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Research Article

A Two-Objective Model for the Multilevel Supply Chain of Blood Products with the Approach of Reducing the Rate of Contagion under the (COVID-19) Epidemic Outbreak Conditions

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The conditions of the coronavirus epidemic have put much pressure on the healthcare system. This disease has hurt the blood supply through the reduction of blood donation and the reduction of access to suitable collection facilities due to dysfunction. Considering the importance of the subject, the purpose of this paper is to design a two-level supply chain network for blood products with the approach of reducing costs and the rate of contagion under the conditions of epidemic outbreaks (COVID-19). After examining the solution methods for multilevel supply chain networks of blood products under the conditions of the spread of the COVID-19 virus, three exact solution methods, including LP-metric, an improved version of the augmented ε-constraint (AUGMECON2), and an improved weighted Chebyshev, are proposed. They are used to solve the model in small dimensions. In order to compare the methods in the obtained solutions, several numerical examples of different sizes are generated and solved. Then, using the statistical assumption test, the obtained results are compared in all numerical examples by Tukey's technique. Also, the TOPSIS is applied to select the best method. Finally, in order to investigate the reaction of the objectives to the changes in the contagion probability parameter, a sensitivity analysis has been performed. The results emphasize that improving the performance of the blood supply chain (BSC) can lead to a reduction in BSC costs and improved service to patients. Also, the adaptation of different components of the BSC and regular coordination between them play an efficient role in controlling and improving this disease and reducing the costs of the BSC. Also, receiving the plasma product of recovered people from type (II) donors can play a vital role in reducing the percentage of disease transmission.

1. Introduction

The occurrence of unpredictable events such as natural disasters with a short term but high demand or widespread diseases such as the COVID-19 virus with a long-term and high contagion rate will cause many disruptions all over the world, and, as a result, the supply chain. It creates various problems, including the BSC [1].

The widespread coronavirus 2019 (COVID-19) is one of the recent crises around the world at the end of 2019. The epidemic of COVID-19 virus caused a decrease in the supply of blood and its products. As a result, it had destructive effects on the activities of organizations and blood facilities in many countries. Also, the epidemic led to the lack of proper response to the demand of other patients and blood applicants. Due to the government's initial intervention, such as general quarantine and strategies to prevent the gathering of people during the outbreak of COVID-19, many blood centers and facilities were suspended, the most significant effect of which is a considerable reduction in the number of blood donors [2].

Wang et al. [3] from the First Hospital Affiliated with the University School of Medicine in China announced that the primary concern of blood donors was the fear of contracting the COVID-19 virus when donating blood. On the other hand, people who have recovered from COVID-19 develop natural defence systems against this disease in their blood. Therefore, the blood plasma of these people contains COVID-19 antibodies, which can be used to prepare the plasma product of recovered people for the treatment of other COVID-19 patients [4]. Nevertheless, the statistics indicated that only 1.88% of those who recovered donated their blood plasma.

According to a report from the World Health Organization, there is no evidence anywhere in the world based on the transmission of the coronavirus or other respiratory viruses through blood transfusion [5]. However, there are concerns and misleading rumors about this disease in the minds of donors. Accordingly, adopting educational policies to inform people correctly will have a significant effect on improving the current conditions and increasing the donation rate again. Meanwhile, the role of blood facilities and related managers in coordinating with new changes and providing a safe environment for donors is undeniable [6].

While the application of some policies is helpful in order to grow the donation of all blood products, it should be kept in mind that blood is not a commonplace commodity, and the unique characteristics of blood and its supply chain (including the fact that the supply of donated blood is relatively irregular, the demand for blood products is uncertain, it is not easy to match supply and demand efficiently, and blood products are perishable) cause more complexity of the problem and ultimately leading to blood shortage as a high cost to the society through increasing the mortality rate. On the other hand, the wastage and expiration of blood are often not accepted, because blood donors are infrequent resources of society. For each donor, a specific period must be considered between two donations, depending on the type of donation. Even after applying for volunteers, only a tiny percentage (5%) of people is eligible to donate. All these conditions emphasize the need to particularly study the issues related to the BSC affected by the crisis of the spread of the coronavirus.

