Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 3783119, 9 pages
https://doi.org/10.1155/2022/3783119

Research Article

A Mixed Integer Programming Optimization of Blood Plasma Supply Chain in the Uncertainty Conditions during COVID-19: A Real Case in Iran

Bijan Baghbani

Department of Industrial Engineering, Science and Arts University, Yazd, Iran

Correspondence should be addressed to Bijan Baghbani; bijan.baghbani@stu.sau.ac.ir

Received 4 April 2022; Revised 6 May 2022; Accepted 18 July 2022; Published 31 August 2022

Academic Editor: Reza Lotfi

Blood and its products, like plasma, are among the most sensitive products for the sake of transportation and storage. Special storage conditions, short shelf life, and lack of particular demand for blood products are among the most significant challenges to managing it. In this respect, it is necessary to implement the problem of supply chain network design in uncertain conditions to find a proper solution for the management of blood products. In this study, a multilevel supply chain is designed to supply plasma in the COVID-19 pandemic. First, the blood is sent to blood donation centers and then to the laboratory. Moreover, after that, it is sent to hospitals. To optimize the transfer rate at each level of the supply chain, a mathematical model is proposed to reduce total costs. Also, the fuzzy programming approach is used to deal with uncertainty in the parameters of the mathematical model. The results of model optimization show that this mathematical model has the required efficiency in finding optimal solutions for the distribution of blood products. According to the obtained results, value objective function in certain and uncertain values is determined. According to the results, the objective certain value is lower than the uncertain value. Uncertain value calculated is of three dimensions. According to this, the categorized objective value increased when the dimension is equal to 0.5. Finally, it shows that when demand increases, more blood and plasma need to be collected to meet the demand, which increases operating and health testing costs and ultimately increases total system costs.

1. Introduction

In previous years, the design network blood chain has been one of the most attractive areas in the field of health care systems. What differentiates this chain from other supply chains is that, unlike business supply chains, that are based on profit, it is based on service. Additionally, deficiency of blood products could significantly lead to death [1]. Supply of healthy and adequate blood and its management has been of particular importance for the salvation of humanity; therefore, timely blood collection and distribution is considered as supply chain management for which detailed planning is required because the slightest disruption in the management of the blood supply chain and its products will cause irreparable damage to the people [2]. Generally, blood products such as red blood cells, platelets, and plasma have different special storage procedures and have different shelf life. A blood supply chain includes various activities such as collecting, producing, storing, and distributing blood and blood products. The main activities of the blood supply chain start from the donors and end with the recipients, which is accompanied by uncertainties along the chain such as supply and demand. Uncertainty in supply chain issues plays a fundamental role in economic performance. Therefore, under such uncertainties, in order to fairly regulate supply and demand in the blood supply chain, a suitable network for adequate blood supply and blood products must be designed [3]. To this objective, new approaches should be provided to make the right decision in order to use resources properly. In addition, it provided proper planning for blood collection and transfusion for better management in emergencies such as pandemics, emergencies, and earthquakes [4]. Therefore, the right decision in blood transfusion is to replace blood with other blood groups. The ideal situation for a blood transfusion is for the donor's blood type to be the same as the recipient's. However, this is not always possible. When there is no recipient blood type, compatible and alternative blood types should be used [5]. The COVID-19 outbreak began in late 2019 in Wuhan, China, and spread worldwide by 2020 [6]. Given that the loss of life was initially greater than the impact of COVID-19, only quarantine and social distancing was the only way to deal with the pandemic because the research of COVID-19 vaccine was not completed and was not widely available to all people in the world [7]. The pandemic COVID-19, caused by acute respiratory inflammation, is causing major disruptions to health care at a global scale at all levels. A key activity for blood transfusion facilities is to monitor supply and demand so that enough blood reserves are saved to support ongoing critical requirements [8]. Plasma taken from the blood of improved patients, which contains COVID-19 antibodies, can be beneficial for improving the performance of new patients. Therefore, incorporating donors recovered from COVID-19 can play an important role in improving the function of the blood supply chain.

According to the above mention, basic goals of the research are as follows:

(O1) Create a blood network to consider the value of receiving blood plasma during the COVID-19 epidemic

(O2) Minimize the collected plasma blood cost in the COVID-19 pandemic

(O3) Apply deterministic mathematical programming to measure the behavior of the model presented in a real-world case study

Therefore, the main question of the research is as follows:

(Q1) How can the amount of blood plasma collected be calculated at the lowest cost in a COVID-19 pandemic?

The structure of the paper is categorized in such a way that the literature review is provided in Section 2. The mathematical model is presented in Section 3. Numerical results are presented in Section 4, and finally, conclusion and future directions are explained in Section 5.

