Negar Armaghan [1]

Mohsen Yaghoobi Pazani

A MODEL FOR DESIGNING A BLOOD SUPPLY CHAIN NETWORK TO EARTHQUAKE DISASTERS (CASE STUDY: TEHRAN CITY)

Abstract: One of the most devastating events is earthquake. Along with planning for supply and the proper distribution of relief goods including food and cloths, one of the most vital issues is to relieve to injured people who are in need of blood. In this research, we design a blood supply chain when the earthquake takes place, should the need arises by people requesting the blood units. Based on this need, a multi-level multi-objective mathematical model is designed during several periods based on minimizing the cost of the blood supply chain network and maximizing the reliability of the selectable paths for blood transportation. This model determines the optimal number and locations for establishing the facilities as well as determining the allocation of blood to various facilities, and, on the other hand, optimal routes for blood transportation among facilities. The mathematical model presented is validated by data acquired from implemented model of Tehran city.

Keywords: Earthquake, Blood supply chain, Multi-level multi-objective mathematical model, Reliability

1. Introduction

Healthy blood is a life savior. One person of various ages and races on the planet needs to blood transfusion to survive per second. Recent events indicate the effect of disorders and disasters to blood supplying services (Fahiminia et al., 2015). For example, Japan's 2011 earthquake disturbed supplying the blood in Tokyo since all donated blood was not transfused to injured people. Also, the Sichuan's earthquake taken place in 2008, created a quality disordering in China's blood management system since not considering the lab in various cases and lacking the proper management of transportation caused that healthy blood was not sufficiently provided to injured people. In the tsunami of 2004 due to the influx of donors, the problems created concerning the blood excess and loss. Inadequate blood supply chain design in the Bam city's earthquake of 2003 caused in a waste of about 77% of donated blood. Thus, from 108,000 blood units donated, only 21,000 units, approximately 23% have been released to earthquake strikers (Aghyani et al., 2015).

In such a situation, needing the crisis management plan is felt. Crisis management refers to a set of specific operations and processes that are used and planned to prevent and reduce the effects before the crisis, during and after that (Jabbarzade et al., 2014). Logistics plays a crucial and deterministic role in the supply chain and crisis management support since the entire crisis management process is disrupted if the role does not act correctly. Relief logistics

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[1] Corresponding author: Negar Armaghan
Email: armaghan@irost.ir

relates to processes and systems coordinating the people, resources, skills, and required knowledge to help injured people in natural disasters (Liang et al., 2012).

The crisis in the field of blood transportation services generally refers to a situation where the ability of the chain to receive and supply blood is temporarily or completely lost, or a circumstance that causes suddenly an over-request for blood, and a large influx of donors to blood donation locations, which causes problems in the blood collection system. Therefore, managing blood system during a crisis is one of the main challenges in the field of blood transportation services. The occurrence of natural disasters such as earthquakes can make a bad effect on blood donators, staffing, blood transportation, procurement and facilities, and generally blood supply chain (Zendeh Del et al., 2014).

For this reason, at the time of the earthquake crisis, the issue of the design of the blood supply chain should be taken into account in accordance with the real world needs and circumstances. The BSCN includes blood donors, temporary and permanent blood facilities, and blood establishments seeking the location and determination of the number of permanent and temporary facilities, hospitality Facilities, total blood donated at each facility and the amount of blood inventory at the end of each period. After the occurrence of a destructive earthquake, selection and transportation of blood collected from high reliability routes is of very important. On the other hand, according to the previous research, taking into consideration of laboratory levels in the blood supply chain is of very important (Nahafti et al., 2016). Because in the aftermath of the earthquake, we are faced with a sharp rise in blood demand from the injured. The aim of the study is supply and distribution of blood in a timely manner, such that to minimize costs and maximize the reliability of the selected path. In this regard, this study presents a mathematical model for blood supply and distribution in

different crisis periods. Hence, in this research, we design a unified network of blood supply and distribution for post-crisis situations and for reducing the damage caused by lacking the blood. Thus, providing a dual mathematical model, we seek to minimize network costs and increase the reliability of the selected pathways for blood transportation. In this research, a two-objective mathematical model is presented for designing a blood supply chain network. The first objective is to minimize the costs of the entire supply chain, and the second one is to maximize the reliability of the selected pathways for blood transportation.

2. Literature review

Designing an effective and efficient blood supply-chain network calls for the adoption of several decisions, including strategic or long-term decisions, operational or short-term ones. These decisions are the location of blood collection centers, transferring the collected blood from blood collection centers to blood centers, as well as from blood centers to hospitals. Additionally, the inventory level in each period in blood centers is one of the major decisions in designing a Blood Supply-Chain Network (BSCN). As blood demand is different in various periods after an earthquake (e.g., in the first 24 hours of the earthquake, demand is much higher), for this reason, dynamic network design should be used in designing a BSCN (Jabbarzadeh et al., 2014). In one of the first studies in the field of supply chain design regarding the location and inventory together, Deskin et al. (2002) proposed a mathematical model for network design considering location and two types of inventory costs, including variable and fixed costs. They proposed a nonlinear mixed integer model for the problem and used a Lagrange liberation method to solve it (Deskin et al., 2002). In the problems of designing dynamic network, the location and capacity of facilities can vary in different periods. This shows the importance of using

a dynamic network design in designing BSCN, because, using dynamic network design to provide dynamic demand at various rates in each period is very important. The first study on locating dynamic facilities was done by Ballou (1968).

Although, dynamic facility location has many advantages compared to the static facility location where the facilities' location is constant during the planning period, but, few studies have been conducted concerning designing supply chain network using a dynamic network design. Hinojosa et al. (2000) studied the location of dynamic facilities for minimizing total network costs. They proposed a mixed integer programming (MIP) model for the problem where the capacity of the suppliers had been considered as well. Melo et al. (2006) have provided a mathematical framework for the dynamic location problem that considers many assumptions of dynamic network design. They considered the inventory decisions besides the capacity constraints for facilities in the dynamic design of the network. In more recent studies, Correia et al. (2013) provided a mathematical model for designing a supply chain network in two levels and multi-product to maximize the profitability of the whole supply chain network by identifying the optimum location of facilities. Oar and Piraskav (1979) proposed a mathematical model taking into account the location and allocation for designing supply chain network. They assumed that demand for the blood needed by hospitals would be possible by assigning them to the nearest blood banks.

