive. Heart, liver, lung and kidney are the most common organ for transplantation. One of the biggest major problem in the logistic of the OT is, there is not a well-balanced flow between supply and demand due to the gap between the number of people which have to wait for a long times even some years in the waiting list and the number of BD patients that are satisfied for donate an organ. (R.A.M, et al., 2011) mentioned the medical education is a vital factor to reducing the waiting list for transplantation. Appropriate medical information and education is required to encourage people for organ donation after their death. It can be extraordinary increase the availability of potential organs and reduce the waiting list for patients. Organ Transplantation centers (OTC) are responsible for collecting information about people are registered electively for donating their organs after death and also cooperating with hospitals when emergency situations occur. Once one person afoul an BD in hospital, coordinator should inform OTC for existing such a case on that hospital, an expert person is sent from OTC for checking and diagnosis the brain death and after approving it, OTC representative arrange a meeting with the family of the dead person and after satisfaction achievement, different types of transportation are organized for transport the patient and dead person to the center. The logistic in healthcare has a considerably importance and vital due to perishable characteristic of organ in some situations. According to the medical procurement of organ, there is limited time for transplant after removal organ from the human body that we comprehensively discuss about constraints, procedure, and medical rules for transplantation in next chapter.

It is needed to locate a certain center in order to meet the requirement and manage all supply and demand between all hospitals. Iran with approximately 75 million populations is one of the most populated countries in the Middle East with around 3000-6000 brain-death in a year. Moreover, 1600-1700 transplantation surgery is done per year in Iran. This fact obviously indicates that the usage of the BD capacity located is on low level compared to other countries. The well located OTC can significantly reduce the transportation between hospitals and centres and also can cover high percentage of the populations. As a result, common human organs such as heart, kidney, lung and liver can’t be stored like a blood and also can’t be accessible by hospitals in any time. One of the major difficulties in the OTC is, once BD is diagnosed in hospital, simultaneously some transportation should be arranged, recipient is prepared to transferred to the candidate center while organ or dead person is transported to the center. As mentioned before, there is a limited allowable time for surgery after removal the organ, that it is different for each organ. Unfortunately because of special equipment and personnel for transplantation surgery, not all hospitals are capable of doing this surgery; it is strictly needed in Iran to locate some center between different provinces especially in high populated regions for meeting the demand.

The reminder of this research is organized as follows. A comprehensive literature review about different healthcare modeling for facility location is presented in chapter 2, 3 along supply chain management in healthcare and medical rules for organ transplantation surgery respectively. The data collection and mathematical models for considering a problem are described respectively in section 4 and 5. A computational results and sensitivity analysis are presented in section 6. At last, conclusion and future research are presented in section 7.

Chapter 2

LITERATURE REVIEW

2.1 Logistic in Healthcare

First of all, it is necessary to mention this point that, we checked SCOPUS as one of the comprehensive database before start this study to check the related studies. It is interesting to mention that, we tested different keyword in this database such as, healthcare logistic, supply chain management (SCM) in healthcare and hospitals transportation. Totally 933 cases were found (from 2005 until early April) which include 444, 448 and 41 cases for each of them respectively. SCM has different concept in the healthcare sector due to perishability of some commodities like blood and organ but all the definitions that have been applied in the manufacturing environment are used in the healthcare sector. It also promotes the integration of activities such as the procurement, logistic, production and distribution of products to client (Stadler, 2008) (Zanjirani, Farahani, & Davarzani, 2009). Recently the concept of SCM in healthcare is applied for various purposes such as measuring the SCM performance in public sectors, enhance the ability of SCM for valuable items by means of radio-frequency identification (RFID), generalized the comprehensive model for perishable commodity in healthcare and use the diverse strategic for e-adoption in healthcare SCM. (Pierskalla, 2005) Comprehensively consider the supply chain management (SCM) of blood banks and investigate the strategic overview related to level of inventory, how much communities should be located in the specific region, how supply and demand should be coordinated, delivery and assigning blood to different locations. SCM in blood banking consider different levels of services in a specific region including community blood center (CBC) and various hospital blood center (HBC). The following figure indicates the hierarchical structure for blood banking:

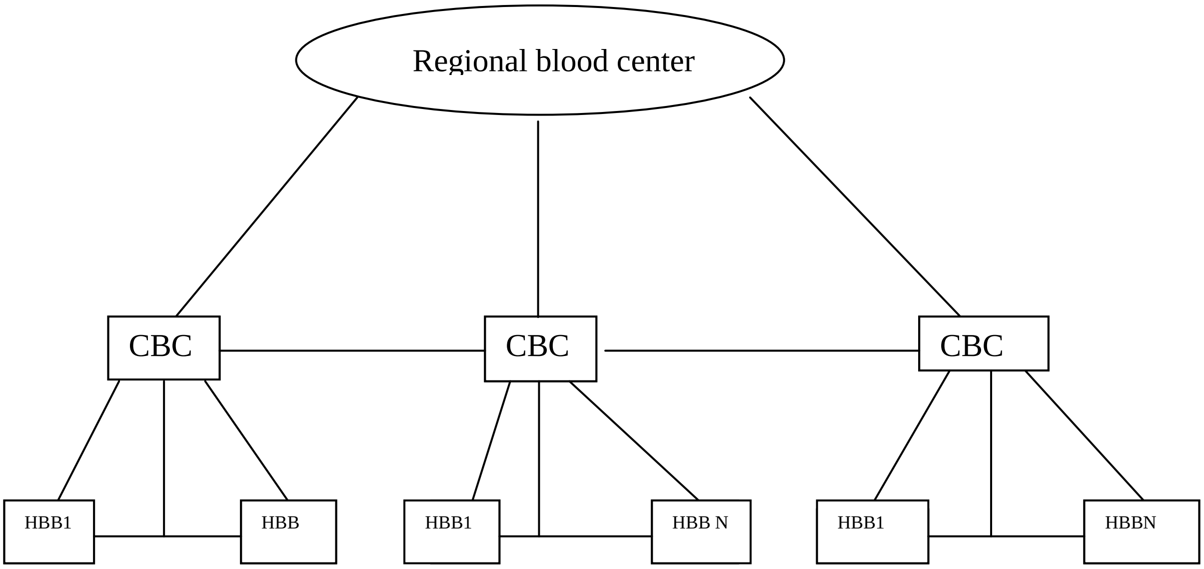

Figure 2.1: Hierarchical Territorial structure

As stated before many authors focus on different aspect of SCM in healthcare. (Bendavid & Harold, 2011) explains about financial aspects of SCM in healthcare and propose an SCM perspective in order to reducing waste in healthcare. Some authors (Lai, Nagi, & Cheng, 2002; Sharahi & Abedian, 2009) state that measurement of performance in SCM is one of the major problems. SCM council provides a valuable framework for evaluation the SC performance of firms and it developed the SC reference model. (Lega, Marsilio, & Villa, 2012) propose a framework for assessing SCM performance in the public healthcare sector. (Masoumi, Yu, & Nagurney, 2012) with respect to product perishability of medicines consider a generalized network oligopoly model with arc coefficients for SCM of pharmaceutical commodities in order to compete in the competitive market taking into account perishability of goods, brand differentiation as well as eliminating expenditure.

2.2 Healthcare Facility Location

The selection of the location of a facility is a significant decision in both healthcare and industry environment and any erratic decisions may lead to increase some factors such as cost of transportation, inventory cost etc. In healthcare, the facility location has a great importance, because if too many facilities are employed or if they are not located well this fact may lead to mortality and morbidity (Daskin & Dean, 2005). Generally due to importance of facility location in strategic planning many factors are considered such as number of facilities, cost, distance and congestion of demand nodes. Many mathematical models based on these factors have been proposed in this area. Covering problem is popular models among facility location due to their application in the healthcare delivery system and emergency services (Zanjirani Farahani, Asgari, Heidari, Hosseininia, & Goh, 2011). In the covering models which it is explained completely in this chapter, the coverage is an important notion and also facility is located to cover demand nodes with respect to coverage limitation between facility and demand nodes. As mentioned before, the coverage problem has a significant application in real problems for considering the location of (EMS), blood banking, hospitals, military centers, radar installation, public schools and libraries (Francis & White, 1974). (Daskin & Dean, 2005) state there are basic location models that are used in healthcare application named set covering model, maximal covering model and p-median model. (Schilling, Jayaraman, & Barkhi) Classify models that are applied the concept of covering in two categories: (1) Set covering problem (SCP) and (2) maximal covering location problem. (Daskin, Hesse, & ReVelle, 1997) Present an overview of stochastic and dynamic characterization of facility location. (Drezner, Drezner, & Goldstein, 2010) present an overview of covering problem according to three different areas: (1) gradual covering model, (2) cooperative covering model, (3) variable radius model. In this section with respect to importance of basic facility location models, set covering, maximal covering and p-median models are stated. All three models are assumed that the number of demand nodes compacted in the finite number of points that refer to discrete characterization of these models. The set covering model is formulated as follow:

$$\text{Min } \sum_{j\in J} c_j x_j \qquad (2\text{-}1)$$

$$\text{Subject to: } \sum_{j\in J} h_{ij} x_j \geq 1 \qquad \forall\ i\in I \qquad (2\text{-}2)$$

$$x_j \in \{0,1\} \qquad \forall\ j\in J \qquad (2\text{-}3)$$

$$x_j = \begin{cases} 1 & \text{if we locate at site } j \\ 0 & \text{otherwise} \end{cases}$$

$$h_{ij} = \begin{cases} 1 & \text{if the node } i \text{ can be covered by a facility at site } j \\ 0 & \text{otherwise} \end{cases}$$

I : set of demand nodes

J : set of candidate locations

c_j : fixed cost for locating facility at site j

The objective function (2-1) attempts to minimize the cost of locating candidate facility. Constraint (2-2) specifies that each demand node can get a service by at least one of the candidate facility and the last constraint indicates the integrality constraint. (Daskin & Dean, 2005) mention about several general goal in real application and explain it’s preferable to minimize the number of located facilities instead of cost in the location problems. (Murry, Tong, & Kim, 2010) present implicit and explicit location problem based on set covering model that assume each demand node can get service by more than one facility. The maximal covering location problem (MCLP) first proposed by (Church & Revelle, 1974) and applied in healthcare planning because of budget limitation in order to maximize the population that should be covered (Radiah Shariff, Moin, & Omar, 2012). The MCLP is formulated as follow:

$$\text{Max } \sum_i a_i z_i \tag{2-4}$$

Subject to:

$$z_i \leq \sum_j c_{ij} .x_j \qquad \forall\, i \in I \tag{2-5}$$

$$\sum_j x_j \leq p \tag{2-6}$$

$$d_{ij} + M c_{ij} \leq S + M \tag{2-7}$$

$$z_i \in \{0,1\} \qquad \forall\, i \in I \tag{2-8}$$

$$x_j \in \{0,1\} \qquad \forall j \in J \tag{2-9}$$

$$c_{ij} \in \{0,1\} \qquad \forall i \in I, j \in J \tag{2-10}$$

Where:

I	set of demand nodes
J	set of candidate site
p	the maximum number of facilities
d_{ij}	distance from current facility (i) to candidate center (j)
a_i	demand volume at node i
s	acceptable service distance
M	large number

$$c_{ij} = \begin{cases} 1 & \text{if } d_{ij} \leq s \\ 0 & \text{otherwise} \end{cases}$$

$$x_j = \begin{cases} 1 & \text{if we locate at site } j \\ 0 & \text{otherwise} \end{cases}$$

The objective function (2-4) maximize the volume of covered demands, constraint (2-5) specifies that we should locate at least one facility in order to count node (i) as covered demand. Constraint (2-6) indicates that the number of located candidate site should be less than the maximum number of facility(p) . Constraint (2-7) indicates that distance for the located facility should be less than the maximum allowable service distance, it also shown in our proposed models in last Chapter. Finally constraints (2-8), (2-9) and (2-10) are the integrality constraints. (Revelle & Hogan, 1989) propose a probabilistic version of MCLP with considering the probability of maximized the covered population in order to locate (p) facilities.

In healthcare facility location problem, apart from maximize the coverage demand, it's preferable for strategic planner to minimize the maximal distance that patient have to take for getting the service from hospitals or other centers and in order to specify such problems (Hakimi, Optimum locations of switching centers and the absolute centers and medians of a graph, 1964; Hakimi, Optimum Distribution of Switching Centers in a Communication Network and Some Related Graph Theoretic Problems, 1965) addresses p-median model that minimize the average distance. It is stated as follow

$$\text{Min} \quad \sum_{j\in J} \sum_{i\in I} a_i \, d_{ij} \, h_{ij} \tag{2-11}$$

Subject to:

$$\sum_{j\in J} h_{ij} = 1 \qquad \forall\, i \in I \tag{2-12}$$

$$h_{ij} \leq x_{ij} \qquad \forall i \in I;\ \forall j \in J \tag{2-13}$$

$$\sum_{j\in J} x_j \leq p \tag{2-14}$$

$$x_{j,}\ y_{ij} \in \{0,1\} \qquad \forall\, i \in I;\ \forall j \in J \tag{2-15}$$

Where:

$$h_{ij}=\begin{cases}1 & if\ demand\ at\ nodes\ i\ are\ assigned\ to\ a\ candidate\ facility\ j\\0 & otherwise\end{cases}$$

$$x_j=\begin{cases}1 & if\ we\ locate\ at\ candidate\ site\ j\\0 & otherwise\end{cases}$$

a_i $\quad demand\ volume\ at\ node\ i$

p $\quad maximum\ number\ of\ facility\ that\ should\ be\ located$

d_{ij} $\quad distance\ from\ current\ facility\ (i)\ to\ candidate\ center\ (j)$

The objective function (2-11) minimizes the average distance for covered demand. Constraint (2-12) states that all demand nodes should be covered exactly by one candidate site. Constraint (2-13) stipulates that demand nodes should be designated to open candidate sites. Constraint (2-14) states that the number of located facility must be less than (p) and constraint (2-15) presents an integrality constraint. For the

readers who are interested to know more about the location of healthcare literature these studies are proposed: (Farahani & Hekmatfar, 2009) (Drezner & Hamacher, 2002) (Shariff & Sarifah Radiah , 2012).

Chapter 3

GENERAL RULES FOR ORGAN ENGRAFTMENT

According to medical point of view, transplantation surgery (TS) is known as one of the vital and difficult surgery in the world. Meanwhile, because of many various types of diseases such as heart and kidney failure many people for being alive need to get a new organ. TS play a vital role for those who are waiting in the waiting list for obtaining an organ. OTC is established in order to supply necessary information about this surgery and gathering medical information for those who are prepared for TS. There are many experts who work in this center such as transplant surgeon, transplant coordinator, ambulance technician and etc. The main importance part of OTC duties is once one person is afoul a (BD) in one hospital, hospital coordinator announce the OTC about existence of such a patient and immediately an expert person from OTC is sent to the hospital in order to diagnosis the BD and after approve it, the coordinator contact to patient family in order to getting a satisfaction for engraftment surgery. After achieving an expert team with equipped ambulance from OTC is sent to hospital for transport the BD patient to center. There are different types of transportation and cooperation between hospitals and OTC. First cooperation include transport the BD patient from hospital to the OTC after diagnosis, second type is transport the organ from OTC to the secondary hospital and the last one is transport the candidate patient to the OTC.

