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Multi objective organ transplant supply chain with effective location and time consideration

Seyed Mahdi Aghazadeh[1], Mohammad Mohammadi[1]*, Bahman Naderi[1]

[1]*Department of Industrial Engineering, Faculty of Engineering, Kharazmi University, Tehran, Iran*

sma.aghazadeh@gmail.com, Mohammadi@khu.ac.ir, bahman.naderi@aut.ac.ir

Abstract

Nowadays, working alone on a context is not sufficient and reaching good and worthy results, demands cooperation of multi sciences. Healthcare supply chain is one of these sciences that bridges engineering and healthcare sciences. This paper proposes a new multi–objective model for organ transplant supply chain, which is one of consequential fields in Healthcare supply chain, by aiming at having a more effective system. First objective function tries to minimize costs of opened centers, shipping organs, information, and allocations. In this regard, to increase number of transplantations and decrease shortage of demands, a penalty figure is also considered for remained inventory at the end of each period. The second objective function considers three important aspects of location in organ transplant supply chain which have not been studied yet, including; expected number of donors, coverage of other locations by taking into consideration the maximum remaining time for each organ out of body, and safety index. The last objective function tries to find routs with final total minimum time. At the end, some numerical experiments are done with using GAMS optimization software.

Keywords: Healthcare management, organ transplant supply chain, location efficiency, bi-objective MIP optimization

1- Introduction

Generally, in the strategic supply chain designing phase, the main problem is about configuration of the network which satisfies customer demand and minimizes network costs simultaneously. In other words, Supply Chain (SC) is an integrated system of different activities and facilities that transforms row materials to final products and distributes these products to consumers. Supply chain management (SCM) consists of approaches that increase efficiency of integrated units such as suppliers, factories, warehouses, retailers, etc. So, the primary purpose of this system is minimizing total costs with acceptable service level to produce and distribute products to the proper locations at the proper quantities and a proper time. These transported goods may include things like commercial products and even body organs. Consequently, due to the circulation of the products between these units, the notion of SC units shifts.

*Corresponding author.
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Location in healthcare systems is a pivotal issue because of minimizing the social costs or maximizing the people's benefits equivalently. Satisfied and allocated demands of locations have a substantial impact on the system's efficiency. Moreover, it is important to build hospitals on the locations in which they only are not harmed by natural events, but also can answer people's demands at the concurrent time and cover more other locations.

Another difficulty is long waiting lists that are imposed on patients. In addition, elapsed time between transportation and donor notification is one of the important and impressive things in the process of organ donation. We will explain more about processes of organ transplant supply chain later by taking a glance at researchers' work.

Many previous studies have been done on facility location problems such as review papers and a structured analysis of operation and SCM research in healthcare since 1982 until 2011, like arrangement topics and strategies. In this regard, some researchers have proposed many different models for location-allocation of healthcare systems facility. Syam and Côté (2012) presented a location-allocation model for treatment department of traumatic brain injuries. They used data from Department of Veterans Affairs (DVA) to evaluate model applicability. Sharif, Moin, and Omar (2012) modeled a capacitated maximal covering location problem in healthcare and proposed a new genetic algorithm for solving this problem. Benneyan, Musdal, Ceyhan, Shiner, and Watts (2012) adduced multi-period, location-allocation model which balances coverage, cost, capacity and service locations synchronic. Sha and Huang (2012) presented a multi-period location-allocation model for emergency blood supply system in Beijing. They used a heuristic algorithm to solve problem which was based on the Lagrangian relaxation method. Zahiri, Tavakoli-Moghaddam and Pishvaee (2014) alleged a Mixed Integer Linear Programming (MILP) model under uncertainty for multi-period, location-allocation organ transplant center (TC) based on robust probabilistic approach.

Now, based on these studies, the picture that seems to be emerging is that, for many diseases that would have been fatal, transplantation has become a successful treatment. The network of organ transplant SC involves two people, one who donates an organ for transplant, named donor, and one who receives an organ, named recipient, hospitals, TCs, shipping agents and recipient zones. Organ removing process has been done on the volunteered or brain-dead patients in donor hospitals. After registration, blood sampling and presurgical operations are done to transplant by shipping agents from hospitals to the TCs. It is worthy to remind that, one of the main differences between traditional SC and the organ transplant SC is perishability of the products. In this light, the main specification of each organ is its cold ischemia time defined as the maximum time period that the organ can be kept outside the body. If the organ's transport time between hospital and transplant center is less than cold ischemia time, the organ can transport, otherwise we are not allowed to transport the organ. Within this perspective of transplant, Bruni, Conforti, Sicilia, and Trotta (2006) formulated a MILP model to achieve an efficient transplant system in Italy. They optimized the model with assuming special centers named OPO (Organ Procurement Organization in the USA).

Later, Kong, Schaefer, Hunsaker, and Roberts (2010) used a branch-and-price approach to maximize the efficiency of USA liver allocation systems. Belien, De Boeck, Colpaert, Devesse, and Van den Bossche (2013) proposed a MILP location model for organ transplant, which minimizes the total weighted travel time. They also took five organs including: liver, kidney, heart, lung and pancreas. Their model applied to a case study in Belgium. In addition, they submitted a discrete location problem for shipping agents with Belgium real numerical experiments. In complementing their model, Zahiri, Tavakoli-Moghaddam and Pishvaee (2014) suggested a multi objective design of organ transplantation by considering time. They solved the model with a hybrid meta-heuristic algorithm. Ghane and Tavakoli-Moghaddam (2016) proposed a stochastic optimization approach to a location-allocation problem of organ transplant centers. Also, they have considered recipient regions as another component of organ transplant supply chain. Rajmohan, Theophilus, Sumalatha and Saravanakumar (2017) propounded a model to facility location of organ procurement organizations. They applied the proposed model to Indian healthcare supply chain.