In more recent studies, a mathematical model has been examined considering location to allocation in multi-cycle mode for designing a supply chain network (Dohamel et al., 2016). Yadavalli and Balcou (2016) presented an inventory model for perishable commodities such as blood and identified the optimal order level for each product. Hosseinifard and Abbasi studied the effect of sustainability and centralization on the blood supply chain. In a case study, they showed that centralization is one of the best factors in designing a supply chain network. They found that reducing the number of hospitals that keep blood supply could have a great effect on preventing shortages in emergencies. Osorio et al. (2018) presented a simulation-optimization model for planning production in the supply chain of blood. They showed that the mathematical model provided by them could significantly stop deficiency. Dillon et al. (2017) presented a random two-stage mathematical model to design a BSCN and inventory management. In a case study, they showed that the proposed mathematical model can greatly affect the cost minimization and maximization of service levels. Cheraghi et al. (2016) provided a fuzzy-random MPI model for designing a BSCN. Their innovation in the mathematical model presented was that they considered the main parameters of the mathematical model as uncertain.

After a strong earthquake in Turkey in 1999, Şahin et al. (2007) presented several location-allocation models for local blood bank location. They implemented the proposed models in various case studies and showed their effectiveness. Sha and Huang (2012) developed a mathematical multi-period locating-allocation model for designing a BSCN in emergencies. To solve the proposed mathematical model, they used Lagrange liberation method. Nagurney et al. (2012) presented a network optimization model for designing a BSCN. They considered different levels in BSCN, such as blood collection centers, storage facilities and distribution hubs. Jabbarzadeh et al. (2014) presented a robust optimization math model for designing a BSCN in an earthquake. In a case study in Tehran, they showed the effectiveness and efficiency of their mathematical model where the goal of designing a BSCN with the cost of 3 levels of blood donors, blood collection centers, and blood centers was to minimize the total cost of the supply chain. In order to expand

the proposed mathematical model, they presented a two-way randomized mathematical model for designing supply network. Besides the cost function, they considered the minimization function of the entire transportation time as well. To solve the proposed mathematical model, they used Epsilon constraint and Lagrange liberation methods (Jabbarzadeh et al., 2014) (Fahimnia et al., 2015). Arvan et al. (2015) presented a mathematical model for designing a BSCN that included multiple levels such as donors, collection centers, laboratories, and blood centers. The purpose in the mathematical model presented by them was to determine the location of blood centers and to allocate other facilities to this location. This was done so that the costs of the entire supply chain network besides the delivery time are minimized and the main challenges in optimizing and designing the supply chain network and the management of the parameters of the mathematical model

and the real world conditions are presented as in some cases these parameters are unpredictable. Considering the uncertainty in the main parameters of the mathematical model, a mathematical optimization model was presented.

In recent studies and papers, Kohneh et al. (2016) presented a two-way model for designing a BSCN. The goal of the mathematical model provided by them was to minimize the cost of the supply chain and to maximize the coverage of donors. They showed the efficiency of the proposed mathematical model in a case study. In one of the most recent papers, Zahiri and Pishvaee (2017) presented a two-objective mathematical model to minimize the costs of the entire supply chain and minimize unmet demand. Table 1 is provided to compare the mathematical models presented in previous papers and the mathematical model presented in this paper.

Table 1: Comparison of the innovation of this study and the papers in the literature review

Study	Objective function					The number of levels	Multi-period	Case study	Sensitivity analysis
	Cost	Distance	Risk	Safety	Reliability				
Şahin (2007)	No	yes	No	No	No	3	No	yes	No
Nagurney et al. (2012)	yes	No	yes	No	No	7	No	No	No
Sha and Huang (2012)	yes	No	No	No	No	2	yes	No	No
Jabbarzadeh (2014)	yes	No	No	No	No	3	yes	yes	No
Arvan (2015)	yes	No	No	No	yes	4	No	No	No
Fahimnia (2015)	yes	No	No	No	yes	4	yes	No	No
Nahofti Kohneh et al. (2016)	yes	No	No	No	No	5	yes	yes	No
Zahiri and Pishvaee (2017)	yes	No	No	No	No	5	yes	yes	No
Our study	yes	No	No	No	yes	4	yes	yes	yes

As the mathematical model presented in this study is a two-objective mathematical model, using multi-purpose optimization solutions is significant in obtaining Pareto's

answers. This is because Pareto's answers (including a set of Pareto's answers) allow decision makers to select one of the different Pareto's answers (which, regarding priorities

is like the priorities and the significance of the higher-objective functions). As is seen in Table (1), various papers with different mathematical models have been presented for designing supply chain networks in an earthquake. Most of cited papers in table 1, have presented an optimization model for designing a BSCN based on model presented in Jabbarzadeh et al. (2014). In this regard, Fahimnia et al. (2015) considered the time of blood supply in critical situations in their model. They added another function in the BSCN for minimizing transportation time to the mathematical model. Nahofti Kohneh et al. (2016) showed that in the real world, two other levels, laboratories and hospitals, should also be considered in BSCN, because, laboratories are responsible for blood testing, and there is a demand for blood in hospitals, and, hospitals should be considered in designing BSCN. In their mathematical model, they added labs and hospitals to the mathematical model and tested the efficiency of their mathematical model in a case study in Tehran. Zahiri and Pishvaee (2017) considered a realistic assumption in their study. In their mathematical model, they assumed that different blood groups could donate blood to each other.

This research has tried to present a comprehensive mathematical model for designing BSCN in the earthquake, based on the mathematical model presented by Jabarzadeh et al. (2014) in order to cover two research gaps; 1- Previous researches have been just considered the cost objective function in their model, whereas, in crisis situations, the transfer of blood collected between facilities could be considered as well. While, routing and determining the optimal transportation routes are very important in the real world. 2- Reliability is one of the important factors in designing supply chain networks in the aftermath of a crisis that, has not been considered in any of the previous papers. According to previous studies, considering the level of labs in blood supply chain is very important (Nahofti Kohneh et al., 2016). In this study, a dual

mathematical model will be presented for designing BSCN. The first goal is to minimize the costs of the entire supply chain and the second is to maximize the reliability of the selected routes for blood transfusion as after a destructive earthquake, the selection and transfer of blood collected from high reliability routes is very important. it has been tried to use different resolution methods to provide decision makers with various Pareto's answers to be able to select the best answer according to their priorities and the importance of each of the objective functions.