An important constraint in this surgery is time limitation for keeping an organ alive after removal, according to medical point of view these constraints for common organs are shown as follows:

Table 3.1: Available time for organs after removal

Type of organ	Available time after removal
Heart	4
Lung	6
Kidney	72
liver	17

Although in some situations, it is possible to increase this time. Lung, liver, heart and kidney are the most common organs for engraftment. The donor organ leakage is an important problem in transplantation nowadays and is one where organ preservation technology has a vital role to play (McAnulty, 2009). The average waiting list for each organ according to national data is show as follows:

Table 3.2: Average national waiting list of organs

Type of organ	Average waiting List
Heart	113 days
Lung	141 days
Kidney	1219 days
Liver	361 days

The important duty of OTC is matching requirement before surgery; different factors are checked before surgery such as blood type, Human Leukocyte Antigens (HLA), height and weight of candidate patient. The close matching of HLP can enhance the chance of successful engraftment.

Chapter 4

DATA COLLECTION

In this study, we selected Iran as a most populated country in the Middle East with about 75 million population. Furthermore, four neighbor provinces are selected in order to investigate and analyze the location of OTC. These provinces are Tehran (capital), Mazandaran, Semnan and Qom. The populations and geographical locations of these areas are shown in Table 4.1:

Table 4.1: population of selected areas

Area	Population
Tehran	12,183,391
Mazandaran	3,073,943
Semnan	631,218
Qom	1,151,672

In this research, we selected 20 hospitals in these regions that include both public and private in order to collecting information about patients which need to obtain an organ. In this study, different criteria were considered for hospitals selection such as reputation, medical equipment and patient's satisfaction. As can be seen in the Table 3.2, nine hospitals were selected in Tehran due to logistical importance of the city. Many people from close cities to Tehran have to travel to Tehran for achieving medical services

Figure 4.1: Geographical location of selected areas

of equipment shortage in their local hospitals. This evidence indicates that Tehran hospitals have a high demand and because of this reason, nine hospitals were selected in Tehran that four of them are private and the rest of them are public. The number of demands for TS is collected in each hospital. The Table 4.2 states the number of demand and hospitals location:

Table 4.2: The location and demand for selected hospitals

Hospital i	Name	Location	Demand
1	Milad*	Tehran(Teh)	243
2	Apadana*	Tehran(Teh)	162
3	Asia	Tehran(Teh)	115
4	Bahman	Tehran(Teh)	135
5	Erfan	Tehran(Teh)	162
6	Chamran	Tehran(Teh)	64
7	Pars	Tehran(Teh)	165
8	Bazargan	Tehran(Teh)	150

Hospital i	Name	Location	Demand
9	Heart center*	Tehran(Teh)	264
10	Rohani*	Babol(Mazandaran)	135
11	Khomeyni	Sari(Mazandaran)	145
12	17 shahrivar	Amol(Mazandaran)	124
13	Razi	Chalus(Mazandaran)	67
14	Omidi	Behshahr(Mazandaran)	49
15	Fatemi*	Semnan	62
16	Rezaei	Damghan(semnan)	40
17	Khatam	Shahrud(semnan)	32
18	Khomeyni	Garmsar(semnan)	46
19	Gholpaygani	Qom	100
20	Kamkar	Qom	80

Generally, some hospitals have special medical equipment's for TS. In this case, the number and location of these hospitals was investigated and it is specified in table (4.2) with *. Meanwhile, these hospitals can be selected as a peripheral hospital in this research in order to transfer the patients from ordinary hospitals to peripheral hospital for TS because in some situations, it is not possible or is not convenient for OTC team to transfer the brain death patient directly to the OTC.

The Geographical locations of these hospitals are shown on figure 4.2:

Figure 4.2: Geographical locations of selected hospitals

As mentioned before, due to high population of Tehran, nine important hospitals in Tehran are considered for investigation, it is aimed to find the best locations of OTC with respect to coverage distance, total transportation and maximum acceptable service distance. Capacity for the OTC is one of the important factors that have been considered in this research. With respect to these hospitals, medical information's of 50 patients among these hospitals have been collected that specify some factors before and after engraftment surgery. These factors include patients in the waiting list (PWL), blood type of patient (BTP), location of patient (LOP), arrival date in list (ADL), location of BD patient (LBDP), distance of BD patient to candidate center (DBDPC), date of receive an organ (DRO), waiting time in list (WTIL), distance to peripheral hospital (DTPH),blood type of brain death (BTOBD), number of lost organ (NOLO), distance of peripheral hospital to center (DPHC), distance of candidate patient to center (DCPC) that are used for simulation. We collected these data from Masi Daneshvari Transplant Organ Providing Center as one of the important medical centers in Iran in order to apply in our simulation. As mentioned before, medical information of 50 patients were collected, that are used for simulation in Chapter 6, in order to computing average of three type of transportation based on different candidate sites that are obtained from our mathematical models in chapter 6. In this section, with respect to these 50 patient information's, two arbitrary locations are selected as our candidate sites in order to preliminary computation and analyzing different type of transportation. It is noticeable that in transportation computation in this section, different factors have been considered for arbitrary selection of sites such as population congestion, demand for organ engraftment and deprived areas. As explained completely in Chapter 2, there are some vital factors that are very important for transplantation surgery such as blood type and HLA. In this research just blood type is considered because of the data about HLA of patients wasn't available in the Masi Daneshvari center. Furthermore, due to matching system between donors and receivers, in some cases some organs maybe lost, therefore the number of lost organs is considered also in this system. The results that are obtained in this section can be very useful for concluding and comparison with the real located facility in the last chapter. The first computation for arbitrary locations is shown in Table 4.3:

Table 4.3: Computation Result For Two Arbitrary Locations

PWL	BTP	LOP	ADL	LBDP	DBDPC1	DBDPC2	DRO	WTIL	DTPH	BTOBD	NOLO	DPHC1	DPHC2	DCPC1	DCPC2
1	O+	LOP	ADL	Apadana(Thr)	17.5	267	3/28/2011	326	0	O-	0	17.5	267	198	45.5
2	O+	Qom	1/9/2010	Asia(Thr)	15.5	268	4/4/2011	328	3.3	O+	0	17.5	267	164	421
3	O+	Tehran	2/3/2010	Rohani(babol)	198	37.8	5/1/2011	323	0	O+	0	198	37.8	17	273
4	O+	semnan	2/20/2010	Golpaygani(Qom)	161	411	5/14/2011	320	169	A+	0	17.5	267	223	180
5	B+	shahrud	3/16/2010	17shahrivar(Amol)	170	68.8	6/3/2011	319	32.2	B+	0	198	37.8	404	248
6	A+	Damghan	4/6/2010	Bahman(Thr)	22.2	276	6/13/2011	310	7.3	O+	0	21.8	276	341	185
7	B+	sari	4/15/2010	Omidi(Behshahr)	312	55	6/20/2011	308	91	A+	0	198	37.8	260	3.6
8	O+	Tehran	5/3/2010	Chamran(Thr)	14.4	264	6/25/2011	300	14.2	o+	0	17.5	267	17	273
9	O+	Amol	5/18/2010	Khomeyni(Sari)	265	6	7/5/2011	296	44.4	O+	0	198	37.8	170	75.1
10	A+	Tehran	5/21/2010	Heart centre(Thr)	20.2	274	7/13/2011	299	4.9	O+	0	20.2	274	17	273
11	O+	Qom	6/4/2010	Rezaei(damghan)	343	180	7/26/2011	298	120	O-	1	225	173	164	421
12	O+	Garmsar	7/18/2010	Khatam(shahroud)	398	240	7/31/2011	270	183	O+	0	225	173	113	264
13	O+	Behshahr	7/26/2010	Milad(Thr)	21.8	276	8/7/2011	270	0	A-	0	21.8	276	310	47.6
14	O+	tehran	8/19/2010	Bahman(Thr)	22.2	276	8/19/2011	262	7.3	A+	0	21.8	276	17	273
15	O+	chalus	8/29/2010	Razi(chalous)	159	167	8/29/2011	261	129	A+	0	198	37.8	158	173
16	A+	shahrud	9/12/2010	Erfan(Thr)	24.9	276	9/3/2011	255	10.3	A+	0	21.8	276	404	248
17	A+	Qom	9/20/2010	Khomeyni(garmsar)	115	257	9/21/2011	263	115	O+	0	225	173	164	421
18	A+	Babol	10/6/2010	Kamkar(Qom)	160	410	9/17/2011	248	148	O+	0	17.5	267	198	45.5
19	O+	sari	10/12/2010	Erfan(Thr)	24.9	276	10/4/2011	256	10.3	A+	0	21.8	276	260	3.6
20	A+	Tehran	10/15/2010	Omidi(Behshahr)	312	55	10/19/2011	264	91	O+	0	198	37.8	17	273
21	A-	Tehran	10/22/2010	Rezaei(damghan)	343	180	10/27/2011	265	120	A+	0	225	173	17	273
22	A+	Tehran	10/29/2010	Fatemi(semnan)	225	173	10/29/2011	261	0	O+	0	225	173	17	273
23	O+	Tehran	11/10/2010	Golpaygani(Qom)	161	411	11/16/2011	266	169	A+	0	17.5	267	17	273
24	O+	Qom	11/21/2010	bazargan(Thr)	18.8	269	12/3/2011	270	5.7	B+	0	17.5	267	164	421
25	O+	Amol	11/30/2010	Pars(Thr)	22.4	277	12/12/2011	270	3.2	O+	0	17.5	267	170	75.1
26	A+	Babol	1/2/2011	Razi(chalous)	159	167	12/22/2011	254	129	A+	0	198	37.8	198	45.5
27	A+	shahrud	1/17/2011	Asia(Thr)	15.5	268	12/29/2011	249	3.3	B+	0	17.5	267	404	248
28	A-	semnan	2/19/2011	Rohani(babol)	198	37.8	1/16/2012	236	0	O+	0	198	37.8	223	180
29	A+	Tehran	2/23/2011	Khatam(shahroud)	398	240	1/21/2012	238	183	O+	0	225	173	17	273
30	O+	sari	3/3/2011	17shahrivar(Amol)	170	68.8	1/30/2012	238	32.2	A+	0	198	37.8	260	3.6
31	A+	Amol	3/7/2011	Khomeyni(garmsar)	115	257	2/14/2012	247	115	O+	0	225	173	170	75.1
32	B+	Tehran	3/7/2011	Milad(Thr)	21.8	276	3/1/2012	259	0	O+	0	21.8	276	17	273
33	O+	Tehran	3/18/2011	Omidi(Behshahr)	312	55	3/6/2012	253	91	B+	0	198	37.8	17	273
34	B+	Tehran	4/3/2011	bazargan(Thr)	18.8	269	3/19/2012	251	5.7	B+	0	17.5	267	17	273
35	A-	Garmsar	4/12/2011	Erfan(Thr)	24.9	276	3/23/2012	249	10.3	B+	0	21.8	276	113	264
36	O+	semnan	4/15/2011	Apadana(Thr)	17.5	267	3/25/2012	246	0	B+	1	17.5	267	223	180
37	A+	chalus	5/8/2011	Razi(chalous)	159	167	4/6/2012	240	129	O+	0	198	37.8	158	173
38	O+	Qom	5/16/2011	Kamkar(Qom)	160	410	5/3/2012	254	148	O-	1	17.5	267	164	421
39	AB+	Behshahr	5/21/2011	Asia(Thr)	15.5	268	5/21/2012	261	3.3	B+	1	17.5	267	310	47.6
40	A+	Tehran	6/17/2011	bazargan(Thr)	18.8	269	5/27/2012	246	5.7	A+	0	17.5	267	17	273
41	O+	shahrud	7/21/2011	17shahrivar(Amol)	170	68.8	6/3/2012	227	32.2	A+	0	198	37.8	404	248
42	A+	Babol	8/13/2011	Khomeyni(Sari)	265	6	6/7/2012	214	44.4	A+	0	198	37.8	198	45.5
43	A+	Qom	9/8/2011	Heart centre(Thr)	20.2	274	6/22/2012	207	4.9	O+	0	20.2	274	164	421
44	A+	Tehran	9/10/2011	Fatemi(semnan)	225	173	6/24/2012	205	0	A+	1	225	173	17	273
45	A+	chalus	9/16/2011	Golpaygani(Qom)	161	411	7/7/2012	211	169	A+	1	17.5	267	158	173
46	A+	Tehran	10/7/2011	Milad(Thr)	21.8	276	7/12/2012	200	0	O+	0	21.8	276	17	273
47	O+	Garmsar	10/13/2011	Rohani(babol)	198	37.8	7/21/2012	202	0	A+	1	198	37.8	113	264
48	O+	qom	10/19/2011	Khatam(shahroud)	398	240	7/23/2012	199	183	A+	1	225	173	164	421
49	O-	Behshahr	10/27/2011	Kamkar(Qom)	160	410	8/4/2012	202	148	A+	1	17.5	267	310	47.6
50	A+	Babol	12/5/2011	Apadana(Thr)	17.5	267	8/9/2012	179	0	A+	1	17.5	267	198	45.5

As can be seen, diffrenet factors have been considered for colleceting information and three different transportation was measured based on two fixed facility. It also can be seen the number of lost organ in each case, when the blood type of the receiver and doner is not same.

The results of this computation are shown in Table 4.4:

Table 4.4: Result of first computation

Facility site j	Coordinates		Average DBDPC (km)	Average DCPC (km)	Average DPHC (km)
	x	y			
1	51.34	53.04	140	161	107
2	35.43	36.34	223	214	188

Three type of transportations from among the 20 existing hospitals were computed with considering two arbitrary facility locations. It is necessary to consider this approach based on arbitrary locations before using mathematical modeling because of realize the distance between hospitals and also check the feasibility of locating facility among these regions. This approach is also used to find out the maximum acceptable service distance that it has been considered in our mathematical model. The geographical locations of selected facility are described on Figure 4.3:

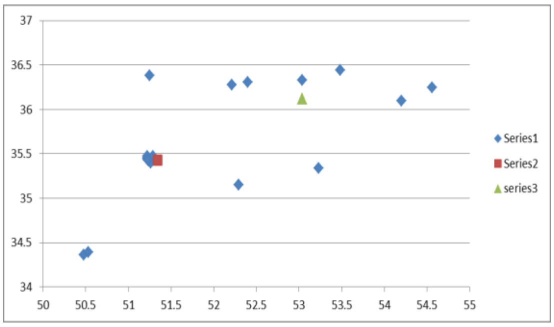

Figure 4.3: Locations of the selected facility

It is noticeable that, this collected information's are applied for Monte Carlo simulation in order to extent this system with considering higher percentage of people among these regions. Meanwhile the results that are obtained from our mathematical models are selected as an objective for simulation and it is shown the comparison the simulation results with mathematical models in Chapter 6 completely.

