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RESEARCH PAPER

Designing a Multi-Level Blood Supply Chain Network With the Likelihood of Shortage and Perishability in the Inventory

Majid Alimohammadi Ardekani[a,*], Mehdi Kabiri Naeini[b]

a. *Department of Industrial Engineering, Faculty of Engineering, Ardakan University, Ardakan, Iran*
b. *Department of Industrial Engineering, Faculty of Engineering, Payame Noor University, Yazd Center, Yazd, Iran*

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Abstract

Blood is a vital substance for human life. A blood unit goes through various stages from its donation by the donor until its reception by the person in need of blood. This process can be explored the context of supply chain management. For this purpose, a mathematical model is developed in this study to design a blood supply chain network. The noticeable feature of this network is the inclusion of the shortage and perishability of blood products as two important indicators. The mathematical model proposed in this regard has the two objective functions of minimizing the blood supply chain costs and, at the same time, maximizing the average amount of blood sent from blood centers to hospitals. The model examines the problem in the case of a single product. The modified weighted Chebyshev, the improved version of ε-constraint (AUGEMCON2), and unscaled goal programming are used to solve the mathematical model. Then, to evaluate and compare the proposed solution methods and select the best one, the statistical hypothesis test and the VIKOR technique are used respectively. Also, to investigate the reaction of the objective functions to the changes in the model parameters, several sensitivity analyses are performed. The results show that the model proposed for the blood supply chain is efficient and acceptable; hence, it can be of benefit in different types of blood supply chains where the shortage and perishability of blood products are taken into account.

Keywords:
Blood Supply Chain Management;
Multi-Objective Decision-Making;
Vikor Technique;
Exact Solution Methods;
Shortage and Perishability of Blood Products

Introduction

Body health is vital to human life and has significant impacts on many aspects of life. Nowadays, advances in science and technology have greatly improved human health. The great bulk of research conducted in various scientific fields shows the undeniable importance of health for human activities. In this regard, blood plays a vital role, hence worth addressing. Despite efforts to find an alternative to blood, none has been found yet. In other words, the only way to supply the blood needed by patients is to receive it from one human body and inject it into another body, which involves certain processes. Initially, the donor refers to a blood donation center. The received whole blood is then sent to the corresponding laboratories to be converted into blood products. The types of blood products and the characteristics of each are reported in Table 1. Finally, the products are distributed among hospitals and demand centers

* Corresponding author: (M. Alimohammadi Ardekani)
Email: m.alimohammadi@ardakan.ac.ir

to be injected into those in need. Since all these processes are related, they can be best managed in a supply chain network. This issue has attracted academics and stakeholders ([13]).

Table 1. Features of blood products ([33] ; [7])

Blood products	Usage	Shelf life	Color	Storage conditions
Whole blood	• Trauma • Surgery	21 - 35 days	Red	18 - 24 °C
Red cells	• Trauma • Surgery • Anemia • Blood loss • Blood disorders	42 days	Red	2 - 10 °C
Platelets	• Cancer treatment • Organ transplant • Surgery	3 - 7 days	Colorless	20 - 24 °C
Plasma	• Burn patients • Shock • Bleeding disorders	1 year	Yellowish	Less than or equal to -30 °C
Cryo	• Hemophilia • Von Willebrand disease	1 year	White	Less than or equal to -30 °C

Lack of blood supply can lead to loss of lives. On the other hand, over-donation and lack of proper management can lead to blood loss and increased costs. Therefore, to prevent the shortage or loss in the inventory of blood products, different components of a blood supply chain have to be integrated. Besides, the reliability of blood centers for the on-time delivery of blood is a crucial factor. Designing an efficient blood supply chain network, thus, seems to be necessary. On this account, the present study gains importance for the following reasons:

- Human blood is a precious and rare substance formed only by man himself, and there is no alternative for it in the outside world;
- Managing such a valuable substance requires proper and accurate planning;
- Balancing the supply and demand of blood efficiently is problematic because blood and its derivatives are perishable;
- Lack of blood or delayed delivery of blood products to patients leads to their death. This may lead to a crisis in the case of pervasive incidents.

In addition, the novelties of this study are as follows:

- Designing a suitable blood supply chain network which integrates the diverse levels of the chain;
- Maximizing the reliability of blood centers to meet the needs of demand points;
- Minimizing the amount of spoiled blood in the chain;
- Minimizing the shortage of blood products;
- Minimizing the total costs of the blood supply chain;
- Calculating the optimal quantity of the donated blood and the blood sent from blood centers to demand points, the blood inventory in blood centers and demand points at the end of each period, and the optimum number of fixed and mobile blood centers.

The rest of this manuscript is organized in several parts. In the second part, the literature is reviewed in different categories. The third part is dedicated to the description of the recommended mathematical model. The fourth part proposes exact methods to solve the mathematical model, including modified weighted Chebyshev, the improved version of ε-constraint (AUGEMCON2), and unscaled goal programming. In the fifth part, after some numerical examples, the computational results of the model are evaluated with the GAMS software, and the criteria are defined to compare the proposed model. In the following, statistical analyses are performed, and a superior solution method is selected from the proposed ones. Then, to examine the reaction of the objective functions to the change of the model parameters, several sensitivity analyses are carried out. Next, some managerial implications related to our paper are presented in part seven. Finally, the last part presents the conclusion of the study and suggestions for future research.

Literature review

In order to provide a better understanding of the subject, the corresponding literature is reviewed in several areas.

Supply chains for perishable products

The management of supply chains for perishable products has long been the focus of many scholars. In general, perishable goods are the products that lose their value over time and may become unusable. The research on perishable items began with [44] . [14] conducted the first research about the effect of perishable goods on the performance of supply chain inventories. In this regard, [29] presented a model to study the inventory management of perishable products.

Basically, the proper management of perishable goods can play an influential role in the performance of a supply chain, including reducing the costs of various parts of the chain, improving the performance of distribution units for the on-time delivery of goods to demand points, and even reducing environment pollutants. [9] presented a multi-period inventory and a pricing model to design a single-product supply chain with a fixed consumption period. For this purpose, they used the Wagner-Whitin dynamic programming method. Perishable and non-perishable products were also used to investigate the problem. [41] developed an economic output quantity model for perishable goods in a two-level supply chain to maximize profits by identifying the optimal selling price and credit period as well as the appropriate time. In another study, [40] proposed a simulation model using the dynamic systems method to study the behavior and the relationships in fruits and vegetables supply chains. [43] presented a three-level supply chain including a manufacturer, a distributor and a retailer to optimize the inventory control policies for perishable products. [30] designed a multi-objective mathematical model and worked out the problem of routing a drug distribution network to hospitals and other points of demand. They took into account the expiration date of the manufactured drugs. In another study, [35] suggested a supply chain model to identify the optimal policy for ordering several types of perishable goods under conditions of inflation and the possibility of shortage and delays in payment.