3. Proposed mathematical model

As mentioned earlier, the mathematical model presented by Jabbarzadeh et al. (2014) considered only the cost objective function in their mathematical model. Considering that they have provided their mathematical model for crises, considering spending in such circumstances is far from the real world (Fahimnia et al. 2015). This is because goals such as minimizing time and maximizing reliability can be regarded as another important goals for decision makers. On the other hand, in the mathematical model provided by them, there is no level associated with the labs, whereas considering the level of labs can lead to a more comprehensive model. Additionally, in their proposed model, there has been no focus on the distribution of blood collected by blood collection centers to laboratories and blood centers. However, in real world, decisions such as transportation and routing are important decisions that decision-makers face. According to the above, this study has tried to consider the others factors and provide a comprehensive mathematical model for designing BSCN. In doing so, a second objective function is added to the example, whose purpose is to maximize the reliability of transport routes. As the proposed model is a mathematical model for designing a BSCN after an earthquake, increasing reliability can be critical. On the

other hand, a new level called lab is considered in the mathematical model, so that the blood collected by blood collection centers is first sent to labs and then sent to blood centers. Among the other innovations in the mathematical model presented in this study, one can mention the decisions related to the transportation of the blood collected to labs and its distribution to blood centers. In the mathematical model presented in this study, ambulances to laboratories and from laboratories to blood centers distribute blood collected in a blood collection center. Figure 1 shows a graphical profile of the network considered in the study.
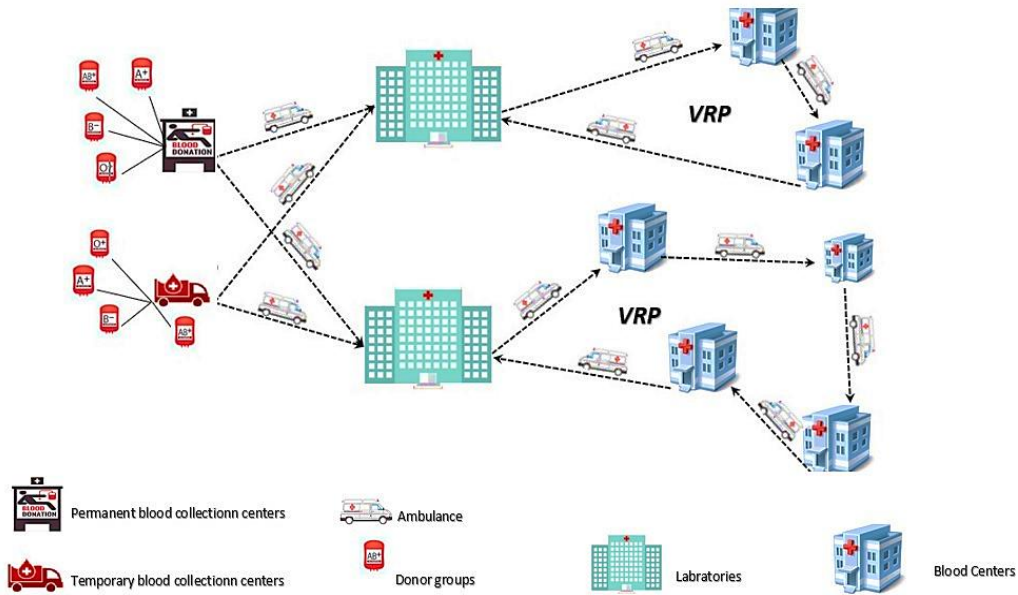
Figure 1. Graphical presentation of the proposed BSCN

According to the above figure, it is clear that the mathematical model presented in this study takes more realistic assumptions compared to the basic mathematical model. In the BSCN in question, blood donors are assigned to blood collection centers. Blood collection centers are located at predetermined potential points and it is known at each potential location that a type of blood collection center (fixed or mobile) is constructed. After assigning blood donors to the blood collection centers, the blood collected is transferred to labs by the ambulances with specified capacity. Blood sent to laboratories is then sent to blood centers by ambulances of a specified capacity. The mathematical model presented in this study tries to answer the following questions: "Where is the location of fixed and mobile blood collection centers? How many blood donation centers are needed? How many ambulances are needed to send blood from blood collection centers to laboratories? How is the blood send from labs to blood centers and ambulance routes? What is the level of blood counts in each period in each blood center? Sets, parameters and decision variables are used to provide a proposed mathematical model in this study (Table 2, 3).

Table 2. The parameters of the proposed model (*Parameter / index*)

Blood donors	i
Potential centers for establishing blood collection centers	j
Blood centers	k
Different periods	t
Labs	u
The fixed cost of building a fixed blood collection center in place j	f_j
The cost of transferring temporary blood collection centers (such as blood collection buses) from city l to j in period t	v_{jlt}
The operational cost of blood collection from blood donors in the J blood collection center in Period t	o_{ijt}
The cost of maintaining each blood unit at the blood center k	h_k
The demand of the blood center k in period t	d_{kt}
Distance of donors i from blood collection center j	r_{ij}
The coverage scope of blood collection centers	R
Capacity of blood collection centers j in period t (Temporary centers)	b_{jt}
Capacity of blood collection centers j in period t (constant centers)	c_{jt}
Maximum blood supply by donors i	m_i
The cost of purchasing and sending each ambulance from the blood collection center j to the lab u	$c1_{ju}$
The cost of sending any ambulance from lab u to the blood center k	$c2_{uk}$
The cost of sending any ambulance from the blood center k to the blood center k'	$c3_{kk'}$
The reliability of paths between blood centers as well as blood centers and laboratories	$reliability_{ee'}$
Capacity of each ambulance	cap
Maximum capacity of blood centers to maintain blood	$maxcap_k$
Maximum capacity of laboratories to test blood in each period	Ca_{ut}
A large number	M

Table 3. The decision variables of the proposed model

Binary variable: 1 if the junction center is founded j, otherwise zero	X'_j
Binary variable: 1 if donors i are assigned to the collection center j in t period t; otherwise, zero	y_{ijt}
Binary variable: 1 if the intermediate blood center of the city l in the period t-1 goes to the city j at the period t, otherwise zero	Z_{jlt}
The blood donated by the donor i in the blood collection center j in period t	Q_{ijt}
The blood in the blood center k at the time t	I_{kt}
Binary variable: I if the blood center k is assigned to the lab u at t period t; otherwise zero	f_{ukt}
Binary variable: I if the ambulance of center e' visited after center e in period t as the path to the lab u; otherwise, zero	$x_{ee'ut}$
The blood transmitted from the blood collection center j to the lab u at period t	n_{jut}
The number of vehicles needed to send blood collected from the blood collection center j to the lab u in period t	vv_{jut}
The blood transmitted from laboratory u to the blood center k in the period t	m_{ukt}
Some variables to observe the ambulance capacity constraints and to prevent sub-treatment; this variable shows the blood in the ambulance after referral to the blood center K	w_{kt}
The reliability of the route specified between laboratories and blood centers as well as blood centers with each other	$reli_{ee'ut}$