Chapter 5

DEFINITION AND MODELING OF THE PROBLEM

In this chapter, various mixed integer programming models are presented for considering the problem based on different purposes. It has also been tried to use the basic concepts and models in healthcare facility location such as covering problems and maximal covering models. As it has been stated in the previous chapter, different types of transportation were considered to investigate the best locations of OTC. The first model which is proposed in this research described as follows:

5.1 Complete Service with Minimal Transportation Cost

Parameters

Parameters are as follow:

i	$index\ of\ hospitals$	$i = 1,2,\dots,n$
j	$index\ of\ candidate\ locations$	$j = 1,2,\dots,m$
I	$the\ set\ of\ hospitals$	
J	$the\ set\ of\ candidate\ TC$	
p	$the\ maximum\ number\ of\ facilities\ to\ be\ located$	

f_i	$frequency\ of\ candidate\ patients$
g_i	$frequency\ of\ organ\ donations\ at\ hospital\ i$
d_{ij}	$distance\ from\ \ hospital\ i\ to\ candidate\ facility\ j$
T	$number\ of\ transplant\ unit$
F	$number\ of\ removal\ units\ (\ peripheral\ hospitals)$
h_1	$upper\ bound\ for\ organ\ donation$
h_2	$upper\ bound\ for\ candidate\ patients\ (ill\ person)$
α	$weight\ for\ the\ transportation\ of\ the\ BD\ patient\ from\ hospital\ i\ \ to\ the\ \ OTC$
β	$weight\ for\ the\ transportation\ of\ the\ organ\ from\ hospital\ i\ to\ \ OTC$
γ	$weight\ for\ the\ transportation\ of\ the\ candidate\ patient\ to\ the\ OTC$
xh	$coordinate\ of\ the\ hospitals$
xf	$coordinate\ of\ the\ candidate\ facility$

Decision Variables

The decision variables for the first model can be stated as follows:

$$z_j = \begin{cases} 1 & if\ a\ transpantation\ center\ is\ located\ at\ site\ j \\ 0 & otherwise \end{cases}$$

$$y_i = \begin{cases} 1 & if\ hospital\ i\ is\ a\ \ organ\ removal\ unit \\ 0 & otherwise \end{cases}$$

$$u_{ij} = \begin{cases} 1 & if\ BD\ patient\ is\ transported\ from\ i\ to\ j \\ 0 & otherwise \end{cases}$$

$$v_{ij} = \begin{cases} 1 & if\ organ\ is\ transported\ from\ i\ to\ j \\ 0 & otherwise \end{cases}$$

$$w_{ij} = \begin{cases} 1 & if\ candidate\ patient\ is\ transported\ from\ i\ to\ j \\ 0 & otherwise \end{cases}$$

$$m_{ij} = \begin{cases} 1 & if\ demand\ at\ node\ i\ is\ assigned\ to\ the\ candidate\ facility\ j \\ 0 & otherwise \end{cases}$$

Model formulation:

$$\min \quad \alpha \textstyle\sum_i \sum_j d_{ij}\, u_{ij} + \beta \sum_i \sum_j d_{ij}.v_{ij} + \gamma \sum_i \sum_j d_{ij}.w_{ij} \tag{5-1}$$

The objective function (5-1) minimize three types of transportation in the system which include the transportation of the organ from removal unit to the OTC, transport the candidate patients to OTC and transport the BD patient from the hospitals to the OTC.

$$d_{ij} \geq xh(i,1) - xf(j,1) + xh(i,2) - xf(j,2)$$

$$d_{ij} \geq xh(i,1) - xf(j,1) - xh(i,2) + xf(j,2) \tag{5-2}$$

$$d_{ij} \geq -xh(i,1) + xf(j,1) + xh(i,2) - xf(j,2)$$

$$d_{ij} \geq -xh(i,1) + xf(j,1) - xh(i,2) + xf(j,2)$$

Constraint (5-2) states the Manhattan distance form that used in this research for the computing distance between hospitals and candidate sites.

$$\sum_{j\in J} z_j = T \tag{5-3}$$

$$\sum_{i\in I} y_i = F \tag{5-4}$$

Constraint (5-2) and (5-3) specify the number of candidate facilities to be located and number of removal units. It is also noticeable that the removal units is a peripheral hospitals which in some situations due to some medical difficulties, BD patients have to be transported to this hospitals and after removal the organ, medical team transport the organ to the OTC.

$$\forall j: \quad z_j \le y_i \tag{5-5}$$

Constraint (5-5) stipulates that number of removal hospitals should be greater or equal to the number of the OTC.

$$\forall i: \ \sum_{j\in J} u_{ij} = 1 \tag{5-6}$$

Constraint (5-6) states that all BD patients should be transported to exactly one facility site.

$$\forall i,j: \ u_{ij} \le y_i \tag{5-7}$$

Constraint (5-7) states that BD patient is transported from hospital i to removal unit

j.$\forall i: \quad \sum_{j\in J} v_{ij} = 1$ (5-8)

Constraint (5-8) states that all organs are transported exactly to one candidate site.

$$\forall i,j: \ v_{ij} \le z_j \qquad j \in TC, i \in I \tag{5-9}$$

Constraint (5-9) mention the second type of transportation that organ is transported from hospital i to the candidate site$j$.

$$\forall\, i: \quad \textstyle\sum_{j\in J} w_{ij} = 1 \tag{5-10}$$

Constraint (5-10) stipulates that all candidate patients are transported exactly to one candidate site.

$$\forall\, i,j: \quad w_{ij} \le z_j \qquad\qquad j \in TC \tag{5-11}$$

Constraint (5-11) mentions the third type of transportation that patients are transported to the candidate sites.

$$\forall\, j: \quad \textstyle\sum_i g_i\,.\,u_{ij} \le h_1 \tag{5-12}$$

$$\forall\, j: \quad \textstyle\sum_i f_i\,.\,w_{ij} \le h_2 \tag{5-13}$$

Constraints (5-12),(5-13) state the specific upper bound for candidate patients and organ donation.

$$(0.7).d_{ij} \le 72 + M(1 - m_{ij}) \tag{5-14}$$

$$(0.7).d_{ij} \le 17 + M(1 - m_{ij}) \tag{5-15}$$

$$(0.7).d_{ij} \le 6 + M(1 - m_{ij}) \tag{5-16}$$

$$(0.7).d_{ij} \le 4 + M(1 - m_{ij}) \tag{5-17}$$

Finally constraints (5-14),(5-15),(5-16),(5-17) describe the time limitation for kidney, lung, heart and liver, in order to transport from hospital to the OTC that it has been completely explained in chapter 2 about the medical rules for organ transportation. It is also assumed that ambulance can take distance between hospital and candidate facility with 70 km/h.

5.2 Maximal Service under Capacity Constraint

The second model that is used in this research has a remarkable importance in the healthcare facility location and it has been used in various applications for healthcare facility location. In this model, it is aimed to find the best facility location based on some important concepts such as demand, capacity and maximal allowable service distance, and it is tried to maximize the population assigned to the candidate site under capacity constraint. This model is introduced by (Pirkul & Schilling, 1991) and formulated as follows:

Parameters:

i	index of hospitals	$i = 1,2,\dots,n$
j	index of candidate locations	$j = 1,2,\dots,m$
I	the set of hospitals	
J	the set of candidate TC	
p	the maximum number of facilities to be located	
d_{ij}	distance from hospital i to candidate facility j	
s	maximum allowable service distance	
a_i	demand volume at node i (population of people)	
k_j	capacity for candidate center j	
xh	coordinate of the hospitals	

$xf \quad coordinate\ of\ the\ candidate\ facility$

$M \quad large\ number$

Decision variables

$$x_{ij} = \begin{cases} 1 & if\ demand\ \ node\ i\ is\ served\ by\ facility\ j \\ 0 & otherwise \end{cases}$$

$$c_{ij} = \begin{cases} 1\ if\ d_{ij} \leq s \\ 0\ \ otherwise \end{cases}$$

$$y_j = \begin{cases} 1 & if\ facility\ is\ located\ at\ site\ j \\ 0 & otherwise \end{cases}$$

Model formulation

$$Max \quad \sum_i \sum_j c_{ij} \, . \, a_i . x_{ij} \tag{5-18}$$

The objective function (5-18) maximize the demand assigned to the candidate site such that c_{ij} is equal 1 if distance between hospitals and candidate site is less than maximum allowable service distance.

$$d_{ij} \geq xh(i,1) - xf(j,1) + xh(i,2) - xf(j,2)$$

$$d_{ij} \geq xh(i,1) - xf(j,1) - xh(i,2) + xf(j,2) \tag{5-19}$$

$$d_{ij} \geq -xh(i,1) + xf(j,1) + xh(i,2) - xf(j,2)$$

$$d_{ij} \geq -xh(i,1) + xf(j,1) - xh(i,2) + xf(j,2)$$

Constraint (5-19) indicates the form of Manhattan distance that is used in this model for measuring the distance between hospitals and candidate sites.

$$\sum_{j \in J} y_j \leq p \tag{5-20}$$

Constraint (5-20) indicates that the number of located facility should be less than the maximum number of them.

$$\sum_{j \in J} x_{ij} = 1 \qquad \forall\, i \in I \tag{5-21}$$

Constraint (5-19) specifies that all demand nodes are assigned to open sites.

$$\sum_{i \in I} a_i \,.\, x_{ij} \leq y_j . k_j \qquad \forall j \in J \tag{5-22}$$

Constraint (5-22) stipulates the capacity constraint for the candidate sites.

$$\forall i, j \;\; d_{ij} + M c_{ij} \leq s + M \tag{5-23}$$

Constraint (5-23) states that the distance between hospitals and candidate sites should be less than the maximum allowable service distance.

$$x_{ij}\,, y_j = \{0,1\} \qquad \forall\, i \in I, j \in J \tag{5-24}$$

The last constraint presents an integrality conditions. As it has been shown in previous models, different concepts have been applied for modeling a problem which these definitions are used for next models

5.3. Maximal Allowable Service Distance

The third model that is presented in this chapter is based on maximum allowable service distance. In some cases it is preferable for planner to minimize the service distance between nodes. This approach can generate an accretion distance among hospitals. The proposed model is stated as follows:

Parameters

i	index of hospitals $i = 1,2,\dots,n$
j	index of candidate locations $j = 1,2,\dots,m$
I	the set of hospitals
J	the set of candidate TC
p	the maximum number of facilities to be located
d_{ij}	distance from hospital i to candidate facility j
s	maximum allowable service distance
a_i	demand volume at node i (population of people)
k_j	capacity for candidate center j
xh	coordinate of the hospitals
xf	coordinate of the candidate facility
M	large number

Decision variables

$$x_{ij} = \begin{cases} 1 & \text{if demand node } i \text{ is served by facility } j \\ 0 & \text{otherwise} \end{cases}$$

$$c_{ij} = \begin{cases} 1 & \text{if } d_{ij} \leq s \\ 0 & \text{otherwise} \end{cases}$$

$$y_j = \begin{cases} 1 & if\ facility\ is\ located\ at\ site\ j \\ 0 & otherwise \end{cases}$$

Model formulation

$$\mathrm{V}(p) = \min s \tag{5-25}$$

The objective function (5-25) tries to minimize the maximum distance that everybody is covered that generally this objective function indicates that in some situations, it’s preferable to minimize the worst case.

$$d_{ij} \geq xh(i,1) - xf(j,1) + xh(i,2) - xf(j,2)$$

$$d_{ij} \geq xh(i,1) - xf(j,1) - xh(i,2) + xf(j,2) \tag{5-26}$$

$$d_{ij} \geq -xh(i,1) + xf(j,1) + xh(i,2) - xf(j,2)$$

$$d_{ij} \geq -xh(i,1) + xf(j,1) - xh(i,2) + xf(j,2)$$

The constraint (5-26) states the Manhattan distance form that is used to evaluate the distance between hospitals and candidates sites.

$$\sum_{j \in J} y_j \leq p \tag{5-27}$$

Constraint (5-27) indicates that the number of located facility should be less than the maximum number of them.

$$\sum_{j \in J} x_{ij} = 1 \qquad \forall\, i \in I \tag{5-28}$$

Constraint (5-28) specifies that all demand nodes are assigned to open sites.

$$\forall i,j \;\; d_{ij} + Mc_{ij} \leq s + M \qquad (5\text{-}29)$$

Constraint (5-29) states that the distance between hospitals and candidate sites should be less than the maximum allowable service distance.

$$\textstyle\sum_{i\in I} a_i \,.\, x_{ij} \leq y_j . k_j \qquad \forall j \in J \qquad (5\text{-}30)$$

Constraint (5-30) stipulates the capacity constraint for the candidate sites.

$$d_{ij} . c_{ij} \leq s \qquad \forall i \in I, j \in J \qquad (5\text{-}31)$$

Constraint (5-31) forces that distance between hospitals and candidate centers should be less than maximum allowable service distance.

$$x_{ij} \leq c_{ij} \qquad \forall i \in I, j \in J \qquad (5\text{-}32)$$

Constraint (5-32) states that distance between hospitals and candidate site should be less than maximum allowable service distance if any node is assigned to open site.

$$x_{ij}, c_{ij}, y_j = \{0,1\} \qquad \forall i \in I, j \in J \qquad (5\text{-}33)$$

The last constraint, states the integrality conditions.

