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A bi-objective natural disaster blood supply chain network considering blood transfusion: A case study in Babol

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1 Blood supply chain
2 Blood transfusion
3 Location-allocation
4 Bi-objective

ABSTRACT

Mismanagement of the blood supply chain is one of the reasons that intensifies the crisis during natural disasters. In this paper, a multi-echelon blood supply chain consisted of donors, portable blood facilities, blood transfusion centers, hospitals, and blood receivers, is considered. The fact that in addition to hospitals that help injured people, childbearing medical centers also have significant demand for blood is also considered in the proposed model. In case of a disaster, roads or medical centers may be devastated by incidents such as earthquakes and floods. The presented model is shown to be capable of proposing alternative routes and medical centers. Since blood is highly perishable, considering the time needed for processing the received blood and minimizing the amount of wasted blood are critical. The model consists of two objective functions: the first considers the economic dimensions of the supply chain and the second focuses on minimizing the blood transfusion time from portable facilities to the hospitals. The proposed bi-objective model is solved using the lexicographic method. The results obtained from a case study in Babol show the applicability of the model and provides some managerial insights to the problem.

1- Introduction

Natural disasters are worldwide and Iran is one of the countries most affected by such occurrences. However, the most painful issue is the happenings following the natural disaster which result in life loss of people. In recent years, there have been various natural disasters such as Rudbar earthquake in 1990, Bam earthquake in 2003, Neka flood in 1999 and Kermanshah earthquake in 2017. In all of these happenings, demand for blood and their by-products was very high for the casualty people and hospitals. This is as important as food and hence it is very important to have a systematic blood distribution and transfusion mechanism for the adverse effects of the event to minimize. Such effects can be observed during Bam earthquake. Although a remarkable amount of blood was received from people, only 23% of this was sent to devastated regions, and in some cases, there was a lack of compatibility between demanded and received blood groups.

Researchers have focused on location, allocation, routing and available blood. Babaveisi and Paydar (2018) put their aim of the proposed model to the solution methodology for a closed-loop supply chain (CLSC) network including used products and new products to both collect and distributing the required blood. They also introduced a mathematical model which consisted of three objective functions, i.e. maximizing the profit, minimizing the total risk and shortages of products, respectively. They used several approaches, NSGA-II algorithm, MOSA algorithm and MOPSO algorithm as well. Alizadeh Afrouzi et al (2018) emphasized some factors, customer satisfaction and production of new products in addition to profit for a more efficient supply chain network. They proposed a tri-objective multi-echelon multi-product multi-period supply chain model, and they considered suppliers, manufacturers, distributors and customer groups. Nourifar et al (2018) represented a multi-period decentralized supply chain network and introduced a bi-level mixed integer linear programming model considering demand uncertainty and price of the final product. Then, they used a novel heuristic algorithm based on Kth-best algorithm, fuzzy approach, and chance constraint approach. Or and Pierskalla (1979) allocated each hospital to a regional blood bank to periodically provide blood demanded by the hospital and to meet emergency demands in emergency times. They represented an algorithm for decision making about the number of blood banks for operation, positioning, allocating hospitals to banks and periodic distribution operation so that all transportation costs (periodic and emergency) and system costs could be minimized. Duan and Liu (2014) emphasized the importance of blood storing to minimize deterioration of blood and represent a model for optimum management of blood with the highest predicted allowable shortage level. They also considered ABO (+) and RBC age for higher accuracy. Finally, they solved the problem using TA-TS algorithm. Zahiri and Pishvaee (2017) proposed a multi-objective mathematical model to minimize total costs and not met demands. They used robust possibilities as their input parameters were uncertain. The obtained results indicated that developed models were superior and could reduce the costs compared to the current supply chain. For crisis management, a case study and considering uncertainties would be very useful. Ramezanian and Beboudi (2017) designed a supply chain network considering uncertainties in demand and supply based on social aspects. They focused on improving the performance of tools to motivate people for blood transfusing. The considered parameters included distance of people to blood facilities, experience of people in blood facilities and advertisement budget in medical centers as social aspects. A positioning – certain allocation model- was represented using mixed integer linear programming for optimization. They also emphasized random nature of demand and cost parameters from an optimization point of view. They used Tehran as their case study.

Kohne et al (2016) represented a multi-objective model to respond to demands on blood products in crisis condition. They considered uncertain parameters (such as demand, some costs, and people) in their model as a fuzzy number. In addition, they used interactive possibilistic programming to consider uncertainties. Tehran was used as a case study for earthquake situation using the information of Blood Transfusion Organization. Brislford and Katsaliki (2016) proposed their policies about blood management system aiming to improve the methods and results, by modeling the whole supply chain for a hospital from the donor to the receiver. Blood supply chain was divided into the material flow and information flow. They used discrete event modeling for determining policies that reduced shortage and wastages, improved service level, improved safety methods and reduced costs. Zahraee et al. (2015) proposed a model for improving the efficacy of the blood supply chain using dynamic simulation and Taguchi method. They explained four primary factors for Taguchi model as input rate of representers, maximum amount of stored blood, minimum amount of stored blood and blood delivery policy and an innovative factor that was demand variable. Diabet et al. (2017) proposed a positioning model for designing a supply chain network with some distribution centers and retailers. The model determined the number and location of distribution centers, allocated retailers to distribution centers and determined the size and time of orders for each distribution center. Uncertain nature of demand and the time needed for recovery in the model was considered using the row approach. They proposed an algorithm based on angling and direct search method for solving the problem. The results showed that the saving resulted from the approach would be considerable.

Starr and Wassenhove (2014) identified that the issue of equity fairness was pervasive in humanitarian operations, and last-mile logistics was taken into consideration. Williamson and Devine (2013) emphasized that during the following years, blood availability in developed countries would need to increase again to meet the demands of ageing populations. Increasing the blood supply raises many challenges. Also, they displayed integrated procedures in blood stock management between transfusion services and hospitals would be important to minimize wastage.

Zahiri et al. (2018) presented a novel bi-objective mixed-integer model for different levels of supply chain network of blood products, considering perishability of blood products and uncertainty in donation and demand sizes. They also sought to simultaneously optimize the total expenses and freshness of transported blood products to hospitals. In their research a stochastic method and combined scenario tree in order to cope with the inherent uncertainty of input data. They displayed a novel differential evolution algorithm which benefited from the variable neighborhood search with fuzzy dominance sorting. Habibi Kouchaksaraei et al. (2018) put the aims of the proposed model to minimize expenses and scarcity of blood. Furthermore, the quantity and location of facilities and the best strategy to allocate them are determined under three different scenarios. Mansur et al. (2018) emphasized the complexity of problems and found the solutions in BSCM. This complexity was brought by several factors as follows: its inflicted risk, the uncertainty of supply and demand, blood nature as a perishable commodity, demand uniqueness and occurred cost. Nowadays, natural disasters can cause a crisis in the field of local blood banks. Ma and Wang (2019) are sought to cover maximum blood demand and its products by considering blood groups. They used the heuristic algorithm, and in the end, it was stated that appropriate blood groups could significantly increase efficiency. Nagurney el al. (2012) modeled a flexible supply chain network which specifies optimal allocations and almost satisfies uncertain demands while minimizes the cost of blood wastage disposal. Arvan et al. (2015) proposed a mixed linear integer programming model to determine location allocation components in the network. This model follows two objectives of minimizing the time of blood product being in the supply chain network and minimizing the whole costs. They applied the perishability nature of blood products, blood waste, and transferring blood between demand centers in their mathematical model. for deep reviews, consider the below references. (e.g. Delen et al. (2011), Beliën J. and Forcé H. (2012), Nagurney et al (2012), Fahimnia et.al (2017) and Piraban et.al (2019)).