3.1. Objective functions

In this study, the cost and reliability objective functions are considered. First, we will consider calculating the cost objective function, formulated as follows:

1) $Min\ Z_1$

$$= \sum_j f_j X_j + \sum_j \sum_u \sum_t c1_{ju} vv_{jut}$$
$$+ \sum_k \sum_u \sum_t x_{0e'ut} c2_{uk} + x_{e0ut} c2_{uk}$$
$$+ \sum_j \sum_u \sum_t c3_{kk'} x_{kk'ut}$$
$$+ \sum_i \sum_j \sum_t o_{ijt} \cdot Q_{ijt}$$
$$+ + \sum_j \sum_l \sum_t v_{jlt} \cdot Z_{jlt} + \sum_t \sum_k h_k I_{kt}$$

(1)

The above objective function (Number 1) is as the sum of the total cost of the blood supply network. Thus, the cost of building blood collection centers, the cost of transporting blood from blood collection centers to the labs, transportation costs for the transfer of blood from laboratories to blood centers, the operational costs blood collection from blood donors, transportation costs of mobile blood collection centers such as blood collection buses, maintenance costs associated with blood supply to blood centers and deficits in the objective function are considered.

The second objective function considered in this study is an objective function for maximizing the reliability of blood transfusion routes by ambulances from labs to blood centers as shown below:

2) $Max\ Z_2$ (2)

$$= \prod_e \prod_{e'} \prod_u \prod_t reli_{ee'ut}$$

Where we have:

$$reli_{ee'ut}$$ (3)
$$= reliability_{ee'} x_{ee'ut}$$

In other words, $reli_{ee'ut}$ is the reliability of the routes used by the model to transfer blood by ambulances from laboratories to blood centers.

Constraints**:**

We will present all the constraints used in this study.

$$X_j + \sum_l Z_{jlt} \leq 1$$ (4)

$$\sum_l Z_{jlt} \leq \sum_l Z_{jlt-1}$$ (5)

$$y_{ijt} \leq X_j + \sum_l Z_{jlt}$$ (6)

$$\sum_j r_{ij} y_{ijt} \leq R$$ (7)

$$Q_{ijt} \leq M \cdot y_{ijt}$$ (8)

$$\sum_j \sum_t Q_{ijt} \leq m_i$$ (9)

$$\sum_i Q_{ijt} \leq c_{jt} X_j + b_{jt} \sum_l Z_{jlt}$$ (10)

$$vv_{jut} \geq \frac{n_{jut}}{cap}$$ (11)

$$\sum_u n_{jut} = \sum_i Q_{ijt}$$ (12)

$$\sum_j n_{jut} = \sum_k m_{kt} \cdot f_{kut}$$ (13)

$$\sum_u f_{kut} = 1$$ (14)

$$\sum_k x_{0kjt} = \sum_k x_{k0ut}$$ (15)

$$\sum_e x_{ekut} = f_{kut}$$ (16)

$$\sum_e x_{keut} = f_{kut}$$ (17)

$$w_{kt} - w_{k't} + cap \sum_u x_{kk'ut} \leq cap - m_{kt} \tag{18}$$

$$m_{kt} \leq w_{kt} \leq cap \tag{19}$$

$$I_{kt-1} + m_{kt} - I_{kt} = d_{kt} \tag{20}$$

$$I_{kt} \leq \text{maxcap}_k \tag{21}$$

$$\sum_j^n n_{jut} \leq Ca_{ut} \tag{22}$$

$$reli_{ee'ut} \geq (1 - x_{ee'ut}) \tag{23}$$

$$reli_{ee'ut} \leq reliability_{ee'} x_{ee'ut} + (1 - x_{ee'ut}) \tag{24}$$

$$reli_{ee'ut} \geq reliability_{ee'} x_{ee'ut} \tag{25}$$

Constraint (25) is a constraint related to the construction of fixed and mobile blood transfusion centers, ensuring that at any potential location j, only one of two types of fixed and mobile blood collection center should be established.

$$X_j + \sum_l Z_{jlt} \leq 1 \tag{26}$$

Equation (27) constraints show and determine the movement of moving blood centers between potential locations in each period, as formulated below.

$$\sum_l Z_{jlt} \leq \sum_l Z_{jlt-1} \tag{27}$$

Constraint (28) is related to how blood donors donate to blood collection centers. This constraint shows that blood donors can only be allocated to a blood collection center where at least one fixed or mobile blood collection center is located.

$$y_{ijt} \leq X_j + \sum_l Z_{jlt} \tag{28}$$

Constraint (29) shows the scope of coverage of blood collection centers. It ensures that the blood donator is assigned to a blood collection center and the distance from that to the center should be less than the scope of coverage of the blood collection center.

$$r_{ij} y_{ijt} \leq R \tag{29}$$

Constraint (30) shows that blood donors can donate blood at a blood collection center assigned to a blood collection center.

$$Q_{ijt} \leq M \cdot y_{ijt} \tag{30}$$

Constraint (31) shows that blood donations donated by blood donors in all periods cannot be more than the maximum blood donated by them.

$$\sum_j \sum_t Q_{ijt} \leq m_i \tag{31}$$

Constraint (32) shows the capacity constraints of blood collection centers and ensures that the blood volume received by the fixed and mobile blood centers in each period of the blood donors cannot increase the capacity of blood collection centers.

$$\sum_i Q_{ijt} \leq c_{jt} X_j + b_{jt} \sum_l Z_{jlt} \tag{32}$$

Constraint (33) shows how many ambulances with specific capacity are needed to transfer blood from each blood collection center to each laboratory.

$$vv_{jut} \geq \frac{n_{jut}}{cap} \tag{33}$$

Constraint (34) shows the balance in the blood collection centers. As it ensures that all blood collected in blood collection centers is transferred to labs by ambulances of a specified capacity.

$$\sum_u n_{jut} = \sum_i Q_{ijt} \tag{34}$$

Constraint (35) shows the balance in experiments, as it ensures all blood transmitted from the blood collection centers to the labs is transmitted to the blood centers by ambulances of known capacity.

$$\sum_j n_{jut} = \sum_k m_{kt} \cdot f_{kut} \qquad (35)$$

Constraint (36) shows that each blood center is assigned only to one lab.

$$\sum_u f_{kut} = 1 \qquad (36)$$

Constraint (37) shows that the number of ambulances from a lab for the transfer of blood-to-blood centers should be equal to the number of ambulances returned to the laboratory.