5.4 Fixed Service Level with Minimal Longest Distance

The fourth model applies an important notion in healthcare emergency services. In this model, percentage of demand nodes to be covered is considered in order to cover the specific demand volume. This model is described as follows:

Parameters

i	index of hospitals	$i = 1,2,\dots,n$
j	index of candidate locations	$j = 1,2,\dots,m$
I	the set of hospitals	
J	the set of candidate TC	
p	the maximum number of facility to be located	
d_{ij}	distance from hospital i to candidate facility j	
s	maximum allowable service distance	
a_i	demand volume at node i (population of people)	
k_j	capacity for candidate center j	
xh	coordinate of the hospitals	
xf	coordinate of the candidate facility	
π	the percentage to be covered	
M	large number	

Decision variables

$$x_{ij} = \begin{cases} 1 & if\ demand\ \ node\ i\ is\ served\ by\ facility\ j \\ 0 & otherwise \end{cases}$$

$$c_{ij} = \begin{cases} 1\ if\ d_{ij} \leq s \\ 0\ \ otherwise \end{cases}$$

$$y_j = \begin{cases} 1 & if\ facility\ is\ located\ at\ site\ j \\ 0 & otherwise \end{cases}$$

Model formulation

$$\mathrm{V}(\pi) = \min s \tag{5-34}$$

As can be seen, the objective function (5-34) minimizes the maximum allowable service distance between demand nodes and candidate sites.

$$d_{ij} \geq xh(i,1) - xf(j,1) + xh(i,2) - xf(j,2)$$

$$d_{ij} \geq xh(i,1) - xf(j,1) - xh(i,2) + xf(j,2) \tag{5-35}$$

$$d_{ij} \geq -xh(i,1) + xf(j,1) + xh(i,2) - xf(j,2)$$

$$d_{ij} \geq -xh(i,1) + xf(j,1) - xh(i,2) + xf(j,2)$$

The constraint (5-35) states the Manhattan distance form that is applied in this research for measuring the distance between demand nodes and candidate TC.

$$\sum_{j\in J} y_j \leq p \tag{5-36}$$

Constraint (5-36) stipulates that the number of located facility should be less than the maximum number of them.

$$\sum_{j\in J} x_{ij} \leq 1 \qquad \forall\, i \in I \tag{5-37}$$

As can be seen, we modified this constraint in order to assign more than one facility to demand at node i. The new constraint can be modified for previous models in order to comparing results.

$$\sum_i \sum_j a_i \,.\, x_{ij} \geq \pi \sum_i a_i \tag{5-38}$$

This constraint indicates that covered demand volume should be greater or equal to the specific percentage.

$$d_{ij}.c_{ij} \leq s \qquad \forall i \in I, j \in J \tag{5-39}$$

Constraint (5-39) states that distance between hospitals and candidate TC should be less than maximum allowable service distance.

$$x_{ij} \leq c_{ij} \qquad \forall i \in I, j \in J \tag{5-40}$$

This constraint forces that distance between hospitals and candidate sites for the located facility should be less than the maximum allowable service distance.

$$\forall i,j \;\; d_{ij} + Mc_{ij} \leq s + M \tag{5-41}$$

Constraint (5-41) states that the distance between hospitals and candidate sites should be less than the maximum allowable service distance.

$$x_{ij}, c_{ij}, y_j = \{0,1\} \qquad \forall i \in I, j \in J \tag{5-42}$$

The last constraint indicates the integrality conditions.

5.5 Fixed Service Level with Threshold Distance

The last model that is applied in this chapter use two important notions simultaneously, percentage to be covered and maximum allowable service distance. Threshold distance is an important factor that has been considered in this model. In some situations, it is obligatory to considered specific distance due to time limitation for organs which they should be arrived within a specific time. It also due to some medical difficulties for patients, they are not able to transport a long distance between hospitals to centers.

The fifth model is stated as follows:

Parameters

$i \qquad index\ of\ hospitals \qquad i = 1,2,\dots,n$

$j \qquad index\ of\ candidate\ locations \qquad j = 1,2,\dots,m$

I	$the\ set\ of\ hospitals$
J	$the\ set\ of\ candidate\ TC$
p	$the\ maximum\ number\ of\ facility\ to\ be\ located$
d_{ij}	$distance\ from\ hospital\ i\ to\ candidate\ facility\ j$
s	$maximum\ allowable\ service\ distance$
α	$is\ a\ very\ small\ positive\ number$
T	$threshold\ distance$
π	$the\ percentage\ to\ be\ covered$
M	$large\ number$

Decision variables

$$x_{ij} = \begin{cases} 1 & if\ demand\ node\ i\ is\ served\ by\ facility\ j \\ 0 & otherwise \end{cases}$$

$$c_{ij} = \begin{cases} 1 & if\ d_{ij} \leq s \\ 0 & otherwise \end{cases}$$

$$y_j = \begin{cases} 1 & if\ facility\ is\ located\ at\ site\ j \\ 0 & otherwise \end{cases}$$

Model Formulation

$$V(T) = \max \pi - \alpha s \qquad (5\text{-}43)$$

The objective function (5-43) maximizes the percentage covered within a coverage distance S.

$$d_{ij} \geq xh(i,1) - xf(j,1) + xh(i,2) - xf(j,2)$$

$$d_{ij} \geq xh(i,1) - xf(j,1) - xh(i,2) + xf(j,2) \tag{5-44}$$

$$d_{ij} \geq -xh(i,1) + xf(j,1) + xh(i,2) - xf(j,2)$$

$$d_{ij} \geq -xh(i,1) + xf(j,1) - xh(i,2) + xf(j,2)$$

As mentioned before in previous models, the Manhattan distance is used in this research for measuring distance between demand nodes and candidate TC.

$$\sum_{j \in J} y_j \leq p \tag{5-45}$$

Constraint (5-45) forces that the number of located facility should be less than the maximum number of them.

$$\sum_i \sum_j a_i . x_{ij} \geq \pi \sum_i a_i \tag{5-46}$$

This constraint states that covered demand volume should be greater or equal to the specific percentage.

$$\sum_{j \in J} x_{ij} \leq 1 \qquad \forall\, i \in I \tag{5-47}$$

This constraint states that demand at node i can be assigned to more than one TC.

$$\forall i,j \;\; d_{ij} + Mc_{ij} \leq s + M \tag{5-48}$$

Constraint (5-48) indicates that the distance between hospitals and candidate TC should be less than the maximum allowable service distance.

$$s \leq T \tag{5-49}$$

New constraint (5-49) stipulates that maximum service distance should be less than the threshold distance.

$$x_{ij} \leq c_{ij} \qquad \forall i \in I, j \in J \tag{5-50}$$

As stated before in previous model, distance between hospitals and candidate TC for the located facility should be less than the maximum allowable service distance

$$x_{ij}, c_{ij}, y_j = \{0,1\} \quad \forall i \in I, j \in J \tag{5-51}$$

The last constraint mentions the integrality conditions.

In this chapter, it has been tried to use different integer programming models with various concepts for considering the whole system based on coverage, maximum service distance, percentage of covered demand and threshold distance. In the next chapter, we use the data that have been collected in chapter 2 in order to find the best locations for OTC in selected regions of Iran.

Chapter 6

COMPUTATIONAL RESULTS AND SENSITIVITY ANLYSIS

In this Chapter, the powerful optimization tool, Xpress optimizer is used to solve the proposed linear programming models. It is aimed to find the best facility locations for OTC among selected areas in Iran based on different objective functions which completely explained in the previous chapter. The performance of all optimal solutions is simulated as well. It is also noticeable that X and Y represent the geographical latitude and longitude for the selected hospitals that it was obtained from Google-earth. These coordinates are converted to universal transverse Mercator (UTM) system in order to compute the distances based on kilometer. Meanwhile different cases are investigated for each model in order to carry out sensitivity analysis. Results of the first model are shown in Table 6.1:

Table 6.1: Results of the first proposed model

Case i	Fac no	coordinates x	y	Z (km)
1	2	51.25, 53.23	35.42, 36.31	149.5
2	3	51.24, 53.23, 52.21	35.43, 36.2, 38.27	125
3	4	54.2, 53.04, 50.53, 51.25	36.2, 36.33, 34.39, 35.44	113.33
4	5	53.48, 50.53,51.26,52.21,51.25	36.31,34.36,35.42,36.27,35.44	100.06

As it can be seen, different cases were investigated based on different number of candidate sites. It is noticeable that the first proposed model tries to minimize the total transportation in the system. It is obvious that total transportation would be reducing if number of OTC is increased. The value of Z indicates the objective function that contains a total transportation in the system.

The geographical locations of located facilities for each case are shown as follows:

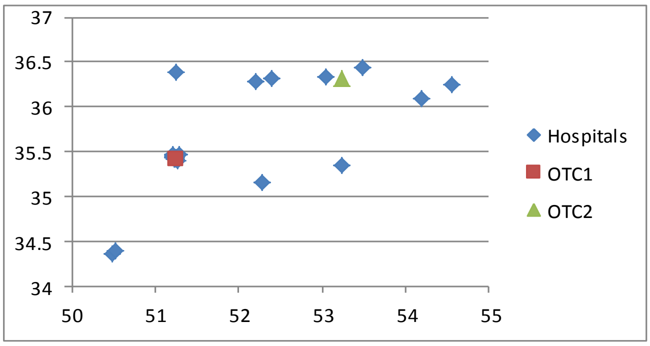

Figure 6.1: Geographical locations of case1-1

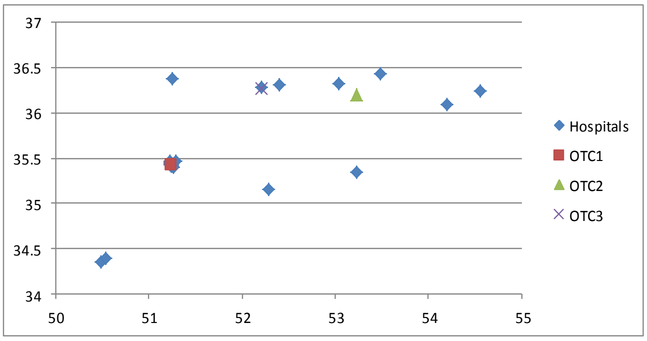

Figure 6.2: Geographical locations of case1-2

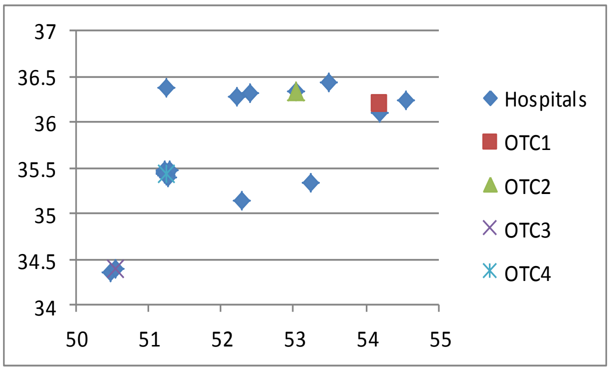

Figure 6.3: Geographical locations of case1-3

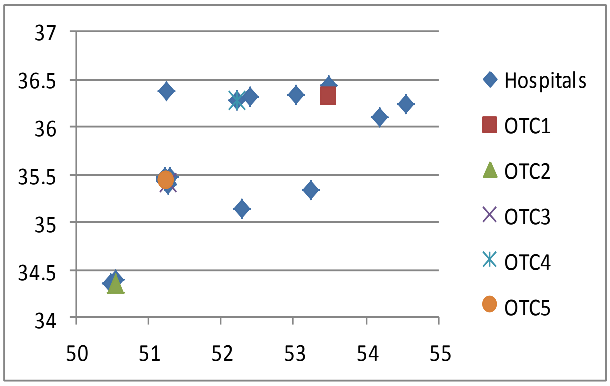

Figure 6.4: Geographical locations of case1-4

According to results that have been obtained from first model, it shows that Tehran due to high volume of demand has an important city and as can be seen in each of four figure at least one facility located in this city. Mazandaran is the second important region in this system that contains five hospitals among this province. This regions with five hospitals have a second highest demand volume after Tehran. This fact indicates that if OTC can be located in these two regions then the total transportation is remarkably reduced. Meanwhile, it can be find out from preliminary results that total transportation in the system has a direct relation with the number of facility and the shortage of these centers certainly may lead to increase the transportation in the system. For instance, in Figure 5.4 where five OTC were located, OTC2 was located in Qom where two hospitals exist and the destination between this region and nearest service provider is at least 154 km which can be reduce significantly if any center is located in this region.

The results for the second model that tries to maximize the total demand assigned to the candidate sites are stated in Table 5.2:

It this model, Maximum allowable service distance and different number of facilities simultaneously are considered in order to investigate and analyze the different cases.

Table 6.2: Computational results for the second model

case	Facility	S	location coordinates		z
i	no		x	y	
1	2	50	51.31, 35.39	35.47, 35.39	2218
2	2	100	50.48, 52.40	35.23, 36.32	2516
3	2	200	51.31, 53.49	35.55, 34.59	2676
4	2	250	52.20, 51.29	35.39, 36	2781
5	2	300	51.26, 51.24	35.44, 35.43	2781
6	3	50	51.13, 52.51, 52.22	35.28, 36.27, 36.27	2426
7	3	100	50.20, 52.57, 52.38	35.16, 36.10 ,36.31	2621
8	3	200	52.38, 50.54, 51.26	35.15, 35.25, 35.17	2781
9	3	250	51.57, 50.53, 51.14	35.45, 35.24, 35.20	2781
10	3	300	51.26, 50.48, 51.12	35.44, 35.18, 35.17	2781
11	4	50	51.13, 53.20, 52.51, 50.20	35.36, 35.38, 36.27, 35.11	2531
12	4	100	51.11, 54.34, 52.53, 53.08	35.21, 35.41, 36.17, 35.26	2706
13	4	200	51.15, 52.24, 50.26, 53.18	35.38, 36.28, 34.39, 35.23	2781
14	4	250	51.20, 50.23, 52.59, 50.13	35.44, 35.07, 35.18, 35.14	2781
15	4	300	51.26, 51.28, 50.43, 50.54	35.44, 35.43, 35.18, 34.36	2781
16	5	50	51.14, 53.23, 52.51, 50.52, 54.20	35.33, 35.34, 36.27, 34.38, 36.10	2616
17	5	100	50.20, 53.30, 52.57, 53.23, 50.52	35.10, 36.41, 36.10, 35.34, 34.38	2746
18	5	200	51.20, 50.55, 50.52, 50.14, 51.38	35.44, 34.37, 34.41, 35.12, 35.19	2781
19	5	250	52.49, 50.49, 50.53, 50.53, 51.29	35.16, 34.37, 34.39, 35.14, 36	2781
20	5	300	51.26, 50.55, 50.52, 50.14, 51.38	35.44, 34.37, 34.41, 35.12, 35,19	2781

As it can be seen, different facilities have been selected for each case. The value of the objective function shows by Z that indicates the total demands assigned to the candidate sites. Obviously, the maximum population assigned to the candidate OTC among all cases is 2781 while more than three facilities were located with at least 200 km acceptable service distance. In contrast, the minimum population assigned to candidate sites occurs in case 1 where 2218 person was assigned to two candidate centers. As it can be seen in figure 6.5, one facility in case 1 was located in Tehran which with respect to the value of S in this case, this candidate site is able to cover just demands that are located in Tehran city due to low level of allowable service distance. Clearly, the number of located candidate sites and the quantity of S has a direct affect in order to enhance the total population assigned in this system. The geographical locations of located OTC are described as follows:

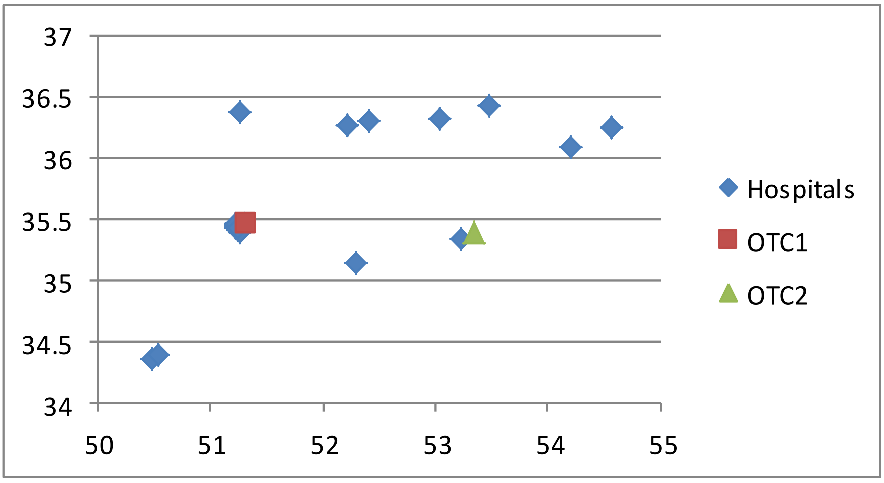

Figure 6.5: Geographical locations of case2-1

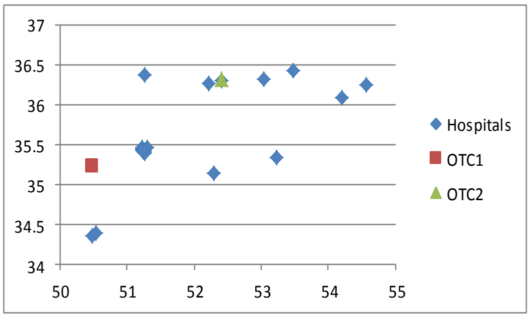

Figure 6.6: Geographical locations of case2-2

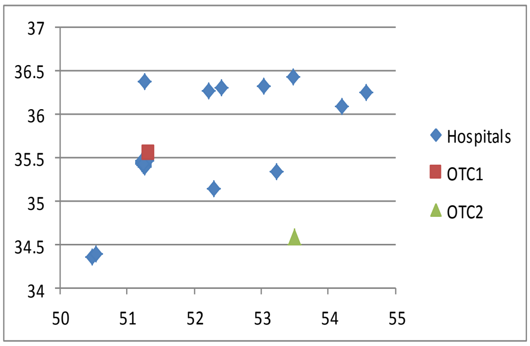

Figure 6.7: Geographical locations of case2-3

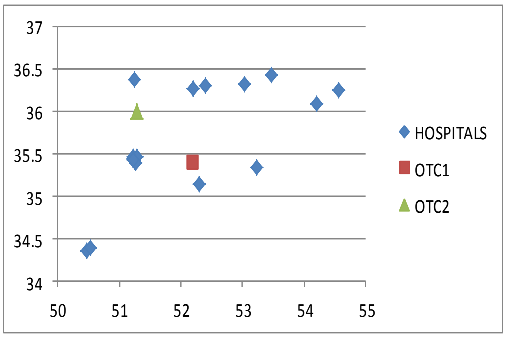

Figure 6.8: Geographical locations of case2-4

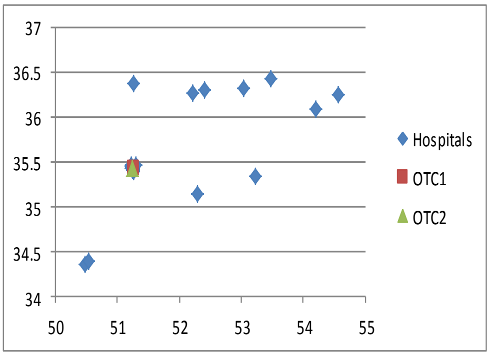

Figure 6.9: Geographical locations of case2-5

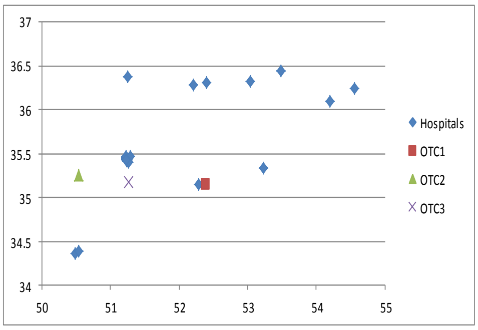

Figure 6.10: Geographical locations of case2-6

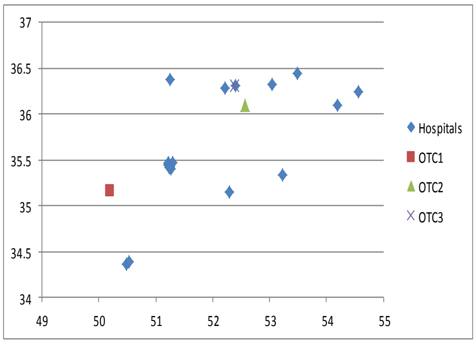

Figure 6.11: Geographical locations of case2-7

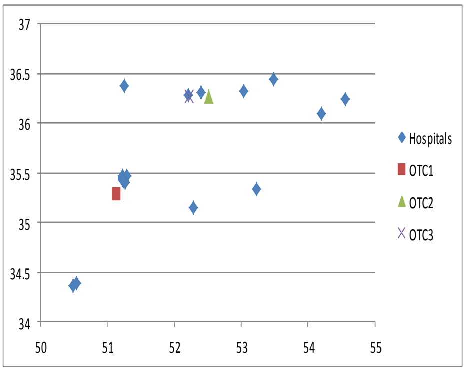

Figure 6.12: Geographical locations of case2-8

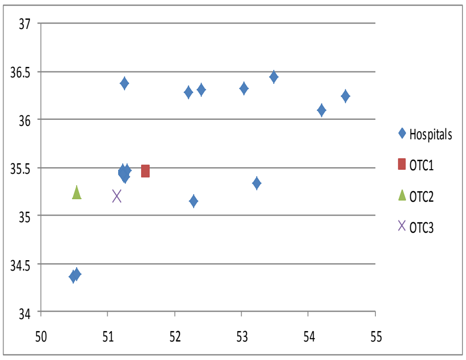

Figure 6.13: Geographical locations of case2-9

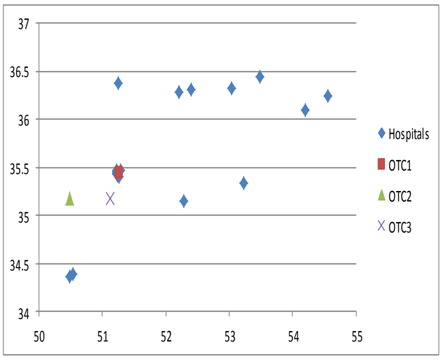

Figure 6.14: Geographical locations of case2-10

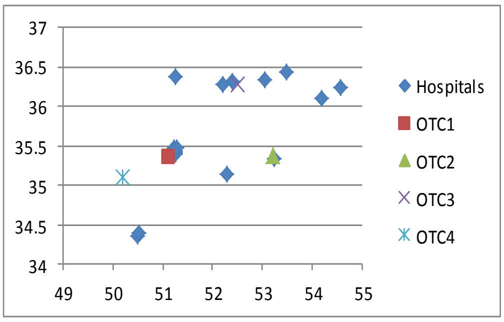

Figure 6.15: Geographical locations of case2-11

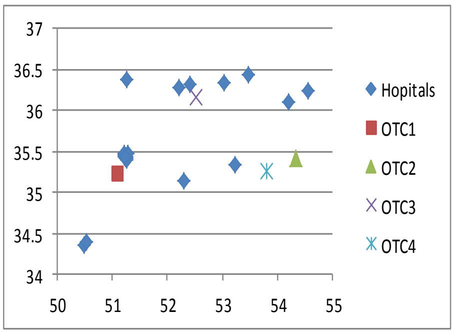

Figure 6.16: Geographical locations of case2-12

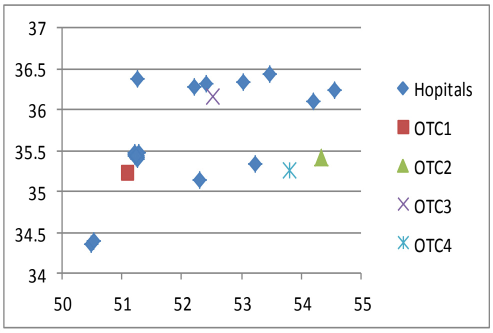

Figure 6.17: Geographical locations of case2-13

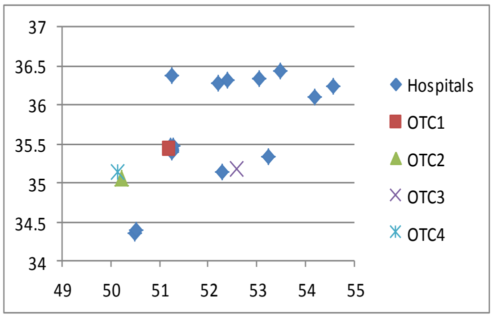

Figure 6.18: Geographical locations of case2-14

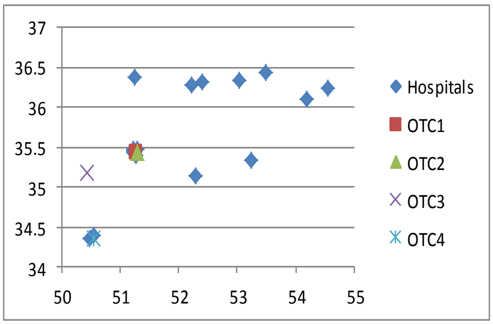

Figure 6.19: Geographical locations of case2-15

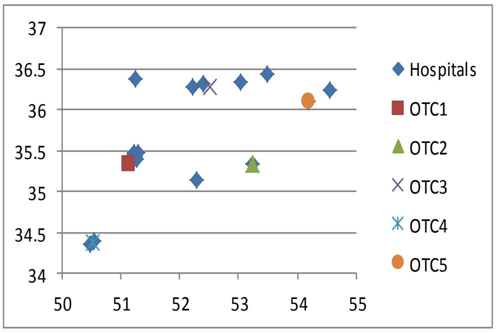

Figure 6.20: Geographical locations of case2-16

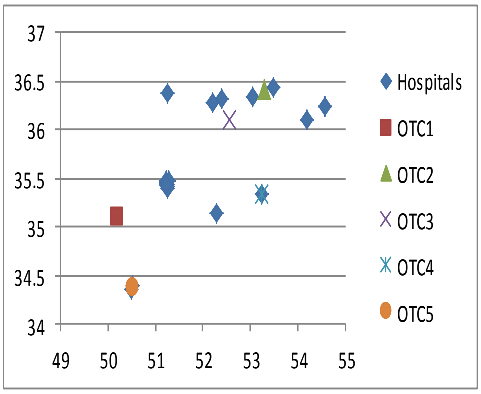

Figure 6.21: Geographical locations of case2-17

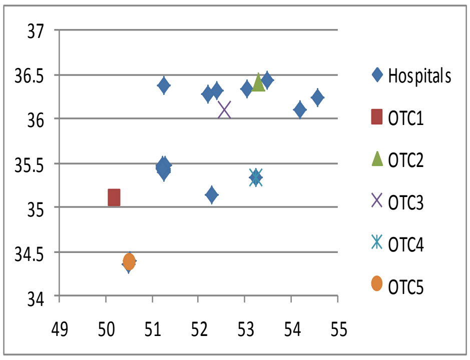

Figure 6.22: Geographical locations of case2-18

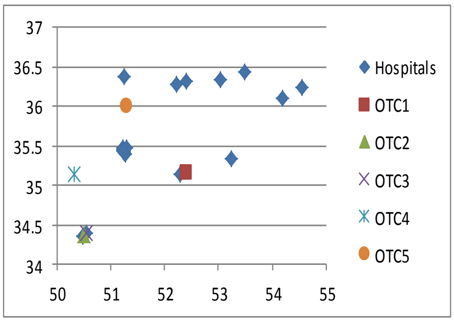

Figure 6.23: Geographical locations of case2-19

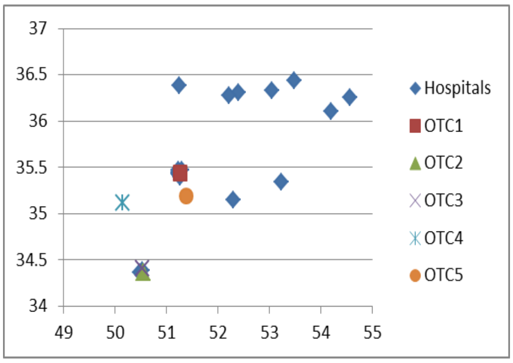

Figure 6.24: Geographical locations of case2-20

As it can be seen, the second model was solved for different cases with respect to different values of S and for different number of facility because S parameter has an important role in this model. The results for the third model are illustrated in Table 6.3:

Table 6.3: Computational result of third proposed model

case	Fac	Location coordinates		Z
i	no	x	y	
1	2	52.41, 52.21	36.2, 36.19	282.95
2	3	52.38, 52.22, 52.24	35.15, 36.27, 36.28	244.67
3	4	52.48, 51.56, 52.48, 51.56	36.2, 35.78, 36.2, 35.48	248.4
4	5	52.38, 50.58, 52.38, 50.58, 52.38	36.1, 36.31, 36.1, 36.31, 36.1	230.7

The third objective function tries to minimize the maximum allowable service distance that everybody is covered. The geographical locations of located sites are shown as follows:

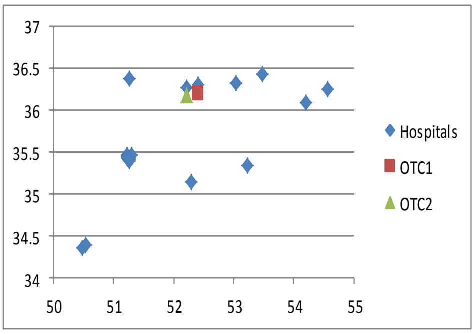

Figure 6.25: Geographical locations of case3-1

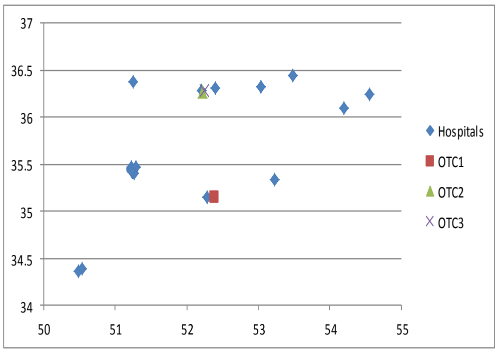

Figure 6.26: Geographical locations of case3-2

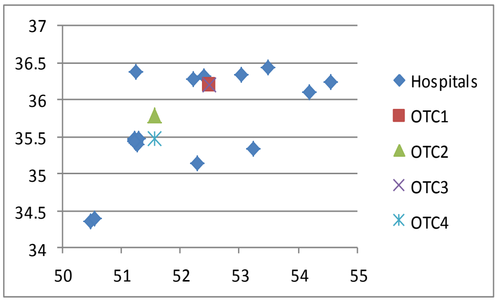

Figure 6.27: Geographical locations of case3-3

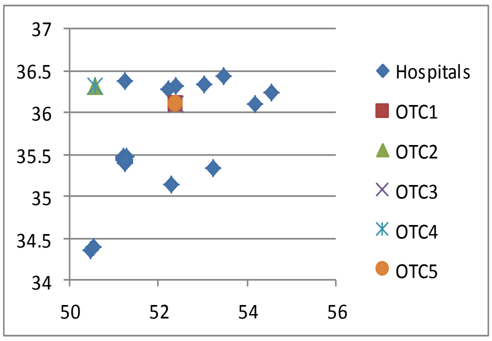

Figure 6.28: Geographical locations of case3-4

This procedure is applied again for analyzing the fourth model, this model is solved with respect to different number of facilities. The computational results are shown in Table 6.4:

Table 6.4: computational results of fourth model

case i	Fac no	location coordinates x	y	Z
1	2	52.31,52.31	35.45,35.45	305.2
2	3	52.21,52.21,52.57	36.35,36.35,34.87	195.85
3	4	52.24,50.27,50.25,50.27	35.43,35.45,35.47,35.45	103.65
4	5	51.27,51.24,51.26,51.24,51,26	35.44,35.39,35.44,35.39,35.44	98.35

In the fourth model, maximum allowable service distance is minimized with respect to percentage of covered demands. In case four, when five facilities were located, the maximum allowable service distance was remarkably reduced. This is mainly due to existence of three OTC in Tehran. Generally increase in the number of facilities will lead to reduce the maximum allowable service distance.