Blood supply chain

Studies on the management of supply chains for perishable products in general and blood products in specific were started in the 1960s by [42] . [16] developed a model utilizing Markov dynamic programming and a simulation method for blood banks in the Netherlands. Their study focused more on the costs of producing and managing blood platelet. [6] evaluated the problem of blood collection. They tested their model considering the cost of setting up fixed and mobile blood collection bases. Their model regarded different blood collection processes, donor behavior, and required human resources. The model was implemented in France as a case study. [18] developed integer programming models to decide which hospitals should be enclosed by blood transfusions from blood donation bases on a daily basis. [12] designed a model for a supply chain network in crises. The outcome of the model was the optimal locations for the construction of facilities and the optimal allocation of demand points to the supply points of blood products. [19] investigated the effects of inventory concentration on the stability of blood supply chains. By presenting a mathematical model and comparing the results with the situation where the inventories were distributed in a decentralized network, they concluded that the concentration of the inventory in a blood supply chain makes it more stable. [34] studied blood inventory management through mathematical modeling. They identified several independent sources of blood supply as perishable instances. They used an extensive dataset from a healthcare center to validate their model. [11] introduced a multifunctional competitive supply chain network model for the blood banking industry, focusing on the United States. There were economic relations among three rows of stakeholders including blood service organizations, hospitals or health centers that donated blood to patients, and payment groups to which the patients belonged. Furthermore, the supply chain framework for this life-saving product included competition between blood service organizations and their various supply chain activities. Recently, [17] have presented a robust two-objective optimization model to design blood supply chains resistant to disaster scenarios. They suggested a Lagrangian-based algorithm that was able to solve large-scale models. In the study by [15] , a dynamic, robust location-allocation model was proposed to design a blood supply chain network under the hazards of facility disruption and uncertainty in catastrophic conditions. On a large scale, two meta-heuristic algorithms including the self-adaptive imperialist competitive algorithm and the invasive weed optimization algorithm were introduced to unravel the model. [20] studied stimulus measures through advertising, education, and medical credit so as to inspire blood donors to maintain adequate blood supply. In that study, a flexible, robust feasibility-random mixed programming model was proposed.

Research gap

As mentioned, blood is a rare and highly perishable substance the lack or shortage of which can lead to the loss of lives of those who need it. Excessive donation and improper management can also cause blood loss and increased costs. To properly manage the blood inventory and prevent the shortage of blood products, it is essential to integrate the different components of the supply chain and examine all the chain levels together. Also, the reliability of blood centers in the on-time delivery of blood is a critical factor that should be seriously considered. A blood supply chain with integrated levels can increase the reliability of blood centers in delivering blood products to demand points.

At the end of the literature review, Table 2 shows a summary of the literature review.

Table 2. Reviewed studies

Authors (Year)	Problem			Shortage and perishability	Objective(s)		Solution approach	Network's element				
	Inventory	Location	Allocation		Single-objective	Multi-objective		Blood donors	Mobile blood collectors	Fix blood collectors	Blood centers	Hospitals
[35]	✓				✓		M					✓
[16]	✓			✓		✓	M					
[41]	✓					✓	H					
[18]	✓	✓	✓		✓		E	✓		✓	✓	✓
[6]	✓				✓		M				✓	✓
[40]		✓		✓	✓		E		✓			
[30]		✓	✓			✓	E	✓		✓	✓	✓

[12]	✓					✓	H	✓	✓		✓	✓
[34]	✓			✓	✓		E			✓	✓	✓
[19]	✓	✓		✓		✓	E		✓		✓	✓
[17]	✓	✓				✓	E	✓			✓	✓
[15]		✓	✓	✓	✓		M				✓	✓
[20]	✓	✓			✓		H	✓	✓		✓	✓
This Paper	✓	✓	✓	✓		✓	**E**	✓	✓	✓	✓	✓

Note: E: Exact, H: Heuristic, M: Metaheuristic

Model description

Although a great deal of research has been done on blood management, much of it has only examined a specific level of blood supply chains; only a few studies have dealt with different levels of the chains. So, the inclusion of all the influential factors in a chain is a step to optimize it. The present study introduces a mathematical model to design a proper blood supply chain network. The model is a bi-objective one to minimize the total costs of the blood supply chain and maximize the reliability of blood centers to send blood products to demand points. It examines the chain in a single-product mode, but the product has a limited consumption time. After the expiration of the intended time, it becomes corrupt and unusable. The blood supply chain proposed in this study is illustrated in Fig. 1. The chain includes donors, mobile blood collection units, fixed blood collection units, primary blood centers, and hospitals.

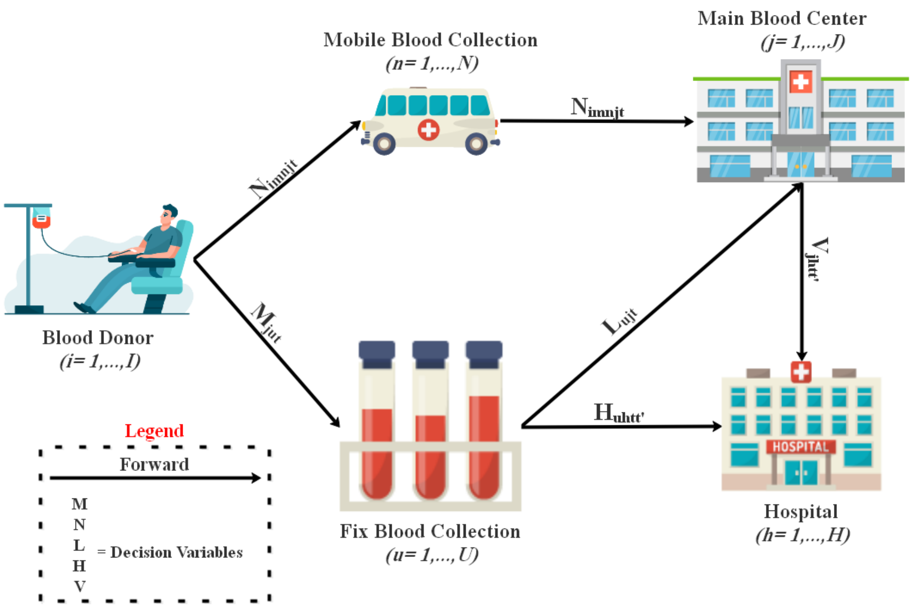

Fig. 1. The proposed blood supply chain network

The assumptions made for the designed blood supply chain network are as follows:

- Blood donors can donate their blood to any mobile or fixed blood collection unit, taking into account the specified geographical distance. However, blood donation does not take place in the main blood centers.
- Mobile blood collection units are only responsible for collecting the donated blood and transferring it to the main blood centers. They lack the equipment needed to produce blood products.
- Fixed blood collection units are the centers that not only collect the donors' blood but are also responsible for performing the required tests and producing blood products. However, the facilities of these centers are not as large as those in the main blood centers. It is, thus, possible to send some donated blood to the main blood centers to

perform certain processes on it. Also, the blood products produced by the fixed blood collection units are sent directly to the demand points.

- The main blood centers can perform all the necessary processes on the blood. After receiving the collected blood from the mobile or fixed blood collection units, the main blood centers convert it into blood products, which are finally sent to the demand points.
- The proposed mathematical model examines the problem in the form of a single product.
- The fixed blood collection units as well as the main blood centers have uncertainties in delivering blood products to the demand points. They may not be able to meet the needs of hospitals over a period. This uncertainty obeys an exponential distribution with average λ_{it} (for the main blood centers) and λ_{ut} (for the fixed blood collection units). Thus, the average of the total blood products sent from the main blood centers and the fixed blood collection units to the demand points is equal to $V_{jhtt'}e^{-\lambda_{jt}\tau}$ and $H_{uhtt'}e^{-\lambda_{ut}\tau}$.