$$\sum_k x_{0kjt} = \sum_k x_{k0ut} \qquad (37)$$

Constraints (38) and (39) ensure that each blood center is met exactly following the departure of the ambulance from the lab and is satisfied with the demand, either on the path to the ambulance and after having met a blood center and meeting its blood demand by ambulance. These constraints also help create paths between bloods centers exactly assigned to a specific lab.

$$\sum_e x_{ekut} = f_{kut} \qquad (38)$$

$$\sum_e x_{keut} = f_{kut} \qquad (39)$$

Constraints (40) and (41) are considered for the purpose of eliminating sub-tour and imposing ambulance capacity constraints.

$$w_{kt} - w_{k't} + cap \sum_u x_{kk'ut} \qquad (40)$$
$$\leq cap - m_{kt}$$

$$m_{kt} \leq w_{kt} \leq cap \qquad (41)$$

Constraint (42) ensures that the level of inventory at the end of the previous period plus the amount of blood received during this period, minus the level of inventory at the end of this period, plus the amount of deficits should be equal to the demand for the blood center in this period.

$$I_{kt-1} + m_{kt} - I_{kt} \qquad (42)$$
$$= d_{kt}$$

Constraint (43) shows the capacity constraints of blood centers.

$$I_{kt} \leq maxcap_k \qquad (43)$$

Constraint (44) shows the capacity of the labs.

$$\sum_j^n n_{jut} \leq Ca_{ut} \qquad (44)$$

The constraints (45) and (46) and (47) are considered to calculate the reliability of the specified routes.

$$reli_{ee'ut} \geq (1 - x_{ee'ut}) \qquad (45)$$

$$reli_{ee'ut} \leq reliability_{ee'} x_{ee'ut} \qquad (46)$$
$$+ (1 - x_{ee'ut})$$

$$reli_{ee'ut} \qquad (47)$$
$$\geq reliability_{ee'} x_{ee'ut}$$

Considering the three recent constraints, as the reliability of the route is equal to the multiplication of the selected routes and our goal from applying these constraints is to prevent the multiplication of these paths from being zero (i.e. all the selectable path are reliable) provide a new variable (Reliability = X.R), which once gives zero to x and put in the three constraints that the answer to the three constraints is Reliability = 1 (ensuring the reliability of the path) and once give one to x where the answer of the sum of the three constraints is Rx. As x is the path selection and must be one, the reliability of the path is guaranteed in this

case as well. Finally, the mathematical model presented in this study was presented as Equation (48):

$$Min\ Z_1 = \sum_j f_j X_j + \sum_j \sum_u \sum_t c1_{ju} vv_{jut}$$
$$+ \sum_k \sum_u \sum_t x_{0e'ut} c2_{uk}$$
$$+ x_{e0ut} c2_{uk}$$
$$+ \sum_j \sum_u \sum_t c3_{kk'} x_{kk'ut}$$
$$+ \sum_i \sum_j \sum_t o_{ijt}. Q_{ijt}$$
$$+ + \sum_j \sum_l \sum_t v_{jlt}. Z_{jlt}$$
$$+ \sum_t \sum_k h_k I_{kt}$$

$$Max\ Z_2 = \prod_e \prod_{e'} \prod_u \prod_t reli_{ee'ut}$$

Subject to:

$$X_j + \sum_l Z_{jlt} \le 1$$

$$\sum_l Z_{jlt} \le \sum_l Z_{jlt-1}$$

$$y_{ijt} \le X_j + \sum_l Z_{jlt}$$

$$r_{ij} y_{ijt} \le R$$

$$Q_{ijt} \le M. y_{ijt}$$

$$\sum_j \sum_t Q_{ijt} \le m_i$$

$$\sum_i Q_{ijt} \le c_{jt} X_j + b_{jt} \sum_l Z_{jlt}$$

$$vv_{jut} \ge \frac{n_{jut}}{cap}$$

$$\sum_u n_{jut} = \sum_i Q_{ijt}$$

$$\sum_j n_{jut} = \sum_k m_{kt}. f_{kut}$$

$$\sum_u f_{kut} = 1$$

$$\sum_k x_{0kjt} = \sum_k x_{k0ut}$$

$$\sum_e x_{ekut} = f_{kut}$$

$$\sum_e x_{keut} = f_{kut}$$

$$w_{kt} - w_{k't} + cap \sum_u x_{kk'ut} \le cap - m_{kt}$$

$$m_{kt} \le w_{kt} \le cap$$

$$I_{kt-1} + m_{kt} - I_{kt} = d_{kt}$$

$$I_{kt} \le maxcap_k$$

$$\sum_j^n n_{jut} \le Ca_{ut}$$

$$reli_{ee'ut} = reliability_{ee'} x_{ee'ut}$$

$$reli_{ee'ut} \ge (1 - x_{ee'ut})$$

$$reli_{ee'ut} \le reliability_{ee'} x_{ee'ut} + (1 - x_{ee'ut})$$

$$reli_{ee'ut} \ge reliability_{ee'} x_{ee'ut}$$

$$X'_j \in \{0,1\}$$

$$y_{ijt} \in \{0,1\}$$

$$Z_{jlt} \in \{0,1\}$$

$Q_{ijt} \geq 0$

$I_{kt} \geq 0$

$\sigma_{kt} \geq 0$

$f_{ukt} \in \{0,1\}$

$x_{ee'ut} \in \{0,1\}$

$n_{jut} \geq 0$

$vv_{jut} \geq 0$, integer

$m_{kt} \geq 0$

$w_{kt} \geq 0$

$reli_{ee'ut} \geq 0$

4. Findings

4.1. Criteria of Comparison

In this research, three comparison criteria for evaluating the efficiency of the five multi-criteria decision making methods proposed are considered. These criteria including the value of the first objective function, the value of the second objective function, and Cpu-Time are considered. The firstly and thirdly mentioned criteria are of the minimum type. This means that the lower the corresponding values of these criteria, the better results obtain. Since the second criterion is of maximization type, the higher this index, the better concludes.

In order to solve the mathematically presented model, multi-criteria decision-making methods have been used. The five methods mentioned have been coded by the Gomez software and the results of their calculations are presented in table 4. The mathematical model presented in table 4 is applied to the case study and is solved by solving methods and the amount of each of the objective functions as well as the computational time of each solution method has been reported.

Table 4. The computational results

Methods	The value of the first objective function	The value of the second objective function	Time to solve
Max-Min	2665.927	0.217	10783
LP-metric	2663.860	0.217	7515
Achieving the ideal	2660.494	0.198	8645
Utility function	2658.884	0.168	7381
Ideal planning	2656.087	0.125	8048

The figures 2 and 3 show a schematic representation of the Pareto solutions obtained from the above solution methods as well as the solution time of each of them.