In this paper, a multi-echelon blood supply chain including donors, portable blood facilities, blood transfusion centers, hospitals and blood receivers were considered. Portable blood centers are subjected to interventions and may not be available due to the fact that roads may be blocked or centers may be devastated during natural disasters. In the proposed model, the cover radius was considered to propose the donors the nearest portable blood center or blood transfusion center. The maximum blood amount that an adult could be represented in addition to the capacity of blood centers. Considering the blood groups of donors and receivers, demands of hospitals and medical centers can be responded. The issue was regarded had two objectives: minimizing the costs of establishment, operation, transportation, and holding; and minimizing the time of blood delivery to hospitals. Transportation vehicles were different and their speed and capacity were considered in objective functions and problem limitations. It was attempted to take a step towards promoting science in blood supply chain area. Although small, the step would be hopefully effective. Therefore, there were some novel ideas in this research:

1. At the earthquake time, many available facilities are destroyed or, in other words, some of them are blocked. For this reason, the problem model was considered to be non-active in case of obstruction.
2. What is so important is that the blood groups of the receiver and donor be considered, because they have different demand and can also cover some blood groups with the help of other blood groups.
3. Maternity hospitals are one of the most important centers that must be given special attention to covering the demand, because in these centers the number of people who are under risk is almost higher, both mother and children. These centers have often been hidden from the perspective of the authors, but in the case of this research, they were stressed.
4. Another issue was that due to the earthquake fault in Mazandaran province– Babol, and the information of the crisis management center, high risk areas should be identified and considered in the definition of the location of portable facilities.
5. A remarkable proportion of donated blood is often from unhealthy adults which is detected in the process of purifying in the blood transfusion center. Therefore, in this study, the percentage of unhygienic blood that could not be used was also defined.

The data used in the research are obtained from a case study in Mazandaran province–Babol. In addition to hospitals that help to victims, childbirth medical centers are also considered as one of the organizations with the high demand for blood. What has been stated is an introduction to the blood supply chain problem and its importance in times of natural disasters. Also, a brief overview of the research background in recent years has also been reviewed. By expressing the research innovation, it is tried to convey the importance of the present research, and in the following, the second section is devoted to problem definition and mathematical modeling of the blood supply chain network. Also, in this section, the problem-solving method, Lexicographic method, is considered. In the third section, a case study of the problem is conducted. As well, the results obtained by solving the model of the case study are discussed in the fourth section. In the fifth section, the conclusions of this study are included, in addition, there are also suggestions in this direction at the end. Finally, the references used in this study are mentioned.

2- Problem formulation

One of the cases that intensified crisis during natural disasters was mismanagement of blood supply chain. Shortage and incorrect delivery of blood were two serious problems in natural disasters. The supply chain network included donators and blood distribution. A bi-objective model is considered with minimizing the cost as the first objective function and minimizing the delivery time as the second objective function. To sum up, Fig.1 shows the schematic of the supply chain problem is demonstrated.

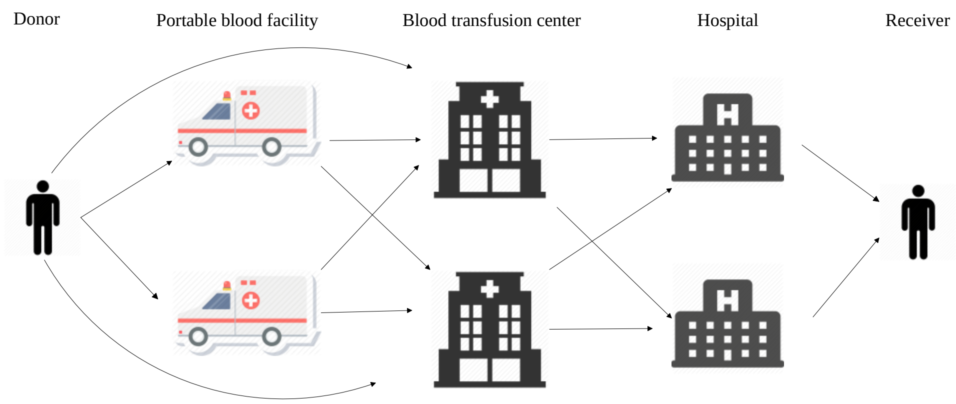

Fig 1. The proposed blood supply chain network

As shown in Fig.1, the blood supply chain network begins with the donors who can donate blood to the portable blood facilities or the blood transfusion centers, then, the network displays the transference process to the patients.

In the current research, the following policies are considered:

1. People can go to portable blood facilities and blood transfusion centers to donate but blood processing is performed in blood transfusion centers.

2. The represented blood is transported to hospitals from blood transfusion centers.
3. The received blood from portable facilities and blood transfusion centers is processed in blood transfusion centers before delivering to hospitals.
4. Compatibility of blood group between representor and receiver.
5. An accurate management on amount of blood stored and minimum wastage

The output of the proposed model in each period is as follows:

1. The number of portable facilities that activates.
2. The number of portable facilities that allocates for delivering the received blood from people in blood transfusion centers in each period of time.
3. The amount of blood with a given blood group delivered to blood transfusion centers at various times from portable blood facilities.
4. The amount of blood with a given blood group delivered to hospitals at various times from blood transfusion centers.
5. The amount of blood stored in blood transfusion centers with various blood groups at the end of each period of time.