The main goal of the current study is to design a two-level supply chain network for blood products, focusing on the conditions of the spread of the coronavirus. In such a way that taking into account the critical conditions, i.e., the outbreak of the widespread disease of COVID-19, not only the amount of supply of blood products in two dimensions related to regular patients and patients with corona will increase, and as a result, the rate of contagion of this disease will decrease, but also, by managing the entire supply chain network, cost wastage and, more importantly, wastage or lack of blood products can be prevented.

Some of the special features and innovations of the proposed formulation are as follows: (a) comprehensive minimization of all types of costs of the entire network is considered as the first objective. (b) For the first time, the objective of minimizing the spread of the coronavirus has been developed. This goal is pursued by increasing the supply of plasma from recovered people to reduce the shortage of this product at various demand points. Also, the minimization of the spread of the disease through the maximization of the satisfaction of the applicants of this type of plasma is also followed in the second objective function.

2. Literature Review

In this context, the review of the research background shows that, for example, Hsieh [7] has presented the BSC in two levels of collection and distribution with the goals of minimizing costs and maximizing the satisfaction of applicants. The results indicated an improvement in the cost and quality indicators of health services. In another study, Habibi et al. [8] solved the problem of the location of facilities to optimize costs and blood shortage by presenting the BSC network in three levels: collection, processing, and distribution in crisis conditions.

Zahiri et al. [9] also investigated the reliability, effectiveness, and efficiency in a three-level supply chain of blood products to optimize the total cost and also the useful life of the products. Ramazanian and Behbodhi [10] have designed a dynamic location problem in a three-level blood supply network including donors, blood donation bases (fixed and mobile), and blood centers, considering only one objective of usefulness from the donors' point of view. The results of solving the mixed integer programming model indicated that in order to reduce costs, bases close to blood centers must be selected for construction.

Heydari Fathian and Pasandideh [11] also proposed a sustainable BSC network for three products: red cells, platelets, and plasma, at all levels and with the goals of minimizing costs and minimizing the environmental effects caused by the activities of the blood chain network. Diabat et al. [12] designed a blood product supply chain network including red blood cells, platelets, and plasma in four donation levels to reduce the time and cost of transporting the product by taking into account the disruption in the facilities and the route between them. They have designed the BSC in four levels: donation, collection, product production, and distribution. Kamran et al. [13] formulated a new stochastic multiobjective, multiperiod, and multicommodity simulation-optimization model for the COVID-19 vaccine's production, distribution, location, allocation, and inventory control decisions. Their supply chain network includes four echelons of manufacturers, hospitals, vaccination centers, and volunteer vaccine students. Ghasemi et al. [14] developed a novel multiobjective mathematical model for a plasma supply chain network during the COVID-19 outbreak conditions to maximize the coverage of blood donors during periods and minimize the blood transportation costs between different nodes, relocation cost of temporary mobile facilities, inventory holding cost of the blood, and the costs of newly established blood centers.

Numerous factors can affect the process of blood transfusion, blood donation, and rate of contagion under the conditions of epidemic outbreaks (COVID-19). In this regard, it is necessary to plan and create strategies to improve the efficiency of BSC and reduce the rate of contagion under the conditions of epidemic outbreaks (COVID-19). Accordingly, an efficient approach is designed in the present study to optimize the overall cost and the contagion rate under the conditions of epidemic outbreaks (COVID-19). Indeed, an attractive environment can help to remove barriers to blood donation and improve blood health.

3. Mathematical Modeling

After examining the solution methods for multilevel supply chain networks of blood products under the conditions of the spread of the coronavirus, three exact solution methods, including LP-metric, augmented improved ε-constrained, and improved weighted Chebyshev, are presented. They are applied to solve the proposed mathematical formulation in small dimensions. In order to compare the methods in production responses, 20 numerical test examples are presented. Then, due to the statistical hypothesis test, the results of the methods are compared with each other in all numerical test examples using Tukey's technique. Also, TOPSIS is applied to select the best method. Finally, in order to investigate the reaction of the objectives to the changes in the contagion probability parameter, a sensitivity analysis is performed.

Table 1 shows the proposed mathematical model in an overview, where the objective functions, features, and solution method can also be seen.