Ultimately, this paper models a new MILP organ transplant SC with contemplation of vital parameters in designing this network like number of expected donors, index of location's safety and coverage criterion.

2- Problem description and mathematical formulation

In the first step, it is necessary to have information about transplant SC and interactions between its facilities. As mentioned before, donor and recipient are two major elements of transplant SC that perform some operations. SC operations begin with donor person's information to get ready for organ donation. For transporting required information yielding from blood sample, a shipping team is sent to donor hospital. Bear to mind that, donor person can be a volunteer or a brain-dead patient. After required sampling, shipping team returns to origin hospital for getting the results of experiments. If experiments are successful, organ removal process begins at donor hospital. Thus, organ is sent to TC for transplantation on recipient's body. After performing registration, investigation of samples, and at last transplantation operations, concomitantly, TCs inform recipient for being present at the specific time to start transplantation operations. Similarly, for supporting foreign donors and recipients, some airports which have minimum transportation time to hospitals or TCs were considered. For the sake of simplicity, a schematic view has been shown in figure 1.

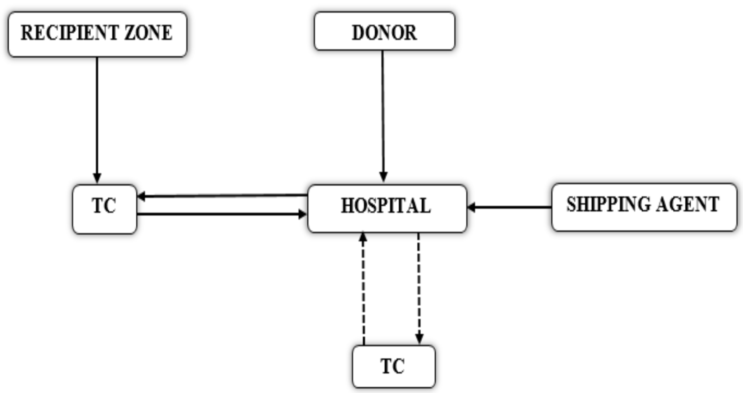

Figure 1. Existence flows between facilities (dashes are information flow)

In this section a bi-objective functions are demonstrated to decrease network costs which is accompanied by an increase in its efficiency. After model proposition, this will be discussed in more details. Sets, parameters, and all kinds of used variables are explained as follows:

2-1- Sets

H	Location of potential hospitals, $h \in H$
K	Location of potential TC's, $k \in K$
V	Location of potential shipping agents, $v \in V$
Z	Location of recipient zones, $z \in Z$
O	Organ types, $o \in O$
A	Airports, $a \in A$
T	Time periods, $t \in T$

2-2- Parameters

F_h	Fixed costs for opening hospital h
F'_k	Fixed costs for opening TC k
r_{ho}	Cost of removal process of organ o at hospital h
r'_{ko}	Equipment cost of TC k for organ o
C_{vh}	Contract cost of hospital h with shipping agent v
C_{hk}	Shipping cost of samples and required information from hospital h to TC k
C'_{hk}	Shipping cost of an organ from hospital h to TC k
C_{ak}	Shipping cost of an organ from airport a to TC k
C_{zk}	Shipping cost of a unit from zone z to TC k
Id_h^t	Number of domestic donors at hospital h at period t
Od_h^t	Number of foreign donors at hospital h at period t
NO_{ho}^t	Number of obtained organ o from a single body at hospital h at period t
t_{hko}^t	Traveling time of organ o from hospital h to TC k at period t
M	Violation cost in demand satisfaction
M'	Penalty cost for inventory of the end of the each period
rd_h^t	Entrance rate of domestic donors at hospital h at period t
ra_h^t	Entrance rate of foreign donors at hospital h at period t
D_{zo}^t	Total demand of organ o at zone z
t'_o	Cold ischemia time of organ o
Ω_h	Expected number of donors and recipients at location h
Ω^{Max}	$Max\{h \mid \Omega_h\}$
ζ_{hh_1o}	Number of covered zones as organ's cold ischemia view point by hospital h
ζ^{Max}	$Max\{h.o \mid \zeta_{hh_1o}\}$
φ_h	Safety index for location $h \in [0.1]$
φ^{Max}	$Max\{h \mid \varphi_h\}$

2-3- Variables

$q_h \in \{0.1\}$	1 if hospital h is open and 0 otherwise.
$q'_k \in \{0.1\}$	1 if TC k is open and 0 otherwise.
$y_{ho} \in \{0.1\}$	1 if hospital h is open and capable of donating organ o and 0 otherwise.
$y'_{ko} \in \{0.1\}$	1 if TC k is open and capable of transplantation of organ o and 0 otherwise.
$W_v^t \in \{0.1\}$	1 if shipping agent v is select at period t and 0 otherwise.
$U_{vh}^t \in \{0.1\}$	1 if hospital h is covered by shipping agent v at period t and 0 otherwise.
X_{hko}^t	Flow of information and required facilities of organ o flow from hospital h to TC k at period t.
$X_{hko}^{\prime t}$	Flow of organ o from hospital h to TC k at period t.
X_{hao}^t	Flow of organ o from hospital h to airport a at period t.
X_{ako}^t	Flow of organ o from airport a to TC k.
X_{zko}^t	Flow of recipients of organ $o$from zone z to TC k at period t.
$Id_{ho}^{\prime t}$	Number of available organ o at hospital h at period t by domestic donors.
$Od_{ho}^{\prime t}$	Number of available organ o at hospital h at period t by foreign donors.
I_{ho}^t	Inventory level of organ o at hospital h at period t.
S_z	Unsatisfied amount in demands of zone z.
W	Total numbers of available shipping agents at each period.