2. Literature Review

There have been many studies in recent years on the blood supply chain. There are various approaches to blood supply chain modeling, such as simulation models, integer programming, and ideal programming. For the first time, Van Zyl [9] conducted studies in the field of transmission and distribution management of blood products and supply chain of perishable materials. The first mathematical model for managing the inventory of blood products was also proposed by Nahmias [10]. Derikvand et al. [11] suggested a new mathematical model with the aims of minimizing the cost of developing blood collection centers, the cost of deficiency, and the cost of corrupted blood and minimizing the maximum demand met in the affected areas. Ghorashi et al. [12] considered a mathematical planning model with the aims of reducing the cost of organizing permanent and temporary centers, operating cost of blood collection, cost of transporting blood between chain levels, cost of inventory maintenance, maximizing reliability of created path from permanent blood centers to medical center, and minimizing blood transportation times between chain levels in disaster conditions. Han Shih and Rajendran [13] designed a mathematical model for designing a blood supply chain network with the aim of reducing the cost of deficiency, the cost of transporting blood between chain levels, the cost of corrupted blood, the operating cost of collecting blood, and the cost of maintaining inventory in conditions of uncertainty. Kaya and Ozkok [14] provided a mathematical planning model for designing a blood supply chain network with the aim of minimizing the cost of establishing permanent centers, the cost of transporting blood between chain levels, and the cost of maintaining inventory. Adrang et al. [15] provided a robust location-routing mathematical model for heath care centers. The objectives of this mathematical model are to reduce relief time and the costs of the entire supply chain. The total costs considered are derived from the sum of the local costs and the costs of covering the path with the transporter. In this research, two types of ambulance vehicles and helicopters have been considered. Tirkolaee et al. [16] provided a robust mathematical allocation and scheduling model for mishap amendment. For this purpose, a robust MILP model is designed to achieve the objectives of the problem. Asadpour et al. [2] proposed a mathematical model with the goal of minimizing the environmental effects of blood collection between chain levels and minimizing the cost of implementation blood centers, the cost of maintaining inventory, and the cost of transporting blood between chain levels. Considering the need for blood and its products, whole blood and COVID-19 plasma were used simultaneously in this research. This research is also the first study in Shiraz metropolis. Rezaei et al. [17] in their study proposed a mathematical model for routing blood-carrying vehicles in critical situations by considering adaptive blood supply through alternative blood groups. In this article, two types of vehicles, buses, and helicopters are considered. Helicopters are used to prevent unnecessary travel of blood buses from the blood supply station to the crisis-stricken city. The proposed model considers two objectives. First, maximize the blood collected in blood donation centers. Second, minimize the arrival time of blood-sucking vehicles to the crisis-stricken city. Jahangiri et al. [6] presented a new approach for analysis of the emergency department in the general hospital under COVID-19 condition according to simulation-based optimization. According to the obtained results, effective resource combination was determined using an approximate regression model. Jahangiri et al. [7] presented a hybrid decision framework to ranking key resources for implication of humanitarian supply chain in the emergency department during the COVID-19 pandemic. Arani et al. [18] proposed a mathematical model based on mixed integer programming for a stable blood supply chain. In this study, the issue of routing of blood flow vehicles under conditions of

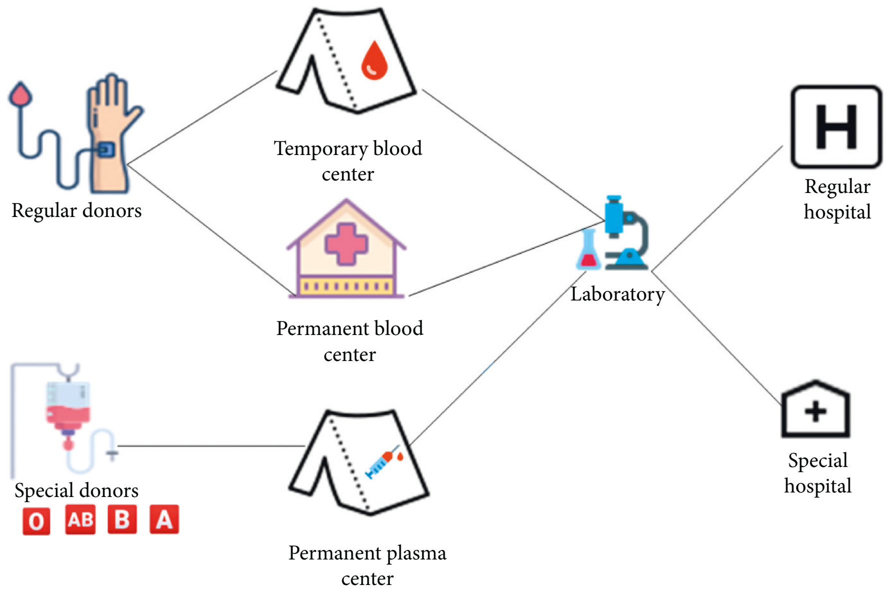

Figure 1: Schematic of blood supply chain of the proposed model.

uncertainty for supply and demand parameters is addressed. In addition, by considering scenarios, a scenario-based optimization model is developed using the proposed model. Goodarzian et al. [19] proposed a mathematical planning model for a sustainable drug supply chain with uncertainty in mind. In this paper, a fuzzy complex LIP model is proposed to deal with the existing uncertainty.

2.1. Research Gap. According to the literature review in the previous section, the main gap of the research is as follows.

The blood supply network is not observed to consider the amount of plasma collected in the COVID-19 pandemic, so that it can minimize the cost of blood plasma collection and also be used in a real system.