To provide further details of the solution obtained by the above methods and validation of the mathematically presented model, the solution obtained from the utility function method is shown in detail. The figure 4 shows the network created in the first period (first 24 hours). According to Jabarzadeh et al. (2014), each period is considered to be 24 hours, since the highest level of demand occurs during that period.

The second laboratory is not used and the blood centers demands are met from the first laboratory. Also, the figure 5 shows the supply chain network created in the second period.
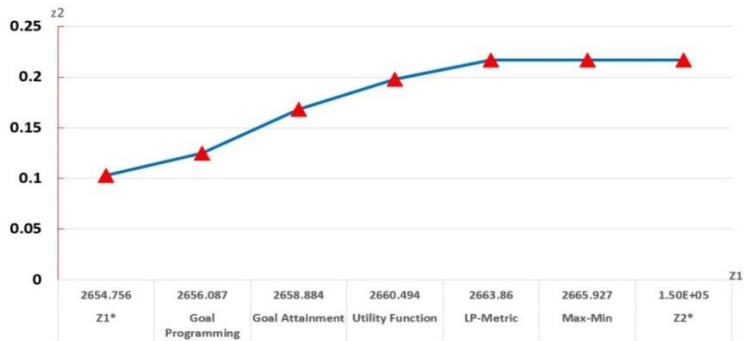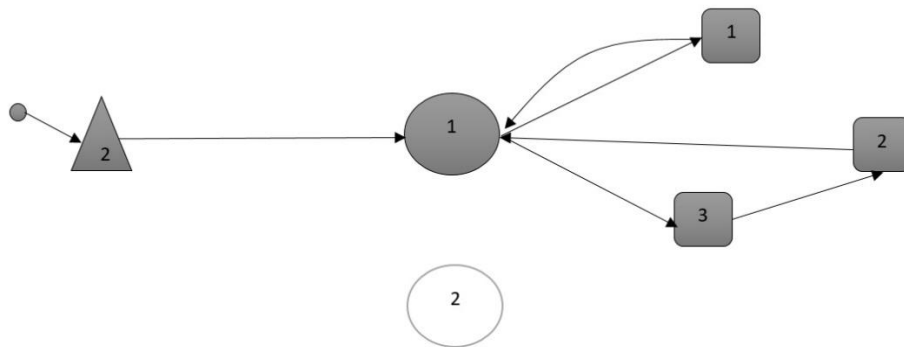
Figure 2. The obtained Pareto solutions using five solution methods as well as the optimized solution obtained from optimization of the objective functions
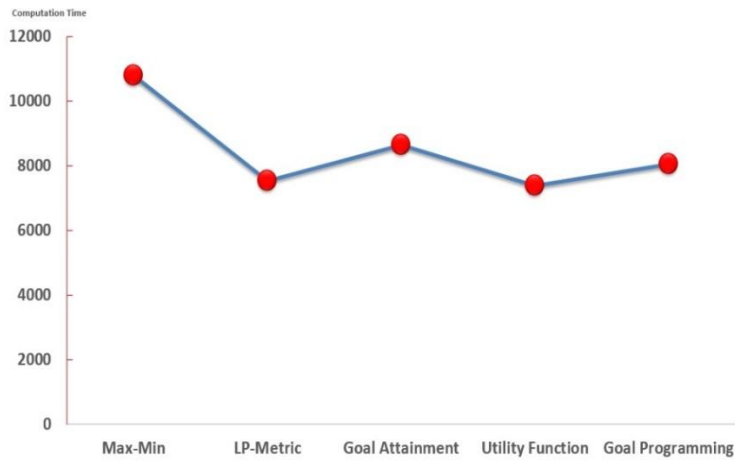
Figure 3. The computational time of each of the five solution methods
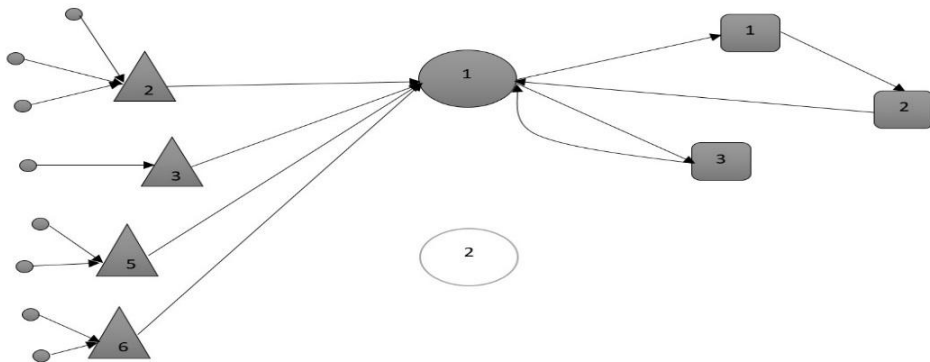
Figure 4.The figure of created network by the first period

Figure 5. The figure of created network by the second period

The tables 5 and 6 are presented to provide detailed results regarding the amount of blood donation per unit and the level of blood transportation among facilities. Table 5 shows the donated blood amounts in each blood collection center. Also, the blood transported from each blood collection center to each laboratory per period is shown in Table 6.

Table 5. The donated blood amounts in each blood collection center per period

Donors	Blood Collection Centers	period	Donation amount
1	2	1	166
2	2	1	278
5	2	1	6
4	3	1	200
2	5	1	119
22	5	1	81
2	6	1	2
3	6	1	198
5	2	2	305

Table 6. The amount of blood transported from each blood collection unit to each laboratory per period

Blood Collection Centers	Laboratory	period	transmission amount
2	1	1	450
3	1	1	200
5	1	1	200
6	1	1	200
2	1	2	305

One observes that the flows in the above network are properly established and the mathematical model of the problem is correctly formulated. In the discussion of Pareto or Cara solutions, the solutions making the good balance among the optimization of all target functions are better.

On the other hand, a large number of various solutions let the blood transfusion organization to have the capability to choose preferred solution among the different solutions of different costs and reliability. According to the results, it is observed that the utility function methods, the LP-metric, and the goal attainment method have obtained better results because the answers provided by them provide a good balance between the amounts of the two objective functions. However, if reliability is preferable to the blood organization, the organization can make use of the Max-Min method because it offers a high reliability solution. On the other hand, if minimizing the total cost of the supply chain is of more important to the blood organization, it can make use of a method like of goal programming, since this method offers a solution of lower than cost to that of other methods.