2-4- Modeling

According to the previous explanations, we model the problem mathematically with three objective functions aiming at reducing costs of operation and transferring, effective site selection for the establishment of hospitals, and ultimately minimizing the members’ transfer time which is a critical factor in this model as follows. Later, the objective functions and restrictions will be explained more.

$$Min\ Z_1 = \sum_h F_h \cdot q_h + \sum_k F'_k \cdot q'_k + \sum_o \sum_k r'_{ko} \cdot y'_{ko} + \sum_o \sum_h r_{ho} \cdot y_{ho} + \sum_t \sum_h \sum_v C_{vh} \cdot U^t_{vh} + \sum_t \sum_o \sum_k \sum_h C_{hk} \cdot X^t_{hko} + \sum_t \sum_o \sum_k \sum_h C'_{hk} \cdot X'^t_{hko} + \sum_t \sum_o \sum_a \sum_k C_{ak} \cdot X^t_{ako} + \sum_t \sum_o \sum_k \sum_h C_{zk} \cdot X^t_{zko} + \sum_h M \cdot S_z + \sum_t \sum_h \sum_o M' \cdot I^t_{ho} \tag{1}$$

$$Min\ Z_2 = \sum_h q_h \left(\frac{\Omega^{Max} - \Omega_h}{\Omega^{Max}}\right) + \sum_h \sum_{h_1 \neq h} \left(q_h \sum_o \frac{\zeta^{Max} - \zeta_{hh_1o}}{\zeta^{Max}}\right) + \sum_h q_h \left(\frac{\varphi^{Max} - \varphi_h}{\varphi^{Max}}\right) + \sum_h M \cdot S_z \tag{2}$$

$$Min\ Z_3 = \sum_h \sum_k \sum_o \sum_t X^t_{hko} \cdot t_{hk} + \sum_h \sum_k \sum_o \sum_t X'^t_{hko} \cdot t_{hk} + \sum_h \sum_a \sum_o \sum_t X^t_{hao} \cdot t_{ha} + \sum_a \sum_k \sum_o \sum_t X^t_{ako} \cdot t_{ak} + \sum_z \sum_k \sum_o \sum_t X^t_{zko} \cdot t_{zk} + \sum_h M \cdot S_z \tag{3}$$

$$y_{ho} \leq q_h \qquad \forall\ h.o \tag{4}$$

$$y'_{ko} \leq q'_k \qquad \forall\ k.o \tag{5}$$

$$\sum_h y_{ho} \geq 1 \qquad \forall\ o \tag{6}$$

$$\sum_k y'_{ko} \geq 1 \qquad \forall\ o \tag{7}$$

$$\sum_v W^t_v \leq W \qquad \forall\ t \tag{8}$$

$$U^t_{vh} \leq W^t_v \qquad \forall\ t.v.h \tag{9}$$

$$y_{ho} \leq \sum_v U^t_{vh} \qquad \forall\ t.h.o \tag{10}$$

$$W^t_v \leq \sum_h U^t_{vh} \qquad \forall\ t.v \tag{11}$$

$$\sum_{v} U_{vh}^{t} \leq 1 \qquad \forall\, t.h \qquad (12)$$

$$\sum_{k} X_{hko}^{t} = (Id_{ho}^{\prime t} + Od_{ho}^{\prime t}) y_{ho} \qquad \forall\, t.h.o \qquad (13)$$

$$X_{hko}^{t} \leq (Id_{ho}^{\prime t} + Od_{ho}^{\prime t})\, y_{ko}^{\prime} \qquad \forall\, t.h.k.o \qquad (14)$$

$$X_{hko}^{\prime t} = 0 \quad if\ t_{hko}^{t} > t_{o}^{\prime} \qquad \forall\, t.h.k.o \qquad (15)$$

$$X_{hko}^{\prime t} \leq Id_{ho}^{\prime t} y_{ko}^{\prime} \qquad \forall\, t.h.k.o \qquad (16)$$

$$\sum_{k} X_{hko}^{\prime t} \leq Id_{ho}^{\prime t} y_{ho} \qquad \forall\, t.h.o \qquad (17)$$

$$\sum_{a} X_{hao}^{t} \leq Od_{ho}^{\prime t} y_{ho} \qquad \forall\, t.h.o \qquad (18)$$

$$\sum_{a} X_{ako}^{t} \leq \sum_{h} Od_{ho}^{\prime t}\, y_{ko}^{\prime} \qquad \forall\, t.k.o \qquad (19)$$

$$\sum_{k} X_{ako}^{t} \leq \sum_{h} X_{hao}^{t} \qquad \forall\, t.a.o \qquad (20)$$

$$Id_{ho}^{\prime t} = [Id_{h}^{t}.NO_{ho}^{t}.rd_{h}^{t}] \qquad \forall\, t.h.o \qquad (21)$$

$$Od_{ho}^{\prime t} = [Od_{h}^{t}.NO_{ho}^{t}.ra_{h}^{t}] \qquad \forall\, t.h.o \qquad (22)$$

$$\sum_{z} X_{zko}^{t} = \sum_{h} X_{hko}^{\prime t} + \sum_{a} X_{ako}^{t} \qquad \forall\, t.k.o \qquad (23)$$

$$\sum_{k} X_{zko}^{t} + S_{z} \geq D_{zo}^{t} \qquad \forall\, t.z.o \qquad (24)$$

$$I_{ho}^{t} = I_{ho}^{t-1} + Id_{ho}^{\prime t} + Od_{ho}^{\prime t} - (\sum_{k} X_{hko}^{\prime t} + \sum_{a} X_{hao}^{t}) \qquad \forall\, t.h.o \qquad (25)$$

$$q_{h}, q_{k}^{\prime}, y_{ho}, y_{ko}^{\prime}, W_{v}^{t}, U_{vh}^{t} \in \{0.1\} \qquad (26)$$

$$X_{hko}^{t}, X_{hko}^{\prime t}, X_{hao}^{t}, X_{ako}^{t}, X_{zko}^{t}, Id_{ho}^{\prime t}, Od_{ho}^{\prime t}, I_{ho}^{t}, S_{z}, W \ \geq 0.integer \qquad (27)$$

