Applied Mathematical Modelling 112 (2022) 282–303

Contents lists available at ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

A possibilistic-robust-fuzzy programming model for designing a game theory based blood supply chain network

Peiman Ghasemi [a,*], Fariba Goodarzian [b], Ajith Abraham [c], Saeed Khanchehzarrin [d]

[a] Department of Logistics, Tourism & Service Management, German University of Technology in Oman (GUtech), Muscat, Oman
[b] Engineering Group, School of Engineering, University of Seville, Camino de los Descubrimientos s/n, Seville 41092, Spain
[c] Machine Intelligence Research Labs (MIR Labs), Scientific Network for Innovation and Research Excellence, 11, 3rd Street NW, P.O. Box 2259. Auburn, WA 98071, USA
[d] Department of Industrial Engineering, Mazandaran University of Science and Technology, Babol, Iran

ARTICLE INFO

Article history:
Received 15 April 2021
Revised 26 July 2022
Accepted 1 August 2022
Available online 5 August 2022

Keywords:
Blood supply chain network
Bi-level mixed-integer linear programming model
Game theory
COVID-19 pandemic
Mixed possibilistic-robust-fuzzy programming

ABSTRACT

This paper presents a bi-level blood supply chain network under uncertainty during the COVID-19 pandemic outbreak using a Stackelberg game theory technique. A new two-phase bi-level mixed-integer linear programming model is developed in which the total costs are minimized and the utility of donors is maximized. To cope with the uncertain nature of some of the input parameters, a novel mixed possibilistic-robust-fuzzy programming approach is developed. The data from a real case study is utilized to show the applicability and efficiency of the proposed model. Finally, some sensitivity analyses are performed on the important parameters and some managerial insights are suggested.

1. Introduction

Plasma is a vital commodity in human life that expires within 5–7 days. The shortage of this vital commodity can cause fundamental problems for human life [1,2]. The patients recovering from each type of disease usually generate permanent antibodies or antibodies [3]. To convert this fluid into a medicine, the harvested plasma and antibodies as the final product are injected into the patient's body. Today, the COVID-19 virus has spread and no country is immune to this disease [4]. Many people are quarantined in different countries across the world and in many places, special social and communication restrictions have been imposed according to the cultu aral and social status of the countries [5,6].

Pursuant to the statistics, 28,706,473, 3,583,135, 2,388,417 and 1,566,081 people were infected in the United States, France, Germany and Iran, respectively, and 509,875, 84,147, 68,343 and 59,409 people were killed in the above countries by February 19, 2021, respectively [7].

One way to save the COVID-19 suffering patients is to use the blood plasma from the recovered individuals [8]. After a while, the recovered individuals-induced plasma turns out as virus-free, but it is still full of antibodies as being effective in treating critically ill patients. The antibodies or the recovered patients' generated antibodies improve the new sufferers'

* Corresponding author.
E-mail address: Peiman.Ghasemi@gutech.edu.om (P. Ghasemi).

https://doi.org/10.1016/j.apm.2022.08.003

immune system until the time the patient's immune system can generate its own antibodies [9]. These valuable antibodies are extracted by a method called plasmapheresis [10]. During the mentioned process, the whole blood is taken from the donor, then its plasma is separated and the red and white blood cells and other blood components are returned to the donor. This process takes from 30 to 45 min [11].

The recovered individuals donate their blood using both leukoreduction and normal methods. Leukoreduction is the removal of the white blood cells (or leukocytes) from the blood or blood components supplied for blood transfusion [12]. After the removal of the leukocytes, the blood product is termed as the reduced leuko. In the Leukoreduction method, after separating the plasmas from the blood, other blood components are returned to the donor's body [13]. This method is useful for the patients with platelet deficiency [14].

In the meantime, it is the duty of the government to use various advertising methods such as social networks, TV commercials, and banners to encourage the potential donors to donate blood [15]. During the COVID-19 pandemic outbreak, while maintaining social distancing, the donors can donate their blood under two situations, including non-working hours and working hours. This facilitates blood donation and keeping social distance better. The plasma supply chain network in this research consists of donors, collection centers, manufacturers, and hospitals. Government and NGOs have always been the two main players in the plasma supply chain. The NGOs are responsible for managing the collection centers and the government is in charge of managing the manufacturers and hospitals. The manufacturers are responsible for preparing the collected blood for hospitals. Therefore, the Stackelberg game is suggested to minimize the chain costs. The competition mechanism proposed in this paper attempts to point out that both the NGOs and the government communicate with each other by minimal information sharing, except their private information such as the requested demand. Therefore, the government and the NGOs do not want other players to know about their costs and profits. The NGOs and the government are faced with significant competition on the cost and might be forced to minimize the information sharing between the members of the supply chain. Therefore, the players have to decentralize their operation for security and minimal information sharing [16]. Bi-level optimization is a special kind of optimization where one problem is embedded (nested) within another. The outer optimization task is commonly known as the upper-level optimization task, and the inner optimization task as the lower-level optimization task. These problems involve two kinds of variables, termed as the upper-level variables and the lower-level variables. Bi-level optimization was first realized in the field of game theory by a German economist called Heinrich Freiherr von Stackelberg who published Market Structure and Equilibrium in 1934 that described this hierarchical problem [17]. Therefore, the proposed model is bi-level, but due to minimal information sharing (information security), we have to use the game theory approach. The designed competition mechanism determines how the two levels of the bi-level model are related.

Plasma demand increases sharply in the event of a COVID-19 outbreak [18]. Therefore, it seems necessary to consider the inherent uncertainty of demand. Then, in this study, to cope with the uncertain parameters, a mixed possibilistic-robust-fuzzy programming is developed for the first time as a significant novelty in this paper. Another important goal of this study is to calculate the amount of the produced plasma in the manufacturing centers, the amount of the received plasma from the donors, the amount of the stored inventory in the collection centers, manufacturers, and hospitals, and the amount of the perished plasma in hospitals during the COVID-19 pandemic outbreak. In our study, the donors can donate their blood under two conditions, namely, non-working hours and working hours. This facilitates blood donation and keeping social distancing better. The patients recovering from COVID-19 usually generate permanent antibodies or antibodies. To convert this fluid into a medicine, the harvested plasma and antibodies as the final product are injected into the patient's body. Therefore, in this study the types of donors have been defined based on the COVID-19 condition including the first type: the recovered donors, the second type: the recovered donors along with other diseases, and the third type: the healthy donors. The recovered donors donate blood using both leukoreduction and normal methods. The main research questions are as it follows: (1) What is the amount of blood collected and sent to each hospital? (2) What is the proposed supply chain's total cost and the utility of the donors? (3) How can information security be ensured between the members of the blood supply chain?

The rest of this paper is organized as the following: After a quick literature review in section two, the problem description and mathematical modeling are presented in the third and fourth sections. In the fifth section, the uncertainty approach is given and in the sixth section, the case study is proposed. In the seventh section, the results, sensitivity analysis and managerial insights are illustrated. Finally, the conclusion and future works are described in the last section.

2. Literature review

This section intends to review the previous papers relevant to the current paper by reviewing the literature in the field of the blood supply chain network (BSCN). Zahiri and Pishvaee designed a bi-objective blood supply chain network based on blood group compatibility. They considered two goals including minimizing the maximum unsatisfied demand and minimizing the total costs and then, proposed two novel robust possibilistic programming models to cope with uncertainty [19]. Ramezanian and Behboodi developed blood supply chain network design under uncertainties in supply and demand parameters. They used some parameters like the donors' experience factor in the blood facilities, the blood facilities' advertising budget, and the distance of blood donors from the blood facilities. Then, their goal was to maximize the motivation and utility of blood donors to donate blood through advertisement. They applied a location-allocation model to propose a mixed-integer linear programming model. In addition, they extended the aforementioned model due to the stochastic nature of cost and demand parameters to cope with uncertainty using robust optimization. They provided a real case study to evaluate the application of their model [20]. Heidari-Fathian and Pasandideh designed a green blood supply chain network by considering various sorts of blood products and their shelf life in their model as well as the uncertain nature of blood demand and supply. They formulated a multi-objective mixed-integer programming model, where they targeted the goal to minimize the total costs and the total environmental effects. They used a robust optimization method to tackle the uncertain parameters. Then, they utilized a bounded objective function approach to convert their presented multi-objective model into a single objective one. In addition, they proposed a complicated mixed-integer linear programming model and developed an approach according to the Lagrangian relaxation technique [21]. Zahiri et al. developed a bi-objective multi-stage stochastic programming method for the integrated production/screening, routing planning, allocation, and distribution problems in supply chain. Also, their main goals were to minimize the total costs and maximize freshness of the transported blood products to hospitals. A new hybrid multi-objective self-adaptive differential evolution algorithm is presented to solve their model [22]. Eskandari-Khanghahi et al. designed a sustainable supply chain network for a blood platelet bank under uncertain condition during pre/post disaster. To cope with uncertain parameters, the Me-based possibilistic approach was presented for a multi-objective and multi-period sustainable blood supply chain network. Their important goals were to minimize the total costs and the environmental aspects and to maximize the social impacts. To solve the model, Epsilon-constraint method and meta-heuristic algorithms including the simulated annealing and harmony search were used [23]. Habibi-Kouchaksaraei et al. designed a bi-objective multi-level multi-period robust blood supply chain in a disaster. Their goal was to specify the number and location of the facilities and the best strategy for allocating them under three various scenarios. Their pursued the goals to decrease the shortages of blood and the total costs. They investigated the application of the model using real data of a case study in Qaemshahr city/Iran. Finally, they utilized the Goal programming method to solve their problem [24]. Rajendran and Ravindran suggested inventory models for each player of blood supply chain network under uncertainty. Their main goal was to minimize the wastage and shortage of platelets. To deal with uncertain parameter, a stochastic approach was proposed. They used a modified stochastic Genetic algorithm to solve their model for large-size problems. To validate their model, a case study and sensitivity analysis were performed [25]. Salehi et al. developed a new robust model for the blood supply network considering a natural disaster. They considered the possibility of transfusion of one blood type and also its derivatives to other sorts according to the medical needs as a novel contribution in their optimization model. Then, their model was customized considering a possible earthquake in Tehran/Iran. Their proposed model was implemented and evaluated in a suitable way utilizing the simulation approach [26]. Rahmani designed a reliable and robust mathematical model for a dynamic emergency blood network. To control uncertain parameters, a robust optimization method was used and to protect the solution against the risk of disruptions a p-criterion approach was utilized. Moreover, in order to indicate the effect of considering disruption scenarios, a numerical example was provided extensively. The efficiency of their presented model was evaluated utilizing a series of experiment problems of different scales [27]. Larimi et al. presented a multi-objective mathematical model for blood supply chain management. Considering social announcements and blood extraction technologies have been among their contributions. Minimizing supply chain costs as well as maximizing the amount of blood delivered is one of the intended objectives. The proposed model is solved using the robust optimization approach and the results indicate that the highest number of advertisements was conducted in newspaper [28]. One of the advantages of our research over Larimi and Yaghoubi, [28], is maximizing the utility of donors. In our study, social distancing under COVID-19 conditions has also been considered. During the COVID-19 pandemic outbreak, regarding maintaining social distancing, the donors can donate their blood in two situations including non-working hours and working hours. This can prevent the spread of the COVID-19 virus at the donation centers. One of the other advantages of our study over Larimi and Yaghoubi, [28], is to take information sharing between supply chain players into account. Therefore, a Stackelberg game is offered. The competition mechanism proposed in our paper attempts to point out that both NGOs and government communicate with each other by minimal-information sharing, except their private information such as the requested demand. Ghorashi et al. formulated a multi-objective model for emergency blood supply chain management considering the blood compatibility, location, routing, and allocation decisions. Their considered network was divided into five echelons, including the collection facilities, donors, hospitals, blood centers, and laboratories. Their main goals were to decrease the total costs and time while increasing the minimum reliability of the established routes. They used a meta-heuristic algorithm to solve their model, including a new algorithm called Multi-objective Grey Wolf Optimizer which was compared with two original algorithms, i.e., Non-dominated Sorting Genetic algorithm-II (NSGA-II) and Multi-objective Particle Swarm Optimization (MOPSO). Then, different examples utilizing powerful measures were provided to evaluate the performance of the algorithms. Finally, a case study in Tehran/Iran was investigated to validate the application of their presented model [29]. Hosseini-Motlagh et al. provided stable and robust flexible blood supply chain network design under motivational initiatives. They evaluated blood supply chain network based on three interdependent challenges, including (*i*) optimizing the location and capacity decisions, (*ii*) controlling the robustness and reliability of the network under combinatorial risk, and (*iii*) the donors' motivation. They suggested motivational efforts for encouraging blood donors using an augmented Data Envelopment Analysis (DEA) model to determine the most efficient candidate locations. Additionally, they formulated a mixed-integer programming model by considering the capacity and location decisions simultaneously. To cope with the uncertain parameters, they developed a new mixed stochastic-possibilistic flexible robust programming [30]. Wang and Chen studied blood supply network optimization based on disasters. They presented a two-stage robust optimization model. According to their model, they described the uncertain distributions of blood demand by a moment-based ambiguous set to optimize relief activities and blood inventory prepositioning together. To solve their intractable model with integer recourse, they developed an approximate way to convert it into a semidefinite program. They provided a real case study according to the Longmenshan fault in China. Also, they confirmed that their proposed method outperforms typical benchmarks containing stochastic, robust, deterministic programming [31]. Haghjoo et al. presented a reliable blood supply chain network with facility disruption. They proposed a dynamic robust allocation-location model under uncertainty under a disaster situation and facility disruption risks. To tackle the inherent uncertain parameters, a scenario-based robust method was suggested. They used two meta-heuristic algorithms, including the invasive weed optimization and the self-adaptive imperialist competitive algorithms to solve their model. Finally, they validated their model based on several numerical instances [32]. Khalilpourazari et al. presented a model for managing the blood supply chain during a disaster. The most important objectives of their study included minimizing the costs and supply chain risk along with minimizing the unsatisfied demand. Location, flow monitoring, and inventory control were among their model decisions. The proposed model was solved using the Lexicographic weighted Tchebycheff approach [33]. Moslemi et al. presented a sustainable mathematical model for pharmaceutical supply chain management. The main purpose of the research was to minimize the supply chain costs. The Anderson Peterson Network Data Envelopment Analysis (AP-NDEA) was used to evaluate the effectiveness of the proposed model. The results indicated the Neuro-AP-NDEA model allowing for an accurate prediction and more efficient than the AP-NDEA model [34]. Kees et al. used fuzzy theory to make strategic and tactical decisions in the blood supply chain. They assumed blood supply and demand and the number of donors as a triangular fuzzy number and customized their model for a real study for Bahía Blanca city in Argentina [35]. Seyfi-Shishavan et al. employed fuzzy sets to model the blood supply chain in the Asian side of Istanbul. They considered the demand, supply, failure rates, costs, and the rate of usable blood as fuzzy [36]. Miller et al. used fuzzy theory for manufacturing planning. They used fuzzy triangular numbers to model the tomato packinghouse in Ruskin, Florida problem. They considered the parameters of Harvest Time, Packing Rate and Shortage Cost as fuzzy [37]. Yuan used fuzzy sets in a furniture manufacturing company to minimize cost, where the inventory costs and demand were considered as a fuzzy set [38].