Mathematical model

Before the description of the proposed mathematical model, the indices, parameters and decision variables used in it are defined as follows:

Indices

i	Number of blood donor groups
j	Number of main blood centers
h	Number of hospitals
t, t'	Number of periods with interval τ (t, t'= 1,2, …, T)
m,e	Number of candidate locations for the presence of mobile blood collection units (m, e = 1,2, …, M)
n	Number of mobile blood collection units
u	Number of fixed blood collection units

Parameters

Ca_j	The capacity of main blood center *j*
$d1_{im}$	The distance of donor group i from place m
md	The maximum distance that blood centers can cover
BN	A big positive number
CM_{ment}	The cost of moving mobile blood collection unit n from location e to location m in period t
MCa_{it}	The maximum blood donation capacity of group donors i in period t
$CO1_{mnt}$	The operation cost of receiving blood from donors in mobile blood collection unit n at location m in period t
$CO2_{ut}$	The operation cost of receiving blood from donors in fixed blood collection unit u in period t
$CS1_{mnjt}$	The cost of sending a whole blood unit from mobile blood collection unit n at location m to main blood center j in period t
$CS2_{ujt}$	The cost of sending a whole blood unit from fixed blood collection unit u to main blood center j in period t
Ca_n	The capacity of mobile blood collection unit n
Ca_u	The capacity of fixed blood collection unit u
$d2_{iu}$	The distance of donor group i from fixed blood collection unit u
α_{jt}	The inability rate of main blood center j to send blood products to hospitals in period t
w	The rates of sending blood by fixed blood collection units to main blood centers

α_{ut}	The inability rate of fixed blood collection unit u to send blood products to hospitals in period t
CE_{ht}	The unit cost of the spoilage of the blood products sent to hospital h in period t
$HC1_{jt}$	The unit cost of holding blood in main blood center j in period t
$CO3_{jt}$	The operation cost per unit of blood in main blood center j in period t
$CS2_{uht}$	The cost of sending a unit of blood from fixed blood collection unit u to hospital h in period t
$CS3_{jht}$	The cost of sending a unit of blood from main blood center j to hospital h in period t
$HC2_{ut}$	The unit cost of holding blood in main blood center j in period t
LC_{ht}	The shortage cost per unit of hospital demand h in period t
$CT1_{jt}$	The consumption duration of the blood product sent to hospitals from the main blood center j in period t
$CT2_{ut}$	The consumption duration of the blood product sent to hospitals from fixed blood collection unit u in period t
D_{ht}	Hospital demand h in period t

Decision variables

X_{ment}	If mobile blood collection unit n in period t moves from location e to location m 1; otherwise, 0.
Y_{imnt}	If mobile blood collection unit n at location m in period t is assigned to donor group i 1; otherwise, 0.
T_{jut}	If fixed blood collection unit u in period t is assigned to donor group i 1; otherwise, 0.
N_{imnjt}	The amount of the blood received from donor group i by mobile blood collection unit n at location m which is sent to main blood center j in period t
R_{ujt}	If fixed blood collection unit u is assigned to main blood center j 1; otherwise, 0.
M_{jut}	The amount of the blood received from donor group i by fixed blood collection unit u in period t
L_{ujt}	The amount of the whole blood sent from fixed blood collection unit u to main blood center j in period t
$H_{uhtt'}$	The amount of the blood product sent from fixed blood collection unit u to hospital h in period t to be consumed in period t'
$V_{jhtt'}$	The amount of the blood product sent from main blood center j to hospital h in period t to be consumed in period t'
IF_{ut}	The inventory of fixed blood collection unit u at the end of period t
IM_{jt}	The inventory of main blood center j at the end of period t
S_{ht}	The shortage rate of hospital demand h at the end of period t

Considering the above items, the purpose of presenting a mathematical model is to minimize the total costs of the supply chain and enhance the reliability of the main blood centers and the fixed blood collection units. The objective functions and the constraints of the proposed mathematical model are as follows:

$$\begin{aligned}\text{Min}\quad Z_1 = &\sum_e\sum_m\sum_n\sum_t CM_{ment}X_{ment} + \sum_i\sum_m\sum_n\sum_t CO1_{mnt}(\sum_j N_{imnjt}) + \sum_u\sum_t CO2_{ut}(\sum_i M_{iut})\\ &+\sum_j\sum_t CO3_{jt}(\sum_i\sum_m\sum_n N_{imnjt} + \sum_u L_{ujt}) + \sum_i\sum_m\sum_n\sum_j\sum_t CS1_{mnjt}N_{imnjt}\\ &+\sum_u\sum_j\sum_t CS2_{ujt}L_{ujt} + \sum_u\sum_h\sum_t\sum_{t'} CS2_{uht}H_{uhtt'} + \sum_j\sum_h\sum_t\sum_{t'} CS3_{jht}V_{jhtt'}\\ &+\sum_u\sum_t HC2_{ut}IF_{ut} + \sum_j\sum_t HC1_{jt}IM_{jt} + \sum_h\sum_t LC_{ht}S_{ht}\\ &+\sum_h\sum_t CE_{ht}(\sum_j\sum_{t'\succ t+CT1_{j,t}} V_{jhtt'} + \sum_u\sum_t\sum_{t'\succ t+CT2_{u,t}} H_{uhtt'})\end{aligned} \tag{1}$$

$$\text{Max}\ Z_2 = \left(\sum_j\sum_h\sum_t\sum_{t'} V_{jhtt'}e^{-\lambda_{jt}\tau} + \sum_l\sum_h\sum_t\sum_{t'} H_{uhtt'}e^{-\lambda_{ut}\tau}\right) \tag{2}$$

Subject to:

$$\sum_e\sum_n X_{ment} \le 1, \qquad \forall m,t, \tag{3}$$

$$\sum_e\sum_n X_{ment} \le \sum_e\sum_n X_{ment-1}, \qquad \forall m,t, \tag{4}$$

$$\sum_n Y_{imnt} \le \sum_e\sum_n X_{ment}, \qquad \forall i,m,t, \tag{5}$$

$$N_{imnjt} \le BN \times Y_{imnt}, \qquad \forall i,m,n,j,t, \tag{6}$$

$$M_{iut} \le BN \times T_{iut}, \qquad \forall i,u,t, \tag{7}$$

$$\sum_m\sum_n\sum_j N_{imnjt} + \sum_u M_{iut} \le MCa_{it}, \qquad \forall i,t, \tag{8}$$

$$d1_{im}\sum_n Y_{imnt} \le md, \qquad \forall i,m,t, \tag{9}$$

$$d2_{iu}T_{iut} \le md, \qquad \forall i,u,t, \tag{10}$$

$$\sum_j R_{ujt} \le 1, \qquad \forall u,t, \tag{11}$$

$$L_{ujt} \le BN \times R_{ujt}, \qquad \forall u,j,t, \tag{12}$$

$$L_{ujt} \le w\sum_i M_{iut}, \qquad \forall u,j,t, \tag{13}$$

$$IF_{ut} = IF_{ut-1} + (1-w)\sum_i M_{iut} - \sum_h\sum_{t'} H_{uhtt'}, \qquad \forall u,t, \tag{14}$$

$$IM_{jt} = IM_{jt-1} + (\sum_i\sum_m\sum_n N_{imnjt} + \sum_u L_{ujt}) - \sum_h\sum_{t'} V_{jhtt'}, \qquad \forall j,t, \tag{15}$$

$$S_{ht} = S_{ht-1} + D_{ht} - (\sum_u\sum_{t-CT2_{u,t'}\le t} H_{uhtt'} + \sum_j\sum_{t-CT1_{j,t'}\le t} V_{jhtt'}), \qquad \forall h,t, \tag{16}$$