2-1- Indices

i	:	Donation groups
m	:	Nominated places for portable blood facilities
o	:	Blood transfusion centers
h	:	Hospitals and medical centers
t	:	Time periods
v	:	Vehicles
g, r	:	Blood groups of donors and recipients

2-2- Parameters

f_m	:	The cost of creating a portable facility m
ocm_{imt}	:	The unit cost of facilitating portable blood m from i groups of donors in period t
oco_{ot}	:	Unit operating cost in transfusion centers o in period t
tcm_{motv}	:	The cost of the unit's transportation from facilitating blood m to transfusion centers o during the period t using the vehicle v
tco_{ohtv}	:	The cost of the unit's transportation from transfusion center o to hospital h in period t using the vehicle v
hco_{ot}	:	The unit cost of holding in transfusion center the center o in period t
atm_{mot}	:	Allowed time to facilitate portable blood m to transfusion center o in period t
ato_{oht}	:	Maximum allowed time from transfusion center o to hospital h in period t
d_{htr}	:	Blood demand of recipient with blood type r in hospital h in period t
tmo_{movg}	:	Time of blood transfusion with blood type of donor g from facilitating blood m to blood transfusion center o using the vehicle v

toh_{ohvg}	:	Time of blood transfusion with blood type of donor g from blood transfusion center o to hospital h using the vehicle v
sc_{og}	:	Blood storage capacity with blood type of g in blood transfusion center o
cm_{mt}	:	Capacity of facilitating portable blood m in period t
co_{ot}	:	Capacity of blood transfusion center o in period t
ms_{ig}	:	Maximum blood storage with donor blood type g from donor i
ddm_{im}	:	Distance between donor i and facilitating portable blood m
ddo_{io}	:	Distance between donor i and blood transfusion center o
dmo_{mo}	:	Distance between facilitating portable blood m from blood transfusion center o
dm	:	Coverage area of blood facilities
Mr	:	Maximum coverage radius for portable blood facility to blood transfusion center
P_{mt}	:	1 if portable blood facility m in different period t is available, unless 0
t_{gr}	:	1 if blood type g is transferable to blood type r, unless 0
M	:	A very large number
α		Percentage of blood that is processed (usable)

2-3- Decision variables

AO_{imotvg}	:	Amount of taken blood from donor i with blood type g by portable facility m deliver to transfusion center o using vehicle v in period t
AH_{iohvtg}	:	Amount of taken blood from donor i with blood type g by transfusion center o deliver to hospital h in period t
A_{imtg}	:	Amount of taken blood from donor i with blood type g by portable facility m in period t
AOH_{ohtvg}	:	Amount of delivered blood from transfusion center o to hospital h with blood type g using vehicle v in period t
IO_{otg}	:	Blood inventory level in blood transfusion center o with donor blood type g at the end of period t
Y_{imt}	:	1 if a portable facility m is allocated to a donor i in period t, otherwise 0
U_{iot}	:	1 if transfusion center o is allocated to a donor i in period t, otherwise 0
E_{mot}	:	1 if portable facility m is allocated to transfusion center o in period t, otherwise 0
x_m	:	1 if portable facility m is activated, otherwise 0

2-4- Mathematical model

The proposed model has two objective functions. The first function minimizes the cost of the supply chain. The components of the supply chain cost including the cost of organizing the blood facilities, operating costs, transportation costs, and holding costs are formulated in equation (1). The second function minimizes the average time of blood delivery from portable blood facility to blood transfusion centers and blood transfusion centers to hospitals in equation (2).

$$\min F_1 = \sum_{m\in M} f_m X_m + \sum_{i\in I}\sum_{m\in M}\sum_{t\in T} ocm_{imt} (\sum_{v\in V}\sum_{g\in G}\sum_{o\in O} AO_{imotvg}) + \sum_{o\in O}\sum_{t\in T} oco_{ot} (\sum_{i\in I}\sum_{h\in H}\sum_{v\in V}\sum_{g\in G} AH_{iohvtg}) + \sum_{i\in I}\sum_{m\in M}\sum_{o\in O}\sum_{t\in T}\sum_{v\in V}\sum_{g\in G} tcm_{motv} AO_{imotvg} + \sum_{o\in O}\sum_{h\in H}\sum_{t\in T}\sum_{v\in V}\sum_{g\in G} tco_{ohtv} AOH_{ohtvg} + \sum_{o\in O}\sum_{t\in T}\sum_{g\in G} hco_{ot} IO_{otg} \quad (1)$$

$$\min F_2 = \sum_{i\in I}\sum_{m\in M}\sum_{o\in O}\sum_{t\in T}\sum_{v\in V}\sum_{g\in G} AO_{imotvg} tmo_{movg} + \sum_{o\in O}\sum_{h\in H}\sum_{t\in T}\sum_{v\in V}\sum_{g\in G} AOH_{ohtvg} toh_{ohvg} \quad (2)$$

Due to the fact that during the earthquake some centers are disrupted, and they cannot provide services, a constraint is defined, on the other hand, there are some constraints on the capacity of portable and permanent receiving blood centers, also the limitation on maximum blood storage cause the problem will be confronted with some limitations. Of course, there are some constraints on location-allocation of the centers by considering distances between different centers that affect supply chain network. Model constraints are as follows:

$$Y_{imt} \le x_m \qquad \forall i, m, t \quad (3)$$

$$x_m \le p_{mt} \qquad \forall m, t \quad (4)$$

$$\sum_{m\in M}\sum_{o\in O}\sum_{t\in T}\sum_{v\in V} AO_{imotvg} + \sum_{o\in O}\sum_{h\in H}\sum_{t\in T}\sum_{v\in V} AH_{iohvtg} \le ms_{ig} \qquad \forall i, g \quad (5)$$

$$AO_{imotvg} \le M \times E_{mot} \qquad \forall i, m, o, t, v, g \quad (6)$$

$$\sum_{i\in I}\sum_{g\in G} A_{imtg} \le cm_{mt} \qquad \forall m, t \quad (7)$$

$$\sum_{i\in I}\sum_{h\in H}\sum_{v\in V}\sum_{g\in G} AH_{iohvtg} \le co_{ot} \qquad \forall o, t \quad (8)$$

$$\sum_{i\in I}\sum_{g\in G}\sum_{t\in T} A_{imtg} \le M \times x_m \qquad \forall m \quad (9)$$

$$AO_{imotvg} \le M \times Y_{imt} \qquad \forall i, m, o, t, v, g \quad (10)$$

$$AH_{iohvtg} \le M \times U_{iot} \qquad \forall i, o, h, v, t, g \quad (11)$$

$$ddm_{im} \times Y_{imt} \le dm \qquad \forall i, m, t \quad (12)$$

$$ddo_{io} \times U_{iot} \le dm \qquad \forall i, o, t \quad (13)$$

$$\sum_{o\in O} E_{mot} = 1 \qquad \forall m, t \quad (14)$$

$$IO_{O,t-1g} + \left(\sum_{i\in I}\sum_{m\in M}\sum_{v\in V} AO_{imotvg} + \sum_{i\in I}\sum_{h\in H}\sum_{v\in V} AH_{iohvtg} \right) - \sum_{h\in H}\sum_{v\in V} AOH_{ohtvg} \le IO_{otg} \qquad \forall o, t, g \quad (15)$$

$$\sum_{v\in V}\sum_{o\in O}\sum_{g\in G} AOH_{ohtvg} t_{gr} + \sum_{o\in O}\sum_{g\in G} IO_{otg} t_{gr} \ge d_{htr} \qquad \forall h, t, v, r \quad (16)$$