The detailed specifications of the recent research cases in the field of disaster relief have been summarized Table 1.

Therefore, according to the examined literature review, the research challenges are compiled as it follows:

- Not paying attention to the design of a competitive game between the players of the plasma supply chain and the plasma therapy approach during COVID-19 pandemic outbreak.
- Most of the previous studies have focused on the numerical examples and the proposed model has not been used for a real case study, while in this paper, a real case study is suggested based on the proposed model.
- Ignoring the patients' types of diseases and their conditions during donating plasma considered in this paper for the first time.
- Overlooking the government's efforts to attract more donors through some methods such as advertising, TV, etc.
- Not paying attention to the separation of men and women to donate blood, but it has been considered in this paper.
- Considering the technologies called Blood Component Extractor (BCE) to be allocated to hospitals for the first time.

In regarding to the effective usage of fuzzy theory in managerial decision making in industries and real world, we use the fuzzy sets to cope with the uncertain parameters.

3. Problem statement

The considered supply chain includes the donors, collection centers, manufacturers, and hospitals. In this study, three types of donors have been considered, including the first type: the recovered donors, the second type: the recovered donors along with other diseases, and the third type: the healthy donors. The recovered donors donate blood using both leukoreduction and normal methods. The important point is that women cannot use leukoreduction method due to the increased rate of vasovagal reactions. Therefore, the gender of donors is also considered in the present study. The recovered donors along with other diseases need special equipment called a Blood Component Extractor (BCE) to receive blood. Due to the shortage and high costs of this technology, a limited number of hospitals are equipped with this technology. Therefore, the recovered donors along with other diseases are not required to go to the collection centers to donate blood and of course, they should go to hospitals. Since such patients are few in number and they require special care. . Then, after taking blood from the patients for separating plasma, it is sent to the manufacturers. Eventually, the healthy donors donate at the blood collection center, but the received blood does not enter the supply chain, of course, it is used for other purposes, such as for the hemophilia patients. In the COVID-19 pandemic outbreak, most donors prefer to go to the collection center at a prearranged and reserved time. In addition, the donors are allowed to visit the centers during non-working hours. Therefore, the donors can be referred to the collection centers during working and non-working hours, both reserved and unreserved. Blood donations can be different based on age. In this paper, age-based donated blood is provided as three types: fresh, medium, and old. The fresh type of blood taken from the leukoreduction method is suitable for long-term hospitalized patients. The medium type of blood is suitable for the patients with short-term hospitalization. And finally, the old type of blood is appropriate for the COVID-19 patients requiring surgery.

Fig. 1 depicts the proposed the structure of the blood supply chain network (BSCN). This chain has two players, including the blood donors and the collection centers (the first player as the NGOs) and the manufacturers and the hospitals (the second player as the government). The manufacturers are responsible for preparing the collected blood for the hospitals. It should be noted that non-governmental organizations are in charge of collecting the donated blood. The government

Table 1
A review of literature on disaster relief.

Author	Number of objective functions (Single/ Multi Objective-(SO)/(MO), Bi-level (Bi))	Type of objective functions (Cost (C)/ Humanitarian (H))	Cooperative(C)/ Non-cooperative game (N)	Planning horizon (Static-(S), Dynamic (D))	Data type (Deterministic (D), Uncertain (U))	Uncertainty sources (Demand (D)/ Production cost(P)/ Transportation cost(T))	Optimization method (Deterministic (DtO)/ Stochastic (StO)/ Scenario (Sc)/ Robust (Ro), FuzzyOptimization (F))	COVID-19 condition	Model characteristic			
									Donors' utility	Blood Component Extractor	Donor attraction methods	Types of donors
Zahiri and Pishvaee, [19]	MO	CH	-	D	U	D	F	-	-	-	-	-
Ramezanian and Behboodi, [20]	SO	C	-	S	U	D	StO	-	-	-	-	-
Heidari-Fathian and Pasandideh, [21]	MO	CH	-	D	U	D	Ro	-	-	-	-	-
Zahiri et al. [22]	MO	CH	-	S	U	DP	StO	-	-	-	-	-
Eskandari-Khanghahi et al. [23]	MO	CH	-	D	U	DPT	F	-	-	-	-	-
Habibi-Kouchaksaraei et al. [24]	MO	CH	-	D	U	D	Ro	-	-	-	-	-
Rajendran and Ravindran, [25]	MO	CH	-	D	U	D	F	-	-	-	-	-
Salehi et al. [26]	SO	C	-	D	U	D	Sto	-	*	-	-	-
Rahmani, [27]	SO	C	-	D	D	DT	Ro	-	-	-	-	-
Ghorashi et al. [29]	SO	C	-	D	U	D	Ro	-	-	-	-	-
Larimi and Yaghoubi [28]	MO	CH	-	D	U	D	Ro	-	-	*	*	*
Hosseini-Motlagh et al. [30]	SO	C	-	D	U	DT	Ro	-	*	-	-	-
Wang and Chen, [31]	Bi	CH	-	S	U	D	Ro	-	-	-	-	-
Haghjoo et al. [32]	SO	C	-	D	U	D	Sc	-	-	-	-	-
Khalilpourazari et al. [33]	MO	CH	-	D	D	-	DtO	-	-	-	-	-
Moslemi et al. [34]	MO	CH	-	D	U	D	F	-	-	-	-	-
Our paper	Bi	CH	N	D	U	DPT	F,Ro	*	*	*	*	*

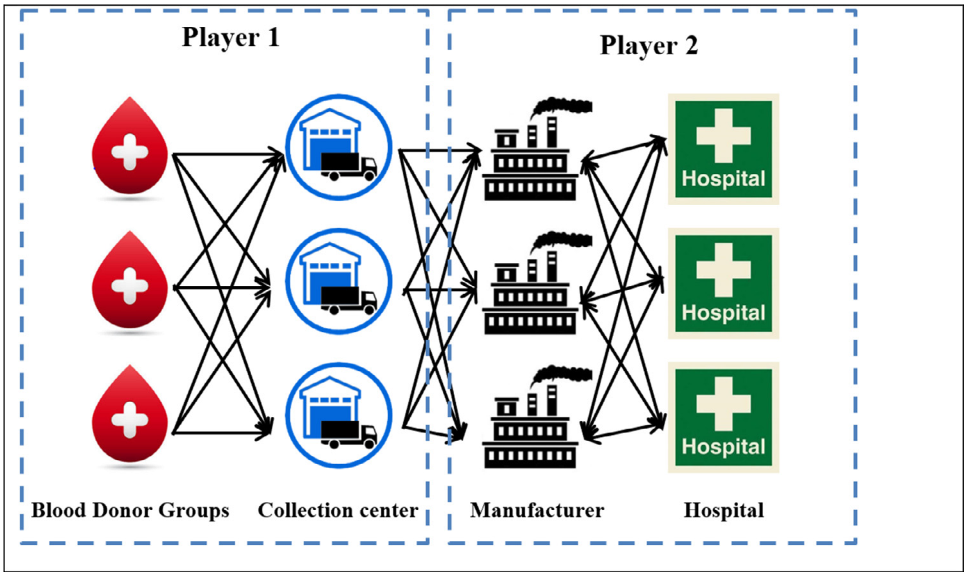

Fig. 1. . The framework of the blood supply chain network.

conduct local propaganda and calls to attract more plasma of the recovered individuals. These ads use social networks, TV commercials, and banners in the city. This can encourage the reserved and unreserved donors. Therefore, in the proposed mathematical model, the effect of various government advertisements on attracting donors is considered. Another point is to consider a Stackelberg competition between the players. The donors try to increase their utility while the government makes efforts to reduce the chain costs as much as possible.

The main and the important purpose of the current study is to calculate the amount of the produced plasma in the manufacturing centers and the amount of the received blood from the donors under the COVID-19 pandemic outbreak. Additionally, controlling the inventory in the manufacturing centers s and the hospitals and calculating the amount of the expired blood in the hospitals are performed in this paper. The contributions of this paper are stated as the following:

- Considering a competitive game between the government and the NGOs and designing a custom competition mechanism for the problem of plasma collection under the outbreak of COVID-19,
- Customizing the designed mathematical model for a case study in Mazandaran Province/ Iran,
- Providing the types of donors containing the first type: the recovered donors, the second type: the recovered donors along with other diseases, and the third type: the healthy donors,
- Considering various types of advertisements, including social networks, TV commercials, and banners to attract more donors,
- Separating men and women for blood donation and also considering leukoreduction and normal methods for those who have recovered among the COVID-19 patients,
- Employing Blood Component Extractor (BCE) along with allocating it to the hospitals,
- Suggesting a new mixed possibilistic-robust-fuzzy programming to tackle the uncertain parameters.