$$\sum_i\sum_m\sum_j N_{imnjt} \le Ca_n, \qquad \forall n,t, \tag{17}$$

$$IF_{ut} \le Ca_u, \qquad \forall u,t, \tag{18}$$

$$IM_{jt} \le Ca_j, \qquad \forall j,t, \tag{19}$$

$$N_{imnjt},\ M_{iut},\ L_{ujt},\ S_{ht},\ H_{uhtt'},\ V_{jhtt'},\ IF_{ut},\ IM_{jt} \ge 0, \tag{20}$$

$$X_{ment},\ Y_{imnt},\ T_{iut},\ R_{ujt} \in \{0,1\}. \tag{21}$$

Eq. 1 shows the first objective function of the model, which aims to minimize the total costs of the blood supply chain network. The first part of this objective function is related to the transferring cost of mobile blood collection units. The rest of it includes operation costs in those units, operation costs in fixed blood collection units, operation costs in the main blood centers, cost of blood transfer from mobile blood collection units to the main blood centers, cost of blood transfer from fixed blood collection units to the main blood centers, cost of transferring blood products from fixed blood collection units to hospitals, cost of transferring blood products from the main blood centers to hospitals, cost of holding inventories in fixed blood collection units, cost of holding inventories in the main blood centers, cost of the shortage in hospital demand, and cost of the expiration of blood products. In Eq. 2, the second objective function seeks to maximize the reliability of the main blood centers and fixed blood collection units by maximizing the average sum of the blood products sent from these centers to the demand points. Constraint (3) shows that a maximum of one mobile blood collection unit can stop at each candidate location in each period. Constraint (4) states that a mobile blood collection unit cannot be moved from the place where it has never belonged to it. Constraint (5) holds that blood donor groups cannot be assigned to locations with no blood collection unit. In constraint (6), mobile blood collection units are not allowed to receive blood from donor groups to which they are not assigned. However, constraint (7) allows fixed blood collection units to receive blood only from the donor groups to which they are assigned. The maximum capacity of blood donation by donor groups is shown in constraint (8). Constraints (9) and (10) prevent the allocation of donor groups to mobile and fixed blood collection units outside the geographical area of service. Constraint (11) states that each blood collection unit can refer its blood to a maximum of one main blood center in each period. Fixed blood collection units are not allowed to send blood to the main blood centers to which they are not assigned; this is done by constraint (12). In other words, fixed blood collection units can send blood only to the main blood centers to which they are assigned. Constraint (13) also specifies the maximum rate of the blood returned from fixed blood collection units to the main blood center. The blood inventories of the fixed blood collection units and the main blood centers at the end of each period are shown in constraints (14) and (15) respectively. Constraint (16) calculates the demand level for hospitals. Constraints (17) to (19) show the capacity of mobile blood collection units, fixed blood collection units, and main blood centers respectively. Ultimately, the type and the possible values of the decision variables of the proposed mathematical model are shown by constraints (20) and (21).

Solution methods

In many real-world decision problems, the number of objectives is higher than one. The objectives conflict together in many cases; therefore, optimizing one objective function makes at least one other objective function deviate from its ideal value. For example, in an optimization problem with the two objective functions of cost minimization and quality maximization, it is often impossible to provide a solution that simultaneously minimizes costs and maximizes quality. In such cases, the use of multi-objective decision-making methods is recommended ([21] ; [38] ; [1] ; [4]). These methods turn a multi-objective problem into a single-objective one through a particular procedure. Thus, this study presents three solution methods to deal with a multi-objective problem. This section of the study is dedicated to the methods to solve the proposed model.

The improved version of the augmented ε-constraint method (AUGMECON2)

Most real-world problems are required to optimize several contradicting objectives simultaneously ([2] ; [5]). In these problems, the optimal value of one objective makes the other objectives go far from their optimal values. Generally, there are several methods for solving multi-objective models, such as the widely-used weighted sum method ([27]). This method changes multi-objective functions into single-objective ones and provides a Pareto optimal solution set. Another effective method of solving a multi-objective function is AUGMECON2, which is the improved version of the augmented ε-constraint. It was introduced by [26] to create a balance among objective functions, provide non-dominated solutions and reduce the time of computation ([25] ; [26]). This is illustrated as the following equation:

$$\text{Max}\left(Z_1(x) + e \times \left(S_2 / r_2 + 10^{-1} \times S_3 / r_3 + \ldots + 10^{-(P-2)} \times S_P / r_P \right) \right)$$

subject to: (22)

$$Z_k(x) - S_k = \varepsilon_k, \qquad \forall k \in \{2, \ldots, P\}.$$

Where $Z_k(x)$ refers to the objective functions which need to be optimized, e is a small number between 10^{-6} and 10^{-3}, ε_k represents the right-hand side of each objective function, S_k is the surplus variable, and r_1, r_2, ..., r_P are the range of the parameters for objective functions. The AUGMECON2 algorithm is provided in several steps as follows:

Step 1. Creating a payoff table by lexicographic optimization;
Step 2. Calculating the ranges (r_k) and setting a lower bound (lb_k) to objective function k based on the payoff table;
Step 3. Creating the identical intervals (g_k) by dividing the k^{th} objective function range;
Step 4. Obtaining the right-hand side of the associated constraint of the specific objective function using $\varepsilon_k = lb_k + i_k \times step_k$, where i_k is the k^{th} objective function counter and $step_k$ is calculated using $step_k = r_k / g_k$;
Step 5. Solving the problem;
Step 6. Checking the S_k associated with the innermost objective function for each iteration using the bypass coefficient, $b = \text{int}(S_k / step_k)$. When S_k is greater than $step_k$, the same solution is set for the next iteration with the only difference being a surplus variable. This makes the iteration redundant; therefore, it can be bypassed, whereas no new Pareto optimal solution is generated;
Step 7. Obtaining a Pareto set based on the number of bypasses and grid points.

Unscaled goal programming

Goal programming is a popular way to solve multi-objective optimization problems. It was presented first by [10] . Nowadays, goal programming is conducted by many researchers to solve various problems such as renewable energy production ([45]), portfolio management ([8]) and supply chain management ([39]). The method seeks to find a solution to minimize the differences between the objective functions and their optimal values using Eq. 23:

$$\text{Min} \quad \sum_{g=1}^{p} a_g h_g (d_g^+, d_g^-)$$

Subject to: (23)

$$f_g - d_g^+ + d_g^- = f_g^* \qquad \forall g$$
$$d_g^+, d_g^- \geq 0$$

Where p is the number of the conflicting objective functions whose preference over one another is shown with parameter a_g, and d_g^- and d_g^+ represent the negative and the positive deviations of objective function g from its optimal values. Also, $h_g(d_g^-, d_g^+)$ is calculated as Eq. 24:

$$h_g(d_g^+, d_g^-) = \begin{cases} d_g^+ & \textit{for Min Problem} \\ d_g^- & \textit{for Max Problem} \\ d_g^+ + d_g^- & OW \end{cases} \tag{24}$$