3. Research Method

3.1. Problem Statement. In this research, blood supply chain modeling has been performed at four levels. The first level of supply chain includes donors, the second level is blood and plasma collection centers, the third level is health testing center, and the fourth level is demand points. In Figure 1, the schematic of the blood supply chain of the proposed model is shown.

Regular donors donate blood to temporary or permanent centers, and donors who have recovered from COVID-19 donate plasma to permanent centers. Donated blood is transferred from interim centers to continual centers. Then, the blood collected in the permanent centers as well as the blood plasma maintained in the permanent center is transferred to the laboratories, and after confirming the health, they are sent to demand points. The goal of the presented mathematical model is to define optimum decisions about the location of blood centers, blood donation by donors through temporary and permanent centers, and COVID-19 plasma donation by donors who have recovered from this disease through a permanent center and blood and plasma transfer to permanent centers and laboratory and demand points in each time period. The goal function of the presented model is to reduce the fixed costs of establishing the facility, the operating cost of collecting blood and plasma from donors in blood centers, the cost of transportation between supply chain levels, and the cost of blood and plasma health testing. In this model, real-world constraints such as meeting blood and plasma demand in each period, blood and plasma storage capacity, and establishing temporary facilities were considered. Parameters of blood and plasma demand, system costs, and blood and plasma inventory storage capacity are considered uncertain. In the following, the assumptions, sets, parameters, and decision variables and the structure of the mathematical model are described.

3.2. Problem Assumptions. In this paper, mathematical modeling has some assumptions as follows:

(1) Two types of donors are considered: regular donors and those who have recovered from COVID-19
(2) There are two types of demand points for response to whole blood and COVID-19 plasma
(3) Blood collected in the interim and continual centers and plasma collected in the continual center must be taken to a laboratory for blood health testing
(4) Two kinds of blood donation vehicles are considered: interim and continual and a permanent center for COVID-19 plasma
(5) Any donor can donate to blood centers or interim vehicles
(6) The model is intended as a multiperiod model for controlling complex decisions and satisfying different demands

(7) Storage is not possible in temporary centers, and storage can only be done in permanent centers and laboratories

3.3. *Notation.* In this section, the sets, parameters, and decision variables used in the model are given in Table 1.

3.4. *Model Formulation.* In this section, mathematical modeling formulation that include objective function and constraint are described.

3.4.1. *Objective Function*

$$\begin{aligned} \min Z = {} & \sum_{m'} FR_{m'} XR_{m'} + \sum_{t} \mathrm{FUPR}_t + \sum_{m} \mathrm{FR}_m \mathrm{XR}_m + \sum_{m'}\sum_{k'}\sum_{t} Q'''_{m'k't}\widetilde{C_{m'k'}} \\ & + \sum_{j}\sum_{k}\sum_{t} Q_{jkt}\widetilde{C_{jk}} + \sum_{k}\sum_{m}\sum_{t} Q'''_{mkt}\widetilde{C_{mk}} + \sum_{j}\sum_{m}\sum_{t} Q'_{mkt}\widetilde{\mathrm{CA}_{jmt}} \\ & + \sum_{m}\sum_{l}\sum_{t} Q''_{mlt}\widetilde{\mathrm{CT}_{mlt}} + \sum_{m'}\sum_{l}\sum_{t} Q''''_{m'lt}\widetilde{CD_{m'lt}} + \sum_{l}\sum_{n}\sum_{t} Q'''_{lnt}\widetilde{\mathrm{CB}_{lnt}} \\ & + \sum_{l}\sum_{n'}\sum_{t} Q''''_{ln't}\widetilde{CB_{ln't}} + \sum_{m}\sum_{l}\sum_{t} Q''''_{mlt}\widetilde{C_l} + \sum_{m'}\sum_{l}\sum_{t} Q''''_{m'lt}\widetilde{C_l}. \end{aligned} \tag{1}$$

3.4.2. *Constraints*

$$\sum_{j} \mathrm{YU}_{jkt} + \sum_{m} YR_{mkt} \le 1 \forall k, t, \tag{2}$$

$$Q_{jkt} \le \mathrm{MYU}_{jkt} \forall j, k, t, \tag{3}$$

$$Q''_{mkt} \le \mathrm{MYR}_{mkt} \forall m, k, t, \tag{4}$$

$$Q''''_{m'k't} \le \mathrm{MYR}'_{m'k't} \forall m', k', t, \tag{5}$$

$$\sum_{j_1}\sum_{j} \mathrm{XU}_{j_1 j_t} = Pr_t \forall j1, t, \tag{6}$$

$$\sum_{j} \mathrm{XU}_{j1jt} \le \mathrm{XU}_{j1jt-1} \forall j1, j, \tag{7}$$

$$\mathrm{XR}_m + \sum_{j} \mathrm{XU}_{j1jt} \le 1 \forall m, j, t, \tag{8}$$

$$\sum_{j} Q_{jkt} + \sum_{m} Q''_{mkt} \le d_{kt} \forall k, t, \tag{9}$$

$$\sum_{m'} Q''''_{m'k't} \le d'_{k't} \forall k', t, \tag{10}$$

$$\sum_{j}\sum_{m}\sum_{t} Q''_{jmt} + \sum_{m}\sum_{l}\sum_{t} Q'''_{mlt} + \sum_{l}\sum_{n}\sum_{t} Q''''_{lnt} \ge \sum_{n} \widetilde{D_{nt}} \forall t, \tag{11}$$

$$\sum_{m'}\sum_{l}\sum_{t} Q''''_{m'lt} + \sum_{m'}\sum_{n}\sum_{t} Q''''_{m'n't} \ge \sum_{n'} \widetilde{D'_{n't}} \forall t, \tag{12}$$

$$Q''_{mlt} \le \widetilde{capl_{lt}} \forall m, l, t, \tag{13}$$

Table 1: Sets, parameters and variables of the set model.