It should be noted that as the second objective, the percentage of the spread of the COVID-19 virus is minimized along with the costs of the entire network. Since this epidemic has affected many sections and subsystems of the blood supply network after the outbreak, in the proposed model, the rate of the spread of this disease has been taken into consideration and added as a separate objective function to the proposed mathematical formulation. The purpose of this objective is to minimize the spread of corona disease in the presence of blood donors in mobile, regional, and local blood centers in the BSC.

3.1. Assumptions. The main assumptions of the proposed model are as follows:

(1) Mobile facilities are in local blood centers and potential areas while there are hospitals as well

(2) Donors are a group of people dispersed in an area, and it is impossible to design a blood collection program for each person

(3) Donors are divided into regular and improved groups

(4) Donors who have recovered from COVID-19 only go to apheresis centers to donate plasma

(5) Mobile facilities receive blood from different donor groups only by apheresis

(6) Regional blood centers are equipped with both simple and apheresis methods

(7) It is possible to store different products in hospitals and regional blood centers, while it is not possible in mobile facilities and local centers

(8) The age of blood products will be specified from the production time in regional centers

(9) Blood products with a lifespan of fewer than two days will not be sent from regional centers to the regional points of demand

(10) Depending on the type of each center and the data collected from the Blood Transfusion Organization (BTO) of a given country, the model is solved with the capacity parameters of each facility determined in advance

(11) Blood expiration has a penalty cost

(12) In the face of some uncertain parameters, the stochastic programming approach is used. So, scenarios with a definite probability are used in a discrete case, and normal log distribution is practiced in a continuous case

3.2. Notations. The indices, parameters, and decision variables applied in the mathematical formulation are represented as follows.

3.2.1. Sets and Indices

$I = I' \cup I''$ Set of regular donors and those having recovered from coronary heart disease $(i', i'' \in I)$

M Set of candidate locations for mobile facilities $(m \in M)$

L Set of candidate locations for local blood centers $(l \in L)$

R Set of candidate locations for regional blood centers $(r \in R)$

$M \cup L \cup R = W$ The whole set of centers responsive to donors $(w \in W)$

$P_1 \cup P_2 \cup P_3 \cup P_4 \cup P_5 = P$ Whole blood (P_1), red blood cells (P_2), platelets (P_3), plasma type (I) (belonging to normal people) (P_4), and type (II) plasma (belonging to people having recovered from coronary heart disease) (P_5) $(P_i \in P)$

$k_1 \cup k_2 \cup k_3 = k$ Set of lifetimes of whole blood products, red blood cells, and platelets $(k \in K)$ (by day)

H Set of demand points $(h \in H)$

$A = A' \cup A''$ Set of simple blood collection and apheresis methods $(a', a'' \in A)$

T Set of periods $(t \in T)$

S Set of the COVID-19 pandemic status scenarios $(s \in S)$

3.2.2. Parameters

Fa_l The cost of setting up local blood center l

Fb_r The cost of setting up regional blood center r

$Fc_{m'm''t}$ The cost of moving each mobile device from place m' to place m'' during t

Table 1: Characteristics of the proposed mathematical formulation.

Objective functions	Characteristics	Solution method
Minimizing of costs	The coronavirus epidemic imposes higher investment and operating costs on the health and treatment network, the BSC network, and, subsequently, the society's economy, in different ways	To solve the proposed mathematical formulation, the exact solution methods, LP-metric, AUGMECON2, and improved weighted Chebyshev, are used. The model is implemented and compared by them in several sample test problems. Finally, the superior solution method is selected by the TOPSIS technique
Minimizing the spread of the coronavirus	The objective is to minimize the spread of the COVID-19 virus in the presence of blood donors in mobile, regional, and local blood centers in the proposed supply chain	

Ta_{pt} The cost of transporting each unit of blood product p per kilometer per t

Oa_{ipt} The cost of collecting each unit of blood product p from donor group i during t

Pa_{pt} The cost of production per unit of blood product p in regional blood centers in t

Hc_{pt} The cost of maintaining each unit of blood product p during period t

Sa_{lp_1t} Local blood center capacity l to collect whole blood (p_1) during period t