In most multi-objective mathematical models, the objective functions have different scales, and the difference among their values is enormous. It may cause the objective function of the goal programming method to minimize the difference among the functions that are larger in scale. Given that in the basic mathematical model, the scales of the values in the first and the second objective functions are very different. Therefore, to solve the problem, an unscaled version of the goal programming method is used, as formulated in Eq. 25:

$$\text{Min} \quad \sum_{g=1}^{p} a_g h_g(d_g^+, d_g^-)$$
$$\text{Subject to:} \tag{25}$$
$$\frac{f_g}{f_g^*} - d_g^+ + d_g^- = 1 \qquad \forall g$$
$$d_g^+, d_g^- \geq 0$$

Modified Weighted Chebyshev

Another method of solving multi-objective problems is modified Chebyshev. It is based on a precise procedure to find Pareto optimal solutions ([22] ; [23] ; [37] ; [31] ; [24]). The problem solving in this method occurs through the following equation:

$$\text{Min} \left\{ \eta + \omega \sum_{i=1}^{r} \left(\frac{z_i - z_i^*}{z_i^*} \right) \right\}$$
$$\text{Subject to:} \tag{26}$$
$$y_i \left(\frac{z_i - z_i^*}{z_i^*} \right) \leq \eta \qquad \forall i = 1, \dots, r$$
$$u \in S$$

Where η is a free variable and ω is a parameter that takes small positive values. Besides, the preference of the objective function r is determined using the weighting factor y_i, hence $\sum_{i=1}^{r} y_i = 1$.

Numerical results

Consider a blood supply chain that seeks to minimize the total network costs and simultaneously maximize the reliability of blood centers. In order to evaluate the proposed mathematical model and the solution methods for this blood supply chain, first, the corresponding indicators are defined. In this regard, there are three indicators to consider, including the values of the objective functions calculated by each proposed method of executing the model and the time elapsed by that method (CPU time). Then, the proposed methods are compared through different numerical examples, as reported in Table 2.

Table 2. Numerical examples generated for the mathematical model

Example	*i*	*n*	*m*	*u*	*j*	*h*	*t*
1	5	3	5	3	2	6	30
2	8	4	9	4	1	6	30
3	10	5	10	5	2	10	60
4	8	3	9	3	3	13	41
5	13	6	10	3	2	11	30
6	12	6	12	4	1	14	52
7	11	7	10	4	1	10	50
8	7	3	15	5	3	16	45
9	10	6	9	3	1	15	58
10	8	4	8	6	2	17	59
11	13	5	9	3	1	15	43
12	11	8	12	3	2	16	51
13	9	5	16	3	1	16	34
14	10	2	8	6	2	6	80
15	8	3	14	5	1	13	52
16	11	4	11	3	3	10	36
17	12	5	15	3	1	14	38
18	11	5	8	3	2	8	30
19	9	6	8	5	3	7	33
20	11	7	9	4	2	11	60

The rate of transferring the blood received from fixed blood collection units to the main blood centers (w) is considered to be 0.4. Furthermore, the inability of the main blood centers and fixed blood collection units to send blood products to hospitals (α_{jt} and α_{ut}) is considered to be based on a uniform distribution between 0.02 and 0.05 for both types of centers. The other parameter values used in these numerical examples are reported in Table 3, all of which are based on a uniform distribution. In addition, the initial conditions required for the modified weighted Chebyshev method are assumed to be $y_1 = 0.4$ and $y_2 = 0.6$. The results of the modified weighted Chebyshev, unscaled goal programming, and the improved version of ε-constraint (AUGEMCON2) methods are collected in the numerical examples produced in Table 4. It should be noted that the GAMS software and a personal computer with Intel Core i7 6700 HQ specification (16 GB RAM) has been used to solve the model. Besides, the Pareto solutions set is shown in Fig. 2.

Table 3. The parameter values used in the numerical example of the model

Parameter	Value	Parameter	Value
CM_{ment}	~U(500, 900)	CE_{ht}	~U(6, 9)
MCa_{it}	~U(9000, 15000)	$HC2_{ut}$	~U(1.5, 3)
$CO1_{mnt}$	~U(3, 6)	$HC1_{jt}$	~U(1.5, 3)
$CO2_{ut}$	~U(3, 6)	D_{ht}	~U(100, 700)

$CO3_{jt}$	~U(4, 8)	Ca_n	~U(900, 1900)
$CS1_{mnjt}$	~U(1, 3)	Ca_u	~U(120000, 130000)
$CS2_{ujt}$	~U(1, 3)	Ca_j	~U(150000, 170000)
$CS2_{uht}$	~U(2, 6)	$d1_{im}$	~U(50, 350)
$CS3_{jht}$	~U(2, 6)	$d2_{iu}$	~U(50, 350)
LC_{ht}	~U(6, 9)	md	~U(50, 300)
$CT2_{ut}$	~U(0.75,2.5)	$CT1_{jt}$	~U(0.75,2.5)
BN	10000000		

Table 4. Results of performing the numerical examples on the model

Example	**Modified weighted Chebyshev**			**Unscaled goal programming**			**The improved version of ε-constraint (AUGEMCON2)**		
	Z_1 (MU)	**Z_2 (MU)**	**Time (Second)**	**Z_1 (MU)**	**Z_2 (MU)**	**Time (Second)**	**Z_1 (MU)**	**Z_2 (MU)**	**Time (Second)**
1	7799075	3951	1.137	7794253	3353	1.033	7814749	3703	1.057
2	2399371	55217	1.584	2379322	54918	1.547	2543548	55548	1.556
3	28743360	121123	16.757	28096140	119810	11.02	28841680	120960	11.069
4	26444340	37193	7.114	26416860	35773	4.032	26777040	37449	7.999
5	11474440	40307	26.505	11396660	37434	8.111	11359800	40506	12.704
6	52214630	37924	10.909	51992650	34277	7.938	52027300	34359	7.68
7	16783070	130918	124.003	15797020	122155	7.583	14833460	128854	17.23
8	47277670	57787	1006.71	41420800	47301	26.626	40594520	51210	57.275
9	43321640	93198	80.228	42832040	90838	21.475	43012190	92850	36.825
10	64992390	112433	14.853	63187460	111894	11.402	63749920	113167	10.935
11	34954250	47815	6.568	34838950	44649	5.332	34535120	46130	5.2
12	39412040	133293	198.815	38339090	133026	16.099	38341530	133033	15.434
13	119605200	12152	12.956	119563500	9983	12.662	119563600	10027	12.762
14	10894690	156425	42.257	10797580	154067	24.241	14728450	158320	30.664
15	34547540	96494	7.7	33835380	96436	6.417	34254630	97185	6.115
16	7639785	89050	1003.48	7570895	88698	44.28	8003258	89839	1003.684
17	14628710	108865	5.961	14334660	107874	5.778	14748440	108503	5.628
18	5366930	52745	15.644	5326427	51650	5.74	5684550	53174	7.121
19	9453089	21751	9.182	9406150	20456	3.459	9285299	21745	4.774
20	32908920	110288	205.366	32797870	105476	34.691	32130080	108924	66.738
Average	**30543057**	**75946.45**	**139.8862**	**29906185.35**	**73503.4**	**12.9733**	**30141458.2**	**75274.3**	**66.1225**