Set	Description	$\widetilde{capp}_{m't}$	Plasma storage capacity in permanent center m' in period t	
K	Set of regular donors	$\widetilde{capf}_{mt}$	Blood storage capacity in permanent center m in period t	
k'	Set of donors recovered from COVID-19	$\widetilde{C}_l$	Cost of testing each unit of blood and plasma in laboratory l	
M	Blood donation of set of permanent centers	$\widetilde{D}_{nt}$	Amount of blood demands in health care medical center n in period t	
M'	Set of permanent plasma donation centers	$\widetilde{D}_{n't}$	Plasma demand in hospital n' in period t	
J	Set of temporary blood donation centers	d_{kt}	Maximum blood donation from donors k at time t	
T	Set of time periods	$d'_{k't}$	Maximum plasma donation from a donor recovered from COVID-19 K' at time t	
L	Set of laboratories	*Decision variables*	*Description*	*Type of variables*
N	Set of hospitals requesting blood	Q_{jkt}	The amount of blood collected in interim center j from donors k in period t	Continuous
n'	Set of hospitals requesting plasma	Q'_{jmt}	The amount of blood independent of center j to permanent blood center m in period t	Continuous
Parameter	*Description*	Q''_{mkt}	The amount of blood collected in blood center m from donors k in period t	Continuous
$\widetilde{CB}_{lnt}$	Cost of transferring a unit of blood from laboratory l to demand points n in period t	Q'''_{mlt}	The amount of blood independent of permanent blood center m to laboratory center l in period t	Continuous
$\widetilde{CB}_{ln,t}$	Cost of transferring a unit of COVID-19 plasma from laboratory l to demand points n in period t	Q''''_{lnt}	The amount of blood moved from laboratory l to demand points n in period t	Continuous
$\widetilde{CA}_{jmt}$	Cost of transferring a unit of blood from temporary center j to permanent center m in period t	$Q'''''_{m'k't}$	The amount of plasma collected in blood center m' from donors k' in period t	Continuous
$\widetilde{CT}_{mlt}$	Cost of transferring a unit of blood from permanent center m to a laboratory l in period t	$Q''''''_{m'lt}$	The amount of plasma transferred from blood center m' to laboratory l in period t	Continuous
$\widetilde{CD}_{m'lt}$	Cost of transferring a plasma unit from permanent center m' to laboratory l in period t	$Q'''''''_{ln't}$	The amount of plasma transferred from laboratory l to demand points n in period t	Continuous
FR_m	Fixed cost to build blood center m	p_t	Number of interim facilities required in period t	Continuous
$\text{FR}_{m'}$	Fixed cost to build plasma center m'	XU_{jljt}	If the temporary facility in location j in period t-1 in location j_1 is in period t, it is one; otherwise, it is zero.	Binary
FU	Fixed cost to establish a temporary blood center	XR_m	If a permanent blood center is created in location m, it is one; otherwise, it is zero	Binary
$\widetilde{C}_{mk}$	Operating cost for blood collection in blood center m from a donor of group k	$XR_{m'}$	If a permanent plasma center is created in location m', it is one, and otherwise, it is zero	Binary
$\widetilde{C}_{m'k'}$	Operating cost for plasma collection in blood center m' from a donor of group k'	yu_{jkt}	If donor k is assigned to interim facility j in period t, it is one, and otherwise, it is zero	Binary
$\widetilde{C}_{jk}$	Operating cost for blood collection in interim facility j from a donor of group k	M	A very large number	Continuous
$\widetilde{capl}_{lt}$	Blood storage capacity in laboratory l in period t	YR_{mkt}	If donor k is assigned to permanent blood center m in period t, it is one, and otherwise, zero	Binary
$\widetilde{capp}_{lt}$	Plasma storage capacity in laboratory l in period t	$YR'_{m'k't}$	If donor k' is assigned to plasma permanent center m' in period t, it is one, and otherwise, zero	Binary

$$Q'_{jmt} \le \widetilde{capf}_{mt} \forall j, m, t, \tag{14}$$

$$Q''''''_{m'lt} \le \widetilde{capp}_{lt} \forall m', l, t, \tag{15}$$

$$Q'''''_{m'k't} \le \widetilde{capp}_{m't} \forall m', k', t, \tag{16}$$

$$\text{XU}_{j1jt}, \text{XR}_m, \text{XR}_{m'}, \text{YU}_{jkt}, R_{mjt}, \text{YR}_{mkt}, \text{YR}_{m'k't}', \in \{0,1\} \forall m', k', t, \tag{17}$$

$$Q_{jkt}, Q''_{jmt}, Q'''_{mkt}, Q''''_{mlt}, Q''''_{lnt}, Q''''_{m'kt}, Q''''_{m'lt}, Q''''_{ln't}, pr_t \ge 0 \forall j, m, m', k', k, n, n'. \tag{18}$$