$$IO_{otg} \le sc_{og} \qquad \forall o, t, g \quad (17)$$

$$dmo_{mo}E_{mot} \leq M \qquad \forall m,o,t \qquad (18)$$

$$AO_{imotvg}tmo_{movg} \leq AO_{imotvg}atm_{mot} \qquad \forall i,m,o,t,v,g \qquad (19)$$

$$AOH_{ohtvg}toh_{ohvg} \leq AOH_{ohtvg}ato_{oht} \qquad \forall r,h,t,v,g \qquad (20)$$

$$AO_{imotvg} \leq \alpha \times A_{imtg} \qquad \forall i,m,o,t,v,g \qquad (21)$$

$$\sum_{i\in I}\sum_{m\in M}\sum_{t\in T}\sum_{v\in V}\sum_{g\in G}AO_{imotvg} + \sum_{i\in I}\sum_{v\in V}\sum_{t\in T}\sum_{g\in G}AH_{iohvtg} = \sum_{t\in T}\sum_{v\in V}\sum_{g\in G}AOH_{ohtvg} \qquad \forall o,h \qquad (22)$$

$$AO_{imotvg}, AOH_{ohtvg}, IO_{otg}, AH_{iohvtg}, A_{imtg} \geq 0 \qquad \forall i,m,o,t,v,h,g,r \qquad (23)$$

$$x_m Y_{imt}.U_{iot}.E_{mot} \in [0.1] \qquad (24)$$

Constraint (3) indicates when a donor i can refer to portable facility m, which has already been activated. Constraint (4) suggests that portable facility m activate if the path is active when the natural disaster occurs. Constraint (5) indicates that: total amount gained in portable facility m sent to the blood transfusion center o and the amount of blood donated to the blood transfusion center o sent to the hospital should not be exceeded by its maximum storage. Constraint (6) states that if portable facilities are allocated to blood transfusion, the blood gained from the portable facility can be transmitted to blood transfusion. Constraint (7) states that the amount of blood taken in portable facilities m should not be greater than the capacity of the portable blood facility. Constraint (8) also indicates that the amount of blood that is taken at blood transfusion center o to be taken to the hospital should not be greater than its capacity. Constraint (9) states that once the person receives blood in the blood facility, that facilitator is activated. Constraint (10) indicates that if portable blood facility m is allocated to donor i, the received blood in portable blood facility could be transferred to blood transfusion center. Constraint (11) states that if a blood transfusion center o is assigned to donor i, the blood transmitted from blood transfusion center can be transferred to the hospital. Constraint (12) states that the distance between donor i and portable facility m should not be greater than the coverage area of the portable blood facility if the portable facility m allocates to donor i. Constraint (13) shows that the distance between donor i and blood transfusion center o, if the blood transfusion center o allocates to donor i at time t, should not be greater than the blood donation area. Constraint (14) shows that portable blood facility m should be allocated to a blood transfusion center. Constraint (15) The level of blood inventory in each period of time with any blood group in the center of blood transfusion equals the total blood level in the same blood group at the end of the previous period and the amount of blood sent from portable facility at the end of the same period and the amount of blood taken at the center of the blood transfusion to be sent to the hospital at the end of the same period minus the amount of blood in the same blood group sent to the hospital. Constraint (16) shows that the hospital's demand for blood group r over time is equal to the amount of blood transmitted from the blood transfusion center to the hospital with a blood type g (blood type g transmitted to the blood group r) and the amount of blood inventory in the blood transfusion center o with blood type g. Constraint (17) states that: the amount of blood in the blood group g at the blood transfusion center o should not exceed the blood storage capacity of the blood group g in the blood center of the o. Constraint (18) shows that: the distance between the portable facility m from the blood transfusion center o, if the portable facility m is allocated to the transfusion center o, cannot exceed the maximum coverage radius of the portable facility to the transfusion center o. Constraint (19) demonstrates the maximum allowed time for the transfer of blood from portable facility to transfusion center. Constraint (20) shows the maximum allowed time for the transfer of transfusion center to hospital. Constraint (21) states that the amount of blood transmitted from portable facility to the transfusion center is less than the amount of blood gained in portable facility because some of it may be deducted for various reasons. Constraint (22) shows that the total amount of blood transmitted from portable blood facility to the center of blood transfusion and blood gained at the center of the blood transfusion to send to the hospital is equal to the blood sent to the hospital from the transfusion center. Constraint (23) The non-negative variables of the blood samples show that the blood taken at portable facility and the transfusion center, the amount of blood in the portable facility to transfer to the blood transfusion center, the amount of blood in the blood transfusion center for transferring to the hospital and the blood supply in the blood transfusion center as well as the amount of unmet demand in the hospital. Constraint (24) related to the definition of the variables of form 1 and 0.

2-5- Lexicographic method

A bi-objective Decision Making (MODM) optimization problem has a number of objective functions for minimizing or maximizing its value. It has some constraints that each feasible solution must apply, as well as single-objective function optimization problems. The general form of a multi-objective optimization problem is as follows:

$$min\ /\max\ f_m(x) \qquad \forall\ m \in M \qquad (25)$$

Subject to:

$$g_j(x) > 0 \qquad \forall\ j \in J \qquad (26)$$

$$h_k(x) = 0 \qquad \forall\ k \in K \qquad (27)$$

Lexicographic method is one of the procedures applied for multi-objective models. In this procedure, different objectives are categorized in terms of their degree of importance by Decision Maker (DM). After the optimization process is to begin with the most important objective function to optimize, the problem continues to be completely solved in order of importance.

Assume that the importance and priority of the objective functions are according to their indices, f_1 the most important and f_m the least important. Then, problem is solved as follows:

$$\max\ f_1 \qquad (25)$$

Subject to:

$$g_j(x) \le 0 \qquad \forall\ j \in J \qquad (26)$$

$$h_k(x) \le 0 \qquad \forall k \in K \qquad (27)$$

$$x \ge 0 \qquad (28)$$

So, f_1^* is othe ptimal answer to the model written above. By taking into account f_1^*, model below is formulated by considering the second most important objective function.

$$\max f_2 \qquad (29)$$

Subject to:	$g_j(x) \leq 0$	$\forall\, j \in J$	(30)
	$f_1(x) = f_1^*$		(31)

This process continues respectively until considering the last objective function. When several conflicting objectives are of the importance, there is no single optimal answer that minimizes or maximizes all desired objective functions at the same time. The solution output of multi-objective optimization problem is a set of alternate solutions with corresponding values for the desired purposes called Pareto. The solutions in the Pareto sets do not differ in mathematical terms.

The Fig. 2. provides that if $f(1)$ is the first priority object, optimal range answer would be $x_b \leq x \leq x_c$. Due to the minimizing $f_1(x)$, in this circumstance, the $f_2(x)$ will be minimized at the point x_c, accordingly x_c is the answer of the problem. This method is sensitive to the prioritizing by DM, and it is evident that optimal solution of the model changes, if the ranking of objectives alters. As helping is vital during the first hours of crisis and the first objective function is cost and the second one is time, the second objective function is more important and hence, the mathematical model is solved using lexicographic. It should be noted that other methods also can be used but in the current research, Lexicographic is preferred the above method called Lexicographic that is used in this research.