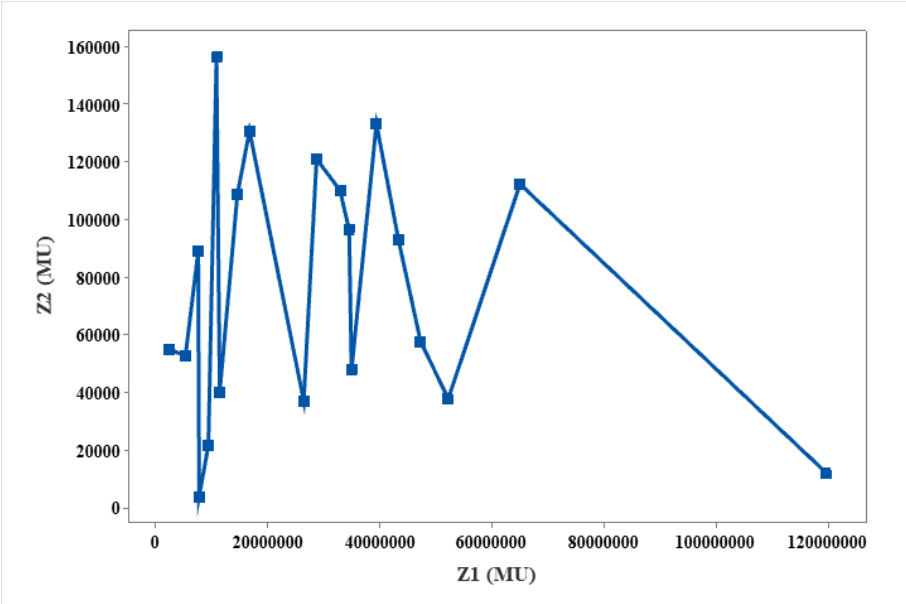

Fig. 2. the Pareto solutions set

Statistical analysis

The Tukey method has been used to analyze the results of the three solution procedures, compare them together and resolve the first mathematical model. This method often serves to compare more than two samples, and it performs well by comparing pairs of mean averages ([28]). Considering the confidence level of 95%, the three proposed solutions are statistically compared for all the three defined evaluation indicators. In each comparison, the zero assumption (H0) is equality of the mean of the proposed solution methods' outcomes. The opposite assumption (H1) seeks to reject this assumption by claiming that at least one of the means is not equal to the others. This hypothesis test is performed for all the three specified indicators, i.e., the values of the first and the second objective functions as well as the CPU time. The results of this test, performed with the Minitab 19 software, are presented in Table 5.

As the table suggests, considering that the P-value for the indices of the first and the second objective functions is higher than the significant level (0.999 > 0.05 for the first function and 0.976 > 0.05 for the second function), the null hypothesis regarding the first and the second indicators is accepted. It means that, based on the confidence level of 0.95 and according to the first and the second objective function values, there is no significant difference among the results obtained from the three proposed solution methods. The zero assumption about the CPU time index is also rejected. According to Table 5, the *P-value* of 0.045, which is less than 0.05, denotes the rejection of the null hypothesis.

Table 5. Results of the statistical hypothesis test for the proposed indicators

	Source	Degree of freedom	SS	MS	P-Value
The first OBJ	Behavior	2	1.72E+12	8.58E+11	0.999
	Error	87	5.16E+16	5.94E+14	
	Total	89	5.16E+16		
The second OBJ	Behavior	2	115246272	57623136	0.976
	Error	87	2.02275E+11	2324997591	
	Total	89	2.02390E+11		
CPU time (s)	Behavior	2	200433	100217	0.045
	Error	87	2703854	31079	
	Total	89	2904287		

The best solution method

Based on the results of the numerical examples and the statistical tests of comparison, it is not possible to determine a superior solution method in terms of all the three criteria. Hence, the VIKOR technique is applied for this purpose. This technique is a practical one for decision-making problems with non-compliant criteria ([32] ; [36] ; [3]). Since the ranking of the criteria depends on their weight, the VIKOR technique is quite responsive. The results of implementing the technique are reported in Table 6. As it turns out, the improved version of ε-constraint (AUGEMCON2) performs the best in most of the examples.

Table 6. Results of implementing the VIKOR technique

Example	W1	W2	W3	Best algorithm
1	0.40	0.30	0.30	The improved version of ε-constraint (AUGEMCON2)
2	0.35	0.35	0.30	The improved version of ε-constraint (AUGEMCON2)
3	0.45	0.20	0.35	The improved version of ε-constraint (AUGEMCON2)
4	0.35	0.25	0.40	Modified Weighted Chebyshev
5	0.25	0.50	0.25	Modified Weighted Chebyshev
6	0.30	0.40	0.30	Unscaled goal programming

Analysis of sensitivity

To evaluate the effect of the variations in the main parameters of the model on the results of the objective functions, a sensitivity analysis is performed in this section. Based on the results of the VIKOR technique, the improved version of the ε-constraint (AUGEMCON2) method has already been selected as the best method. So, the sensitivity analysis is performed using this method. The outcome of the analysis is indicated in Fig. 3. In the first step, the effect of the change in the objective functions is analyzed based on certain changes made in the MCa_{it}, md, Ca_n and w parameters. As the values of these parameters are changed for 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40%, the following results are obtained:

- ✓ According to the diagrams in Fig. 3a, an increase in the value of MCa_{it} parameter leads to a decrease in the first objective function. It increases the value of the second objective function as well. This means that the more blood is donated in each period, the greater the reliability of the blood centers and the lower the costs of the entire chain;
- ✓ An increase in the value of md parameter for 5% raises the first objective function but decreases the second objective function, as compared to their initial values. At the other rates of increase, however, it reduces the first objective function and increases the second one, as compared to their initial values (Fig. 3b);
- ✓ An increase in the value of Ca_n parameter for 5% increases the first objective function, but, at the other rates of increase, it decreases this function. Also, an increase in the value of this parameter at all the rates leads to a rise in the second objective function. These effects are shown in the diagrams of Fig. 3c;
- ✓ As the diagrams in Fig. 3d demonstrate, an increase in the value of parameter w at the rates of 15% and 40% decreases the value of the first objective function and increases that of the second one. At the other rates of increase, however, it leads to a rise in the first objective function but a reduction in the second one.