The corresponding geographical locations of these sites are shown as follows:

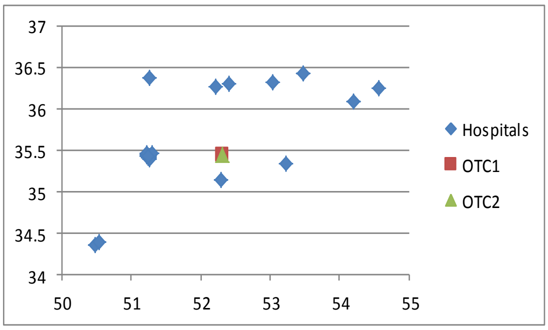

Figure 6.29: Geographical locations of case4-1

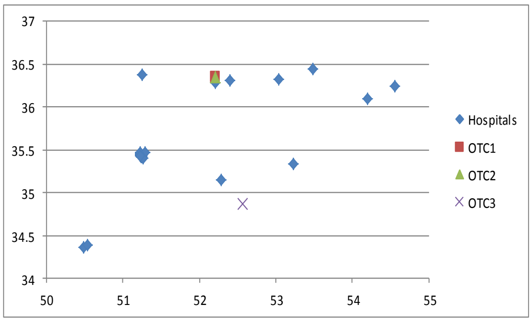

Figure 6.30: Geographical locations of case4-2

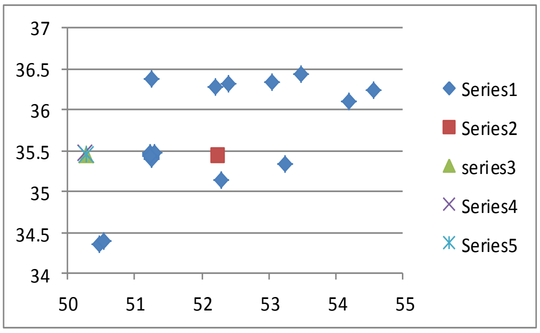

Figure 6.31: Geographical locations of case4-3

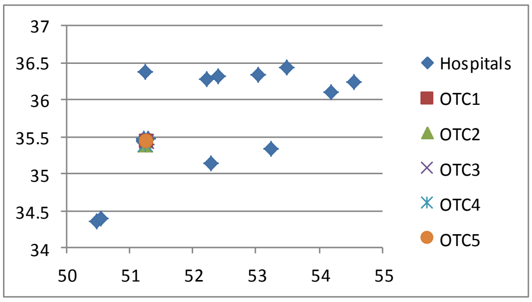

Figure 6.32: Geographical locations of case4-4

Finally, for solving a fifth model threshold distance and maximum allowable service distances are considered simultaneously while different number of facilities are tested for each cases and it is aimed to investigate the all possible cases for candidate sites. The computational results for candidate location coordinates are stated in Table 6.5:

Table 6.5: computational results of fifth model

case i	Fac no	S	Location coordinates		Z
			x	y	
1	2	50	51.13, 52.21	35.28, 36.19	0.37
2	2	100	51.10, 52.46	35.34, 35.45	0.34
3	2	200	51.10, 53.12	35.34, 35.27	0.29
4	2	250	50.23, 52.03	35.06, 35.43	0.26
5	2	300	50.48, 51.26	35.18, 35.44	0.23
6	3	50	51.47, 51.29, 52.20	35.43, 36, 35.13	0.37
7	3	100	51.07, 51.29, 52.20	35.44, 36, 35.13	0.34
8	3	200	51.10, 51.29, 52.38	35.34, 36, 35.15	0.29
9	3	250	51.13, 52.51, 51.38	35.19, 36.27, 35.19	0.26
10	3	300	50.14, 51.10, 50.52	35.12, 35.34, 34.38	0.23
11	4	50	51.48, 50.45, 51.29, 50.48	35.44, 34.38, 36, 35.18	0.37
12	4	100	51.07, 52.51, 52.20, 54.34	35.44, 36.27, 35.13, 35.41	0.34
13	4	200	51.30, 52.51, 52.20, 51.29	35.45, 36.27, 35.13, 36	0.29
14	4	250	51.57, 52.38, 53.35, 51.07	35.45, 36.31, 35.39, 35.42	0.26
15	4	300	50.14, 51.29, 52.46, 53.35	35.12, 36, 35.45, 35.39	0.23
16	5	50	54.34, 50.20, 53.03, 51.13, 54.20	35.41,3 5.16, 36.33, 35.28, 36.08	0.37
17	5	100	53.35, 52.03, 51.11, 52.38, 51.31	35.39 ,35.43, 35.21, 36.31, 35.55	0.34
18	5	200	51.26, 50.55, 50.52, 50.14, 51.26	35.44, 34.37, 34.41, 35.12, 35.44	0.29
19	5	250	52.40, 50.48, 50.53, 50.32, 51.29	35.16, 35.23, 34.39, 35.14, 36	0.26
20	5	300	51.20, 50.55, 50.52, 50.20, 51.31	35.44, 34.37, 34.41, 35.16, 35.55	0.23

The geographical locations of located candidate sites are shown as follows:

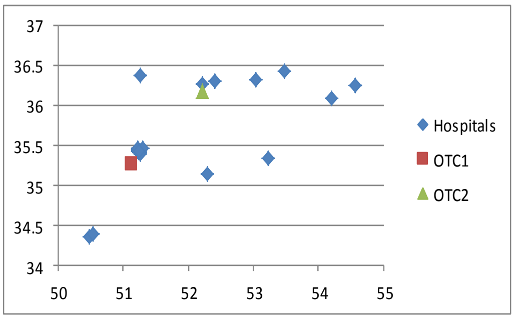

Figure 6.33: Geographical locations of case 5-1

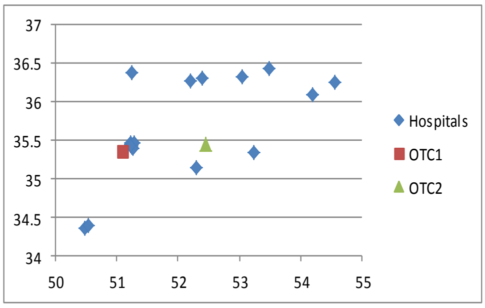

Figure 6.34: Geographical locations of case 5-2

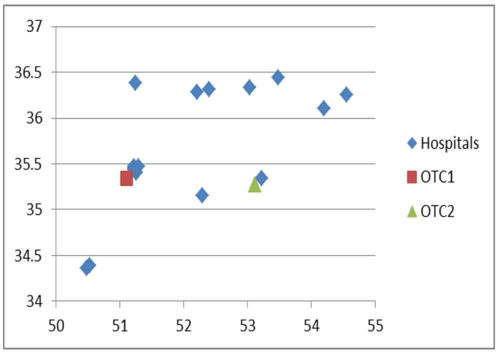

Figure 6.35: Geographical locations of case 5-3

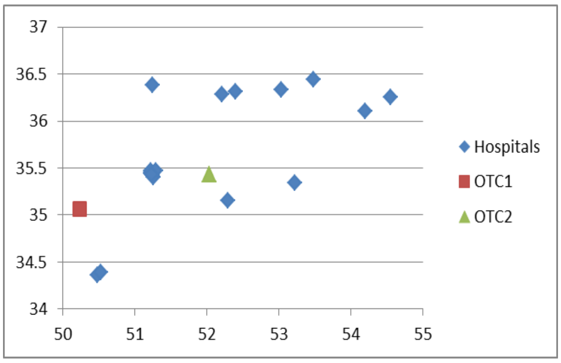

Figure 6.36: Geographical locations of case 5-4

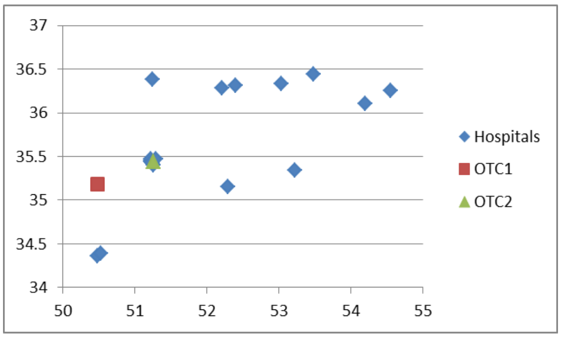

Figure 6.37 Geographical locations of case 5-5

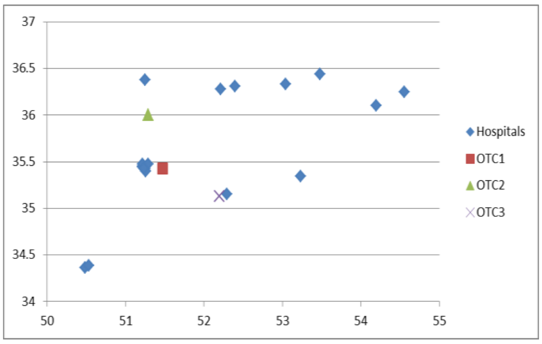

Figure 6.38: Geographical locations of case 5-6

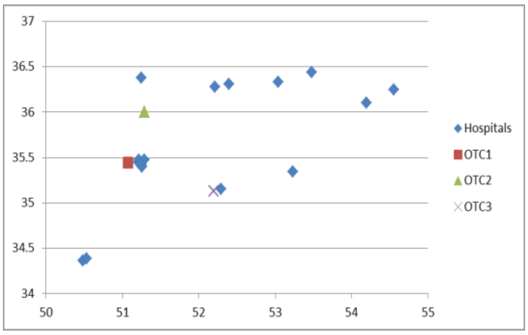

Figure 6.39: Geographical locations of case 5-7

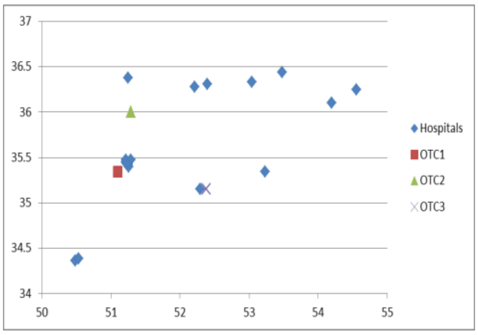

Figure 6.40: Geographical locations of case 5-8

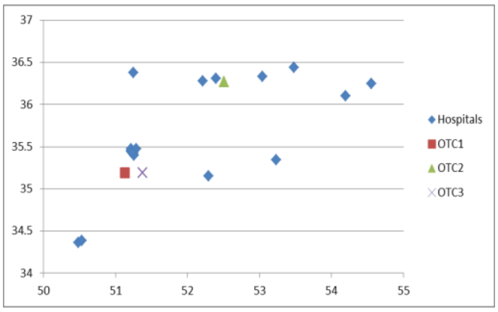

Figure 6.41: Geographical locations of case 5-9

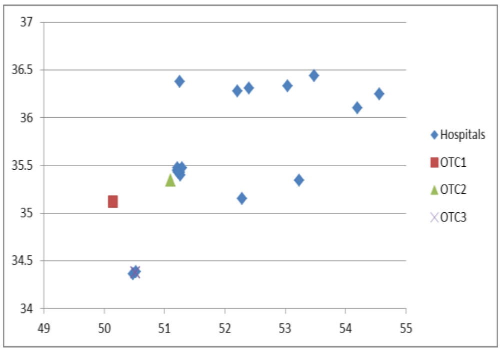

Figure 6.42: Geographical locations of case 5-10

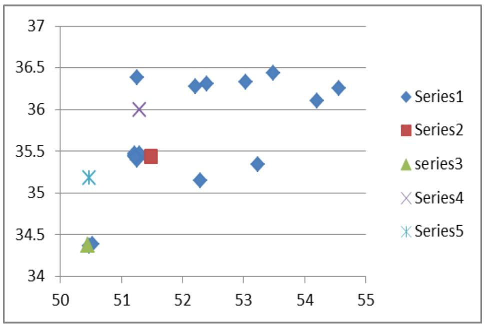

Figure 6.43: Geographical locations of case 5-11

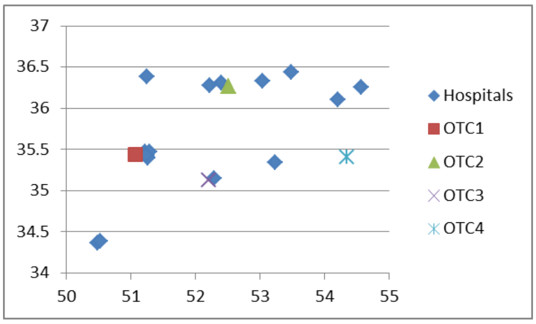

Figure 6.44: Geographical locations of case 5-12

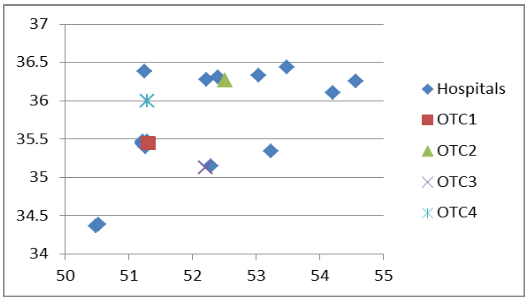

Figure 6.45: Geographical locations of case 5-13

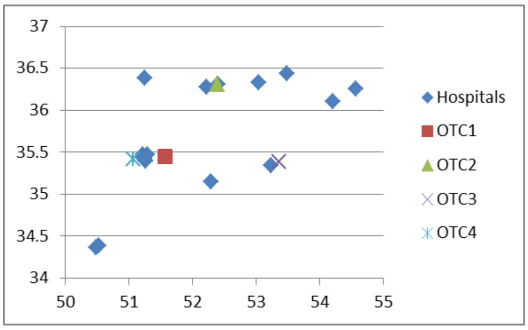

Figure 6.46: Geographical locations of case 5-14

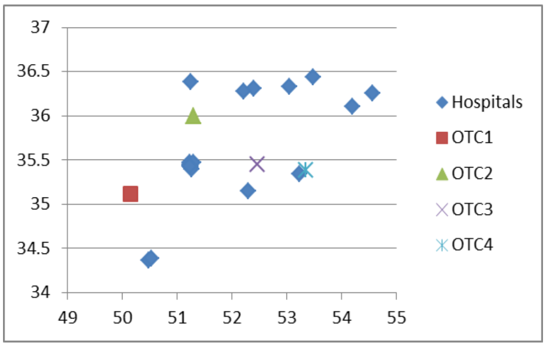

Figure 6.47: Geographical locations of case 5-15

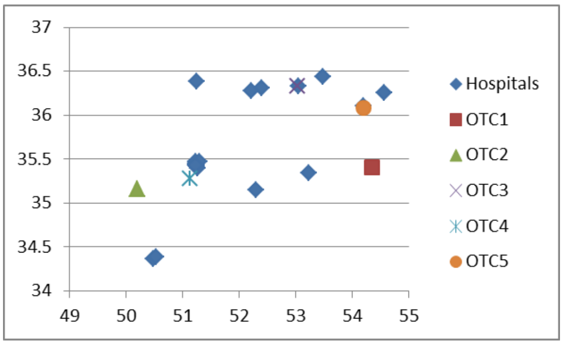

Figure 6.48: Geographical locations of case 5-16

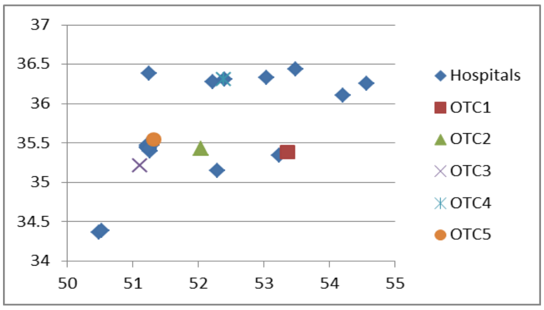

Figure 6.49: Geographical locations of case 5-17

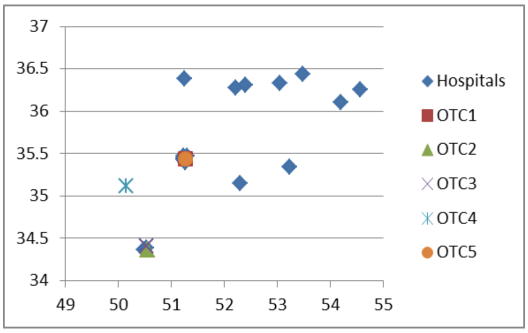

Figure 6.50: Geographical locations of case 5-18

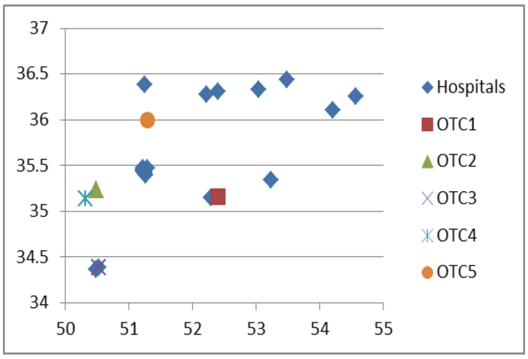

Figure 6.51: Geographical locations of case 5-19

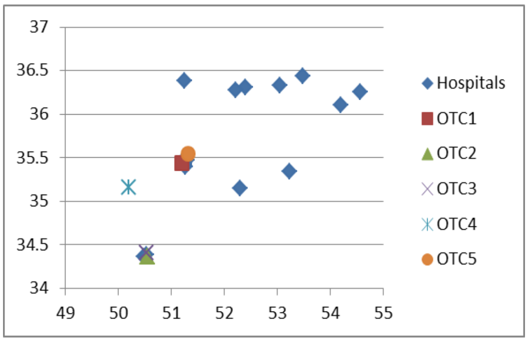

Figure 6.52: Geographical locations of case 5-20

The preliminary results that are obtained from all five models show that increase in the number of facilities has a significant effect in reducing the total transportation in the system, also Tehran as capital city and most populated city among these regions has an important role in this system. As it can be seen, in all models that have been solved at least one facility has been located in Tehran because of some important factors such as a high demand, population and the important thing is that due to presence of three removal centers in this city, the transportation in this region remarkably is less than other regions. In none of the cases, cost factor for locating the OTC is considered which in some cases maybe this factor can be considered by planners. According to medical information that has been collected in among these 20 hospitals, the total demand in Mazandaran province is 520 person per year while the number of removal unit in this region is one and there are three removal units in

Tehran. As far as the number of candidate sites is increased some demand nodes still have a far distance from located OTC like Qom city. This is mainly due to congestion of the demands and population in other nodes as can be seen in the related figures just two hospitals are available in this region. As mentioned before, if among these regions, the minimum transportation between systems is required Tehran has a great priority rather than others and also with respect to other factors, such as number of demand and proximity and number of removal unit.

In this section, Monte Carlo simulation is used to investigate and compare the three types of the transportation, the results that have been obtained in previous section are selected as an objective for simulation in order to simulate the all optimal solutions. Meanwhile, with respect to simulation results total weighted average distance (TWAD) is computed based on different number of patients that have been assigned to different sites. It is tried to analyze the all possible cases for each model in order to measure the three types of transportation. In this simulation, the collected data is extended up to 1000 patient based on randomization, average and standard deviation (SD) of transportation for each type is computed. The following tables state the simulation results:

Table 6.6: Average of three type of transportation in model 1

fac no	DBDPC	DPHC	DCPC	TWAD km
2	130, 107	104, 136	125, 123	129.26
3	134, 65, 77	157, 89, 91	70, 75, 90	117.07
4	96, 102, 126, 130	136, 122, 126, 103	91, 115, 136, 126	105.04
5	114, 126, 130, 77, 130	148, 126, 103, 91, 113	129, 136, 126, 90, 126	96.19

Table 6.7: Standard deviation of three type of transportation in model 1

Fac no	DBDPC	DPHC	DCPC
2	130,107	104,136	125,123
3	134,65,77	157,89,91	70,75,90
4	96,102,126,130	136,122,126,103	91,115,136,126
5	114,126,130,77,130	148,126,103,91,113	129,136,126,90,126

As a result, it is necessary to specify the connection between simulation results and mathematical models. It is aimed to analyze the performance of simulated optimal solutions. As can be seen in Table 6.6 the minimum quantity of DBDPC (transport the BD patient to the OTC) is 122 km that is approximately exist in all four cases. It is important to mention this point that, according to the results that has been obtained from linear programming models in the previous section the distance of 122 km in four cases is corresponding to Tehran coordination. It is mainly due to some reasons, first of all, existing of three removal units in this city and secondly because of vicinity to other cities compared to other regions. These results specify these facts that if it is preferable for planner to locate OTC in Tehran in order to minimize the total transportation. Whenever, five facilities are located in case 4 in Table 6.6, the maximum quantity for DBDPC is related to facility 1 in case4. According to geographical location of this facility, it has been located in west of the Mazandaran. It is noticeable that, from medical point of view the first two type of transportation has a great importance compared to the third one. Since the emergency situation is occurred when BD patient is transported to the other hospitals or the organs are transported to the other sites, and because of this fact, different weights were proposed in previous chapter. According to the DPHC results in Table 5.6, the minimum distance (78km) is related to first case while the candidate OTC is located in Tehran. This is certainly due to existing of three removal units in this city. For the third column in Table 5.6, the minimum average transportation of the candidate patients to the OTC is related to case4 (149km) and maximum quantity is occurred in case 3 (272km). This factor is directly related to the quantity of the demand (number of the candidate patients) among these regions. According to the data that has been collected, it shows this fact that Tehran and Mazandaran have a highest demand compared to other regions, in this satiation, if candidate OTC is located in Tehran or Mazandaran, then the third type of the transportation (transport the candidate patients to the candidate sites) can be dropped significantly. It is noticeable that the quantities of TWAD in Table 6.6 is very close to the results that have been obtained in Table 6.1, this fact shows that simulated optimal solution has a remarkable performance. Table 6.7 states the SD of these three types. As can be seen the minimum quantity of standard deviation for model 1 is situated in case 2 for facility 2 when three facilities are located with 65, 89 and 75km distances respectively for each type. It is possible to check the figures that has been drawn in previous section to see the location of this facility, this facility somehow is located in center of Mazandaran that it very close to removal unit in Rohani hospital in Babol and also if the facility is located in this city, it is near to Tehran and satisfies all the locating requirement. Again, TWAD in Table 6.8 approximately shows the same quantities compare to computational results in Table 6.2.

Table 6.8: Average of three type of transportation in model 2

	DBDPC	DPHC	DCPC	TWAD
i				(km)
1	86, 209	61, 119	68, 200	89
2	140, 191	95, 111	172, 178	130
3	146, 319	136, 253	168, 322	143
4	225, 198	234, 177	214, 210	236
5	222, 129	268, 149	249, 252	241
6	134, 210, 179	85, 102, 110	163, 191, 170	123
7	163, 126, 187	191, 98, 114	185, 136,175	118
8	175, 164, 154	112, 79, 124	190, 197, 185	156
9	132, 242, 161	140, 195, 131	149, 241, 185	233
10	123, 261, 161	183, 253, 218	149, 265, 185	265
11	150, 211, 210, 263	118, 120, 122, 191	182, 204, 192, 275	153
12	177, 253, 191, 215	101, 165, 110, 121	179, 249, 185, 204	164
13	150, 179, 276, 192	118, 110, 201, 109	182, 170, 297, 187	208
14	123, 263, 201, 265	77, 191, 138, 246	149, 275, 212, 275	236
15	122, 122, 181, 236	77, 76, 140, 184	149, 149, 201, 253	248
16	150, 211, 210, 243, 272	119, 120, 102, 193, 186	182, 204, 191, 265, 254	157
17	263, 252, 193, 211, 244	187, 183, 110, 120, 195	275, 247, 185, 204, 265	176
18	123, 211, 236, 238, 153	81, 120, 170, 169, 124	149, 204, 253, 265, 177	209
19	196, 211, 236, 182, 141	110, 120, 170, 141, 96	185, 204, 253, 211, 168	233
20	191, 211, 236, 238, 153	110, 120, 170, 170, 124	185, 204, 253, 265, 177	236

In second model, whenever 20 cases have been analyzed based on different number of facilities and allowable service distances. The Table 6.8 indicates the average of three types of transportation in model 2 that derived from simulation. From this table it can be found out the minimum quantity of first column is 120 km that is nearly occurred in these cases 1, 4, 5, 10, 14, 15, 18. These facilities correspond to Tehran with different allowable service distances. It also confirms the results that have been achieved from mathematical programming. In contrast, the maximum quantity of first column is related to case 3 (319km) for the second located facility that it has been located somehow between Semnan and Damghan. Generally, the first column shows that as far as maximum allowable service distance increased, it is preferable to locate the candidate site between Tehran and Mazandaran in this model. The second model has been designed based on the maximum population assigned to the candidate sites, and since from our previous data, 14 hospitals exist in these two regions which constitute approximately 75% of total demands. For the second type, again the minimum quantity is occurred in Tehran with 61 km in case 1, and also the maximum transportation is related to case 3 with 253 km. For the third column, as stated before the reasons, the lowest level of this transportation belongs to Tehran. The quantity of total weighted average distance was computed for each case with respect to the number of patients assigned to the candidate sites in order to investigate the performance of optimal solutions. Table 6.9 shows the SD for each type of transportation in model 2. The lowest standard deviation for first column belongs to case 1, 11, 18, 19, and 20 with around 60km while the highest one is related to case 11, 13 and 16 with about 138 km. The geographical locations of these cases can be seen in the previous sections.

Whenever a candidate site is located in the center of Mazandaran with respect to its coordinate the minimum SD is occurred for second type of transportation (DPHC). This is certainly due to proximity of this city to the removal unit that is in Rohani hospital in Babol with 70km distance. Apart from removal unit, the important role of this city is vicinity to Tehran that has a highest demand compared to other cities. In contrast, the maximum SD is related to Qom with about 155 km in case 16. As stated before, just two hospitals exist in this city and also due to lack of removal units, patients have to a take a long distances to Tehran for achieving a services. The third column also shows the same result like previous models.

Table 6.9: Standard deviation of three type of transportation in model 2

case i	DBDPC	DPHC	DCPC
1	124, 62	76, 105	120, 69
2	122, 85	110, 100	130, 99
3	121 85	142, 161	117, 89
4	132, 125	100, 101	96, 91
5	130, 133	104, 157	126, 70
6	128, 94, 77	104, 83, 91	123, 108, 90
7	128, 71, 80	141, 81, 100	142, 81, 91
8	73, 124, 115	88, 89, 131	87, 124, 114
9	87, 130, 120	66, 109, 94	83, 126, 121
10	130, 135, 120	114, 148, 124	126, 140, 121
11	138 ,60, 94, 128	143, 103 ,82, 140	136, 68, 107, 129
12	127, 78, 73, 77	94, 128, 89, 98	113, 81, 81, 89
13	138,77, 129, 51	143 ,89, 146, 87	136, 90, 186, 68
14	130, 128, 73, 132	102, 140, 98 ,306	126, 129, 80, 129
15	130, 130, 133, 127	102, 102, 146, 128	126, 126, 142, 137
16	138, 60, 94, 132, 111	144, 103, 82, 155, 139	136, 68, 108, 144, 106
17	128,116,70, 60, 134	136, 140, 89, 103, 156	129, 127, 81, 68, 144
18	130, 60, 126, 131, 115	103, 103, 128, 135, 131	126, 68, 137, 127, 120
19	71, 60, 126, 133, 122	90, 103, 128, 146, 99	82, 68, 137, 133, 117
20	74, 60, 126, 131, 115	90, 103, 128, 135, 131	81, 68, 137, 127, 120

Table 6.10: Average of three type of transportation in model 3

Fac no	DBDPC	DPHC	DCPC	TWAD Km
2	292, 173	238, 148	247, 163	273
3	255, 179, 179	212, 102, 110	290, 170, 170	236
4	227, 153, 192, 232	233, 113, 108, 210	214, 165, 177, 149	214
5	234, 227, 190, 227, 190	186, 162, 108, 222, 108	207, 223, 177, 243, 177	224

Table 6.11: Standard deviation of three type of transportation in model 3

case i	DBDPC	DPHC	DCPC
1	68, 73	86, 84	78, 81
2	73, 77, 77	88, 82, 91	87, 90, 90
3	67, 87, 68, 87	99, 105, 86, 65	79, 87,78, 83
4	67, 93, 67, 93, 67	86, 123, 86, 123, 86	78, 100, 78, 100,78

In the third model, the quantities of TWAD show this fact that the value of S can be reduced if the number of located facilities are increased. The values of objective function in Table 6-3 also confirm this fact. It is noticeable that the third model tries to minimize the maximum allowable distances, the lowest quantity of DBDPC in Table 6.10 belongs to the case 3 for the fourth facility located with 132 km, this facility is located somehow again the center of Mazandaran, and due to reasons that stated before such as proximity and demand congestion this location has a vital role among these regions. Reversely, the highest quantity (227 km) in first column belong to the case 4 corresponding to the facility that is located in the north-west of the Mazandaran. It is interesting to mention at this point that the DPHC shows the same result for these two nodes, the point is that due to lack of removal unit on that part of Mazandaran transport the patients to the peripheral hospitals for engraftment surgery take a long distances while for the fourth facility in case 4, this transportation is 80 km that is the minimum quantity compared to others. Again the third column in Table 6.10 shows the same result. As it can be seen, Table 5.11 shows the SD for the third model corresponding with all cases. The lowest level of SD belongs to case 3 and 4 with 67km where the facility is located between Mazandaran and Damghan. It is better to see the figures from last section. For the second and third column minimum quantity is occurred in case 3 and 4 respectively.