Sb_{pt} The capacity of mobile facilities to collect blood products p during t

Sc_{rpat} The capacity of regional center r to collect and produce blood products p obtained by collection method a during period t

Se_{rpat} The capacity of regional center r to store blood products p obtained by collection method a during period t

Sk_{hpat} Demand point capacity h to store blood products p obtained by collection method a during period t

Da_{im} The amount of route between donor group i and facility m

$Db_{i'l}$ The amount of route between donor group i' and the local center l

Dc_{ir} The amount of route between donor group i and the regional center r

Dd_{mr} The amount of route between facility m and the regional center r

De_{lr} The amount of route between the local center l and the regional center r

Dh_{rh} The amount of route between the regional center r and demand point h

Ra_m Maximum coverage radius of mobile facility m to serve donors

Rb_l Maximum coverage radius of the local center l to serve donors

Rc_r Maximum coverage radius of the regional center r to serve donors

Po_p Percentage of blood product production p

Ea_{hpat} Expiry cost per unit of extra blood product p obtained by collection method a at the demand point h during t

Dm^s_{hpat} Hospital demand h for blood products p obtained by collection method a during t under scenario s

τ_w Time spent on the blood donation process at the blood center w

σ_w Advertising budget in the blood center w

ϑ_w Experience factor in the blood center w

$S\tau_w$ Donor sensitivity to time τ_w

$S\sigma_w$ Donor sensitivity to advertising σ_w

$S\vartheta_w$ Donor sensitivity to the experience factor ϑ_w

Dr^s Average donation rate under scenario s

Pop_w The population of the area allocated to the blood center w

Ub_w The best productivity available in the blood center w

π^s Probability of scenario s

φ A very large number

ε A number from zero to one

α The probability of being infected with the coronavirus by another person in period t

3.2.3. Decision Variables

YL_l If local blood center l is launched, 1; otherwise, 0

YR_r If the center of region r is set up, 1; otherwise, 0

ZA^s_{imt} If donor group i is allocated by mobile facility m in period t under scenario s, 1; otherwise, 0

$ZB^s_{i'lt}$ If donor group i' is allocated to local center l in period t under scenario s, 1; otherwise, 0

ZC^s_{irt} If donor group i is allocated to regional center r during period t under scenario s, 1; otherwise, 0

$MV^s_{m'm''t}$ If the mobile facility passes from place m' to m'' in interval t under scenario s, 1; otherwise, 0

XA^s_{impt} The amount of blood product p donated by donor group i on mobile device m during t under scenario s

$XB^s_{i'lp_1t}$ The amount of whole blood p_1 donated by donor group i' at local center l during t under scenario s

XC^s_{irpt} The amount of whole blood p donated by donor group i in regional center r during t under scenario s

XD^s_{mrpt} The amount of whole blood p transferred by mobile facility m to regional blood center r during period t under scenario s

$XE^s_{lrp_1t}$ The amount of whole blood p_1 transferred from local center l to regional center r during t under scenario s

XG^s_{rhpakt} The amount of blood product p obtained from collection method a with age k days posted by regional center r to the point of demand h during t under scenario s

XH^s_{rhpakt} The amount of blood product p obtained from collection method a with age k day consumed at the point of demand h during t under scenario s

PR^s_{rpat} The amount of blood product p produced by collection method a in regional center r during t under scenario s

SH^s_{hpat} Deficiency of blood product p obtained from collection method a at the point of demand h during t under scenario s

EX^s_{hpat} The amount of extra blood product p obtained from collection method a expired at the point of demand h during period t under scenario s

IR^{s}_{rpat} Blood product inventory level p obtained from collection method a in regional center r during t under scenario s

IH^{s}_{hpakt} Blood product inventory level p obtained from collection method a with age k days at the point of demand h during t under scenario s