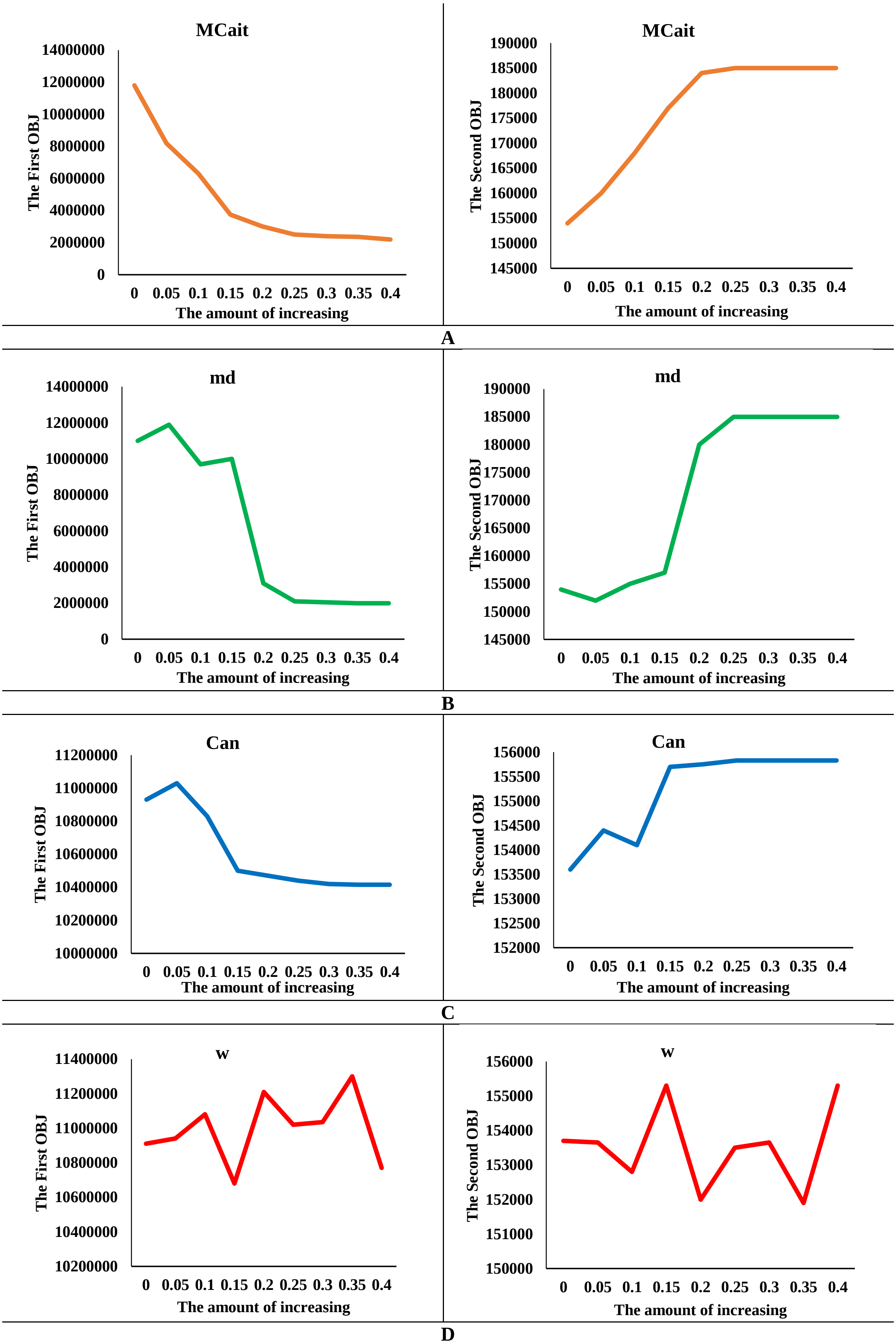

Fig. 3. Reaction of the objective functions to the changes in parameters MCa_{it}, md, Ca_n and w

Managerial insights

As a vital element in human life, blood is an issue that can be very valuable to address. Despite all efforts to find an alternative to blood, there is still no suitable alternative. It means that the only way to supply the blood needed by a patient in need is to receive it from another human body and inject it into the patient's body which involves various processes. Initially, the donor goes to a blood donation center to donate blood. Next, the whole blood received is sent to the relevant laboratories to be converted into blood products and consumed. Finally, the produced blood products are distributed to hospitals and demand centers to be injected into the needy bodies. Given that all the processes mentioned concerning blood are related to each other in a series, it can be examined in supply chain management. Analyzing the blood in the form of a supply chain network helps managers to manage it more easily. It should also be noted that blood supply chain management has fundamental differences from most supply chains mentioned in this manuscript, and managers can pay special attention to it. Making appropriate decisions to collect and receive blood from donors to reduce the risk of not having a complete blood supply is essential that managers can consider and manage using the concept of the supply chain. In addition, excessive blood donation from donors and excess demand for blood products may lead to blood loss and increased costs. On the other hand, a lack of blood products when needed may lead to the loss of patients' lives. All in all, it can be concluded that by using the blood supply chain, managers can prevent the loss of this valuable substance to a great extent and have more control over the consumption or loss of this helpful substance.

Conclusion and recommendations for future research

This study dealt with a supply chain network design problem. Since most of the individual pieces of research in the field of blood resource management have failed to comprehensively examine the major levels in a blood supply chain, the present study undertook the designing of an appropriate blood supply chain network through a different mathematical model. The model accounted for perishability and shortage as two important indicators in the blood supply chain. It also involved two objective functions to minimize the costs of the chain and, at the same time, maximize the average amount of the blood sent from blood centers to hospitals. The problem was examined in the case of a single product. The modified weighted Chebyshev method, unscaled goal programming and the improved version of ε-constraint (AUGEMCON2) were practiced to solve the model. Three indicators, including the values of the two objective functions and the CPU time of the mathematical model, were adopted to evaluate the proposed solution methods, and the model was performed in 20 different numerical examples. The Tukey test was used to statistically compare the three solution methods based on the evaluation indicators. In this test, the equality of the mean values of the numerical examples obtained through all the three proposed solution methods was considered as a null hypothesis. The inequality of at least one of them with the other methods was considered as the opposite hypothesis. The null hypothesis concerning the indices of the objective functions was accepted through the statistical hypothesis test. This means that there was no significant difference among the answers generated in the three solution methods. However, the hypothesis was rejected about the CPU time index, meaning that there was a significant difference between the mean solution times of the three proposed methods. Then, to select the superior method, the VIKOR technique was used; the improved version of ε-constraint (AUGEMCON2) was selected as the best method. Finally, several sensitivity analyses were performed to investigate the reaction of the objective functions to the changes in the model parameters.

Certain recommendations may be taken in future attempts to develop supply chain models. First, uncertainty can be added to models and specific techniques may be used to deal with it, such as fuzzy decisions and scenarios. Secondly, the possibility of using alternative blood groups may be examined for injection into those who need them. Thirdly, heuristic or meta-heuristic approaches can be used to solve mathematical models, especially in large dimensions, and to assess their efficiency in all sizes. Finally, the mathematical model proposed in this study is suggested to be implemented in a real case study to ensure the accuracy of the obtained results according to the selected case. Another important topic that many researchers have considered in recent years is environmental pollution caused by the activities of supply chain components. In supply chains, various factors affect the increase of environmental pollutants, one of the main of which is pollution caused by transportation. Given that the transport of blood and blood products is one of the main components of the blood supply chain, the blood supply chain study under environmental considerations can be significant.

References

[1] Abdolazimi, O., & Abraham, A. (2020). Designing a multi-objective supply chain model for the oil indus-try in conditions of uncertainty and solving it by meta-heuristic algorithms.

[2] Abdolazimi, O., Esfandarani, M. S., & Shishebori, D. (2020a). Design of a supply chain network for determining the optimal number of items at the inventory groups based on ABC analysis: a comparison of exact and meta-heuristic methods. Neural Computing and Applications, 1-16.

[3] Abdolazimi, O., Esfandarani, M. S., Salehi, M., & Shishebori, D. (2020b). Robust design of a multi-objective closed-loop supply chain by integrating on-time delivery, cost, and environmental aspects, case study of a Tire Factory. Journal of Cleaner Production, 121566.

[4] Abdolazimi, O., Esfandarani, M. S., & Abraham, A. (2020d). Design of a Closed Supply Chain with regards to the Social and Environmental Impacts under Uncertainty.

[5] Abdolazimi, O., Salehi Esfandarani, M., Salehi, M., & Shishebori, D. (2020c). A Comparison of Solution Methods for the Multi-Objective Closed Loop Supply Chains. Advances in Industrial Engineering, 54(1), 75-98.

[6] Alfonso, E., Xie, X., Augusto, V., & Garraud, O. (2012). Modeling and simulation of blood collection systems. Health care management science, 15(1), 63-78.

[7] American Red Cross, (2021). Blood Components. https://www.redcrossblood.org/donate-blood/how-to-donate/types-of-blood-donations/blood-components.html. Accessed February 1, 2021.