Table 6.12: Average of three type of transportation in model 4

fac no	DBDPC	DPHC	DCPC	TWAD Km
2	269, 213	247, 227	245, 225	252
3	189, 189, 141	114, 114, 108	172, 172, 157	186
4	123, 112, 209, 112	83, 91, 161, 91	149, 126, 234, 126	118
5	123, 191, 122, 128, 122	109, 110, 77, 97, 77	242, 185, 98, 155, 98	104

Table 6.13: Standard deviation of three type of transportation in model 4

case i	DBDPC	DPHC	DCPC
1	81, 81	86, 85	80, 80
2	78, 78, 111	93, 92, 112	89, 89, 110
3	130, 128, 138, 128	114,105,159,105	126, 126, 137,126
4	133,73,130,133,130	157,90,102,134,103	70,81,126,132,126

As it can be seen from Table 6.12, the quantities of TWAD are reduced by increasing the number of located facilities. The results that have been obtained in aforementioned table are very close to the results that were obtained from proposed model. This fact confirms the performance of optimal solutions. Table 6.12 describes the average of the three types of transportation where the minimum quantity of DBDPC is 122km that belongs to the case 4 for fifth facility. As it can be seen, as far as the number of facilities increased the quantity of DBDPC is reduced. This fact can be seen also in previous tables. This facility also has a minimum quantity in second column and again shows this fact if the facility is located in Tehran, it would have a minimum quantity for all three factors. Reversely, the maximum quantity of DBDPC is 209 km where the candidate site is located out of Tehran that can be seen in the related figure. Table 6.13 shows the SD of fourth model where in first column quantity 78km in case 2 has lowest quantity among others. This facility is located somewhere between Amol and Babol and due to proximity to Tehran has great important and lowest SD compared to other sites. Reversely, the maximum SD of DBDPC is corresponding to case 3 of third facility. The third column in Table 6.13 indicates this fact again if the candidate site is located in Tehran the SD of it can have a lowest quantity compared to other regions. As can be seen, the lowest level of SD is related to case 4 of first facility where the candidate site is located in the middle of Tehran.

Table 6.14: Average of three type of transportation in model 5

case i	DBDPC	DPHC	DCPC	TWAD km
1	139, 171	119, 101	171, 164	154
2	142, 160	92, 68	166, 161	146
3	142, 198	92, 144	166, 196	146
4	123, 145	77, 104	150, 158	129
5	201, 122	154, 77	226, 149	224
6	116, 159, 163	99, 99, 108	124, 150, 172	126
7	147, 159, 163	118 ,99, 108	178, 150, 172	143
8	142, 150, 155	92, 101, 107	166, 174, 164	128
9	170, 201, 141	131, 153, 108	193, 226, 157	142
10	226, 142, 232	175, 92, 167	262, 166, 253	238
11	116, 201, 150, 230	99, 153, 101, 158	124, 226, 174, 248	127
12	147, 210, 150, 285	117, 102, 101, 192	178, 191, 174, 272	159
13	127, 210, 163, 159	87, 102, 108, 98	143, 192, 172, 150	139
14	170, 188, 201, 137	131, 112, 153, 107	193, 166, 226, 166	182
15	226, 165, 160, 201	175, 106, 68, 153	262, 166, 161, 226	209
16	286, 243, 227, 138, 97	199, 201, 147, 118, 198	271, 261, 206, 171, 271	224
17	201, 145, 137, 188, 146	154, 104, 107, 112, 136	226, 158, 166, 166, 168	158
18	123, 211, 236, 238, 122	81, 120, 170, 169, 83	150, 204, 253, 265, 149	198
19	196, 140, 236, 182, 159	110, 95, 170, 141, 98	185, 172, 253, 211, 150	149
20	123, 211, 236, 263, 146	77, 120, 170, 191, 136	149, 204, 253, 285, 168	126

Table 6.15: Standard deviation of three type of transportation in model 5

case i	DBDPC	DPHC	DCPC
1	122, 72	137, 76	134, 82
2	128, 45	105, 54	126, 51
3	128, 54	105, 89	126, 63
4	133, 87	105, 97	130, 80
5	135, 130	149,103	140, 126
6	93, 82, 78	110, 72, 85	97, 78, 85
7	137, 82, 78	141, 72, 85	136, 78, 86
8	128, 122, 75	105, 102, 85	126, 117, 82
9	131, 135, 111	141, 148, 112	128, 140, 110
10	133, 128, 123	166, 105, 126	141, 126, 136
11	93, 135, 122, 126	110, 148, 102, 120	97, 140, 117, 134
12	137, 95, 122, 96	141, 82, 102, 136	136, 108, 117, 91
13	131, 94, 78, 82	132, 82, 85, 71	116, 108, 86, 78
14	131, 80, 135, 141	141, 95, 148, 143	128, 87, 140, 138
15	133, 72, 45, 135	160, 81, 54, 148	141, 77, 51, 140
16	97, 130, 102, 122, 97	140, 180, 122, 137, 139	94, 133, 115, 134, 94
17	135, 87, 141,80,121	149, 97, 143, 95, 141	140, 80, 138, 87, 117
18	130, 60, 126,131,130	103, 103, 128, 135,113	126, 68, 137,127,126
19	71, 122, 126, 133, 82	90, 109, 128, 146,71	82, 130, 137, 133,78
20	123,211,236,203,146	77,120,170,191,136	149,204,253,285,168

Table 6.14 and 6.15 specify the average and SD for fifth model respectively. This model has been solved for different acceptable distances and different number of facilities. The results of this model have been used as an objective to investigate the three types of transportation. As can be seen, the lowest quantity of DBDPC (97 km) in table 5.14 belongs to case 16 of fifth facility. In contrast, case 16 of first facility has a highest quantity of transportation. The second column of Table 6.14 reveals this fact that third facility of case 15 has a minimum quantity of transportation with 68 km among other regions. This site is located somewhere between Mazandaran and Tehran and again this table shows the same result like previous models, whenever any facility is located between these two areas due to existing of four removal units and also the proximity of these two cities has a vital role in our system. It is noticeable that whenever the candidate site is located somewhere like Damghan, Garmsar or Qom due to shortage of the removal unit in these regions, the total service distances can be remarkably increased in this situation. The first located facility in case 16 in Table 6.14 shows 199 km distance where facility has been located in Damghan. Meanwhile the third column in Table 6.14 reveals this fact again that due to congestion of demand in these two regions the third type of transportation can be decreased if candidate OTC is located in these regions. Altogether, there are some considerable points among these results. First of all, the number of OTC can significantly affect the total transportation in the system, as it has been shown, as far as the number of candidate sites are increased the total service distances would be decreased. As explained before, in some situations the BD patient has to transport to the peripheral hospital due to lack of medical equipment. In this case, due to shortage of removal unit in some cities like Qom or Damghan the patients in these cities have to take long distances to reach at Tehran or semnan for achieving services. Obviously, if the number of removal units increase between these cities it can be very helpful in order to reduce the redundant transportation in the system. It is necessary to enhance the level of services especially in the cities with high congestion of demand like Tehran and Mazandaran. Finally, it is necessary to create an integral system of transportation in these regions and certainly from medical point of view, it can be very practical if all these factors are considered simultaneously.

Chapter 7

CONCLUSION AND FUTURE RESEARCH

In this study, the problem of location of OTC and logistic design of them are addressed by introducing different mixed integer and linear programming models. Five mathematical models have been formulated in order to analyze and investigate the system with respect to different concepts such as maximum coverage, maximum allowable distance and percentage of covered demand in order to find the best location of OTC. Iran as a one of the most populated countries in the Middle East is selected and medical information of 50 patients among 11 cities and 20 hospitals have been collected to design the OTC. According to the collected information, the most solicitude in this system is remarkable gap between supply and demand. As a whole, exists of organ donor is necessary and has key role for those who are in the waiting list. Many people are encouraged to donate their organs in the case of their death can be a good policy to drop the gap between supply and demand. The results that have been obtained from Xpress 7.5 were used as an objective for Monte Carlo simulation in order to analyze and comparison the three type of transportation. The simulation results reveal this fact that the shortage of removal unit in some cities can increase the total transportation and also by construct aforementioned units in these cities redundant transportation can be dropped that can be very convenient for both patients and medical team. It can be very helpful if the number of OTC is increased in cities with high congestion of demand, as the simulation results shown, the total transportation significantly can be reduced.

This research can be extended in the future by considering further cities and hospitals in different regions. This procedure also can be applied for multiple applications in the healthcare like emergency medical services, stroke center and tissue banking. Stochastic programming has a wide application in these cases especially in healthcare facility location where the emergency can be occurred randomly. Risk as an important factor in real life can be considered in these systems. Location routing model can be elaborated in order to transfer the patients within a specific route with considering traffic or accident factors.

REFERENCES

Bendavid, Y., & Harold, B. (2011). Using RFID to Improve Hospital Supply Chain Management for High Value and Consignment Items. Procedia computer science, 849-856.

Church, R., & Revelle, C. (1974). The Maximal covering Location problem. *papers of Regional Science Association, 32*, 101-118.

Daskin, M., & Dean, L. (2005). LOCATION OF HEALTH CARE FACILITIES. In M. Brandeau, F. Sainfort, & W. Pierskalla, *OPERATIONS RESEARCH AND HEALTH* CARE A HANDBOOK OF METHODS (pp. 43-76). Boston: Springer.

Daskin, M., Hesse, S., & ReVelle, C. (1997). -Reliable P minimax regret: A new model for strategic facility location modeling. *Location Science, 5*, 227-246.

Drezner, T., Drezner, Z., & Goldstein, Z. (2010). A stochastic gradual cover location problem. *Wiley InterScience, 57*, 367-372.

Drezner, Z., & Hamacher, H. (2002). Facility location: Application and theory.

Farahani, R., & Hekmatfar, M. (2009). Facility location: concepts, models, algorithms and case studies. *International Journal of Geographical Information Science*, *25*(2), 331 - 333.

Francis, R., & White, J. (1974). *Facility layout ana location an analytical approach.* Houston, TX, U.S.A.: Englewood cliffs.

Hakimi, S. (1964). Optimum locations of switching centers and the absolute centers and medians of a graph. *Operations Research, 12*(3), 450 - 459.

Hakimi, S. (1965). Optimum Distribution of Switching Centers in a Communication Network and Some Related Graph Theoretic Problems. *Operations Research, 13*(3), 462-475.

Lai, K., Nagi, E., & Cheng, T. (2002). Measures for evaluating supply chain performance in transport logistics. *Logistic and Transportation Review, 38*(6), 439 - 456.

Lega, F., Marsilio, M., & Villa, S. (2012). An evaluation framework for measuring supply chain performance in the public healthcare sector: evidence from the Italian NHS. *Taylor&Francis*, 1-17.

Masoumi, A., Yu, M., & Nagurney, A. (2012). A supply chain generalized network oligopoly model for pharmaceuticals under brand differentiation and perishability. *Transportation Research Part E, 48*(4), 762 - 780.

McAnulty, J. (2009). Hypothermic organ preservation by static storage methods: Current status and aview to the future. *CRYOBIOLOGY, 60*, s13-S19.

Murry, A., Tong, D., & Kim, K. (2010). Enhancing Classic Coverage Location Models. *International Regional Science Review, 33*(2), 115-133.

Pierskalla, W. P. (2005). SUPPLY CHAIN MANAGEMENT. In F. Sainfort, W. Pierskalla, & M. Brandeau, *OPERATIONS RESEARCH AND HEALTH CARE A HANDBOOK OF METHODSAND APPLICATIONS.* Boston: Springer Science.

Pirkul, H., & Schilling, D. (1991). The maximal covering location problem with Capacities on Total Workload. *Management Science, 37*(2), 233 - 248.

R.A.M, A., C, Q., W.M.L, d., D.F, d., R.V., D., & I.G, M. (2011). Organ Donation and Transplantation From Medical Students'Perspective: Introducing the Experience From an Academic League in Brazil. *Transplantation proceedings, 43*(4), 1311 - 1312.

Radiah Shariff, S., Moin, N., & Omar, M. (2012). Location allocation modeling for healthcare facility planning in Malaysia. *Computer&Industrial Engineering, 62*(4), 1000-1010.

Revelle, C., & Hogan, K. (1989). The maximum reliability location problem and α-reliablep-center problem:Derivatives of the probabilistic location set covering problem. *Annals of operations research, 18*(1), 155-174.

Schilling, D., Jayaraman, V., & Barkhi, R. (n.d.). A review of covering problems in facility location. *Location Science, 1*, 25-56.

Sharahi, S., & Abedian, M. (2009). performance Measurement. In R. Zanjirani, N. Farahani, & H. Davarzani, *Supply chain and logistics in national international and government environment* (pp. 21-41). Heidlberg: springer.

Shariff, S., & Sarifah Radiah . (2012). Dynamic conditional location allocation model for healthcare facilities. *Humanities, Science and Engineering Research (SHUSER), 2012 IEEE Symposium on* (pp. 1389 - 1394). Kuala Lumpur: IEEE.

Stadler, H. (2008). Supply Chain Management and Advanced Planning. In H. Stadler, & C. Kilger, *Concepts, Models, Software, and Case Studies* (pp. 9-33). Berlin: Springer.

Zanjirani Farahani, R., Asgari, N., Heidari, N., Hosseininia, m., & Goh, M. (2011). A Survey Covering problems in facility location: A review. *62*(1), 368-407.

Zanjirani, R., Farahani, N., & Davarzani, H. (2009). *Supply Chain and Logistics in national.* Heidelberg: Springer.