4. Mathematical modeling

In this section, the suggested model's assumptions are stated. Moreover, the indices, the parameters, the variable decisions, and the formulation of the BSCN problem are discussed below.

4. 1 Assumption

The study assumptions are explained as it follows:

- The cost of wastage is the same for all ages,
- Due to the special circumstances of the COVID-19 outbreak, the donors can donate blood, both reserved and unreserved,
- The government is conducting local propaganda and calling to attract more plasma of the recovered individuals. These ads use social networks, such as TV commercials, and banners in the city,
- Blood donors are divided into three categories, including (*i*) the recovered donors, (*ii*) the recovered donors along with other diseases, and (*iii*) the healthy donors,
- The recovered donors donate blood using both leukoreduction and normal methods.

4.2. Indices, parameters, and decision variables

Indices	Description
O	Set of donors indexed by o
I	Set of collection center indexed by i
L	Set of manufacturers indexed by l
H	Set of hospital indexed by h
B	Set of advertisement indexed by b
G	Set of gender indexed by g, $g = 1$ man, $g = 2$ woman
A	Set of the age of plasma indexed by a
T	Set of time periods indexed by t
K	Set of method indexed by k, $k = 1$ normal, $k = 2$ leukoreduction
Parameters	*Description*
α_o	1, if donor o be recovered donor; 0, otherwise
β_o	1, if donor o be recovered donors along with other diseases; 0, otherwise
δ_o	1, if donor o be healthy donor; 0, otherwise
ρ_o	1, if donor o be unreserved donor; 0, otherwise
ϑ_o	1, if donor o donate blood at working time; 0, otherwise
γ_{oit}	1, if donor o ($\alpha_o = 1$ *or* $\delta_o = 1$) donate blood to the collection center i at the period t; 0, otherwise
γ'_{oht}	1, if donor o ($\beta_o = 1$) donate blood to hospital h at the period t; 0, otherwise
μ_{it}	Level of the effectiveness of collection center i at the period t and μ_i belongs to [0,1]
Φ_{ot}	Donor o willingness to receive money at the period t $\Phi_\mathrm{ot} > 0$
$\widetilde{pc''}_{ht}$	The cost of collection one blood unit that taken from a second type donor in hospital h at the period t
$\widetilde{pc}_{lt}$	The cost of producing one plasma unit by the manufacturer l at the period t
$\widetilde{pc'}_{itk}$	The cost of collection one blood unit by collection center i at the period t using method k.
cn_{ilt}	The cost of purchasing and transporting a unit of blood from an unreserved donor from the collection center i to manufacturer l at the period t for working hours
cr_{ilt}	The cost of purchasing and transporting a unit of blood from an unreserved donor from the collection center i to manufacturer l at the period t for non-working hours
cz_{lt}	Start-up cost in manufacturer l at the period t
cp_{ht}	Cost of corruption in hospital h at the period t
cp'_{lt}	Cost of corruption in manufacturer l at the period t
cs_{ht}	Cost of shortage in hospital h at the period t
ca_b	Cost of advertising type b
cm'_{lt}	The holding cost a plasma unit in the manufacturer l at the period t
$\widetilde{cm}_{ht}$	The holding cost a plasma unit in hospital h at the period t
ct'_{hlt}	The cost of transporting a unit of blood from hospital h to manufacturer l at the period t
ct_{lht}	The cost of transporting a unit of plasma from manufacturer l to hospital h at the period t
cb_{ht}	Cost of BCE allocation in hospital h at the period t
cw_{it}	The cost of overtime at the collection center i at the period t
ck_k	The cost of using method k
N	Maximum number of available BCE
u_{ht}	Plasma storage capacity in hospital h at the period t
u'_{lt}	Plasma storage capacity in manufacturer l at the period t
u''_{it}	Total capacity of donors at the collection center i during working hours at the period t
u'''_{it}	Total capacity of donors at the collection center i during non-working hours at the period t
cap_{lt}	Capacity of produce plasma at manufacturer l at the period t
ra_b	Attraction rate of donors for advertising type b
sf_{aht}	Amount of plasma confidence inventory with stored age a in hospital h at the period t
ob_{gt}	The amount of blood unit taken from a donor with gender g to produce a unit of plasma at the period t
ro_{it}	The number of reserved and unreserved recovered donors at collection center i at the period t
$\tilde{D}_{ht}$	Plasma demand in hospital h at the period t
sn_{ht}	The number of second type donors that enrolled in hospital h at the period t
M	A big number
Decision variables	*Description*
bed_{it}	The number of empty beds in the collection center i for unreserved donors at the period t
b^a_{ht}	1, If hospital h at the period t has to use the confidence reserve with age a; 0, otherwise
q^l_t	1, If plasma are produced in the manufacturer l at the period t; 0, otherwise
w^{og}_{itk}	1, If unreserved donor o with gender g are registered at collection center i at the period t using method k; 0, otherwise
y_h	1, If BCE is assigned to hospital h; 0, otherwise
z^a_{lt}	Inventory of plasma with age a in manufacturer l at the period t
z'^{a}_{ht}	Inventory of plasma with age a in hospital h at the period t
s^a_{lht}	Fraction of maximum demand for plasma with age a delivered from manufacturer l to hospital h at the beginning of period t

(continued on next page)

Indices	Description
sh^a_{ht}	The amount of plasma shortage with age a in hospital h at the period t
o^g_{it}	The number of registered unreserved donors with gender g in the collection center i during working hours of period t
o'^g_{it}	The number of registered unreserved donors with gender g in the collection center i during non-working hours of period t
o''^g_{itb}	The number of unreserved donors with gender g in the collection center i at the period t has been attracted to type b advertisements
v^g_{ilt}	The total amount of prepared blood from donors with gender g in the collection center i that transferred to manufacturer l at the period t
av_{itb}	The number of donors attracted by type b advertisements in the collection center i at the period t
$av_{htb}prime$	The number of donors attracted by type b advertisements in the hospital h at the period t
ck^{hl}_t	The number of transferred bloods from hospital h to manufacturer l at the period t
ba_{ght}	The number of produced bloods by a second type donor with gender g in hospital h at the period t
ex^l_t	The number of expired plasma in the manufacturer l at the period t
$ex_{ht}\,prime$	The number of expired plasma in hospital h at the period t
ml^{gl}_t	The amount of produced plasma from gender g in manufacturer l at the period t

The relationship between the parameters is in the form of (1) to (3) as depicted below:

$$ro_{it} = \sum_o \alpha_o.\gamma_{oit}, \ \forall i, t \tag{1}$$

$$\alpha_o + \ \delta_o + \beta_o = 1, \ \forall o \tag{2}$$

$$sn_{ht} = \sum_o \beta_o.\gamma'_{oht}, \quad \forall h, t. \tag{3}$$

4.3. Formulating BSCN model

(I) Upper Model

$$\begin{aligned} \mathrm{Min} f_1 = & \sum_{l,t} q^l_t \cdot cz_{lt} + \sum_{a,l,t} z^a_{lt} \cdot \mathrm{cm}_{lt}\,prime + \sum_{a,h,t} z'^a_{ht} \cdot cm_{ht} + \sum_{a,h,t} sf_{aht} \times \left(1 - b^a_{ht}\right) \cdot cm_{ht} \\ & + \sum_{a,h,t} sh^a_{ht} \cdot cs_{ht} + \sum_{l,t} ex^l_t \cdot cp_{lt}\,prime + \sum_{h,t} ex_{ht}\,prime \cdot cp_{ht} + \sum_{a,h,l,t} s^a_{lht} \cdot \tilde{D}_{ht} \cdot ct_{lht} \\ & + \sum_{h,l,t} ck^{hl}_t \cdot \tilde{t}t''_{hlt} + \sum_{b,h,t} av_{htb}\,prime \cdot ca_b + \sum_{l,g,t} ml^{gl}_t \cdot \tilde{p}c_{lt} \\ & + \sum_{h,t} y_h \cdot cb_{ht} \end{aligned} \tag{4}$$

$$\frac{\left(\sum_i v^g_{ilt} + \sum_h ck^{hl}_t\right)}{ob_{gt}} \geq ml^{gl}_t - M.\left(1 - q^l_t\right), \ \forall l, g, t \tag{5}$$

$$\frac{\left(\sum_i v^g_{ilt} + \sum_h ck^{hl}_t\right)}{ob_{gt}} \leq ml^{gl}_t + M.(1 - q^l_t), \ \forall l, g, t \tag{6}$$

$$sh^a_{ht} \leq M.b^a_{ht}, \forall a, h, t \tag{7}$$

$$z'^a_{ht} \leq M.\left(1 - b^a_{ht}\right), \ \forall a, h, t \tag{8}$$

$$\sum_a z'^a_{ht} \leq u_{ht}, \ \forall h, t \tag{9}$$

$$z'^1_{ht} = \sum_l s^1_{lht} \times \widetilde{D_{ht}} - \widetilde{D_{ht}} + sf_{1ht}.\left(1 - b^1_{ht}\right), \forall h, t \tag{10}$$

$$z'^a_{ht} = z'^{a-1}_{ht-1} + \sum_l s^a_{lht}.\widetilde{D_{ht}} - \widetilde{D_{ht}} + sf_{2ht}.\left(1 - b^a_{ht}\right), \forall h, t, a > 1 \tag{11}$$

$$\sum_g ml^{gl}_t \leq cap_{lt}.q^l_t, \forall l, t \tag{12}$$

$$\sum_{g} ml_t^{gl} \le u'_{lt}.q_t^l,\ \ \forall l,t \tag{13}$$

$$z_{lt}^1 = \sum_{g} ml_t^{gl} - \sum_{h} s_{lht}^1 \times \widetilde{D_{ht}},\ \forall l,t \tag{14}$$

$$z_{lt}^a = z_{lt-1}^a - \sum_{h} s_{lht}^a \times \widetilde{D_{ht}}, \forall l,t \ and \ a > 1 \tag{15}$$

$$\sum_{g} ba_{ght} \le sn_{ht}, \forall h,t \tag{16}$$

$$ba_{ght} \le M.y_h, \forall g,h,t \tag{17}$$

$$\sum_{l} ck_t^{hl} \le ba_{ght} \forall g,h,t \tag{18}$$

$$ex_t^l = \max\left\{0,\ z_{lt-1}^a - \sum_{h} s_{lht}^a.\widetilde{D_{ht}}\right\}, \forall a = |A|, l, t \tag{19}$$

$$ex_{ht}prime = \max\left\{0, z'^{\,a}_{ht-1} - \tilde{D}_{ht-1}\right\},$$

$$\forall h, t > 1, a = |A| \tag{20}$$

$$\sum_{h} y_h \le N, \tag{21}$$

$$av_{htb}prime = [ra_b\ .sn_{ht}],\ \ \forall h,t,b \tag{22}$$

$$ml_t^{gl},\ \ ex_t^l, ex_{ht}prime, ba_{ght}, ck_{at}^{hl},\ \ sh_{ht}^a,\ \ s_{lht}^a,\ \ z_{lt}^a, z'^{\,a}_{ht} \in integer,\ \ \forall l,g,h,t,a \tag{23}$$

$$y_h,\ \ q_t^l,\ \ b_{ht}^a\ \ \in \{0,1\}, \forall l,h,t,a. \tag{24}$$

The first objective function (4) intends to minimize the costs of the set-up and preparation, inventory, shortage, wastage, transportation, social advertising, production and BCE technology allocation. Constraints (5) and (6) calculate the amount of the produced plasma. Constraint (7) ensures that a shortage occurs when the hospital uses the confidence reserve. Constraint (8) states that if you use the confidence reserve, you won't get trapped in any regulatory storage. Constraint (9) represents the maximum storage capacity in the hospital. Constraints (10) and (11) calculate the amount of the plasma inventory in the hospital. Constraint (12) represents the maximum plasma production capacity in the factory. Constraint (13) shows the maximum storage capacity in the factory. Constraints (14) and (15) calculate the amount of the plasma inventory in the factory. Constraint (16) illustrates the maximum amount of the blood supply in the hospital. Constraint (17) states that blood is drawn in a hospital if a BCE device is installed in that hospital. Constraints (18) and (19) indicate the amount of the perished plasmas in the hospital and the factory. Constraint (20) states that the number of BCE devices is limited. Constraint (21) demonstrates the number of the donors attracted through the advertisement. Constraints (22) and (23) indicate the types of the variables.