Occasionally, the solution time index is also important for the decision maker. On the other hand, sometimes, it is difficult picking up a Pareto solution from a set of Pareto solutions. Therefore, in this research, multi-

criteria decision-making methods have been used to select the best solution. These methods consider the simultaneously importance of each of the three comparison indices for determining the best solution method.

4.2. Multi-criteria decision making methods

Considering the five aforementioned methods do not similarly act upon the problem presented in this research, we make use of multi-criteria decision making methods to determine the best solution method in this section. Firstly, the decision matrix with respect to comparison indices is created in table 7.

Table 7. Decision Matrix

Methods	The value of the first objective function	The value of the second objective function	Time to solve
Max-Min	2665.927	0.217	10783
LP-metric	2663.860	0.217	7515
Achieving the ideal	2660.494	0.198	8645
Utility function	2658.884	0.168	7381
Ideal planning	2656.087	0.125	8048

4.3. Entropy method

The results of the entropy method and the weight determined by this method for various indices are shown in the following table. Table 8 shows the determined weight for each index by entropy method.

To determine the best solution method considering the desirable indices, Topsis method (Tadic et al., 2014) has been used. After calculating the positive and negative ideals and determining the similarity rate for each of the solution methods, the following table is obtained as the output of the Topsis method. The table reports the similarity rates for each of solution methods and ranks them out regarding their similarity rates.

Table 8. Calculated weight by Entropy method for each index

Weight	The value of the first objective function	The value of the second objective function	Time to solve
W_j	0.0926	0.6467	0.2607

Table 9. The results of the Topsis method

|	s_i^+	rate
Max-Min	0.6943	3
LP-metric	0.9843	1
Achieving the ideal	0.7613	2
Utility function	0.5466	4
Ideal planning	0.2607	5

According to the obtained results of the Topsis method (table 9), the best method for solving the problem regarding simultaneously consideration of the three indices of the first-objective function value, the second-objective function value and Cpu-Time, is LP-method, since this method is of the highest similarity rate among the other desirable solution methods.

4.4. Sensitivity analysis

In this section, sensitivity analysis is used to determine effects on the objective function values via varying the model parameters ones. For this purpose, the values of the parameters are changed in percentages and their effect on the objective function is investigated. Table 10 and Figure 6 show the results of sensitivity analysis.

Table 10. Results of the sensitivity analysis

Parameter	Changes (%)	The value of the target function
R	-50	1.51E+05
	-25	1.51E+05
	0	1.50E+05
	+25	1.49E+05
	+50	1.49E+05
d_{kt}	-50	1.49E+05
	-25	1.49E+05
	0	1.50E+05
	+25	1.51E+05
	+50	1.52E+05
c_{jt}	-50	1.53E+05
	-25	1.51E+05
	0	1.50E+05
	+25	1.50E+05
	+50	1.50E+05
$maxcap_k$	-50	1.53E+05
	-25	1.52E+05
	0	1.50E+05
	+25	1.50E+05
	+50	1.50E+05
Cap	-50	1.51E+05
	-25	1.51E+05
	0	1.50E+05
	+25	1.50E+05
	+50	1.50E+05
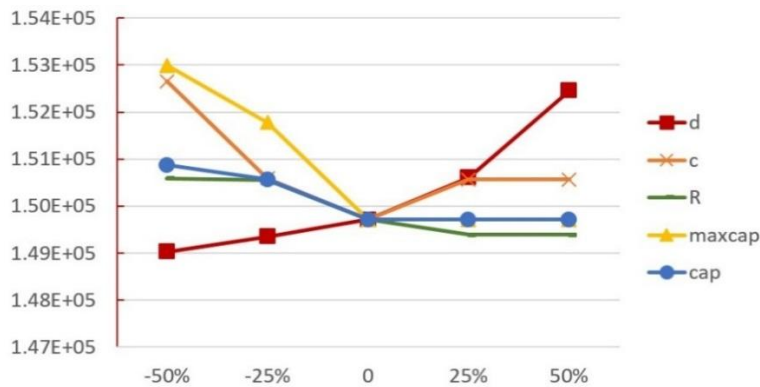
Figure 6. Results of the sensitivity analysis

In the table 10, the value of each of the main parameters of the mathematical model presented of the rates -50, -25,0,+25,+50 percentage are changed and the effect of reducing and increasing them on the optimal value of the objective function are investigated. To take a closer look at the results, the figure 6 is presented and the results are carefully reviewed.

According to the above results, a 50% reduction in demand and an increase of 25% and 50% in the coverage radius of blood collection centers yields the most reduction in costs of the supply chain. Hence, the more increasing the coverage radius of the blood

collection centers, the more reducing the cost of the entire supply chain. On the other hand, a 50% reduction in the capacities of the collection blood and blood centers creates the most increasing in the related costs and the cost of blood supply chain.

5. Discussion

The results obtained in this research showed that, the mathematical model presented creates a low-cost blood supply and high reliability chain after taking place an earthquake to supply hospitals demanding the blood. By analysing the sensitivity, we found out, the more increasing the number of potentially temporary facilities, the more decreasing the amount of the first objective function yields. This decreasing continues until the supply chain encounters a shortage, thus when not encountering with, the first objective function increases with a very small slope. Analysing the sensitivity on the number of permanent facilities, suggests us, the more increasing the number of permanent facilities, the more increasing the first objective function. Also, analysing the sensitivity to the facility capacity parameter determined that totally, the first objective function is reduced, and this reduction continues until we encounter to a deficient. Since the deficit reaches to zero, the first-objective function gradually increases. Another key parameter in which sensitivity analysis was performed is the demand parameter. If demand increases, the cost of the supply chain increases as well. The performed sensitivity analysis shows us off the effect of the number of permanent and temporary facilities, facility capacity, and demanding values on the optimal value of the objective functions and the choice of facilities. Consequently, the model implementation indicates it is consistent with reality. Accordingly, the modelling accomplished by this research creates the possibility for preventing the formation, starting up and increasing the overcapacity of permanent and temporary facilities.

In the mathematical model presented in this research using the implemented real data on Tehran city and different solution methods. The results and solutions obtained from different methods have been investigated. By taking into account different comparison indices, the efficiency of solution methods are investigated and the best solution was determined using entropy and Topsis methods. According to the obtained results, LP- metric method of the similarly highest rate was regarded as the best solution method. As well, the validity of the proposed model was confirmed by analysing the sensitivity for affecting parameters in model, using the results of this analysis and increasing 25% and 50% the radius of coverage of blood collection centers yields the most cost reduction in the supply chain. Therefore, in one hand, increasing the coverage radius of blood collection centers could considerably reduce the total cost of the system. On the other hand, reducing 50% in capacities of blood collection centers and blood centers has the greatest impact on augmentation of costs and the costs of the blood supply chain.