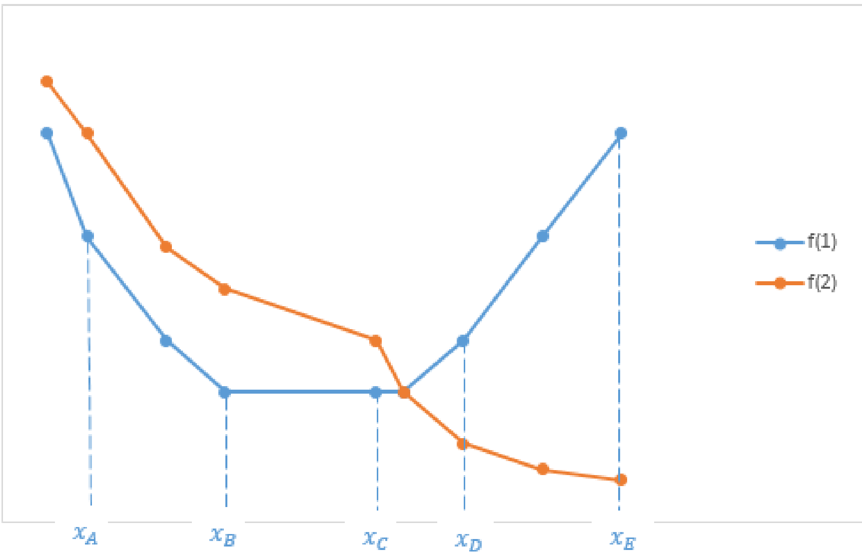

Fig 2. An example of lexicographic method

3- Case Study

Natural disasters always cause many problems for the countries all around the world. The earthquake is also one of the disasters that has occurred in Iran in recent years and has many managerial problems with it; one of them is the problem of blood supply to patients in hospitals. In this paper, a planning model for distributing optimal blood supply and processing is presented which aims to minimize the costs and time of blood transfusion from the bases of receiving blood to hospitals. In this regard, actual data from the Babol blood transfusion center have been collected and analyzed. Babol is located in Mazandaran province in Iran. The area of this city is about 1578.1 sq km with a population of about 531,000 people. The presence of seismic active faults in particular the Khazar fault in southern Mazandaran and on the Kuhdasht border with an approximate length of 550 km from Gonbad to Astara as well as north Alborz fault in the province with an approximate length of 300 km and other secondary and active faults indicate the high seismic potential of this area. During the earthquake portable and temporary facilities and centers are being set up at designated locations to serve hospitals and maternity care centers. In Fig 3, a schematic view of the locations in the case study is presented. It is worth mentioning that due to the high volume of the tables, a brief description of the final results is given at the end of this paper.

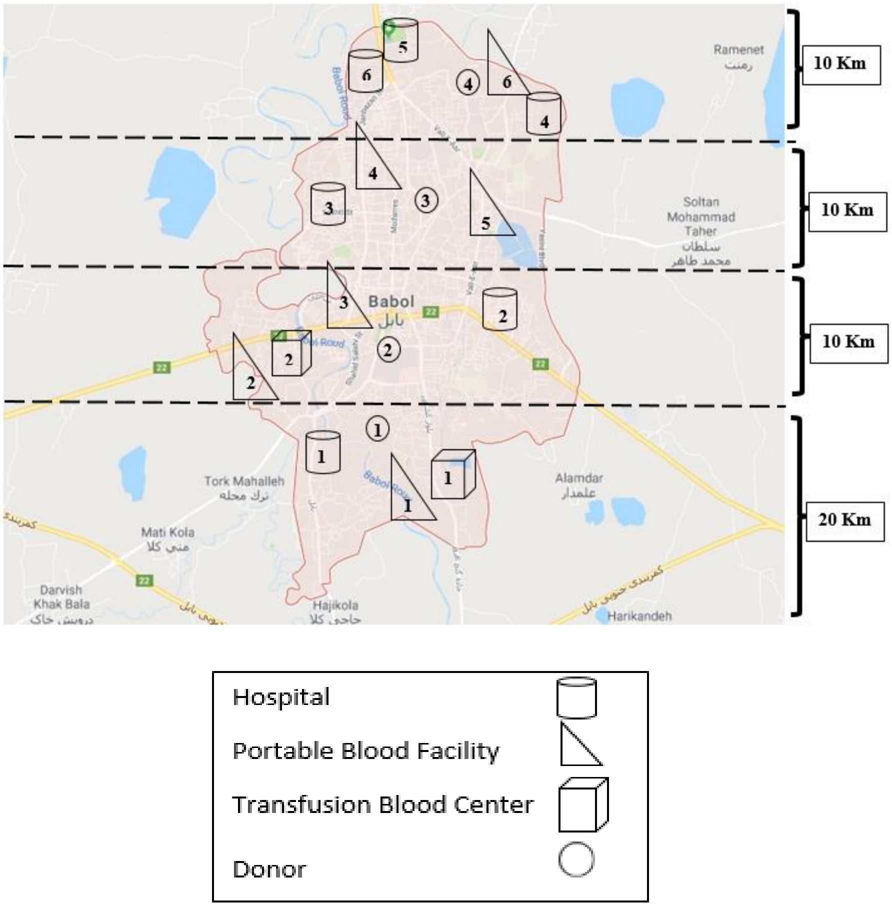

Fig 3. A schematic view of the facilities in the case study

As shown in Fig 3, donors at four locations, six portable blood facilities, two transfusion blood centers and six hospitals are considered in this problem in Babol. Donor's locations have been suggested due to their dispersal from the Babol blood transfusion centers. In this research, four periods are defined that are divided into ranges as (0-24h), (24-48h), (48-72h) and (72h-1w). This classification is considered due to the importance of services in the early hours of the earthquake. As well, two means of transports are included. Furthermore, there are eight recipient and donor blood groups that their compatibility is displayed in table1.

Table1. Compatibility of blood groups

	Donor							
Recipient	O-	O+	A-	A+	B-	B+	AB-	AB+
O-	1	0	0	0	0	0	0	0
O+	1	1	0	0	0	0	0	0
A-	1	0	1	0	0	0	0	0
A+	1	1	1	1	0	0	0	0
B-	1	0	0	0	1	0	0	0
B+	1	1	0	0	1	1	0	0
AB-	1	0	1	0	1	0	1	0
AB+	1	1	1	1	1	1	1	1

It is obvious that once the recipient blood groups can receive blood from donors, its initial condition, compatibility, occurs. According to Table 1, if 1 is displayed, it means that the possibility of receiving blood of the desired blood group can provide, otherwise, it means that there is no possibility to receive blood of that desired blood group. Two types of centers give services for receiving blood:

1. Portable blood facilities which are responsible for receiving blood from donators, and sending blood to blood transfusion centers in order to perform blood processing.
2. Blood transfusion centers that are permanent and fixed.