First objective function (1) reduces the costs of the founded hospitals and transplant centers, the costs of organ removal and equipped transplant centers, the cost of the contract with transfer agents, the costs of transferring between hospitals and transplant centers, airports and transplant centers, populated areas and transplant centers, and ultimately fines related to supply shortages and remained inventory respectively at the end of the period.

Second objective function (2) requires more explanation. First section of (2) aims at maximizing the number of expected donors and recipients of chosen locations. It is worthy to know that this specification has absolutely direct relation with population of zones. The values of these parameters can be obtained statistically from previous data. Also, the value of Ω^{Max} parameter is equal to the maximum of parameters Ω_h which is used in dimensionless.

Second section of (2) aims at choosing locations that have the most coverage of other zones by taking into consideration aspects of time and kind of organ (that is, cold ischemia of each organ). The following example will provide more clarification: Suppose we have a matrix of ζ_{hh_1o} for one kind of an organ: $\begin{bmatrix}1 & 0 & 0\\ 1 & 1 & 0\\ 1 & 0 & 1\end{bmatrix}$, the amount of parameter for location A is 1 and for B and C is 2 (aggregation of each row) so the most quantity is 2. With this function, model goes to choose locations that have the most coverage. Hence, in the future, we'll have fewer problems like shipping costs and supply organs and their allocations. The value of ζ^{Max} parameter is equal to the maximum of ζ_{hh_1o} parameters.

The third section of (2) maximizes safety of locations in facing with natural disasters such as earthquakes, torrents, etc. These locations are significant and more effective especially when we are in disaster. Hence, it is vital that these locations be active and support our patients. The value of φ^{Max} parameter is equal to the maximum of $\varphi_h$parameters.

In the following, there is a mandatory interpretation of the form of the second objective function's (2) sections. It is worth mentioning that mentioned parameters have different dimensions and cannot be summed with each other. Hence, before summation, they are considered dimensionless first (Assume that the importance of them is equal). The amount of each section is between [0, 1] and desired value is taken zero. Similarly, third objective function (3) reduces the total shipping organ's time.

Constraint (4) guarantees that a hospital can donate a particular organ if it is open and constraint (5) has the same duty for each TC. Constraints (6) and (7) demonstrate that our network should have at least one hospital and TC for each particular organ. Constraint (8) ensures the total number of available shipping agent at each period. Constraint (9) guarantees that assignment to hospital can take place at period t if only the shipping agent v is chosen. Constraint (10) demonstrates that each opened hospital should be covered by at least one shipping agent. Constraint (11) decreases the number of shipping agents and unused flows. Constraint (12) indicates that each hospital can be covered by at most one shipping agent (unlike constraint (10)). Constraint (13) and (14) ensure that information flows between a hospital and a TC can be defined if the hospital and the TC are opened. Constraint (15) indicates that the period of delivering time for each particular organ cannot exceed its cold ischemia time; otherwise we should consider 0 flow for that. Constraint (16) and (17) ensure that flows from a hospital to a TC can be defined if hospital and TC are opened. Constraint (18) indicates that flows from hospitals to the airport are feasible if the hospital is capable of donating the organ. Constraint (19) demonstrates that flows from airports to a TC can connect if the TC is opened. Constraint (20) is a balanced constraint between total flows from donor hospitals (for abroad operations) to the airport and total outflows to TCs in each period of time. Constraint (21) considers total available supply organ o in period t for domestic donors and constraint (22) do the same for abroad donors. It is worth mentioning that because of integer variables Id'^{t}_{ho} and Od'^{t}_{ho}, we can use "$\leq$ " instead of "=" and "[ ]" s. Constraint (23) guarantees that total flows from recipient zones to TCs are equal to total flows from hospitals and airports to TCs at each time period. Constraint (24) shows the balance equation of demand satisfaction. Constraint (25) shows inventory level of each organ for each hospital in each period of time. Expectedly, constraints (26) and (27) indicate types of each decision variables.

2-5- linearization

Represented model aimed at multiplication of integer and binary variables in some constraints is non-linear. Solving this kind of non-linear models is difficult and needs using more time and source in

comparison with linear models, especially in large dimensions. In the light of this difficulty, we will convert non-linear sections of model to the equivalent linear types separately as follows:
With regard to what was previously mentioned, in constraints (13), (14) and (16) to (19) we have some non-linear sections. We define "M" as a big reasonable number to convert these constraints to linear types. We start these converts with constraint (13) by transforming it as follows:

$$\sum_k X_{hko}^t \geq Id_{ho}^{\prime t} + Od_{ho}^{\prime t} - M(1 - y_{ho}) \qquad \forall\, h.o.t \qquad (28)$$

$$\sum_k X_{hko}^t \leq My_{ho} \qquad \forall\, h.o.t \qquad (29)$$

The picture that seems to be emerging is that alternative constraints guarantees that if $y_{ho} = 0$ we will have no information flows between facilities, otherwise ($y_{ho} = 1$) our flows can take amounts between $(Id_{ho}^{\prime t} + Od_{ho}^{\prime t})$ and M. Due to deceasing of costs, we can speculate that this flow always takes the lowest amount of its interval (i.e., $Id_{ho}^{\prime t} + Od_{ho}^{\prime t}$). In the same vein, for constraint (14) we will follow linear constraints instead of non-linear ones.

$$X_{hko}^t \leq Id_{ho}^{\prime t} + Od_{ho}^{\prime t} \qquad \forall\, h.k.o.t \qquad (30)$$

$$X_{hko}^t \leq My_{ko}^{\prime} \qquad \forall\, h.k.o.t \qquad (31)$$

Obviously, existence of these constraints assures that if concerned facility is open ($y_{ko}^{\prime} = 0$), its flow can take amounts from 0 to $(Id_{ho}^{\prime t} + Od_{ho}^{\prime t})$, otherwise the flow should take zero.