AT^{s}_{wt} The attractiveness of blood center w under scenario s during t

3.3. Model Representation. Accordingly, the proposed mathematical formulation can be organized as follows:

$$
\begin{aligned}
\text{Min } Z_1 &= \sum_{n} \psi_n \\
\psi_1 &= \sum_{l} Fa_l.YL_l \\
\psi_2 &= \sum_{r} Fb_r.YR_r \\
\psi_3 &= \sum_{m'} \sum_{m''\neq m'} \sum_{t} \sum_{s} \pi^s.Fc_{m'm''t}.MV^{s}_{m'm''t} \\
\psi_4 &= \sum_{i} \sum_{m} \sum_{l} \sum_{r} \sum_{p} \sum_{t} \sum_{s} \pi^s.Oa_{\text{ipt}}.\left(XA^{s}_{impt} + XB^{s}_{i'lp_1t} + XC^{s}_{irpt}\right) \\
\psi_5 &= \sum_{m} \sum_{l} \sum_{r} \sum_{h} \sum_{p} \sum_{a} \sum_{k} \sum_{t} \sum_{s} \pi^s.Ta_{pt}.\left(Dd_{mr}.XD^{s}_{mrpt} + \text{De}_{\text{lr}}.XE^{s}_{lrp_1t} + Dh_{rh}.XG^{s}_{rhpakt}\right) \\
\psi_6 &= \sum_{r} \sum_{p\neq p_1} \sum_{t} \sum_{s} \pi^s.Pa_{pt}.\text{PR}^{s}_{rpa't} \\
\psi_7 &= \sum_{r} \sum_{h} \sum_{p} \sum_{a} \sum_{k} \sum_{t} \sum_{s} \pi^s.Hc_{pt}.\left(IR^{s}_{rpat} + IH^{s}_{hpakt}\right) \\
\psi_8 &= \sum_{h} \sum_{p} \sum_{a} \sum_{t} \sum_{s} \pi^s.Ea_{hpat}.EX^{s}_{hpat},
\end{aligned}
\tag{1}
$$

$$\text{Min } Z_2 = \sum_{i} \sum_{m} \sum_{l} \sum_{r} \sum_{t} \sum_{s} \alpha_t \left(ZA^{s}_{imt} + ZB^{s}_{i'lt} + ZC^{s}_{irt}\right), \tag{2}$$

$$\text{s.t.}: \sum_{p\neq p_1} XA^{s}_{impt} \leq \varphi ZA^{s}_{imt} \quad \forall i, m, t, s, \tag{3}$$

$$XB^{s}_{i'lp_1t} \leq \varphi ZB^{s}_{i'lt} \quad \forall i', l, t, s, \tag{4}$$

$$\sum_{p} XC^{s}_{irpt} \leq \varphi ZC^{s}_{irt} \quad \forall i, r, t, s, \tag{5}$$

$$\sum_{r} \sum_{p\neq p_1} XD^{s}_{mrpt} \leq \varphi \sum_{m'} MV^{s}_{m',m,t} \quad \forall m, t, s, \tag{6}$$

$$\sum_{m} \sum_{p\neq p_1} \sum_{t} \sum_{s} XD^{s}_{mrpt} \leq \varphi YR_r \quad \forall r, \tag{7}$$

$$\sum_{r} \sum_{t} \sum_{s} XE^{s}_{lrp_1t} \leq \varphi YL_l \quad \forall l, \tag{8}$$

$$\sum_{l} \sum_{t} \sum_{s} XE^{s}_{lrp_1t} \leq \varphi YR_r \quad \forall r, \tag{9}$$

$$\sum_{h} \sum_{p} \sum_{a} \sum_{k} \sum_{t} \sum_{s} XG^{s}_{rhpakt} \leq \varphi YR_r \quad \forall r, \tag{10}$$

$$ZA^{s}_{imt}.Da_{im} \leq Ra_{m} \sum_{m'} MV^{s}_{m'mt} \quad \forall\, i, m, t, s, \tag{11}$$

$$ZB^{s}_{i'lt}.Db_{i'l} \leq Rb_{l}.YL_{l} \quad \forall\, i', l, t, s, \tag{12}$$

$$ZC^{s}_{irt}.Dc_{ir} \leq Rc_{r}.YR_{r} \quad \forall\, i, r, t, s \tag{13}$$

$$\sum_{m'} MV^{s}_{m'm''t} \leq 1 \quad \forall\, m'', t, s, \tag{14}$$

$$\sum_{m''} MV^{s}_{m'm''t} \leq 1 \quad \forall\, m', t, s, \tag{15}$$

$$\sum_{m''} MV^{s}_{m'm'',t} \leq \sum_{m} MV^{s}_{mm',t-1} \quad \forall\, m', t \geq 2, s, \tag{16}$$