(II) Lower Model

$$Max\ f_2 = \sum_{i}\sum_{o}\sum_{l}\sum_{g}\sum_{t} \gamma_{oit} \times \mu_{it} \times v_{ilt}^g - \left(\sum_{i}\sum_{o}\sum_{g}\sum_{l}\sum_{t} \Phi_{ot} \times v_{ilt}^g\right)^2 \tag{25}$$

$$\begin{aligned} \text{Min} f_3 = & \sum_{b,i,t} av_{itb} \cdot ca_b + \tilde{p}c_{_{itk}}prime \cdot \sum_{g,l} v_{ilt}^g + \sum_{o,g,i,t} o''^{\,og}_{it} \cdot cw_{it} + \sum_{o,g,i,l,t} o_{it}^{og} \cdot cn_{ilt} \\ & + \sum_{o,g,i,l,t} o'^{\,og}_{it} \cdot cr_{ilt} + \sum_{o,g,i,k,t} ck_k.w_{itk}^{og}, \end{aligned} \tag{26}$$

s.t.

$$v_{ilt}^g \le q_t^l \times ro_{it}, \forall i,g,l,t \tag{27}$$

$$\sum_{l} v_{ilt}^{g} = \sum_{o} (1-\rho_o).\alpha_o.\gamma_{oit} + \sum_{o,k} \rho_o.\alpha_o.w_{itk}^{og}, \quad \forall i, g, t \tag{28}$$

$$\sum_{o,k} \rho_o.(1-\vartheta_o).w_{itk}^{og} \le u'''_{it}, \forall i, t \tag{29}$$

$$\sum_{o,k} \rho_o.\vartheta_o.w_{itk}^{og} \le bed_{it}, \forall i, t \tag{30}$$

$$bed_{it} = u''_{it} - \sum_{o} (1-\rho_o).\alpha_o.\gamma_{oit} - \sum_{o} (1-\rho_o).\delta_o.\gamma_{oit}, \forall i, t \tag{31}$$

$$o_{it}^{g} = \sum_{o,k} \rho_o.\vartheta_o.(1-\beta_o).w_{itk}^{og}, \forall i, o, g, t \tag{32}$$

$$o_{it}^{'g} = \sum_{o,k} \rho_o.(1-\vartheta_o).(1-\beta_o).w_{itk}^{og}, \forall i, o, g, t \tag{33}$$

$$o_{itb}^{''g} = \left\lfloor ra_b.\sum_{o,k} \rho_o.(1-\beta_o).w_{itk}^{og} \right\rfloor, \quad \forall i, g, t, b \tag{34}$$

$$av_{itb} = \left\lfloor ra_b.(\sum_{o,k,g} (1-\beta_o).w_{itk}^{og} + \sum_{o} (1-\beta_o).\gamma_{oit}) \right\rfloor, \forall i, t, b \tag{35}$$

$$w_{itk}^{og} \le (\alpha_o + \delta_o).\ \gamma_{oit}, \forall i, o, g, t, k \tag{36}$$

$$\sum_{g,i,l} v_{ilt}^{g} \le \sum_{h} \widetilde{D_{ht}}, \forall t \tag{37}$$

$$w_{itk}^{og} = 0, \forall i, o, g = 2, t, k = 2 \tag{38}$$

$$o_{it}^{g}, o_{it}^{'g}, o_{it}^{''g}, av_{itb}, x_{bt}^{gi}, v_{ilt}^{g} \in integer, \quad \forall i, o, g, t, b, l \tag{39}$$

$$bed_{it},\ w_{itk}^{og},\ \in \{0, 1\}, \quad \forall i, o, g, t. \tag{40}$$

The objective function (25) represents maximizing the utility of donors. The first part reflects a donor's tendency to donate to a high-performance collection center. In other words, a donor seeks an NGO that uses their donations efficiently. The second part shows that donation is considered as a disadvantage. As a matter of fact, donation actually means loss of capital; therefore, it cannot be a donor's desire and is a disadvantage. The first term multiplies the amount of willingness, effectiveness and the total amount of the prepared blood. Therefore, the unit of this phrase is in terms of desirability. The second term multiplies the amount of willingness to receive money by the total amount of the prepared blood. Therefore, the unit of this phrase is in terms of negative desirability. This objective function is inspired by the research of Fathalikhani et al. [39]. Using power 2 for the second term is to show the importance of negative desirability. The second objective function (26) is to minimize advertising, collection, overtime and transportation costs. Constraint (27) represents the maximum amount of blood units from the collection center to the factory. Constraint (28) represents the total amount of blood units sent to the factories. Constraint (29) indicates the maximum capacity of the collection centers in non-working hours. Constraints (30) and (31) show the maximum remaining capacity for accepting non-reservation patients in the collection centers. Constraints (32) to (34) also calculate the number of non- reservation donors accepted in working hours and non-working hours. Constraint (35) indicates the number of the donors attracted to various advertising about the collecting centers. Constraint (36) states that the patient who has no other diseases is accepted in the collection centers. Constraint (37) shows the demand. Constraint (38) states that women cannot use the leukoreduction method. Constraint (39) and (40) indicate the types of the variables.

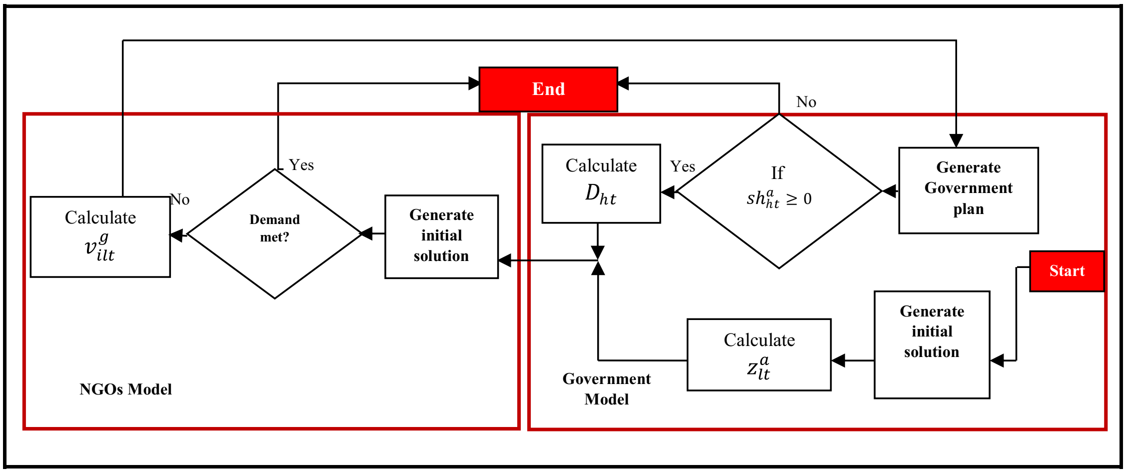

Fig. 2. The structure of the competition mechanism.

4.4. Competition mechanism

In this sub-section, the proposed Stackelberg competitive game mechanism is indicated in Fig. 2. This chain has two players, including the blood donors and the collection centers (the first player as the NGOs) and the manufacturers and the hospitals (the second player as the government). First, a feasible initial solution is calculated for the upper-level model (government). After calculating the amount of the required blood, this parameter enters the first player (NGOs) model. If the required demand is met, the game ends; otherwise, the total amount of the blood collected from the donors and transferred from the collection center to the manufacturer is calculated. Then, the required information about the amount of blood in the collection centers is entered into the government's model. At this stage, the upper-level model is executed. If you do not encounter the shortage, the game ends; otherwise the amount of the required demand is calculated and this amount is reported to the lower-level model. The game continues until the time the supply chain faces no shortage. Because the NGOs and the governments have different goals, they have to compete with each other. In fact, the NGOs avoid letting the government know about their profits and costs for various reasons, such as the taxes and so on. Therefore, in reality, an iterative mechanism is always used to solve the model.

5. Mixed possibilistic-robust-fuzzy programming model

Using fuzzy sets in decision-making is one of the most important applications of this theory compared to classical theories. In fact, this fuzzy mathematical model tries to realize the inherent ambiguity and uncertainties in the preferences, objectives, and constraints of decision-making problems in the model. In the mathematical models, it is always better for the decision to be less dependent on the binary system, because if the solution is incorrect, the error will be 100%, and this error will have a great effect on the results of the mathematical model. Therefore, using the fuzzy sets well reduce the error. In this study, although the competencies and mental abilities of experts are extracted, quantifying the views of the experts is done in a traditional manner, it is not possible to fully reflect the style of human thinking. Therefore, it is better to make decisions in the real world by fuzzy numbers. Due to the uncertain nature of real-world data, it is necessary to provide appropriate approaches for developing the mathematical programming models based on uncertain data. Because in real-world problems, a sudden change in one of the data imposes huge costs on the system and makes the solution impossible and non-optimal (Pishvaee and Torabi, [41]). Due to the nature of the data as uncertain, there are different approaches to deal with such uncertainties. Random programming is used if the input data is random, the source of uncertainty in the input data, and the probabilistic function of the parameter distribution is known. The fuzzy optimization approach is used when there is no historical data of the question parameter and as a result, no probabilistic function can be attributed to that parameter (Pishvaee and Khala, [42]). The robust programming approach, which is a new one to cope with uncertainty, seeks to provide a solution to the problem based on data uncertainty. A robust solution is justified for all uncertain parameters, and the value of its objective function has the least deviation from its optimal value. Hybrid a robust optimization approach with other uncertainty coping approaches such as fuzzy method and probabilistic technique, which leads to exploiting the strengths of different approaches. The advantages of the method presented in this paper include: (1) It can be easily modeled, (2) It can be widely used in decision control and prediction systems, (3) It is used to describe uncertain phenomena, and (4) The complexity of the problem can be reduced by hybridizing a robust approach with fuzzy and possibilistic approaches.