Similarly, we have transformation of constraints (16) to (19) as follows:

$$X_{hko}^{\prime t} \leq Id_{ho}^{\prime t} \qquad \forall\, t.h.k.o \qquad (32)$$

$$X_{hko}^{\prime t} \leq My_{ko}^{\prime} \qquad \forall\, t.h.k.o \qquad (33)$$

$$\sum_k X_{hko}^{\prime t} \leq Id_{ho}^{\prime t} \qquad \forall\, t.h.o \qquad (34)$$

$$\sum_k X_{hko}^{\prime t} \leq My_{ho} \qquad \forall\, t.h.o \qquad (35)$$

$$\sum_a X_{hao}^t \leq Od_{ho}^{\prime t} \qquad \forall\, t.h.o \qquad (36)$$

$$\sum_a X_{hao}^t \leq My_{ho} \qquad \forall\, t.h.o \qquad (37)$$

$$\sum_a X_{ako}^t \leq \sum_h Od_{ho}^{\prime t} \qquad \forall\, t.k.o \qquad (38)$$

$$\sum_{a} X_{ako}^{t} \leq M\, y_{ko}^{\prime} \qquad \forall\, t.k.o \qquad (39)$$

3- Running the model

All of used parameters in modeling follow uniform distribution that is shown in Table 1. For evaluating the results of this problem, at first, the problem is solved in small sizes; then obtained results are evaluated for being correct and reasonable. At the end, the problem will be solved in different sizes.

Table 1. Random distributions of parameters

Parameter	Random Distribution
F_h	$\sim Uniform(2000.3000)$
F'_k	$\sim Uniform(3000.3500)$
r_{ho}	$\sim Uniform(2.5.6)$
r'_{ko}	$\sim Uniform(600.900)$
Id_h^t	$\sim Uniform(1000.2000)$
Od_h^t	$\sim Uniform(1000.2000)$
rd_h^t	$\sim Uniform(0.7.0.8)$
ra_h^t	$\sim Uniform(0.7.0.8)$
D_{zo}^t	$\sim Uniform(40.100)$
C_{vh}	$\sim Uniform(100{,}500)$
C_{hk}	$\sim Uniform(0.06.0.14)$
C'_{hk}	$\sim Uniform(0.13.0.25)$
C_{ak}	$\sim Uniform(45.160)$
C_{zk}	$\sim Uniform(0.03.0.1)$
$M\,.M'$	1000000

And for parameter NO_{ho}^t we have: $NO_h^t(O = 1.2.3.4.5) = 1.2.2.1.1$
(1, 2, 3, 4 and 5 are heart, lung, kidney, liver and pancreas, respectively.)

It is worthy to mention that the model includes three different objective functions in which, certainly, they do not have compatible goals. In addition, they might have apparent contradictions in some points.

For solving this multi objective model, we used existing methods of multi criteria decision making (MCDM). One of these methods is Maximin method which, in short, maximizes the minimum percentage of satisfaction with reaching the desirable point.

For getting more acquaintance, suppose we have N objective functions in which their best values are dedicated with f_i^*. The Maxmin modeling for maximizing problems will be as follows and for minimizing problems will be in reverse.

$$\text{Max}\ (\min\ \{ \frac{f_1}{f_1^*} \cdot \frac{f_2}{f_2^*} \cdot \ldots \cdot \frac{f_i}{f_i^*} \cdot \ldots \cdot \frac{f_N}{f_N^*}\ \}) \tag{1}$$

$$x\ \in X \tag{2}$$

We can show this model as follows:

$$max\ z \tag{1}$$

$$z\ \le \frac{f_1}{f_1^*} \tag{2}$$

$$z\ \le \frac{f_2}{f_2^*} \tag{3}$$

$$\ldots$$

$$z\ \le \frac{f_i}{f_i^*} \tag{4}$$

$$\ldots$$

$$z\ \le \frac{f_N}{f_N^*} \tag{5}$$

$$x\ \in X \tag{6}$$

Results of solving deterministic model were reported in table 2 that includes all three objectives together with the value of Maximin objective function (Z). The problem was solved in ten different sizes and the results are shown in figure 2.