It must be mentioned that portable blood facilities use temporary amenities same as mobile blood facilities. Forasmuch as hospitals are one of the busiest places during the time of the earthquake, it is impossible for them to receive blood from donors. Another reason is that hospitals are one of the main disease transmission factors, particularly during the time of the earthquake, the possibility of transmission of contamination reaches its highest level .Therefore, received blood from donors, whether in portable blood facilities or in permanent establishments, filters in blood transfusion centers so as to ensure that healthy processed blood will be transfused to the receivers.

Table 2. Fixed costs of portable blood facilities

m	1	2	3	4	5	6
f_m	12500	12500	12500	12500	12500	12500

The distances of donors to portable facilities and transfusion centers are shown in Table 3 and Table 4.

Table 3. Distances of donors to portable blood facilities

ddm_{im}						
i \ m	1	2	3	4	5	6
1	1.5	13	12	23	24	34
2	16	3	1	8	9	19
3	27	13	9	3	4	7
4	36	22	18	12	11	3

Table 4. Distances of donors to blood transfusion centers

ddo_{io}		
	1	2
1	3	11
2	16	4
3	26	16
4	37	26

The objective is that the expected costs of the problem to be minimized, while the delivery time of blood in the rout of portable blood facilities to transfusion blood centers, and then hospitals is minimized. All received blood cannot be transferred to hospitals, since some blood donations may not be available to recipients due to contamination, and sometimes not compliance with health standards. This issue distinguishes at blood transfusion centers after blood processing. Therefore, a considerable percentage of blood will not transfer to hospitals due to their unhealthy reasons and blood corruption. This amount is equal to 0.8 percent, and it is shown with α. Blood transfusion centers have the capacity for each blood group, which is for every 1000 units. Hospital demands are considered in state of certain demand that this amount is of importance. It should not be forgotten that not only is time so fundamental in the transfer of blood to a hospital, the coverage of demand is also important because it is linked to the survival of people. In the other words, lack of cover demand, even in one case, may endanger one's life. Undoubtedly, an earthquake, by itself, will cause the loss of many people's lives, accordingly, we should not endanger the lives of stricken people by mismanagement of the crisis in the transfer of blood to the hospital that is why we will not have missed the demands. The demand rate is also based on information predicted by the crisis management center in case of an earthquake of 6 to 7 magnets. They have considered the above information based on historical events and simulation based on this city. One of the reasons why the present article describes an earthquake of this magnitude range in the model is that lower intensity earthquake does not likely cause serious problem in healthcare network, on the other hand, a large number of earthquakes in 6-7 magnitudes have been problematic. This amount is set as the limit, and now the model is solved using the first objective. Regarding the dimensions of the problem is solved approximately 30 minutes long with GAMS software, MIP model was resolver with CPLEX by a computer with Intel Core i5 and 4 GB specification.

4- Discussion and Results

As mentioned, in this research, the modeling of the problem is solved by using lexicographic method. It is evident that the second objective function (minimizing the delivery time of blood to the hospital) is far more important than the costs for the government at the time of the earthquake occurrence. When it comes to relief operations, the government is obligated to provide the highest service to the people. At the time of the earthquake occurrence, the need of blood for stricken people is one of the most important issues why because it directly relates to the health of the people of the community. Although budget constraints always tension governments, in cases which people's lives are at stake, the government tries to allocate the budget, particularly in this area that before the earthquake occurrence the range is defined. Of course, in this research, due to the identification of the earthquake-prone areas on the fault, its results have been as close as possible to the earthquake. The overall result of the problem solving is shown in Fig 4. It is crystal clear that portable blood facilities 2 and 3 are activated. The rest of the information can be received in Fig 4.

As discussed in previous sections, this research is a bi-objective problem, minimizing relief and delivery time of blood received along the route, from portable blood facilities to hospitals, and these two objective functions are in contradiction. In solving, the cost model is normalized. After solving the model with respect to the second objective function, the optimum value for the first objective function, which resulted from the minimization of the relief cost obtained is 95907.106, while the optimum amount for the second objective function is 368884.

Since some of the taken blood from people is lost for various reasons, the transmissible blood is a percentage of the amount of blood taken from people. This portion of the percentage in the mathematical model is shown as α. As shown in Fig 5, increasing blood corruptions and of course getting unhealthy blood will result in less blood being sent resulting in higher delivery times. In other words, the vehicles should reach a predetermined quantified limit to allow blood to be transmitted, regarding the reduction in healthy blood, the time increases to reach the vehicle's level of achievement and movement.