Due to the dynamic nature of some important parameters (including the production costs, demand, and transportation costs) whose determination is beyond planning, as well as the historical data which is required at the design stage being unavailable and unattainable, these parameters are estimated mainly based on the experts' opinions and mental experiences. Therefore, the above uncertain parameters are formulated as the uncertain data in the form of trapezoidal fuzzy numbers as it follows:

$$\widetilde{pc}''_{ht} = \left(pc''^{\,1}_{ht}, pc''^{\,2}_{ht}, pc''^{\,3}_{ht}, pc''^{\,4}_{ht}\right) \tag{41}$$

$$\widetilde{pc}_{lt} = \left(pc^1_{lt}, pc^2_{lt}, pc^3_{lt}, pc^4_{lt}\right) \tag{42}$$

$$\widetilde{pc}_{itk}prime\left(pc'^{\,1}_{itk}, pc'^{\,2}_{itk}, pc'^{\,3}_{itk}, pc'^{\,4}_{itk}\right) \tag{43}$$

$$\widetilde{ct}_{hlt}prime = \left(ct'^{\,1}_{hlt}, ct'^{\,2}_{hlt}, ct'^{\,3}_{hlt}, ct'^{\,4}_{hlt}\right) \tag{44}$$

$$\tilde{D}_{ht} = \left(D^1_{ht}, D^2_{ht}, D^3_{ht}, D^4_{ht}\right) \tag{45}$$

It is worth noting that for long-term decisions, evaluating definite demand is difficult and sometimes even impossible. Even if you can estimate a probabilistic distribution function for these parameters, they may not behave as similarly as the previous data. Moreover, the demand of each plasma in each period along with the costs of the production and transportation of a plasma unit that changes in a long-term planning horizon are considered as fuzzy data (Pishvaee et al. [43]). In addition, the possibilistic chance-constrained programming method is usually used to deal with uncertain constraints where uncertain data are left or right of constraints. If this method is used, to control the confidence level in establishing these uncertainty constraints, the concept of decision making can achieve the minimum confidence level as a suitable safe margin to establish any of such constraints (Pishvaee and Razmi, [44]). To do this, two standard fuzzy method measures are commonly applied with optimistic and pessimistic fuzzy titles. It is clear that optimistic fuzzy represents the level of optimistic probability of the occurrence of an uncertain event, including uncertain parameters, while pessimistic fuzzy shows a pessimistic decision about an uncertain event. However, it is more conservative to use a pessimistic fuzzy, i.e., we assume that the decision has a pessimistic (conservative) attitude to impose uncertain constraints. Moreover, pessimistic fuzzy action is used to ensure the imposition of uncertain constraints.

At the present time, based on the above uncertain parameters and the use of the expected value for the objective function and the pessimistic action for the uncertain constraints, the obvious equivalent of the original uncertain model can be formulated. First of all, consider the abbreviated form of the provided model:

$$Min\ z_1 = K + Rx + Hy \tag{46}$$

$$Min\ z_2 = y \tag{47}$$

$$Max\ z_3 = y \tag{48}$$

s. t.:

$$Dy \geq a \tag{49}$$

$$My \leq Bx \tag{50}$$

$$x \in \{0,\ 1\},\ y \geq 0 \tag{51}$$

where the vectors *a, R, H*, and *B* represent the variable cost, fixed cost, and demand, respectively. Also, *D* and *M* are the matrices of coefficients, and finally, variable *x* is binary while variable *y* is positive. Now it is assumed that the vectors *H* and *a* in the above model are presented as the uncertain parameters. According to the general form of the possibilistic chance-constrained programming, the expected value of the objective function and the pessimistic fuzzy are used to cope with the objective function and the uncertain constraint, respectively. Thus, based on the abbreviated form, the basic model of the possibilistic chance-constrained programming is as it follows:

$$Min\ M[z_1] = K + Rx + M\left[\tilde{H}\right]y \tag{52}$$

$$Min\ z_2 = y \tag{53}$$

$$Max\ z_3 = y \tag{54}$$

s. t.:

$$NEC\ \{Dy \geq \tilde{a}\} \geq s \tag{55}$$

$$My \leq Bx \tag{56}$$

$$x \in \{0,\ 1\},\ y \geq 0 \tag{57}$$

where s controls the minimum certainty degree of the uncertain constraint with a (pessimistic) decision-making approach. According to the trapezoidal probability distribution for the uncertain parameters, the general form of Eqs. (52) to (57) is as depicted below:

$$Min\ M[z_1] = K + Rx + \left(\frac{H^1 + H^2 + H^3 + H^4}{4}\right)y \tag{58}$$

$$Min\ z_2 = y \tag{59}$$

$$Max\ z_3 = y \tag{60}$$

s. t.:

$$Dy \geq (1-s)a^3 \geq sa^4 \tag{61}$$

$$My \leq Bx \tag{62}$$

$$x \in \{0,\ 1\},\ \ y \geq 0 \tag{63}$$

In the possibilistic chance-constrained programming models, the minimum certainty level for establishing the uncertain constraints has to be determined in terms of decision preferences. As seen, in the proposed model, the objective function is not sensitive to deviation from its expected value, which means that in the possibilistic chance-constrained programming model, achieving the robust solutions is not guaranteed. In such cases, a high risk may be imposed on the decision in many real cases, especially in strategic decisions where solution consolidation is largely critical. Therefore, to deal with this inefficient situation, a possibilistic robust approach is used for the problem (Zahiri and Pishvaee, [19]). The possibilistic robust programming approach was first introduced by Pishvaei and Torabi, [12]. This approach benefits from the significant advantages of both the robust and possibilistic programming models, which clearly distinguishes it from other uncertainty programming approaches. In this paper, the possibilistic robust programming based on the proposed model is applied, which is as the following:

$$Min\ z_1 = M[z_1] + \lambda\left(z_{1(max)} - z_{1(min)}\right) + \mu_1\left(a^4 - (1-s)a^3 - sa^4\right) \tag{64}$$

$$Min\ z_2 = y + \mu'_1\left(a^4 - (1-s)a^3 - sa^4\right) \tag{65}$$

$$Max\ z_3 = y \tag{66}$$

s. t.:

$$Dy \geq (1-s)a^3 \geq sa^4 \tag{67}$$

$$My \leq Bx \tag{68}$$

$$x \in \{0,\ 1\},\ \ y, y' \ \geq 0,\ \ o.5 < s \leq 1 \tag{69}$$

where $z_{1(max)}$ and $z_{1(min)}$ can be expressed as it follows:

$$z_{1(max)=H^4 y} \tag{70}$$

$$z_{1(min)=H^1 y} \tag{71}$$

In the first objective function of Eq. (64), the first term refers to the expected value of the first objective function using the mean values of the uncertain parameters of the model. The second term mentions the cost of the penalty for deviating beyond the expected value of the first objective function (optimization robust). Then, the third term also gives the total cost of the demand deviation penalty (uncertain parameter). Hence, parameter λ shows the weight coefficient of an objective function and μ_1 indicates the cost of the penalty for unmet demand. Parameter s represents the correction coefficients numbers in the value of fuzzy surfaces, which should be between 0.5 and 1. As a result, the general model of the fuzzy possibilistic robust approach is as depicted below:

$$Min\ \ f_1 \tag{72}$$

s.t.

$$\begin{aligned} M[f_1] = {} & \sum_{l,t} q_t^l \cdot cz_{lt} + \sum_{a,l,t} z_{lt}^a \cdot cm_{lt}prime + \sum_{a,h,t} z_{ht}^{\prime a} \cdot cm_{ht} + \sum_{a,h,t} sf_{aht} \times \left(1 - b_{ht}^a\right) \cdot cm_{ht} + \\ & \sum_{a,h,t} sh_{ht}^a \cdot cs_{ht} + \sum_{l,t} ex_t^l \cdot cp_{lt}prime + \sum_{h,t} ex_{ht}prime \cdot cp_{ht} + \sum_{a,h,l,t} s_{lht}^a \cdot \left(D_{ht}^4 - (1-s)D_{ht}^3 - \right. \\ & \left. sD_{ht}^4\right) \cdot ct_{lht} + \sum_{h,l,t} ck_t^{hl} \cdot \left(\frac{ct_{hlt}^{\prime\,1} + ct_{hlt}^{\prime\,2} + ct_{hlt}^{\prime\,3} + ct_{hlt}^{\prime\,4}}{4}\right) + \sum_{b,h,t} av_{htb}prime \cdot ca_b + \\ & \sum_{l,g,t} ml_t^{gl} \cdot \left(\frac{pc_{lt}^1 + pc_{lt}^2 + pc_{lt}^3 + pc_{lt}^4}{4}\right) + \sum_{h,t} y_h \cdot cb_{ht} + \sum_{g,h,t} ba_{ght} \cdot \left(\frac{pc_{ht}^{\prime\,1} + pc_{ht}^{\prime\,2} + pc_{ht}^{\prime\,3} + pc^{\prime\,\prime}}{4}\right) \end{aligned} \tag{73}$$

Constraints (5)–(9)

$$z'^{\,1}_{ht} = \sum_l s_{lht}^1 \times \left(D_{ht}^4 - (1-s)\ D_{ht}^3 - sD_{ht}^4\right) - \left(D_{ht}^4 - (1-s)\ D_{ht}^3 - sD_{ht}^4\right) - sf_{1ht} \times \left(1 - b_{ht}^1\right) \forall h, t \tag{74}$$

$$z_{ht}^{\prime\,a} = z_{ht-1}^{\prime\,a-1} + \sum_l s_{lht}^a . \left(D_{ht}^4 - (1-s)\ D_{ht}^3 - sD_{ht}^4\right) - \left(D_{ht}^4 - (1-s)\ D_{ht}^3 - sD_{ht}^4\right) + sf_{2ht} . \left(1 - b_{ht}^a\right), \forall h, t, a > 1 \tag{75}$$

Constraints (12) and (13)

$$z_{lt}^1 = \sum_g ml_t^{gl} - \sum_h s_{lht}^1 \times \left(D_{ht}^4 - (1-s)\ D_{ht}^3 - sD_{ht}^4\right) \forall l, t \tag{76}$$

$$z_{lt}^a = z_{lt-1}^a - \sum_h s_{lht}^a \times \left(D_{ht}^4 - (1-s)\ D_{ht}^3 - sD_{ht}^4\right) \text{Constraints } (16) - (18) \forall l, t \text{ } and \text{ } a > 1 \tag{77}$$

$$ex_t^l = \max\left\{0,\ z_{lt-1}^a - \sum_h s_{lht}^a \times \left(D_{ht}^4 - (1-s)\ D_{ht}^3 - sD_{ht}^4\right)\right\}, \forall a = |A|, l, t \tag{78}$$

$$ex_{ht}prime = \max\left\{0, z_{ht-1}^{\prime\,a} - \left(D_{ht-1}^4 - (1-s)\ D_{ht-1}^3 - sD_{ht-1}^4\right)\right\}, \forall h, t > 1, a = |A| \tag{79}$$

Constraints (21)–(24)

$$Max\ \ f_2 \tag{80}$$

$$Minf_3 = M[f_3] + \lambda\left(f_{3(max)} - f_{3(min)}\right) + \mu_1\left(\sum_{a,h,l,t} s_{lht}^a \times (D_{ht}^4 - (1-s)\ D_{ht}^3 - sD_{ht}^4) \times ct_{lht}\right) \tag{81}$$

S.t.,

$$\begin{aligned} M[f_3] = {} & \sum_{b,i,t} av_{itb} \times ca_b + \sum_{i,k,t} \left(\frac{pc_{itk}^{\prime\,1} + pc_{itk}^{\prime\,3} + pc_{itk}^{\prime\,3} + pc_{itk}^{\prime\,4}}{4}\right) \times \sum_{g,l} v_{ilt}^g + \sum_{o,g,i,t} o_{it}^{\prime\prime\,og} \cdot cw_{it} - \\ & \sum_{o,g,i,l,t} o_{it}^{og} \cdot cn_{ilt} + \sum_{o,g,i,l,t} o_{it}^{\prime og} \cdot cr_{ilt} + \sum_{o,g,i,k,t} ck_k \times w_{itk}^{og} \end{aligned} \tag{82}$$

Constraints (27)–(36)

$$\sum_{g,i,l} v_{ilt}^g \le \sum_h \left((D_{ht-1}^4 - (1-s)\ (D_{ht-1}^4 - s(D_{ht-1}^4\right) \forall t \tag{83}$$

Constraints (38)–(40)

6. Case study

Mazandaran province is one of the most populous regions of Iran in terms of population density and is made up of 22 cities. The number of the people infected with COVID-19 in this province, i.e., 232,336 people until February 1, 2021 has been reported (Rastegar et al. [45]). There are 10 blood collection centers, 15 hospitals, and 4 manufacturers in Mazandaran province. There are also five NGOs, each associated with two collection centers. It is also planned to receive all plasma donors and inject them into the patients over a 72-h period. Therefore, the problem is examined during 2–48 h periods. In this case, three types of donors have been considered, including the first type: the recovered donors, the second type: the recovered donors along with other diseases, and the third type: the healthy donors. The recovered donors donate blood using both leukoreduction and normal methods. In this case, the donated blood according to age is provided including

Table 2
Different costs and demand in manufacturing centers and hospitals.