$$\sum_{m} ZA^{s}_{i'mt} + \sum_{1} ZB^{s}_{i'lt} + \sum_{r} ZC^{s}_{i'rt} \leq 1 \quad \forall\, i', t, s, \tag{17}$$

$$\sum_{m} ZA^{s}_{i''mt} + \sum_{r} ZC^{s}_{i''rt} \leq 1 \quad \forall\, i'', t, s, \tag{18}$$

$$Po_{p}.\left(\sum_{l} XE^{s}_{lrp_{1}t} + \sum_{i'} XC^{s}_{i'rp_{1}t} \right) = \mathrm{PR}^{s}_{rpa't} \quad \forall\, r, p \neq p_{1}, p_{5}, t, s, \tag{19}$$

$$\sum_{m} XD^{s}_{mrpt} + \sum_{i} XC^{s}_{irpt} = \mathrm{PR}^{s}_{rpa''t} \quad \forall r, p \neq p_{1}, a'', t, s, \tag{20}$$

$$\sum_{i} XA^{s}_{impt} \leq Sb_{pt} \quad \forall\, m, p, t, s, \tag{21}$$

$$\sum_{i'} XB^{s}_{i'lp_{1}t} \leq Sa_{lp_{1}t} \quad \forall\, l, t, s, \tag{22}$$

$$\mathrm{PR}^{s}_{rpat} \leq Sc_{rpat}.YR_{r} \quad \forall\, r, p, a, t, s, \tag{23}$$

$$IR^{s}_{rpat} \leq Se_{rpat}.YR_{r} \quad \forall\, r, p, a, t, s, \tag{24}$$

$$\sum_{k} IH^{s}_{hpakt} \leq Sk_{hpat} \quad \forall\, h, p, a, t, s, \tag{25}$$

$$\sum_{i} XA^{s}_{impt} = \sum_{r} XD^{s}_{mrpt} \quad \forall\, m, p, t, s, \tag{26}$$

$$\sum_{i'} XB^{s}_{i'lp_{1}t} = \sum_{r} XE^{s}_{lrp_{1}t} \quad \forall\, l, t, s, \tag{27}$$

$$IR^{s}_{rpat} = IR^{s}_{rpa,t-1} + \mathrm{PR}^{s}_{rpat} - \sum_{h} \sum_{k\geq 2} XG^{s}_{rhpakt} \quad \forall\, r, p, a, t, s, \tag{28}$$

$$IH^{s}_{hpakt} = IH^{s}_{hpa,k-1,t-1} + \sum_{r} XG^{s}_{rhpakt} - \sum_{r} XH^{s}_{rhpakt} \quad \forall\, h, p, a, k \geq 2, t, s, \tag{29}$$

$$\sum_{r}\sum_{k} XH^{s}_{rhpakt} + EX^{s}_{hpat} + SH^{s}_{hpat} = Dm^{s}_{hpat} \quad \forall\, h, p, a, t, s, \tag{30}$$

$$\sum_{r}\sum_{k} XH^{s}_{rhpakt} \geq St.Dm^{s}_{hpat} \quad \forall\, h, p, a, t, s, \tag{31}$$

$$YL_{l}, YR_{r}, ZA^{s}_{imt}, ZB^{s}_{i'lt}, ZC^{s}_{irt}, MV^{s}_{m'm''t} \in \{0,\, 1\}, \tag{32}$$

$$XA^{s}_{impt}, XB^{s}_{i'lp_{1}t}, XC^{s}_{irpt}, XD^{s}_{mrpt}, XE^{s}_{lrp_{1}t}, XG^{s}_{rhpakt}, XH^{s}_{rhpakt}, \mathrm{PR}^{s}_{rpat}, SH^{s}_{hpat}, EX^{s}_{hpat}, IR^{s}_{rpat}, IH^{s}_{hpakt} \geq 0, \text{int}. \tag{33}$$

The objective (1) is to minimize all costs of the entire chain network. They include the costs of establishing the local and regional blood centers, transportation of mobile blood collection vehicles to each location, blood collection in each of the regional and local mobile blood collection centers, blood transfusion from one center to another, product production in regional blood centers, storage of blood in regional blood centers and demand areas, and penalty costs for blood expiration in some areas.