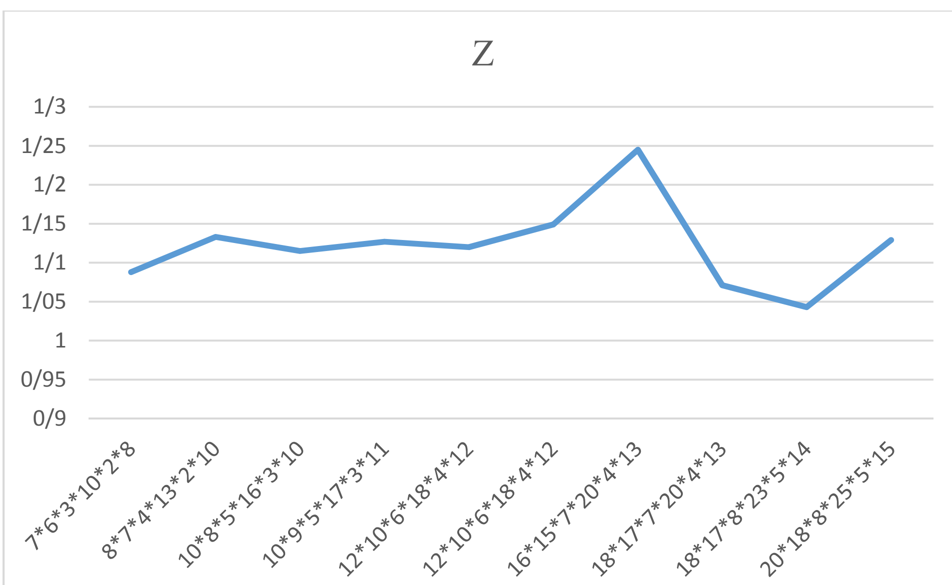

Figure 2. Z value for each problem size

Table 2. Model solving results

Problem size T=3 |H|*|K|*|V|*|Z|*|O|*|A|	Z_1	Z_2	Z_3	Z
7*6*3*10*2*8	69428.654	99.342	2.5814*10^6	1.088
8*7*4*13*2*10	1.2048*10^5	1872.730	4.6016*10^6	1.133
10*8*5*16*3*10	6.065*10^5	6206.169	7.2650*10^6	1.115
10*9*5*17*3*11	8.4537*10^5	43470.821	9.5381*10^6	1.127
12*10*6*18*4*12	1.6230*10^6	1.4338*10^5	9.6086*10^6	1.120
12*10*6*18*4*12	1.7289*10^6	1.5860*10^5	9.6558*10^6	1.149
16*15*7*20*4*13	1.8864*10^6	1.7773*10^5	9.7484*10^6	1.245
18*17*7*20*4*13	4.5733*10^6	4.394*10^5	1.2016*10^7	1.071
18*17*8*23*5*14	5.5884*10^6	5.4043*10^5	1.3481*10^7	1.043
20*18*8*25*5*15	6.3638*10^6	6.2070*10^5	1.4457*10^7	1.129

In table 3 Minimum percentage of satisfaction and time span of solving for each size was reported.

Table 3. Minimum satisfaction percentage and running time of model

Problem size T=3 |H|*|K|*|V|*|Z|*|O|*|A|	Minimum satisfying percentage (%)	Running time (s)
7*6*3*10*2*8	91.91 %	0.816
8*7*4*13*2*10	89.84 %	0.492
10*8*5*16*3*10	89.68 %	1.790
10*9*5*17*3*11	88.73 %	1.528
12*10*6*18*4*12	89.28 %	1.252
12*10*6*18*4*12	87.03 %	1.107
16*15*7*20*4*13	80.32 %	3.830
18*17*7*20*4*13	93.37 %	17.350
18*17*8*23*5*14	95.87 %	176.106
20*18*8*25*5*15	88.57 %	410.923

Minimum satisfaction percentage and running time for each problem size were shown in figure 3 and figure 4, respectively.