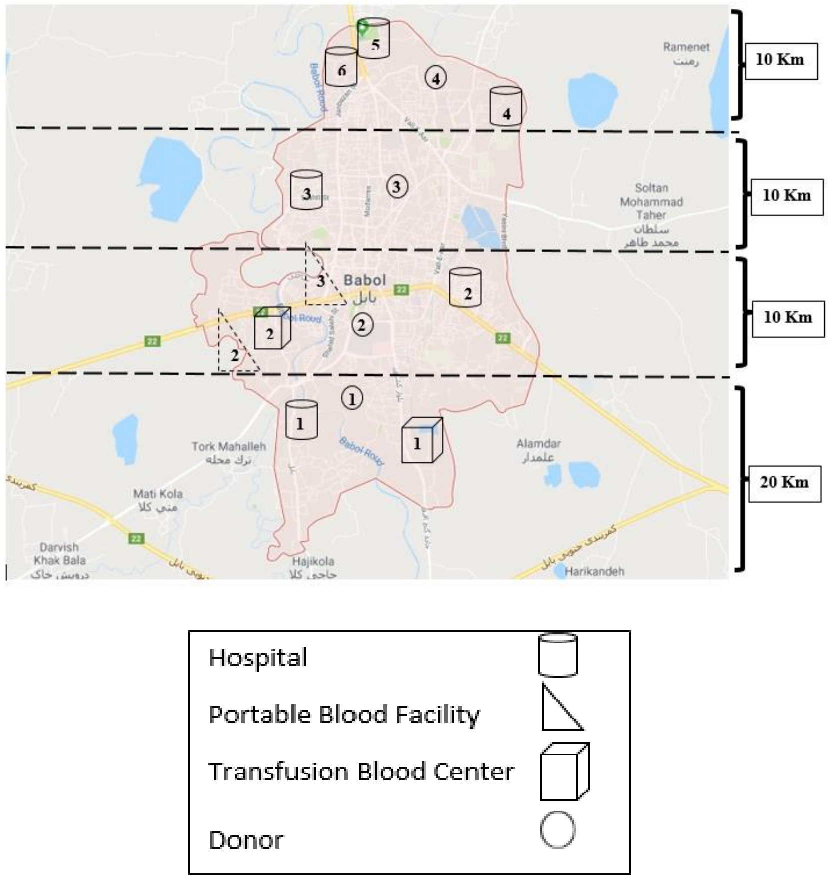

Fig 4. A schematic view of the result of solving problem

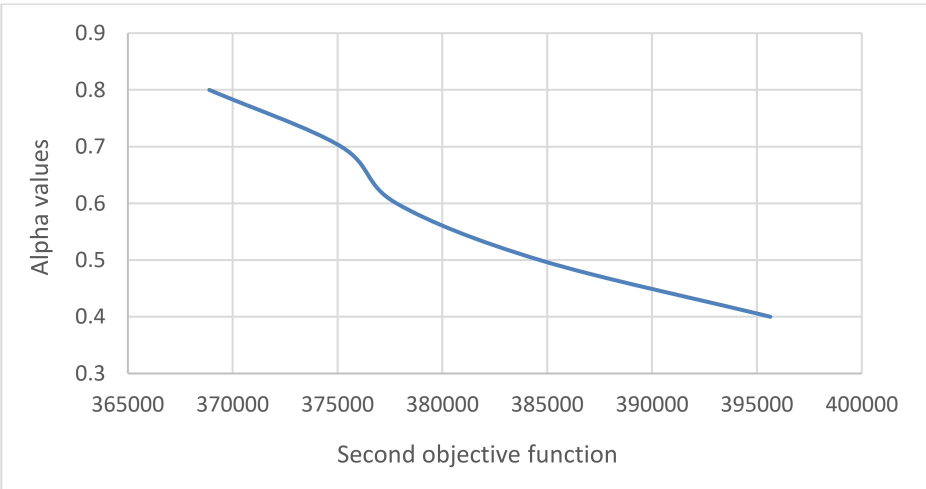

Fig 5. The effect of different α values on the second objective function

Since the objectives of the problem are in conflict with each other and there is no answer at the same time to optimize all objectives, the problem has an optimal response to Pareto. In particular, for each answer that minimizes the function of the first objective, the total cost, the reason for increasing the objective function is the average delivery time, which indicates the conflict between the objectives of the problem. The objective is to find the Pareto-optimality points of the problem. Fig 6 shows the conflict between the first and second objectives of the problem. As it is known, by increasing the second objective function, the amount of the first objective function decreases.

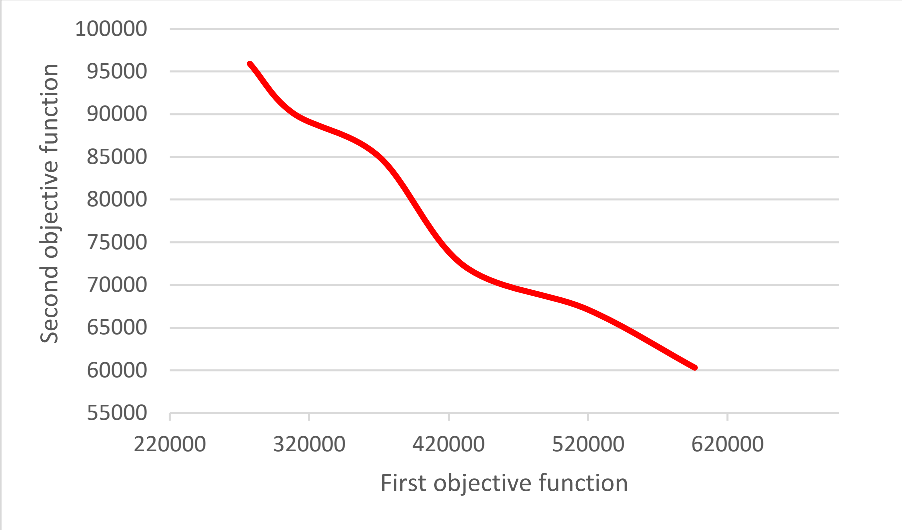

Fig 6. Conflict between the problem objectives

Now, in this section is tried to analyze the existing answers to the problem. As it is clear, two portable blood centers have been activated. These two centers are in the central region that indicate the importance of the blood supply on the margins of these points. Therefore, the system will not tend to open (activate) more mobile centers. Currently, the system has responded to all requests by hospitals, and in the costs dimension, it has tried to provide the most services at the lowest costs. As might be expected, more services can be provided by activating all portable blood facilities, but it should not be forgotten that in this case, not only will the cost of activation of the portable blood center increase, but also variable costs, such as transportation, will increase the surplus of system costs. As it is obvious, the earthquake is a sudden incident, and it is not possible to predict completely the places where will be destroyed. Therefore, each of both fixed and temporary centers of the problem may be disturbed. In the previous section, it was expressed that portable centers 2 and 3 were activated for services, assuming that these portable centers would be disturbed during an earthquake, what changes would occur in the problem and addressed the analysis of system responses. Fig 7 shows the rate of change of the first and second objective function in exchange for the disturbance of these centers.