[8] Aouni, B., Colapinto, C., & La Torre, D. (2014). Financial portfolio management through the goal programming model: Current state-of-the-art. European Journal of Operational Research, 234(2), 536-545.

[9] Bhattacharjee, S., & Ramesh, R. (2000). A multi-period profit maximizing model for retail supply chain management: An integration of demand and supply-side mechanisms. European journal of operational research, 122(3), 584-601.

[10] Charnes, A., Cooper, W. W., & Ferguson, R. O. (1955). Optimal estimation of executive compensation by linear programming. Management science, 1(2), 138-151.

[11] Dutta, P., & Nagurney, A. (2019). Multitiered blood supply chain network competition: Linking blood service organizations, hospitals, and payers. Operations Research for Health Care, 23, 100230.

[12] Fahimnia, B., Jabbarzadeh, A., Ghavamifar, A., & Bell, M. (2017). Supply chain design for efficient and effective blood supply in disasters. International Journal of Production Economics, 183, 700-709.

[13] Farahani, R. Z., Rezapour, S., Drezner, T., & Fallah, S. (2014). Competitive supply chain network design: An overview of classifications, models, solution techniques and applications. Omega, 45, 92-118.

[14] Ghare, P. M. (1963). A model for an exponentially decaying inventory. J. ind. Engng, 14, 238-243.

[15] Haghjoo, N., Tavakkoli-Moghaddam, R., Shahmoradi-Moghadam, H., & Rahimi, Y. (2020). Reliable blood supply chain network design with facility disruption: A real-world application. Engineering Applications of Artificial Intelligence, 90, 103493.

[16] Haijema, R., Van Der Wal, J., & Van Dijk, N. M. (2007). Blood platelet production: Optimization by dynamic programming and simulation. Computers & Operations Research, 34(3), 760-779.

[17] Hamdan, B., & Diabat, A. (2020). Robust design of blood supply chains under risk of disruptions using Lagrangian relaxation. Transportation Research Part E: Logistics and Transportation Review, 134, 101764.

[18] Hemmelmayr, V., Doerner, K. F., Hartl, R. F., & Savelsbergh, M. W. (2010). Vendor managed inventory for environments with stochastic product usage. European Journal of Operational Research, 202(3), 686-695.

[19] Hosseinifard, Z., & Abbasi, B. (2018). The inventory centralization impacts on sustainability of the blood supply chain. Computers & Operations Research, 89, 206-212.

[20] Hosseini-Motlagh, S. M., Samani, M. R. G., & Cheraghi, S. (2020). Robust and stable flexible blood supply chain network design under motivational initiatives. Socio-Economic Planning Sciences, 70, 100725.

[21] Hwang, C. L., & Masud, A. S. M. (2012). Multiple objective decision making—methods and applications: a state-of-the-art survey (Vol. 164). Springer Science & Business Media.

[22] Kaliszewski, I. (1987). A modified weighted Tchebycheff metric for multiple objective programming. Computers & operations research, 14(4), 315-323.

[23] Karimi-Nasab, M., Shishebori, D., & Jalali-Naini, S. G. R. (2013). Multi-objective optimisation for pricing and distribution in a supply chain with stochastic demands. *International Journal of Industrial and Systems Engineering*, *13*(1), 56-72.

[24] Khakestari, M., & Abdolazimi, O. (2020). Determine the optimal number of item groups in the werehouse based on ABC analysis within the framework of a supply chain network. Industrial Management Studies, 18(57), 307-344.

[25] Mavrotas, G. (2009). Effective implementation of the ε-constraint method in multi-objective mathematical programming problems. Applied mathematics and computation, 213(2), 455-465.

[26] Mavrotas, G., & Florios, K. (2013). An improved version of the augmented ε-constraint method (AUGMECON2) for finding the exact pareto set in multi-objective integer programming problems. Applied Mathematics and Computation, 219(18), 9652-9669.

[27] Mehrjerdi, Y. Z., & Shafiee, M. (2021). A resilient and sustainable closed-loop supply chain using multiple sourcing and information sharing strategies. Journal of Cleaner Production, 289, 125141.

[28] Montgomery, D. C. (2017). Design and analysis of experiments. John wiley & sons.

[29] Nahmias, S. (1982). Perishable inventory theory: A review. Operations research, 30(4), 680-708.

[30] Niakan, F., & Rahimi, M. (2015). A multi-objective healthcare inventory routing problem; a fuzzy possibilistic approach. Transportation Research Part E: Logistics and Transportation Review, 80, 74-94.

[31] Nurjanni, K. P., & Carvalho, M. S. (2016). Author' s Accepted Manuscript. Intern. Journal of Production Economics.

[32] Opricovic, S., & Tzeng, G. H. (2007). Extended VIKOR method in comparison with outranking methods. European journal of operational research, 178(2), 514-529.

[33] Pirabán, A., Guerrero, W. J., & Labadie, N. (2019). Survey on blood supply chain management: Models and methods. Computers & Operations Research, 112, 104756.

[34] Puranam, K., Novak, D. C., Lucas, M. T., & Fung, M. (2017). Managing blood inventory with multiple independent sources of supply. European Journal of Operational Research, 259(2), 500-511.

[35] Sarker, B. R., Jamal, A. M. M., & Wang, S. (2000). Supply chain models for perishable products under inflation and permissible delay in payment. Computers & Operations Research, 27(1), 59-75.

[36] Shishebori, D., & Jabalameli, M. S. (2013). A new integrated mathematical model for optimizing facility location and network design policies with facility disruptions. *Life Sci J*, *10*(1), 1896-1906.

[37] Shishebori, D., & Ghaderi, A. (2015). An integrated approach for reliable facility location/network design problem with link disruption. *International Journal of Supply and Operations Management*, *2*(1), 640-661.

[38] Shishebori, D., Yousefi Babadi, A., & Noormohammadzadeh, Z. (2018). A Lagrangian relaxation approach to fuzzy robust multi-objective facility location network design problem. *Scientia Iranica*, *25*(3), 1750-1767.

[39] Subulan, K., Taşan, A. S., & Baykasoğlu, A. (2015). A fuzzy goal programming model to strategic planning problem of a lead/acid battery closed-loop supply chain. Journal of Manufacturing Systems, 37, 243-264.

[40] Teimoury, E., Nedaei, H., Ansari, S., & Sabbaghi, M. (2013). A multi-objective analysis for import quota policy making in a perishable fruit and vegetable supply chain: A system dynamics approach. Computers and electronics in agriculture, 93, 37-45.

[41] Thangam, A., & Uthayakumar, R. (2009). Two-echelon trade credit financing for perishable items in a supply chain when demand depends on both selling price and credit period. Computers & Industrial Engineering, 57(3), 773-786.

[42] Van Zyl, G. J. J. (1964). Inventory Control for Perishable Commodities, Unpublished Ph. D. Dissertation, University of North Carolina, Chapel Hill, NC.

[43] Wang, W., Fung, R. Y., & Chai, Y. (2004). Approach of just-in-time distribution requirements planning for supply chain management. International journal of production economics, 91(2), 101-107.

[44] Whitin, T. M. (1957). Theory of inventory management. Princeton University Press.

[45] Zografidou, E., Petridis, K., Petridis, N. E., & Arabatzis, G. (2017). A financial approach to renewable energy production in Greece using goal programming. Renewable energy, 108, 37-51.