6. Conclusion

In this research, for the first time, we discussed how blood transportations (which routes and what number of ambulances should we choose, and, to which centers should we transmit blood concluding the least paved routes and time for fulfilling the most blood demands) are carried out via ambulance in the transmission paths of high reliability in the supply chain network and how the number of ambulances required are determined.

Also, for the first time, a new level of labs was introduced to the blood supply chain network to provide and design a more realistic model of the supply chain network. Finally, this research implies that the design of the supply chain network and its models are very widespread and the different

solution methods may be considered. Considering new hypotheses, we can develop the previous models and bring them closer to actual and applicable circumstances.

The main limitation in this study was to estimate the reliability of the paths between facilities in the BSCN. Regarding the high complexity of calculating the reliability of blood transfusion pathways, a uniform distribution was used to generate problem data. Determination of exact reliability in an earthquake could be a relevant subject in the future studies. Also, because of considering a definitive blood demand in this research, most of the data are based on the studies of other researches which their model considered in uncertainty condition.

One of the suggestions for future studies in order to expand the mathematical model in the BSCN could be taking into consideration uncertainty in the parameters of the proposed mathematical model, or, studying of other objective functions such as duration of transportation and service. Taking into account other levels of supply chain like hospitals and separation of all blood products in laboratories and transferring them to blood centers, could be among of the other perspectives of this research for future studies. During this research, we tried to improve and optimize the BSCN; however, due to the wide-ranging nature of earthquake crisis, many problems remain to study in the future to develop more comprehensive model in this regard.

References:

Aghyani, M., Jabbarzadeh, A., Sajjadi, S. J. (2015). Presentation of a robust optimization model for network design of the blood supply chain in crisis circumstances considering the reliability. *Journal of Enginerring and Quality Management*, *5*(2), 85-96.

Arvan, M., Tavakkoli-Moghaddam, R., & Abdollahi, M. (2015). Designing a bi-objective and multi-product supply chain network for the supply of blood. *Uncertain Supply Chain Management*, *3*(1), 57-68.

Cheraghi, S., Hosseini Motlagh, S. M., & Ghatreh Samani, M. R. (2016). A Robust optimization model for blood supply chain network design. *International Jourrnal of Industrial Engineering and Production Research*, *27*(4), 425-444. doi: 10.22068/ijiepr.27.4.425

Correia, I., Melo, T., & Saldanha-da-Gama, F. (2013). Comparing classical performance measures for a multi-period, two-echelon supply chain network design problem with sizing decisions. *Computers and Industrial Engineering*, *64*, 366-380.

Dillon, M., Oliveira, F., & Abbasi, B. (2017). A two-stage stochastic programming model for inventory management in the blood supply chain. *International Journal of Production Economics*, *187*, 27-41.

Fahimnia, B., Jabbarzadeh, A., Ghavamifar, A., & Bell, M. (2015). Supply chain design for efficient and effective blood supply in disasters. *International Journal of Production Economics*, *183*, 700-709. https://doi.org/10.1016/j.ijpe.2015.11.007

Hinojosa, Y,. Puerto, J., & Fernández, F. R. (2000). A multi-period two-echelon multi-commodity capacitated plant location problem. *European Journal of Operational Research*, *123*, 271-291.

Hosseinifard, Z., & Abbasi, B. (2018). The inventory centralization impacts on sustainability of the blood supply chain, *Computer and Operation Research*, *89*, 206-212. https://doi.org/10.1016/j.cor.2016.08.014

Jabbarzadeh, A., Fahimnia, B., & Seuring, S. (2014). Dynamic supply chain network design for the supply of blood in disasters: A robust model with real world application. *Transportation Research Part E, Logistics and Transportation Review*, *70*(1), 225-244. doi: 10.1016/j.tre.2014.06.003

Liang, L., Wang, X., & Gao, J. (2012). An option contract pricing model of relief material supply chain, *Omega*, *40*(5), 594-600.

Melo, M. T., Nickel, S., & Saldanha da Gama, F. (2006). Dynamic multi-commodity capacitated facility location: a mathematical modeling framework for strategic supply chain planning.*Computers and Operations Research*, 33, 181-208.

Nagurney, A., Masoumi, A. H., & Yu, M. (2012). Supply chain network operations management of a blood banking system with cost and risk minimization. *Computational Management Science*, *9*(2), 205-31.

Nahofti Kohneh, J., Teymoury, E., Pishvaee, M.S. (2016). Blood products supply chain design considering disaster circumstances (Case study: earthquake disaster in Tehran). *Journal of Industrial and Systems Engineering*, *9*, 51-72.

Osorio, A. F., Brailsford S. C., Smith, H. K., & Blake J. (2018). Designing the blood supply chain: how much, how and where?, *International Journal of Transfusion Medecine*, *113*(8), 760-769. https://doi.org/10.1111/vox.12706.

Şahin, G., Süral, H., & Meral, S. (2007). Locational analysis for regionalization of Turkish Red Crescent blood services, *Computers & Operations Research*, *34*(3), 692-704.

Sha, Y., & Huang, J. (2012). The multi-period location-allocation problem of engineering emergency blood supply systems, *Systems Engineering Procedia*, *5*, 21-8.

Tadic, D., Stefanovic, M., Aleksic, A. (2014). *Journal of Intelligent & Fuzzy Systems*, *27*(4), 2091-2101.

Yadavalli, V. S. S., & Balcou, C. (2017). A supply chain management model to optimize the sorting capability of a third party logistics' distribution center, *Journal of Business Management*, *48*(1), 77-84.

Zahiri, B., & Pishvaee, M. S. (2017). Blood supply chain network design considering blood group compatibility under uncertainty. *International Journal of Production Research*, *55*(7), 2013-2033. https://doi.org/10.1080/00207543.2016.1262563.

Zendeh Del, M. A., Bozorgi Amiri, A., & Omrani, H. (2014). Presentation of a model for locating blood donation centers considering the disturbance at the place of establishment, *Industrial Enginerring Journal*, *48*, 33-43.

Negar Armaghan
DTDS-Department of Technology
Development Studies,
IROST- Iranian Research Organization for
Science and Technology
Tehran,
Iran
armaghan@irost.ir

Mohsen Yaghoobi Pazani
Faculty of Engineering, Khatam
University,
Tehran,
Iran
mohsen_yaghoobipazani@yahoo.com

N. Armaghan, M. Y. Pazani