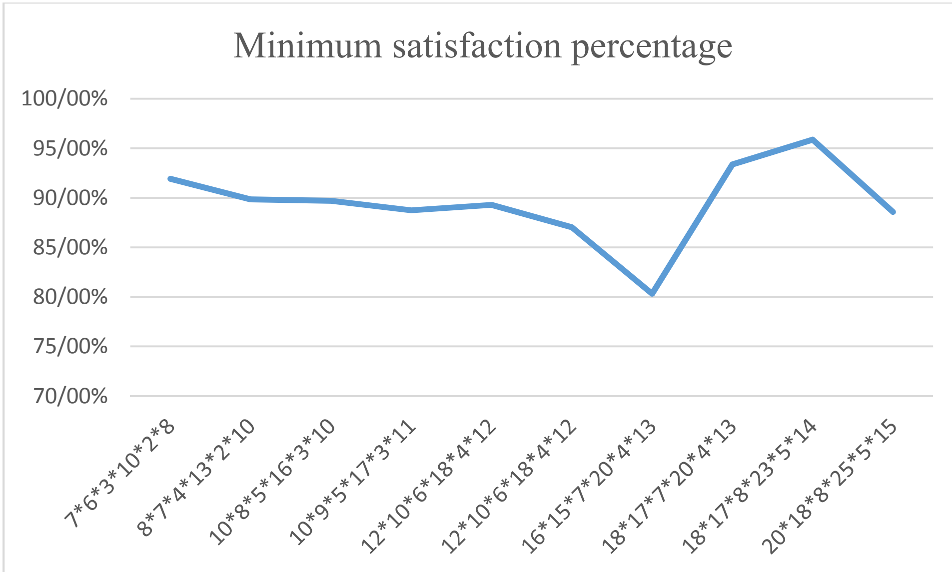

Figure 3. Minimum satisfaction percentage for each problem size

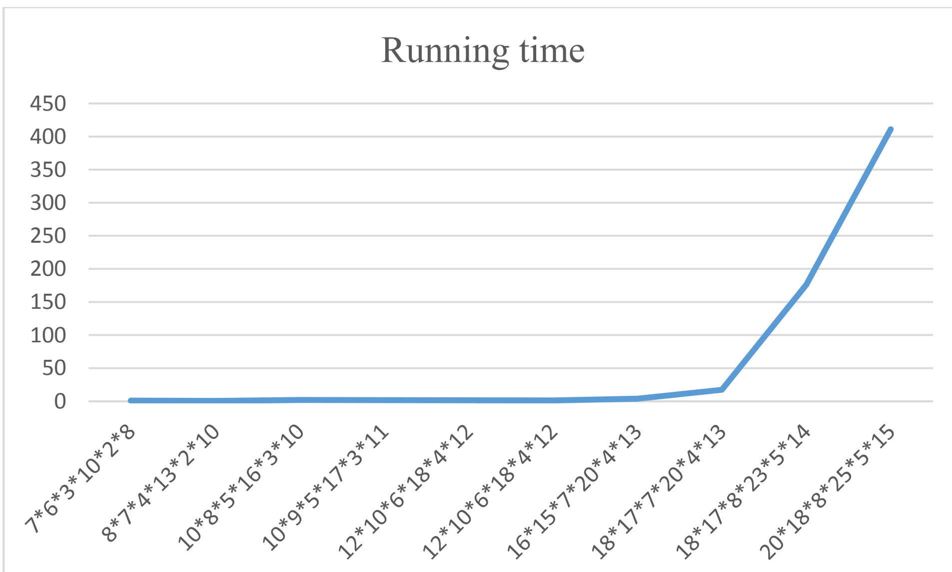

Figure 4. Running time for each problem size

The form of figure 3 is reverse of figure 2 and running time of the model increases like the figure of power 2 equations by increasing of the problem size.

One of the important parameters existing in all objective functions is penalty coefficient which is considered for demand shortage. In second and third objective function, it is such as a link between objective function and constraints. This parameter for each size can be achieved through changes in different values.

Furthermore, this parameter should set a value that satisfies demand in high level. Indeed, for being a reasonable value, simultaneously tries to minimize costs and reaches other goals.

In the following we show and analyze sensitivity of penalty coefficient value for all three objective functions. In this light, we change penalty coefficient in different percentages through which we measure percentages of changes in objective functions. Figures 5, 6, and 7 demonstrate this process for first, second and third objective functions, respectively.

Figure 5. Sensitivity analysis of first objective function

Figure 6. sensitivity analysis of second objective function

Figure 7. Sensitivity analysis of third objective function

In the next step, sensitivity value of objective functions for penalty coefficient will be shown clearly in figure 8.

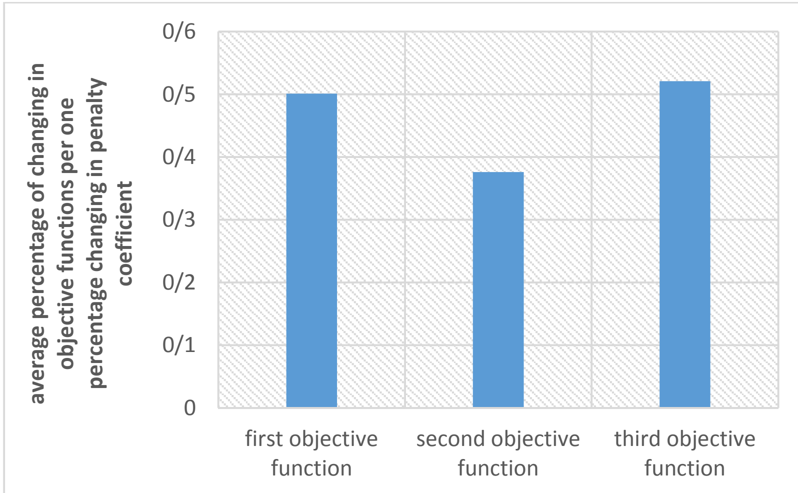

Figure 8. Average percentage of changes in objective functions per one percentage changes in penalty coefficient

As it is evident in figure 8, results show that the third objective function has the most sensitivity and the second objective function has the less sensitivity in facing with changes of penalty coefficient.
Also, some sensitivity analysis has been done on objective functions based on parameters changes as follows:

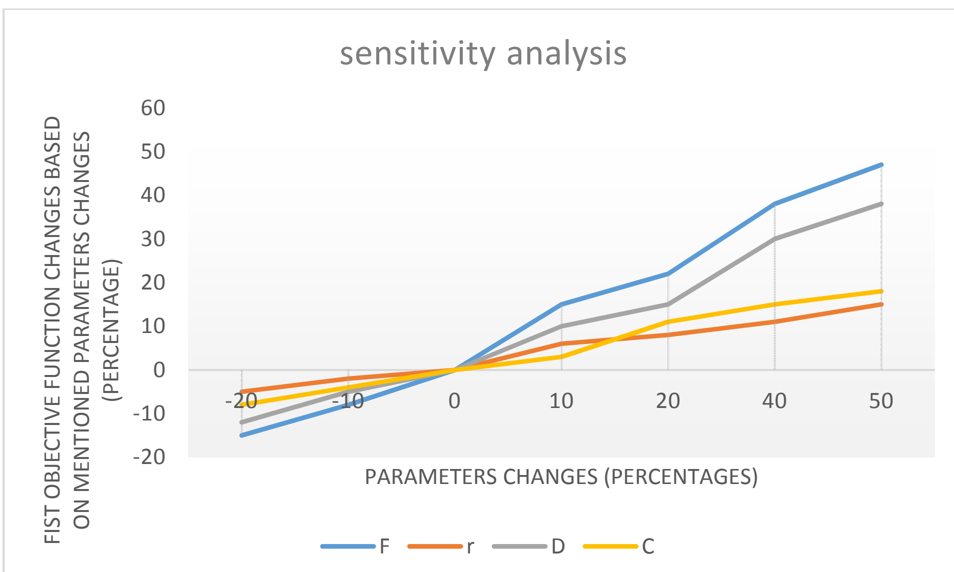

Figure 9. First objective function sensitivity analysis (fix costs, equipment costs and shipment costs)