Objective (2) calculates the spread of the disease in the presence of blood donors in mobile, regional, and local blood centers. In the second objective, by using parameter α, which represents the percentage of disease transmission from a person with COVID-19 disease to healthy people, the percentage of disease transmission in the presence of blood donors in mobile, regional, and local blood centers is calculated (the determining method of parameter α is explained in Section 4).

Constraints (3) state that donating blood in any mobile blood collection device is possible if the donors are assigned to that device. Constraints (4) emphasize that whole blood donation in local blood centers is possible if regular donors are assigned to this facility. Constraints (5) explain that it is possible to donate whole blood or its products in regional blood centers if the donors are assigned to this facility. Constraints (6) and (7) represent that allocating mobile blood collection devices to the regional blood centers is possible if both facilities are established. Constraints (8) and (9) demonstrate that allocating the local centers to the regional centers is possible if both regional and local blood centers are established. Constraints (10) also indicate that hospitals are allocated only to regional blood centers that have been established. Constraints (11) to (13) indicate that donors are served based on the maximum coverage radius. Constraints (14) and (15) indicate that only one mobile blood collection device should go to each place, and also, each mobile device can only go to one place. Constraints (16) emphasize that the movement of the mobile device from the first place to the second is possible if that device was located in the first place in the previous period. Constraints (17) and (18) state that each donor group can be assigned to only one of the related blood centers. Constraints (19) and (20) calculated the production amount of each blood product by the standard method and apheresis method and collected in each regional center. Constraints (21) and (22), respectively, determine the capacity of mobile blood collection devices and the capacity of local blood centers to collect each of the blood products in each time period. Constraints (23) specify the capacity of regional blood centers to collect and produce blood products by standard or apheresis method in each period. Constraints (24) and (25) express the capacity of each warehouse in regional centers and demand points to store each blood product separately by production method. Constraints (26) cause balance in the flow of input and output of mobile blood collection devices. Constraint (27) causes balance in the flow of input and output of local blood centers. Constraints (28) and (29) establish the inventory balance for regional blood centers and demand points, respectively. Constraint (30) deals with calculating the amount of shortage of each blood product according to the production method, at the demand points at the end of each time period. Constraints (31) indicate the minimum demand that must be met. Finally, constraints (32) and (33) represent the status of the decision variables.

4. The Calculating Method of Parameter α

The method of calculating the parameter α_t (probability of being infected with the coronavirus by another person in period t) in the second objective (equation (2) of the proposed mathematical formulation (for example), whose value is considered between [0.02, 0.03], is represented in Figure 1 [15].

5. The Proposed Exact Solution Methods

To exact solve the proposed mathematical model, three solution methods are examined, and the best and most efficient one is selected. The LP-metric, AUGMECON2, and improved weighted Chebyshev are three famous, most popular, and widely used methods for solving multiobjective problems. Since the three mentioned methods are used to solve different problems, these were chosen for comparison to choose the best and most efficient and accurate solution approach for the presented mathematical model. It should be noted that several exact solution approaches have been introduced and presented to solve multiobjective problems. However, the three mentioned methods are the most compatible for solving the proposed multiobjective mathematical model.

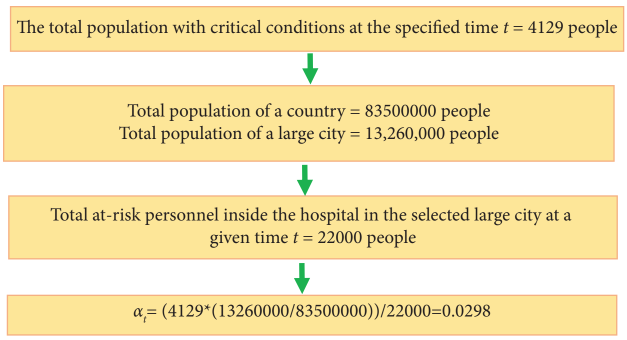


Figure 1: The method of calculating the parameter α_t [1].