According to the above mention constraints, the objective function in equation (1) minimizes the expected costs of the blood supply chain. These costs involve the fixed costs of establishing the facility, the operating cost of collecting blood and plasma from donors in blood centers, the cost of transporting between various stages of the supply chain, and the cost of testing blood and plasma health, respectively. Constraint (2) indicates that only one permanent or temporary blood center can receive blood from each group of donors. Constraints (3)–(5) are related to blood and plasma donation. Constraints (3) and (4) state that the group of blood donors can go to a permanent or temporary blood donation center. Limitation (5) shows that the group of plasma donors can go to a permanent plasma donation center. Constraints (6)–(8) are related to the establishment and number of temporary facilities. Limit (6) shows the number of temporary facilities required. Limitation (7) guarantees that temporary facilities are relocated to a place that has not already been located. Constraint (8) states that only one temporary or permanent center can be located in one place. Constraints (9)–(12) are related to the supply and demand of blood and plasma. Constraint (9) restricts the amount of blood donated in each cycle by each batch of donors to interim and continual centers. Constraint (10) restricts the amount of plasma donated in each period by each batch of donors in the permanent center. Constraints (11) and (12) specify, respectively, that the optimal blood and plasma demand must be met in each period. Constraints (13)–(16) show the saving capacity of blood and plasma in laboratories and permanent centers, respectively. Limitation (17) and (18) determine the nature of the problem decision variables.

3.5. Solution Approach: A Fuzzy Chance-Constrained Programming Approach. In the model provided in Section 3.4, the values of parameters of blood and plasma demand, system costs, and blood and plasma inventory storage capacity are uncertain. To cope with uncertainty, the fuzzy chance-constrained approach is used [11]. Accordingly, the certain equivalent of the proposed uncertain model is as follows:

$$
\begin{aligned}
\min E[z] &= \sum_{m'} \mathrm{FR}_{m'}\mathrm{XR}_{m'} + \sum_{t} \mathrm{FUPR}_t + \sum_{m} \mathrm{FR}_m \mathrm{XR}_m \\
&+ \sum_{m'}\sum_{k'}\sum_{t} Q'''_{m'k't}\left(\frac{C_{m'k'(1)} + C_{m'k'(2)} + C_{m'k'(3)} + C_{m'k'(4)}}{4}\right) \\
&+ \sum_{j}\sum_{k}\sum_{t} Qjkt\left(\frac{C_{jk(1)} + C_{jk(2)} + C_{jk(3)} + C_{jk(4)}}{4}\right) \\
&+ \sum_{k}\sum_{m}\sum_{t} Q''_{mkt}\left(\frac{C_{mk(1)} + C_{mk(2)} + C_{mk(3)} + C_{mk(4)}}{4}\right) \\
&+ \sum_{m}\sum_{l}\sum_{t} Q''_{mlt}\left(\frac{CT_{mlt(1)} + CT_{mlt(2)} + CT_{mlt(3)} + CT_{mlt(4)}}{4}\right) \\
&+ \sum_{m'}\sum_{l}\sum_{t} Q'''_{m'lt}\left(\frac{CD_{m,lt(1)} + CD_{m,lt(2)} + CD_{m,lt(3)} + CD_{m,lt(4)}}{4}\right) \\
&+ \sum_{l}\sum_{n}\sum_{t} Q''_{lnt}\left(\frac{CB_{lnt(1)} + CB_{lnt(2)} + CB_{lnt(3)} + CB_{lnt(4)}}{4}\right) \\
&+ \sum_{l}\sum_{n,}\sum_{t} Q'''_{ln't}\left(\frac{CB_{ln,t(1)} + CB_{ln,t(2)} + CB_{ln,t(3)} + CB_{ln,t(4)}}{4}\right) \\
&+ \sum_{m}\sum_{l}\sum_{t} Q''_{mlt}\left(\frac{C_{l(1)} + C_{l(2)} + C_{l(3)} + C_{l(4)}}{4}\right) \\
&+ \sum_{m'}\sum_{l}\sum_{t} Q'''_{m'lt}\left(\frac{C_{l(1)} + C_{l(2)} + C_{l(3)} + C_{l(4)}}{4}\right).
\end{aligned}
\tag{19}
$$