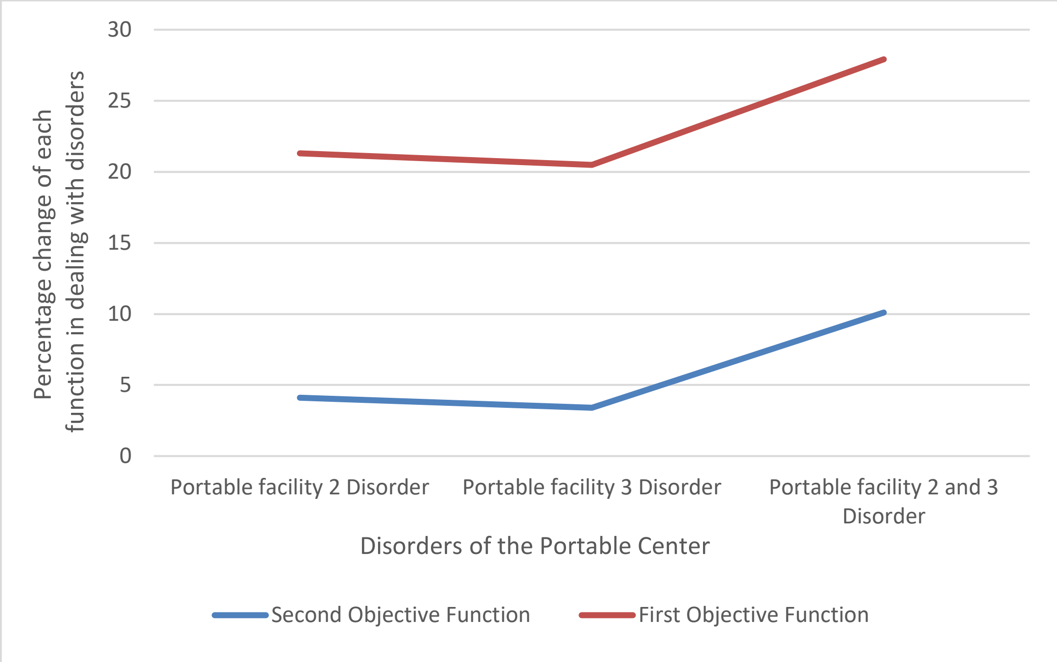

Fig 7. Variations of the objective functions in disturbance of centers

5- Conclusion

In this paper, a multi-echelon supply chain network consisted of donors, portable blood receiving facilities, blood transfusion centers, hospitals and blood receivers was studied. In addition to hospitals that is providing assistance to affected people, this study also emphasized the need for maternity care centers, which tend to need urgent blood supplies in order to deal with the crisis more effectively. In this regard, in case of possible failures of routes in the city of Babol, the model was shown to be capable of suggesting alternatives. The purpose of the study was to locate portable facilities and allocate centers to donors and then to hospitals seeking to receive blood. The problem had two objectives, first reducing the total cost, and second minimizing the blood delivery time from donors to hospitals requiring a blood transfusion. The risk of malfunctioning portable centers, which is one of the serious issues in case of an earthquake, was also incorporated into the model. A bi-objective mathematical model was introduced using a sustainability approach to determining the performance of different dimensions in the multi-echelon supply chain provided by the lexicographic method for the development of a sustainable and resilient supply chain.

Many articles have been published in this area of research, each of which considered important aspects of the problem. This research relied on these articles and presented a study of the case of an earthquake. The main reason for the severity of the crisis is usually the mismanagement of the blood flow through the supply chain. Hence, although a great number of donors volunteer to help their fellows, blood distribution problems lead to a significant amount of waste. Therefore, managerial suggestions were offered in addition to the proposed model:

1. Informing people about the prediction of the earthquake destruction rate and the importance of blood supply to the injured people before the earthquake strikes.

2. Informing people before the earthquake about the approximate level of blood needed from each blood group.
3. Training people to effectively attend important spots and passionate presence to help accelerate the supply chain of basic goods including blood. Also, informing people about the predetermined alternatives in case of the destruction of portable and permanent centers receiving and transfusing blood.

There were some limitations to this study. Many of the parameters of the problem can only be identified during the earthquake. This study was conducted using past data available for the case; therefore, the estimated factors may deviate from those of a real condition. In addition to the current model, one of the other points that can help to solve the blood supply problem during an earthquake is the vehicle routing network. Clearly, the coordination between the proposed supply chain networks in this study with the routing network can be a great help in providing better services to the stricken people and reducing the death rate of earthquake victims. Moreover, in order to solve problems in larger dimensions, innovative solution methods should be used.

In future studies, the risk of disruption and destruction of blood transfusion centers and hospitals and the conditions for the response after their destruction could also be considered in the model. Since many of the parameters of the problem were inherently non-deterministic, for the most approximation of the model to reality, the parameters such as cost, demand, and time can be assumed to be uncertain. Other considerations that can help the process of the problem include taking other blood products, including plasma and platelets.

References

Afrouzy, Z. A., Paydar, M. M., Nasseri, S. H., & Mahdavi, I. (2018). A meta-heuristic approach supported by NSGA-II for the design and plan of supply chain networks considering new product development. Journal of Industrial Engineering International, 14(1), 95-109.

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.

Babaveisi, V., Paydar, M. M., & Safaei, A. S. (2018). Optimizing a multi-product closed-loop supply chain using NSGA-II, MOSA, and MOPSO meta-heuristic algorithms. Journal of Industrial Engineering International, 14(2), 305-326.

Beliën, J., & Forcé, H. (2012). Supply chain management of blood products: A literature review. European Journal of Operational Research, 217(1), 1-16.

Delen, D., Erraguntla, M., Mayer, R. J., & Wu, C. N. (2011). Better management of blood supply-chain with GIS-based analytics. Annals of Operations Research, 185(1), 181-193.

Diabat, A., Dehghani, E., & Jabbarzadeh, A. (2017). Incorporating location and inventory decisions into a supply chain design problem with uncertain demands and lead times. Journal of Manufacturing Systems, 43, 139-149.

Duan, Q., & Liao, T. W. (2014). Optimization of blood supply chain with shortened shelf lives and ABO compatibility. International Journal of Production Economics, 153, 113-129.

Fahimnia B., et al.,"Supply chain design for efficient and effective blood supply in disasters", International Journal of Production Economics,Vol. 183, No., pp. 700-709, 2017.

Habibi-Kouchaksaraei, M., Paydar, M. M., & Asadi-Gangraj, E. (2018). Designing a bi-objective multi-echelon robust blood supply chain in a disaster. Applied Mathematical Modelling, 55, 583-599.

Katsaliaki, K., & Brailsford, S. C. (2016). Using simulation to improve the blood supply chain. In Operational Research for Emergency Planning in Healthcare: Volume 1 (pp. 353-372). Palgrave Macmillan, London.

Kohneh, J. N., 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(special issue on supply chain), 51-72.

Ma Z.-J., Wang K.-M.,Dai Y.,"An Emergency Blood Allocation Approach Considering Blood Group Compatibility in Disaster Relief Operations", International Journal of Disaster Risk Science,Vol. 10, No. 1, pp. 74-88, 2019.

Mansur, A., Vanany, I., & Arvitrida, N. I. (2018). Challenge and opportunity research in blood supply chain management: a literature review. In MATEC Web of Conferences (Vol. 154, p. 01092). EDP Sciences.

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), 205-231.

Nourifar, R., Mahdavi, I., Mahdavi-Amiri, N., & Paydar, M. M. (2018). Optimizing decentralized production–distribution planning problem in a multi-period supply chain network under uncertainty. Journal of Industrial Engineering International, 14(2), 367-382.

Or, I., & Pierskalla, W. P. (1979). A transportation location-allocation model for regional blood banking. AIIE transactions, 11(2), 86-95.

Pirabán, A., Guerrero, W. J., & Labadie, N. (2019). Survey on blood supply chain management: Models and methods. Computers & Operations Research.

Ramezanian, R., & Behboodi, Z. (2017). Blood supply chain network design under uncertainties in supply and demand considering social aspects. *Transportation Research Part E: Logistics and Transportation Review*, *104*, 69-82.

Starr, M. K., & Van Wassenhove, L. N. (2014). Introduction to the special issue on humanitarian operations and crisis management. *Production and Operations Management*, *23*(6), 925-937.

Williamson, L. M., & Devine, D. V. (2013). Challenges in the management of the blood supply. *The Lancet*, *381*(9880), 1866-1875.

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.

Zahiri, B., Torabi, S. A., Mohammadi, M., & Aghabegloo, M. (2018). A multi-stage stochastic programming approach for blood supply chain planning. *Computers & Industrial Engineering*, *122*, 1-14.

Zahraee, S. M., Rohani, J. M., Firouzi, A., & Shahpanah, A. (2015). Efficiency improvement of blood supply chain system using Taguchi method and dynamic simulation. *Procedia Manufacturing*, *2*, 1-5.