No.	Hospitals	Manufacturers Transportation cost per 1000 units ($)				Inventory holding cost ($)	Cost of shortage	Cost of BCE allocation ($)
		Babolsar	Babol	Sari	Behshahr			
1	Mehr Behshahr	1700	1200	1000	600	8	15	30,000
2	Amiri Behshahr	2200	1700	1400	700	6	20	25,000
3	Bo Ali Neka	1400	1100	700	400	7	18	40,000
4	Bo Ali Sari	800	400	300	500	8	15	25,000
5	Zare Sari	1000	800	400	500	9	16	30,000
6	Shafa Sari	800	450	250	350	6	20	40,000
7	Nime Shaban Sari	1000	800	500	800	7	17	20,000
8	Amir Mzandarani Sari	650	550	450	600	9	20	30,000
9	Velayat Sari	600	400	300	500	9	15	40,000
10	Haj Azizi Juybar	1200	700	500	700	11	14	50,000
11	Kudakan Babol	700	500	1200	1700	7	20	25,000
12	17 Sahrivar Babol	900	500	1700	2200	7	14	25,000
13	Mehregan Babol	450	300	550	700	7	12	30,000
14	Hazrat Zeinab Babolsar	400	600	1200	2200	10	15	25,000
15	Shafa Babolsar	400	800	1700	2200	10	20	40,000

Table 3
Plasma storage capacity in manufacturers.

Babolsar	Babol	Sari	Behshahr
(2000,2500,3000)	(3000,4000,5000)	(3000,3500,4000)	(2000,2400,2800)

Table 4
The number of beds in the collection centers, the number of donors, and the capacity of the collection centers for working hours.

No.	Collection centers	Empty beds	Number of normal donors	Total capacity of normal blood donors during working hours
1	Center 1	100	151	50
2	Center 2	300	216	40
3	Center 3	300	408	70
4	Center 4	200	311	30
5	Center 5	150	325	20
6	Center 6	100	200	20
7	Center 7	200	155	30
8	Center 8	100	108	30
9	Center 9	200	318	50
10	Center 10	300	523	60

three types: fresh, medium, and old. Table 2 represents the different costs and demand in the manufacturing centers and hospitals. The transportation cost is estimated based on per 1000 units of blood. The costs of shortage vary with locations. The reason for this is the importance of different locations. The areas with higher populations and higher risk of the disease transmission have higher cost of shortage. Therefore, the priority is to provide service for the locations with higher shortage costs. The data of this research are taken from Shirazi et al. [18]. Table 3 represents the plasma storage capacity of the manufacturers. Table 4 indicates the number of the available beds in the collection centers, the number of the donors, and the capacity of the collection centers for working hours.

The Plasma demand in hospitals is presented as Table 5.

7. Experimental results

In this section, the results of the proposed methodology are reported in Table 6. According to the designed competition mechanism, the first period with two iterations and the second period with 3 iterations will lead to the final solution. As seen in the first period, in the first iteration, the NGO costs are equal to $ 576,764 and the model solution time duration is 11 s. Also, the desirability rate of the NGOs in the first iteration is equal to 26 and the costs of the NGOs are equal to $589403. In the second iteration, due to the updated demand, the government costs are equal to $167,925 and the NGOs' costs are equal to $286,997. The utility rate is equal to 38. In the second period, the government costs are equal to $302,464, $254,480, and $198,237, respectively. Also, the NGO's costs in three iterations are equal to 389,502, 298,581, and 204,511, respectively. The utility of the donors in the second period is equal to 36, 49, and 57 units, respectively. Therefore, the first

Table 5
Plasma demand in hospitals.

No.	Hospital	Plasma Demand	
		Period 1	Period 2
1	Mehr Behshahr	(280,300,320)	(300,350,400)
2	Amiri Behshahr	(400,450,500)	(400,450,500)
3	Bo Ali Neka	(220,250,280)	(250,300,350)
4	Bo Ali Sari	(500,540,580)	(450,460,470)
5	Zare Sari	(200,230,260)	(230,240,250)
6	Shafa Sari	(270,300,330)	(250,300,350)
7	Nime Shaban Sari	(450,500,550)	(410,450,490)
8	Amir Mzandarani Sari	(450,500,550)	(300,400,500)
9	Velayat Sari	(300,400,500)	(250,300,350)
10	Haj Azizi Juybar	(100,150,200)	(160,180,200)
11	Kudakan Babol	(400,500,600)	(340,370,400)
12	17 Sahrivar Babol	(240,300,360)	(300,330,360)
13	Mehregan Babol	(150,250,350)	(150,250,350)
14	Hazrat Zeinab Babolsar	(200,300,400)	(170,210,250)
15	Shafa Babolsar	(400,450,500)	(380,400,420)

Table 6
The results of the case study.

Period	Iteration number	Government Model		NGOs Model		
		f_1	Time (s)	f_1	f_2	Time (s)
1	2	576764	11	26	589403	8
		167925	24	40	286997	16
		302464	18	36	389502	8
2	3	254480	11	49	298581	15
		198237	29	57	204511	20

Table 7
The amount of perished plasma and allocated BCE technology.

No.	Hospital	BCE assigned to hospital		Number of expired platelets	
		Period 1	Period 2	Period 1	Period 2
1	Mehr Behshahr	1	0	8	5
2	Amiri Behshahr	0	1	11	0
3	Bo Ali Neka	1	0	5	0
4	Bo Ali Sari	1	1	9	13
5	Zare Sari	1	1	0	0
6	Shafa Sari	0	0	10	10
7	Nime Shaban Sari	0	1	0	0
8	Amir Mzandarani Sari	1	1	0	0
9	Velayat Sari	1	0	5	10
10	Haj Azizi Juybar	0	0	0	0
11	Kudakan Babol	1	1	0	0
12	17 Sahrivar Babol	0	0	0	19
13	Mehregan Babol	0	0	9	10
14	Hazrat Zeinab Babolsar	1	1	15	15
15	Shafa Babolsar	1	1	8	0

objective function in the first period is 744,689 and that of the second period is 755,181. Also, the second objective function in the first period is equal to 876,400 and that of the second period is equal to 892,594.

Then, Table 7 displays the amount of the perished plasma and the allocated BCE technology in each period. For example, BCE technology has been allocated to Mehr Behshahr Hospital in the first period. Also, the amount of the perished blood in this hospital in the first and second periods is equal to 8 and 5 liters, respectively.

Additionally, the number of the donors attracted by the advertisements about the collection centers is reported in Table 8. For instance, the number of the donors attracted in the first period by social networks, TV commercials, and banners are equal to 55, 41, and 44 people, respectively. Also, the number of the donors that were attracted in the second period by social networks, TV commercials, and banners are equal to 68, 89, and 60 people. As it turns out, the social network persuades more people to donate blood than other methods in each period. Also, TV commercials and banners also persuade more people to donate blood, respectively.

Table 8
The number of donors attracted by advertisements.

No.	Collection center	Period 1			Period 2		
		Social networks	TV ads	banners	Social networks	TV ads	banners
1	Center 1	55	41	44	68	89	60
2	Center 2	148	64	26	154	57	44
3	Center 3	229	86	70	287	49	25
4	Center 4	185	93	62	337	85	76
5	Center 5	271	108	29	187	98	73
6	Center 6	78	52	38	102	96	62
7	Center 7	109	63	39	73	87	31
8	Center 8	68	10	10	73	54	41
9	Center 9	86	62	59	279	145	103
10	Center 10	266	128	100	311	258	127
Sum		1495	707	477	1871	1018	642

Table 9
The amount of platelet shortage.

No.	Hospital	The amount of platelet shortage	
		Period 1	Period 2
1	Mehr Behshahr	12	2
2	Amiri Behshahr	0	0
3	Bo Ali Neka	5	11
4	Bo Ali Sari	13	19
5	Zare Sari	16	10
6	Shafa Sari	5	0
7	Nime Shaban Sari	11	0
8	Amir Mzandarani Sari	10	28
9	Velayat Sari	14	22
10	Haj Azizi Juybar	9	0
11	Kudakan Babol	0	0
12	17 Sahrivar Babol	25	16
13	Mehregan Babol	8	8
14	Hazrat Zeinab Babolsar	5	0
15	Shafa Babolsar	18	11

Table 9 shows the amount of the platelet shortage in liters in each hospital. For example, the amount of the shortage in Sari based Bu Ali Cina Hospital in the period is equal to 13 liters and in the period 2, it is equal to 19 liters.

7.1. Sensitivity analyses

In this section, to recognize the trend of the presented model, a set of sensitivity analyses is carried out on the significant parameters of the proposed model that can affect the structure of the suggested model.

Fig. 3 demonstrates the changes in the amount of demand over costs in the two models (Government and NGO models). It is clear that with a 30% drop in demand, the government's costs and NGOs' costs are reduced to 402,436 units and 339,815 units. Also, with a 30% increase in demand, the government's costs and NGOs' costs increase to 675,902 units and 573,802 units.

Accordingly, with the increase in demand, the slope of the government cost chart increases more rapidly. The reason behind which is the increase in the production costs compared to the collection costs.

Therefore, the changes in the donor's willingness level to donate blood is depicted in Fig. 4. It is evident that with a 30% reduction in donor's willingness, the government's costs reduce to 339,811 units and the NGO's costs to 435,709 units. By demand increase, the government's costs increase by up to %10 to 499,238 units and the NGO's costs by 458516 units. All in all, increasing donor's willingness reduces the advertising costs and increases the production costs. The increase rate in the production costs is more than the advertising and collection costs, so the total government's costs increase, so the slope of the government's costs is greater than that of the NGO's costs. Also, the collection costs increase raises the NGO's costs.

Then, the impact of increasing cost coefficient of effectiveness on the desirability of NGOs is indicated in Fig. 5. The desirability of the NGOs decreases as the cost coefficient of effectiveness increases. As it is known, as the cost coefficient of effectiveness increases from 0.5 to 0.6 for the first NGO, the NGO's utility decreases from 66 to 49. Also, the changes made for the second to the fourth player decrease from 23 to 20, 26 to 20, 31 to 24 and 28 to 22, respectively.

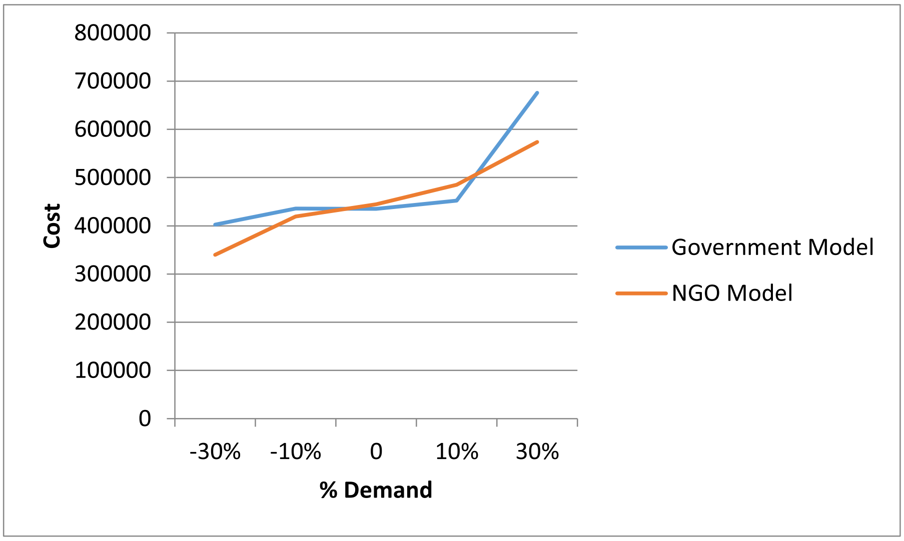

Fig. 3. The sensitivity analysis of the player costs based on demand variations.