According to equations (2), (10), (17), and (18),

$$\sum_{j}\sum_{m}\sum_{t} Q''_{jmt} + \sum_{m}\sum_{l}\sum_{t} Q''_{mlt} + \sum_{l}\sum_{n}\sum_{t} Q'''_{lnt} \geq (1-\alpha)\times\sum_{n} D_{nt(3)} + (\alpha)\times\sum_{n} D_{nt(4)}\forall t, \tag{20}$$

$$\sum_{m'}\sum_{l}\sum_{t} Q''_{m'lt} + \sum_{m'}\sum_{n}\sum_{t} Q''_{m'n't} + \geq (1-\alpha)\times\sum_{n} D''_{nt(3)} + (\alpha)\times\sum_{n} D_{nt(4)}\forall t, \tag{21}$$

$$Q''_{mlt} \leq (1-\alpha)\times capl_{lt(2)} + (\alpha)\times capl_{lt(1)}\forall m, l, t, \tag{22}$$

$$Q'_{jmt} \leq (1-\alpha)\times capf_{mt(2)} + (\alpha)\times capf_{mt(1)}\forall m, l, t, \tag{23}$$

$$Q'''_{m'lt} \leq (1-\alpha)\times capp_{lt(2)} + (\alpha)\times capp_{lt(1)}\forall m', l, t, \tag{24}$$

$$Q'''_{m'k't} \leq (1-\alpha)\times capp_{m't(2)} + (\alpha)\times capp_{m't(1)}\forall m', k', t 0.5 \leq \alpha \leq 1. \tag{25}$$

Table 2: Information of demand points.

No.	Hospital name	Type of need	Number of beds
1	Namazi Hospital	Blood and plasma	780
2	Pars Hospital	Blood	45
3	Shahid Dr. Beheshti Hospital	Blood and plasma	224
4	Zeinabiyyeh Hospital	Blood	179

Table 3: Data on model parameters.

Parameters	Value
$\widetilde{C}_l$	[100000, 7500]
d_{kt}	[150, 30]
$d'_{k't}$	[50, 15]
M	1000000000
$\widetilde{capl}_{lt}$	[350, 200]
$\widetilde{capp}_{lt}$	[1500, 50]
$\widetilde{capp}_{m't}$	[500, 250]
$\widetilde{capf}_{mt}$	[400, 100]
$\widetilde{CB}_{ln't}$	[3200, 1800]
$\widetilde{CA}_{jmt}$	[5000, 1500]
$\widetilde{CT}_{mlt}$	[3500, 1300]
$\widetilde{CD}_{m'lt}$	[4500, 3200]
$\widetilde{D}_{nt}$	[1000, 800]
$\widetilde{D}'_{n't}$	[500, 400]
$\widetilde{CB}_{lnt}$	[5000, 3500]
FR_m	23,000
$FR_{m'}$	25,000
FU	400
$\widetilde{C}_{mk}$	[3000, 1500]
$\widetilde{C}_{m'k'}$	[4000, 2500]
$\widetilde{C}_{jk}$	[3800, 2200]

4. Results

In current section, a real case study in the city of Shiraz is reviewed. According to validation approach the proposed model is test. For this purpose, four sample problems in certain and noncertain states are investigated, and finally, the sensitivity analysis of the goal function in relation to the model parameters is carried out. It should be noted that the proposed mathematical model was coded in GAMS 24.1.2 software on a personal computer with CPU intel Core i7 and 8 GB RAM.

4.1. Case Study. Shiraz is the fifth largest and numerus city in Iran and the most populous city in the south of the country. Due to the shortage of blood and COVID-19 plasma in Shiraz and the urgent need for blood in hospitals and medical centers, as well as plasma to help cure COVID-19 patients as soon as possible and to compensate for blood shortage and meet the rate of blood and plasma demand, it is essential to design a chain blood supply. Three points in Shiraz were considered as candidates for the establishment of temporary facilities. Donated blood in temporary centers is transferred to the blood center on Namazi Street. The blood collected in temporary and permanent centers is then transferred to Shiraz Blood Transfusion Laboratory located in Namazi Street, and after performing health test, it is given to hospitals and medical centers. Also, donors who have recovered from COVID-19 donate their plasma to the blood center on Qasrdasht Street. In this study, four hospitals were considered as demand points. Table 2 shows information of the four demand points. In this study, a one-year planning horizon is considered, and each time unit shows a four-month period and also the model parameters are given in Table 3.

Table 4: The value of the goal function in certain and uncertain states.

Amount of the objective function in certain state	Amount of the goal function in uncertain state		
	0.9	0.7	0.5
103.70	103.90	103.85	103.80

Table 4 indicates the amount of the goal function in the certain and uncertain condition. According to Table 4, as the value of the α parameter increases, the chain costs increase. Therefore, the decision maker can reduce the cost of the α parameter to reduce costs.

It is worth noting that, due to space savings, only period one is shown. As the α parameter increases, the number of potential mobile points in different periods increases to respond to the increase in demand. In the first period, at the level of $\alpha = 0.5$, mobile point 1 and at the level of $\alpha = 0.7$, in addition to the previous point, point 2, and at the level of $\alpha = 0.9$, in addition to the points of the two levels before point 3 are considered to meet the demand of hospitals.

4.2. Sample Problem. Table 5 shows the sample problems created to investigate the efficiency of the model in different dimensions.

The results of solving the problems in certain state and the fuzzy chance-constrained model for various values of α are shown in Table 6. According to this table, it is obvious that, with gaining the dimensions of the problem, the value of system costs increases, and system costs in the uncertainty state are greater than the certain state by increasing the value of α.