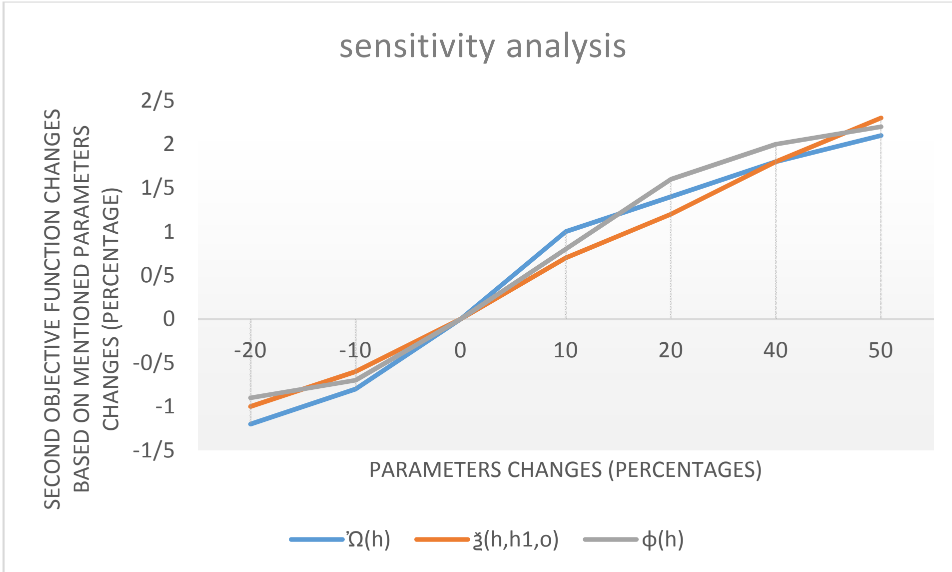

Figure 10. Second objective function sensitivity analysis

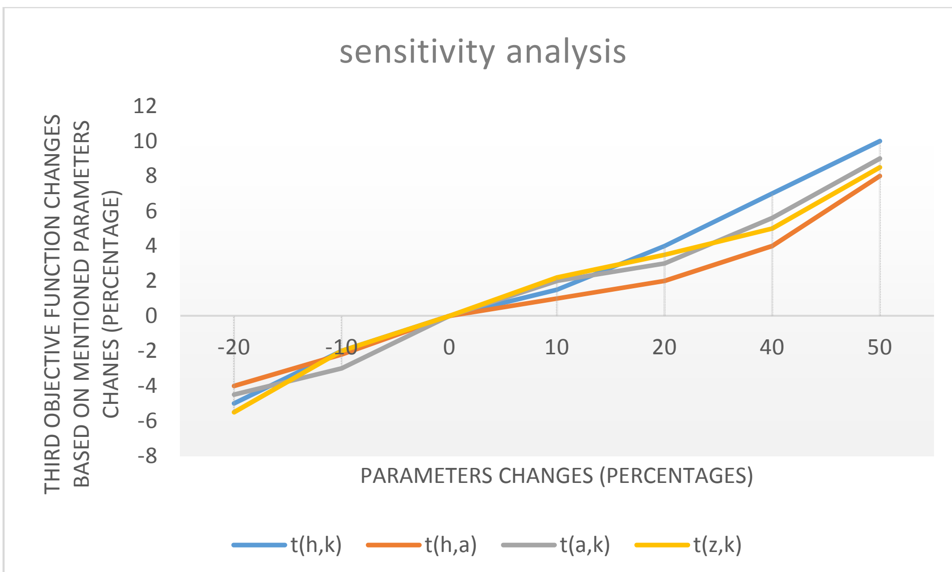

Figure 11. Third objective function sensitivity analysis

4- Conclusion and future study

A picture provided by figure 4 illustrates that running time of model is extremely increasing with increment of problem size. Also, in big sizes with a bit increase in problem size, running time raises so much. In the light of this, we need to use a metaheuristic method to solve problems in big sizes; however, it should be taken into consideration that in these kinds of problems our key goal is not time alone. Hence, this goal and others should be considered with an appropriate allocation of organs to acquire a high level of people survival. Therefore, we should introduce methods which have a desirable quality with reasonable running time. Overall, by introducing an appropriate metaheuristic method, we can create a global organ transplant supply chain with less costs and suitable time in big sizes.

To put in nutshell, by creating a network of international suppliers, one of the other issues that needs more study, due to the critical value of goods exchange, that is member, is the type and number of organs exchanging between countries which can be integrated without a specific law (by considering the benefits of the entire supply chain), or the first priority of each country can be its own patients and then those of other countries despite additional costs imposed on the entire supply chain, or certain exchanging rules can be established between countries. Bearing in mind, each of these rules needs to be reviewed and analyzed to determine their future implications.

More importantly, another issue is the discussion of disaster in the supply chain. That is to say, with occurrence of disaster, one or some of our facilities are damaged and all or part of its capacity to serve is lost. Of course, in this proposed model, we have tried to establish facilities in places that have the highest safety factor in terms of the occurrence of such incidents. However, the occurrence of such incidents is away from human control and may impose damages to our supply chain.

Generally speaking, since our facilities are a type of health facility and should serve the patients, by assuming the occurrence of such incidents in which the number of patients and accident victims will also increase, our facilities not only must continue their previous work, but also have a degree of increased capacity.

From this point, with occurrence of incident, it should be investigated that which of our facilities are safe, which have lost totally and which have been injured slightly and lost part of their capacity. Ultimately, by having this information, a model is proposed that can determine a path to serve patients, exchanges between the facilities, and all necessary works to offset all or part of the damages. In other words, it can be stated that reliability debates and failure probabilities for facilities should be taken into consideration though they are more or less in line with the same mentioned concepts.

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