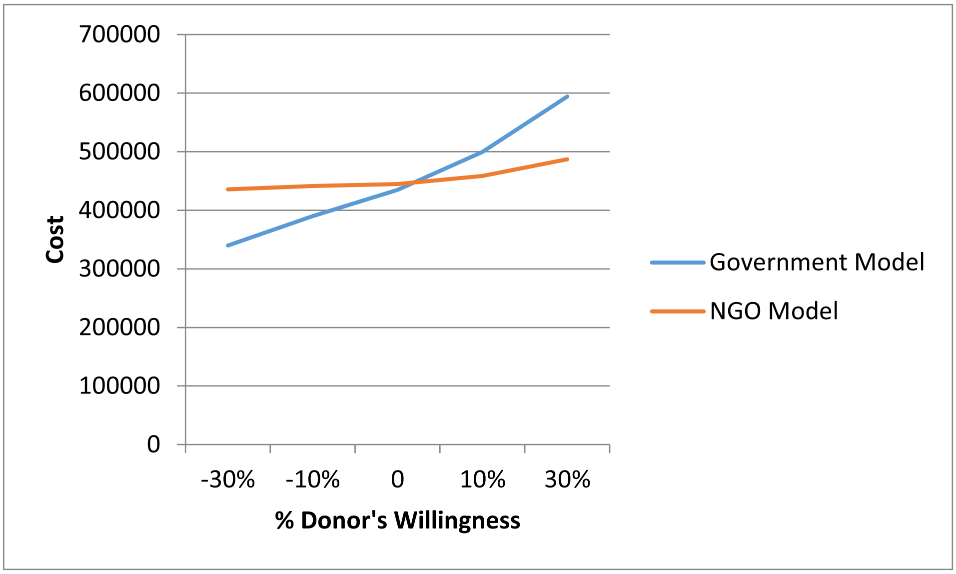

Fig. 4. The sensitivity analysis of costs based on donor's willingness to donate blood to the collection center.

7.2. Managerial insights

In this research, as there was no systematic database for some parts of the transportation cost elements, the driver's estimations and transportation officers were asked to help. So, they defined the upper, lower and middle bounds for the transportation costs. Also, for the same reason, the production experts defined the upper, lower and middle bounds for the production costs. Finally, the demand is considered as optimistic, realistic and pessimistic due to lack of historical data based on the experts' opinions. Therefore, according to the limitation of access to accurate information and the time-consuming calculation of the accurate parameters, the mentioned parameters are considered fuzzy. According to the results of the case study and sensitivity analysis, a competitive game between NGOs and the government minimizes the supply chain costs and maximizes the donor's desirability. Moreover, the managers are advised to pay attention to designing a competitive mechanism between the donors and the government. Accordingly, it is suggested that the government provide financial and non-financial assistance to the NGOs and the collection centers. This will minimize the costs of this organization and maximize desirability. This assistance can also increase the capacity of the collection centers and increase the number of beds and thus, collecting more plasma.

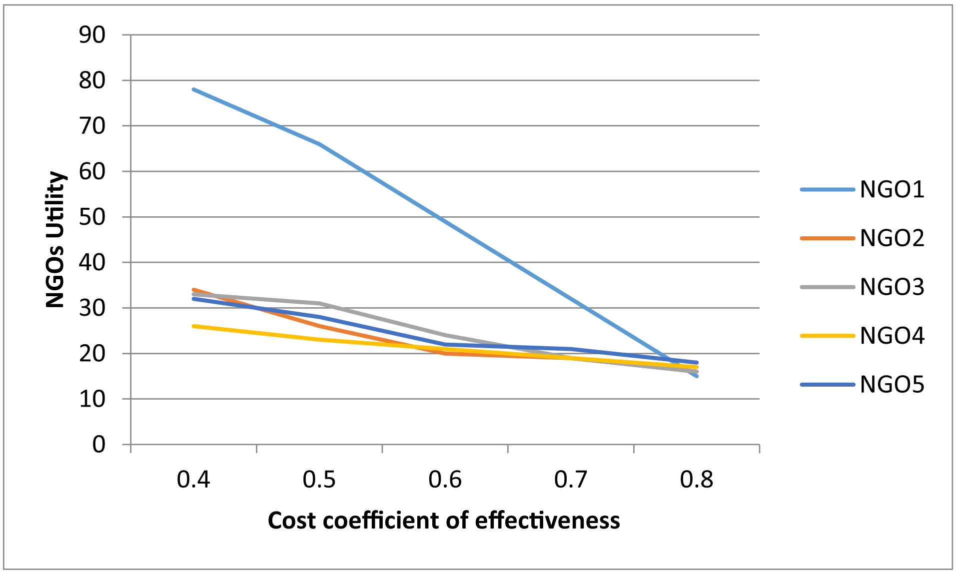

Fig. 5. The sensitivity analysis of the player costs coefficient based on desirability of NGOs

It is a popular fact apart from donations that there is no other way to holding enough bloodstock in the inventory. The COVID-19 pandemic emergence has caused vast concern among the blood donors. In addition, the blood association has been impressed adversely. Making disrupted so many processes worldwide, blood transfusion services are no exception. Moreover, it merited a justifiable and compelling review of demand, blood collection, and also the abolished beyond the date of expiry pattern at blood centers.

Government-imposed restrictions on voluntary blood donation camps as part of the curtailment strategy have directly affected the blood supply chain. Then, governments issue a letter of appointment to volunteer blood donors, encouraging them to come to the blood center separately in the COVID-19 period, according to the National Blood Transfusion Council, to avoid shortages under the rampant difficult circumstances (Shirazi et al. [18]). In addition, they are routinely involved in a blood donor screening program that can prevent blood donation to the individuals with active respiratory symptoms. Thus, the safety of the donors and also that of the blood transfusion service personnel remains our priority during the COVID-19 pandemic outbreak. Table 10 shows the donor and donor agents for considering adequate blood supply in the COVID-19 epidemic outbreak. Additionally, blood use prioritization strategies for the hospitalized patients in the event of a deficiency are evaluated in Table 11.

The present study extracted results can be helpful for the organizations such as the Crisis Relief Organization, the Red Crescent, hospitals, blood transfusion organizations, and emergencies. In addition, as this study seeks to maximize the utility of donors, who are among the beneficiaries of this study. Then, the amount of the shortage, the amount of the expired blood, and the number of the beds needed in the collection centers are calculated. Therefore, in the real world, this research helps the decision makers to be able to calculate the number of the required beds and can effectively manage shortage. Also, the study of donor attraction methods such as social networks, TV commercials, and banners performed in this study, can determine the effectiveness of each of these approaches in the real world.

The game mechanism presented in this research has different applications in the real world. For example, this mechanism has been tested for the business supply chain, bringing about satisfactory results (see Ghasemi et al. [46]). This mechanism has also been used in the disaster relief supply chain in the context of COVID-19 outbreaks. For instance, Ghasemi et al. proposed a similar game mechanism, considering the government and the NGOs, to curb the COVID-19 [40].

8. Conclusion and future works

Due to the spread of the COVID-19 pandemic outbreak and lack of the required vaccine, the importance of blood plasma has been considered once again. This is because antibodies are formed in the body of the people who have already suffered from the COVID-19 disease and recovered and this antibody, which is located in the blood plasma, can be used to treat the COVID-19 patients who are in an acute condition. Therefore, in this paper, a competitive possibilistic-robust-fuzzy model is developed for plasma supply chain management in the context of the COVID-19 outbreak under uncertainty. The government and the NGOs are the two players in this game. To cope with the uncertain parameters, a new mixed possibilistic-robust-fuzzy programming model is developed for the first time in this paper. In this regard, the plasma demand in hospitals, the production and transportation costs are considered as the uncertain parameters. The government aims to minimize the

Table 10
Donor and donation agents to consider keeping a sufficient supply of blood in the COVID-19 pandemic condition.

	Considerations	Possible actions
Availability of personnel	Influence of COVID-19 on personnel: fear of disease, sickness, quarantine	- Encouraging employees to self-report sickness or concerns; - Contingency plans to replace staff have to prepare (For example change jobs and train other unnecessary personnel). - Providing the psychological support of personnel - Employing clear support policies for sick leave.
Inventory management	Demand is difficult to forespeak and may vary at various stages of the epidemic	Stay in touch with hospital customers, containing control activities that need to raise blood utilization (for instance transplantation and elective surgery) evaluate the entire system inventory closely; regular inventory updates.
Protection of donors and personnel	Utilization of private protective equipment for volunteers, personnel, donors; controlling COVID-19 patients between donors and personnel; practicing the distance of the physical; the messages of the donors before entering the blood center about virtue, health, safety, and goodness; Pretesting for signs and symptoms of COVID-19 patients	- Checking the availability of private protective equipment; - Enforcing a communication program for job risk; - Coordinating actions with public health recommendations; - Screening for temperatures and symptoms before entering centers and sites for donors, volunteers, and personnel; - Disseminating guidelines for COVID-19 symptoms and signs between donors, volunteers, and personnel (testing, quarantine, etc.);

Table 11
Approaches to priorities blood utilization for COVID-19 sick in hospitals according to the forespoken shortage.

	Considerations	Possible actions
Major bleeding	The shortages of the blood for sick with bleeding	- Reviewing local policies that are according to the utilization of blood components by ratio-driven therapy is defined, 1:1 for plasma and red blood cells if platelets are not existing or preferably 1:1:1 for platelets, plasma, and red blood cells; - If frozen plasma or cryoprecipitate is in short supply for sick with bleeding, consider prothrombin complex concentrate and fibrinogen concentrates; - Considering the plasma first or blood components at ratios of 1:2:1 (platelets, plasma, and red blood cells), If red blood cells are in short supply; - Providing the utilization of the plasma of type A to transport massively, if the plasma of the type AB is unavailable; - Considering cold-stored or frozen platelets, or whole blood, if platelets are scarce.
The usage of the red blood cells	The shortages of the red blood cells	Examining the red blood cell transfusions threshold for sick who are low risk and stable (for example children and adults along with moderate symptoms)
Alternatives for blood injection	Confirming the utilization of alternatives to blood injection during periods of shortages of the blood	- Tranexamic acid has to provide for sick with outpatients with chronic thrombocytopenia or severe hypo proliferative thrombocytopenia; - Desmopressin has to consider for sick with inherited platelet disorders or uremia who are at bleeding risk since there are little data for other sick populations; - Guarantee that alternative actions for raising hemoglobin are provided if it is needed (For example erythropoietin and parenteral iron).
The use of platelet	The shortages of the Platelet to transport the prophylactic	The platelets usage as prophylaxis have to restrict in sick with hypo proliferative thrombocytopenia without clinical bleeding containing autologous transplantation

supply chain costs along with advertising to attract more donors. The goal of NGOs is to minimize the plasma collecting cost and maximize the utility of the donors.