4.3. Sensitivity Analysis. In this section, variations in the objective function to different values of demand are evaluated. It is worth noting that, due to lack of space, the sensitivity analysis is carried out on only one parameter. For sensitivity analysis, all sample problems are considered.

Table 5: Dimensions of the sample problem.

Sample problem	Sets								
	Recovered donors	Regular donors	Temporary centers	Permanent plasma center	Permanent blood center	Laboratory	Time period	Blood demand points	Plasma demand points
1	8	13	8	2	4	3	6	6	2
2	12	13	10	3	5	5	9	10	6
3	14	17	12	4	6	7	12	14	10
4	16	20	14	5	7	9	18	18	14

Table 6: The amount of the goal function in the certain condition and uncertainty of the parameters.

Solving time (seconds)	Value of the goal function in certain conditions	Value of goal function in conditions of uncertainty						Sample problem
		Solving time (seconds)	$\alpha = 0.9$	Solving time (seconds)	$\alpha = 0.7$	Solving time (seconds)	$\alpha = 0.5$	
30	115.6733	48	115.98	45	115.97	35	115.95	1
50	116.1003	68	116.4005	65	116.3005	55	116.2295	2
70	127.2257	83	127.8675	80	127.4475	75	127.3375	3
85	128.245	108	128.24495	105	128.245	100	128.245	4

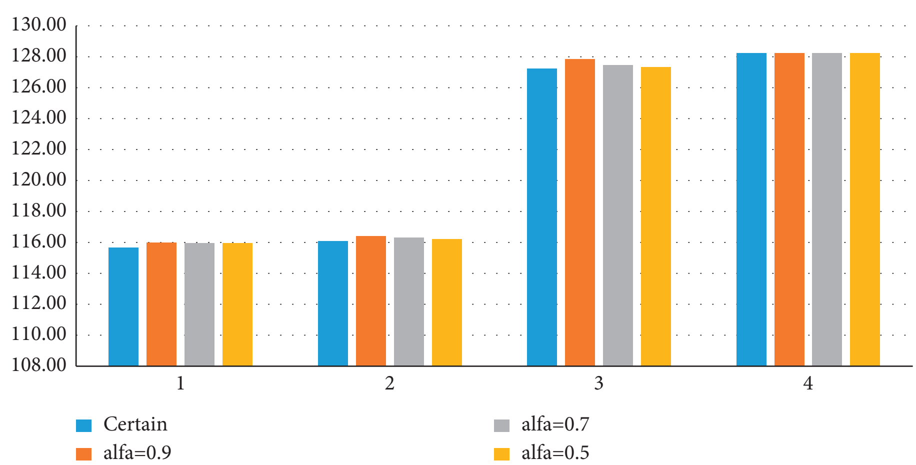

Figure 2: Variations in Z to variations in demand in certain and fuzzy chance-constrained models.

According to Figure 2, as demand increases, more blood and plasma need to be collected to meet demand, which increases operating and health testing costs and ultimately increases total system costs.

4.4. Discussion. In the event of a crisis, blood transfusions and blood products are one of the most vital and important medical emergency measures. According to the importance of blood and blood products, the source of blood supply is very limited. According to the fact that blood and blood products cannot be produced artificially in the laboratory, the only source of supply is donors. Given the importance of this rare factor, it is essential to establish a blood network in critical situations to collect blood products in the event of widespread pandemics. In this study, the presented model is able to reducing the cost of blood plasma collected during a recent pandemic outbreak. Finally, using definitive programming, model behavior is applied in real-world case study.

4.5. Managerial Insights. For implication in the real world to show implication managerial insight, issue of transfusion of blood plasma during a crisis in a crisis city has been investigated by considering the uncertain parameters of supply and transmission. The mathematical modeling presented in this study adds useful knowledge to health managers to design, modify, and evaluate the blood transfusion system in the against of the COVID-19 pandemic.

5. Conclusion and Future Suggestions

In current study, a multilevel and multiperiod MIP model is proposed for designing blood supply chain at different levels such as, permanent and temporary centers, laboratories, set of donors, and demand points considering minimization of chain costs. In the mathematical model, real-world constraints such as meeting blood and plasma demand in each period, blood and plasma storage capacity, and establishing temporary facilities are considered. Parameters of blood and plasma demand, system costs, and blood and plasma inventory storage capacity are considered uncertain. The fuzzy uncertain limited framework was used to consider with the uncertainty of the deterministic values. Finally, the efficiency of the presented model was implemented using a real case study in Shiraz. According to the main results of computational modeling, the proposed model could be calculated as follows:

(i) Value objectives function in the certain and uncertain values.
(ii) According to the results, the objective certain value is lower than uncertain value.
(iii) Uncertain value calculated is of three dimensions. According to this, the categorized objective value increased when the dimension is equal 0.5.
(iv) Finally, it shows that demand increases, more blood and plasma need to be collected to meet demand, which increases operating and health testing costs and ultimately increases total system costs.

For future research, the uncertainty of the model parameters can be controlled from other uncertainty approaches such as random and robust programming, and the results can be compared with the fuzzy chance-constrained approach. The model can also be developed in conditions of crisis.

Data Availability

The data that support the findings of this study are available from the author, upon reasonable request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

References

[1] M. R. Ghatreh Samani, S. A. Torabi, and S. M. Hosseini-Motlagh, "Integrated blood supply chain planning for disaster relief," *International Journal of Disaster Risk Reduction*, vol. 27, pp. 168–188, 2018.

[2] M. Asadpour, O. Boyer, and R. Tavakkoli-Moghaddam, "A blood supply chain network with backup facilities considering blood groups and expiration date: a real-world application," *International Journal of Engineering*, vol. 34, no. 2, pp. 470–479, 2021.

[3] S. Tadarok, M. B. Fakhrzad, M. Jokardarabi, and A. Jafari-Nodoushan, "A mathematical model for a blood supply chain network with the robust fuzzy possibilistic programming approach: a case study at Namazi hospital," *International Journal of Engineering*, vol. 34, no. 6, pp. 1493–1502, 2021.

[4] R. Lotfi, K. Kheiri, A. Sadeghi, and E. Babaee Tirkolaee, "An extended robust mathematical model to project the course of COVID-19 epidemic in Iran," *Annals of Operations Research*, vol. 21, pp. 1–25, 2022.

[5] S. Ambulkar, J. Blackhurst, and S. Grawe, "Firm's resilience to supply chain disruptions: scale development and empirical examination," *Journal of Operations Management*, vol. 33, pp. 111–122, 2015.

[6] Sh. Jahangiri, M. Abolghasemian, P. Ghasemi, and A. Pourghader Chobar, "Simulation-based optimization: analysis of the emergency department resources under COVID-19 conditions," *International journal of industrial and systems engineering*, vol. 1, no. 1, p. 1504, 2021.

[7] S. Jahangiri, A. Pourghader Chobar, P. Ghasemi, M. Abolghasemian, and V. Mottaghi, "Simulation-based optimization: analysis of the emergency department resources under COVID-19 conditions," *International Journal of Industrial and Systems Engineering Journal of Applied Research on Industrial Engineering*, vol. 1, no. 1, pp. 1–10, 2021.

[8] S. J. Stanworth, H. V. New, T. O. Apelseth et al., "Effects of the COVID-19 pandemic on supply and use of blood for transfusion," *The Lancet Haematology*, vol. 7, no. 10, pp. e756–e764, 2020.

[9] G. J. J. Van Zyl, *Inventory Control for Perishable Commodities*, Dissertation, University of North Carolina, Chapel Hill, 1964.

[10] S. Nahmias, "Perishable inventory theory: a review," *Operations Research*, vol. 30, no. 4, pp. 680–708, 1982.

[11] H. Derikvand, S. M. Hajimolana, A. Jabarzadeh, and E. Najafi, "A fuzzy stochastic bi-objective model for blood provision in disastrous time," *Journal of Industrial and Systems Engineering*, vol. 12, no. 2, pp. 223–245, 2019.

[12] S. B. Ghorashi, M. Hamedi, and R. Sadeghian, "Modeling and optimization of a reliable blood supply chain network in crisis considering blood compatibility using MOGWO," *Neural Computing & Applications*, vol. 32, no. 16, pp. 12173–12200, 2019.

[13] H. Shih and S. Rajendran, "Stochastic inventory model for minimizing blood shortage and outdating in a blood supply chain under supply and demand uncertainty," *Journal of Healthcare Engineering*, vol. 2020, pp. 1–14, Article ID 8881751, 2020.

[14] O. Kaya and D. Ozkok, "A blood bank network design problem with integrated facility location, inventory and routing decisions," *Networks and Spatial Economics*, vol. 20, no. 3, pp. 757–783, 2020.

[15] H. Adarang, A. Bozorgi-Amiri, K. Khalili-Damghani, and R. Tavakkoli-Moghaddam, "A robust bi-objective location-routing model for providing emergency medical services," *Journal of Humanitarian Logistics and Supply Chain Management*, vol. 10, no. 3, pp. 285–319, 2020.

[16] E. B. Tirkolaee, N. S. Aydın, M. Ranjbar-Bourani, and G. W. Weber, "A robust bi-objective mathematical model for disaster rescue units allocation and scheduling with learning effect," *Computers & Industrial Engineering*, vol. 149, Article ID 106790, 2020.

[17] M. Rezaei Kallaj, M. Abolghasemian, S. Moradi Pirbalouti, M. Sabk Ara, and A. Pourghader Chobar, "Vehicle routing problem in relief supply under a crisis condition considering blood types," *Mathematical Problems in Engineering*, vol. 2021, pp. 1–10, Article ID 7217182, 2021.

[18] M. Arani, Y. Chan, X. Liu, and M. Momenitabar, "A lateral resupply blood supply chain network design under uncertainties," *Applied Mathematical Modelling*, vol. 93, pp. 165–187, 2021.

[19] F. Goodarzian, S. F. Wamba, K. Mathiyazhagan, and A. Taghipour, "A new bi-objective green medicine supply chain network design under fuzzy environment: hybrid metaheuristic algorithms," *Computers & Industrial Engineering*, vol. 160, Article ID 107535, 2021.