The solution results are evaluated based on a real case study of the plasma supply chain in Mazandaran Province/Iran. The results indicate that the costs of the government in the first period are $744,689 (576,764+ 167,925) and that of the second period is $755,181 (302,464+ 254,480+ 198,237), while the costs of the NOGs in the first period are equal to $ 876,400 (589,403+ 286,997) and in the second period, they are equal to $892,594 (389,502+ 298,581+ 204,511). Additionally, the utility of the NOGs in the first period is equal to 66 and in the second period, it is equal to 142.

The empirical results of the sensitivity analysis indicate that demand increase raises the cost of the government and that of the NGOs. Also, increasing the donor's willingness to donate blood increases the cost of the government and that of the NOGs. This increase reduces the advertising costs and increases the production costs. Finally, the utility of the NGOs decreases as the cost coefficient of effectiveness increases.

The following is suggested for future research:

- Estimating the amount of the required plasma with the approaches such as simulation and fuzzy inference system.
- Providing location and routing problems for the plasma transport vehicles and considering the other components of the supply chain such as the disposal centers for the perished plasmas.
- Performing a cooperative game between the NGOs and the government based on price, especially when cost information is asymmetric, or subsidy design.
- Considering other uncertainty approaches such as stochastic or grey optimization.
- Although fuzzy set theory has been shown to be a promising decision management tool, more effort on the part of researchers is still needed to convince practitioners of such an invaluable tool.

Data availability

Data will be made available on request.

CRediT authorship contribution statement

Peiman Ghasemi: Conceptualization, Project administration, Supervision, Validation, Software, Writing – review & editing. **Fariba Goodarzian:** Data curation, Formal analysis, Investigation, Methodology, Software, Visualization. **Ajith Abraham:** Formal analysis, Investigation, Methodology, Validation, Writing – review & editing. **Saeed Khanchehzarrin:** Conceptualization, Methodology, Writing – review & editing.

References

[1] S.M. Hosseini-Motlagh, N. Gilani Larimi, M. Oveysi Nejad, A qualitative, patient-centered perspective toward plasma products supply chain network design with risk controlling, Oper. Res. 22 (2020) 1–46.
[2] M.M. Ahmed, S.S. Iqbal, T.J. Priyanka, M. Arani, M. Momenitabar, M.M. Billal, An environmentally sustainable closed-loop supply chain network design under uncertainty: application of optimization, in: Proceedings of the International Online Conference on Intelligent Decision Science, 2020, pp. 343–358.
[3] M. Arani, Y. Chan, X. Liu, M. Momenitabar, A lateral resupply blood supply chain network design under uncertainties, Appl. Math. Modell. 93 (2021) 165–187.
[4] S. Khalilpourazari, H.H. Doulabi, A.Ö. Çiftçioğlu, G.W. Weber, Gradient-based grey wolf optimizer with Gaussian walk: application in modelling and prediction of the COVID-19 pandemic, Expert Syst. Appl. 177 (2021) 114920.
[5] H. Shirazi, R. Kia, P. Ghasemi, Ranking of hospitals in the case of COVID-19 outbreak: a new integrated approach using patient satisfaction criteria, Int. J. Healthc. Manag. 13 (4) (2020) 312–324.
[6] M. Akar, N. Momeni Tabar, D. Feili, H.R. Zaghi, M. Ghaderi, Fuzzy mathematical modeling of distribution network through location allocation model in a three-level supply chain design, J. Math. Comput. Sci. 9 (3) (2014) 165–174.
[7] World Health Organization, World Health Organization coronavirus disease 2019 (COVID-19) situation report, 1, World Health Organisation, Geneva: Switzerland, 2020.
[8] S. Alsharidah, M. Ayed, R.M. Ameen, F. Alhuraish, N.A. Rouheldeen, F.R. Alshammari, M.Z. Askar, COVID-19 convalescent plasma treatment of moderate and severe cases of SARS-CoV-2 infection: a multicenter interventional study, Int. J. Infect. Dis. 103 (2021) 439–446.
[9] H. Boenig, Plasma Science and Technology, Cornell University Press, 2019.
[10] T.C. Nguyen, J.E. Kiss, J.A. Carcillo, The role of plasmapheresis in critical illness, Crit. Care Nephrol. 1 (2019) 973–977.
[11] P. Xie, M. Tao, K. Peng, H. Zhao, K. Zhang, Y. Sheng, C. Ronco, Plasmapheresis therapy in kidney transplant rejection, Blood. Purif. 47 (1-3) (2019) 73–84.
[12] T. Nester, Leukoreduction of blood products, in: Transfusion Medicine and Hemostasis, Elsevier, 2019, pp. 267–270.
[13] W.Y. Bassuni, M.A. Blajchman, M.A. Al-Moshary, Why implement universal leukoreduction, Hematol. Oncol. Stem Cell Ther. 1 (2) (2008) 106–123.
[14] W.H. Dzik, Leukoreduction of blood components, Curr. Opin. Hematol. 9 (6) (2002) 521–526.
[15] R. Lotfi, G.W. Weber, S.M. Sajadifar, N. Mardani, Interdependent demand in the two-period newsvendor problem, J. Ind. Manag. Optim. 16 (1) (2020) 117.
[16] S. Ergün, B.B. Kırlar, S.Z.A. Gök, G.W. Weber, An application of crypto cloud computing in social networks by cooperative game theory, J. Ind. Manag. Optim. 16 (4) (2020) 1927.
[17] R. Mohammadi, H.R. Mashhadi, M. Shahidehpour, Market-based customer reliability provision in distribution systems based on game theory: a bi-level optimization approach, IEEE Trans. Smart Grid 10 (4) (2018) 3840–3848.
[18] H. Shirazi, R. Kia, P. Ghasemi, A stochastic bi-objective simulation–optimization model for plasma supply chain in case of COVID-19 outbreak, Appl. Soft Comput. 112 (2021) 107725.

[19] B. Zahiri, M.S. Pishvaee, Blood supply chain network design considering blood group compatibility under uncertainty, Int. J. Prod. Res. 55 (7) (2017) 2013–2033.
[20] R. Ramezanian, Z. Behboodi, Blood supply chain network design under uncertainties in supply and demand considering social aspects, Transp. Res. Part E Logist. Transp. Rev. 104 (2017) 69–82.
[21] H. Heidari-Fathian, S.H.R. Pasandideh, Green-blood supply chain network design: robust optimization, bounded objective function & Lagrangian relaxation, Comput. Ind. Eng. 122 (2018) 95–105.
[22] B. Zahiri, S.A. Torabi, M. Mohammadi, M. Aghabegloo, A multi-stage stochastic programming approach for blood supply chain planning, Comput. Ind. Eng. 122 (2018) 1–14.
[23] M. Eskandari-Khanghahi, R. Tavakkoli-Moghaddam, A.A. Taleizadeh, S.H. Amin, Designing and optimizing a sustainable supply chain network for a blood platelet bank under uncertainty, Eng. Appl. Artif. Intell. 71 (2018) 236–250.
[24] M. Habibi-Kouchaksaraei, M.M. Paydar, E. Asadi-Gangraj, Designing a bi-objective multi-echelon robust blood supply chain in a disaster, Appl. Math. Model. 55 (2018) 583–599.
[25] S. Rajendran, A.R. Ravindran, Inventory management of platelets along blood supply chain to minimize wastage and shortage, Comput. Ind. Eng. 130 (2019) 714–730.
[26] F. Salehi, M. Mahootchi, S.M.M. Husseini, Developing a robust stochastic model for designing a blood supply chain network in a crisis: a possible earthquake in Tehran, Ann. Oper. Res. 283 (1) (2019) 679–703.
[27] D. Rahmani, Designing a robust and dynamic network for the emergency blood supply chain with the risk of disruptions, Ann. Oper. Res. 283 (1) (2019) 613–641.
[28] N.G. Larimi, S. Yaghoubi, A robust mathematical model for platelet supply chain considering social announcements and blood extraction technologies, Comput. Ind. Eng. 137 (2019) 106014.
[29] S.B. Ghorashi, M. Hamedi, R. Sadeghian, Modeling and optimization of a reliable blood supply chain network in crisis considering blood compatibility using MOGWO, Neural Comput. Appl. 32 (2019) 1–28.
[30] S.M. Hosseini-Motlagh, M.R.G. Samani, S. Cheraghi, Robust and stable flexible blood supply chain network design under motivational initiatives, Socioecon. Plann. Sci. 70 (2020) 100725 b.
[31] C. Wang, S. Chen, A distributionally robust optimization for blood supply network considering disasters, Transp. Res. Part E Logist. Transp. Rev. 134 (2020) 101840.
[32] N. Haghjoo, R. Tavakkoli-Moghaddam, H. Shahmoradi-Moghadam, Y. Rahimi, Reliable blood supply chain network design with facility disruption: a real-world application, Eng. Appl. Artif. Intell. 90 (2020) 103493.
[33] S. Khalilpourazari, S. Soltanzadeh, G.W. Weber, S.K. Roy, Designing an efficient blood supply chain network in crisis: neural learning, optimization and case study, Ann. Oper. Res. 289 (1) (2020) 123–152.
[34] S. Moslemi, A. Mirzazadeh, G.W. Weber, M.A. Sobhanallahi, Integration of neural network and AP-NDEA model for performance evaluation of sustainable pharmaceutical supply chain, OPSEARCH 7 (2021) 1–42.
[35] M.C. Kees, J.A. Bandoni, M.S. Moreno, A multi-period fuzzy optimization strategy for managing a centralized blood supply chain, Socio Econ. Plan. Sci. (2022) 101346.
[36] S.A. Seyfi-Shishavan, Y. Donyatalab, E. Farrokhizadeh, S.I. Satoglu, A fuzzy optimization model for designing an efficient blood supply chain network under uncertainty and disruption, Ann. Oper. Res. 3 (2021) 1–55.
[37] W.A. Miller, L.C. Leung, T.M. Azhar, S. Sargent, Fuzzy production planning model for fresh tomato packing, Int. J. Prod. Econ. 53 (3) (1997) 227–238.
[38] G. Yuan, Two-stage fuzzy production planning expected value model and its approximation method, Appl. Math. Model. 36 (6) (2012) 2429–2445.
[39] S. Fathalikhani, A. Hafezalkotob, R. Soltani, Government intervention on cooperation, competition, and coopetition of humanitarian supply chains, Socio Econ. Plan. Sci. 69 (2020) 100715.
[40] P. Ghasemi, F. Goodarzian, A. Gunasekaran, A. Abraham, A bi-level mathematical model for logistic management considering the evolutionary game with environmental feedbacks, Int. J. Logist. Manag. 2 (1) (2021) 13–22.
[41] M.S. Pishvaee, S.A. Torabi, A possibilistic programming approach for closed-loop supply chain network design under uncertainty, Fuzzy Sets Syst. 161 (20) (2010) 2668–2683.
[42] M.S. Pishvaee, M.F. Khalaf, Novel robust fuzzy mathematical programming methods, Appl. Math. Model. 40 (1) (2016) 407–418.
[43] M.S. Pishvaee, M. Rabbani, S.A. Torabi, A robust optimization approach to closed-loop supply chain network design under uncertainty, Appl. Math. Model. 35 (2) (2011) 637–649.
[44] M.S. Pishvaee, J. Razmi, Environmental supply chain network design using multi-objective fuzzy mathematical programming, Appl. Math. Model. 36 (8) (2012) 3433–3446.
[45] M. Rastegar, M. Tavana, A. Meraj, H. Mina, An inventory-location optimization model for equitable influenza vaccine distribution in developing countries during the COVID-19 pandemic, Vaccine 39 (3) (2021) 495–504.
[46] P. Ghasemi, K. Khalili-Damghani, A. Hafezolkotob, S. Raissi, A decentralized supply chain planning model: a case study of hardboard industry, Int. J. Adv. Manuf. Technol. 93 (9) (2017) 3813–3836.