5.1. The Improved Weighted Chebyshev Method. The improved weighted Chebyshev is categorized among the methods for solving multiobjective problems. It uses a precise approach to find Pareto-optimal solutions [16, 17]. The main structure of the applied approach is described in equation (35).

$$\begin{aligned}&\text{Min}\left\{\eta+\omega\sum_{i=1}^{r}\left(\frac{z_i-z_i^*}{z_i^*}\right)\right\}\\&\text{Subject to: } y_i\left(\frac{z_i-z_i^*}{z_i^*}\right)\leq\eta\quad\forall i=1,\cdots,r.\end{aligned}\tag{34}$$

Here, ω is a parameter that takes small and positive values, and η is a free variable. Also, the preference of the objective r is specified by using the weighting factor y_i, in such a way that $\sum_{i=1}^{r}y_i=1$.

5.2. The Improved Version of Augmented Ɛ-Constraint (AUGMECON2). The AUGMECON2 had a significant drawback in that it was very time-consuming to solve any problem with more than two objectives. This weakness led to the AUGMECON2 [18]. Furthermore, the authors of [19] represent this algorithm by introducing a bypass coefficient and also a kind of Lexicographic optimization for all objectives and creating the augmented Ɛ-constraint algorithm.

Using the bypass coefficient, the augmented Ɛ-constraint uses the information provided by the redundant (auxiliary) variables of the objectives, which are in the form of constraints, to avoid unnecessary iterations and speed up the solution. Also, this method can identify the exact Pareto set [20]. Accordingly, the AUGMECON2 is considered as an approach that can compete with meta-heuristic multiobjective Pareto-based approaches [19]. How the AUGMECON2 works is as follows:

$$\begin{aligned}&\textbf{Problem P min}\left(-\mathbf{Z}_1(\mathbf{x})-\mathbf{e}\times\left(\frac{\mathbf{S}_2}{\mathbf{r}_2}+\mathbf{10}^{-1}\times\frac{\mathbf{S}_3}{\mathbf{r}_3}+\cdots+\mathbf{10}^{-(\mathbf{P}-2)}\times\frac{\mathbf{S}_\mathbf{P}}{\mathbf{r}_\mathbf{P}}\right)\right)\\&\textbf{Subject to: } \mathbf{Z}_\mathbf{k}(\mathbf{x})-\mathbf{S}_\mathbf{k}=\boldsymbol{\varepsilon}_\mathbf{k}.\end{aligned}\tag{35}$$

In equation (36), $Z_k(x)$ represents the objectives to be optimized. In addition, x is the element of the problem space, and e takes a value between 10^{-6} and 10^{-3}. Also, ε_k is the parameter on the right side of the equation for the k^{th} objective considering that $k\in\{2,\ldots,P\}$. In addition, $r_2, r_3, \ldots, r_P$ are the domain parameters for the second, third to P^{th} objective function, respectively. In addition, the surplus variables of the problem are represented by $S_2, S_3, \cdots, S_P$. It should be noted that in the improved version of the augmented Ɛ-constraint (II), S_i/r_i should be placed instead of S_i. This avoids scaling issues. The general steps of the AUGMECON2 are as follows [21]:

Step 1: We establish the payoff table by performing lexicographic optimization.

Step 2: We calculate the ranges (r_k) and determine a lower bound (lb_k) for the objective k according to the payoff table.

Step 3: We create equal intervals (g_k) by dividing the domain of the k^{th} objective.

Step 4: Using $\varepsilon_k = lb_k + i_k\times\text{step}_k$, we obtain the right side of the constraint of the specific objective, where i_k is the counter of the k^{th} objective and step_k is determined using $\text{step}_k = r_k/g_k$.

Step 5: We solve the problem.

Step 6: We check the S_k associated with the innermost objective for each iteration by applying the bypass coefficient: $b=\text{int}(S_k/\text{step}_k)$. When S_k is greater than step_k, the same solution is set for the next iteration, the only difference being the redundant (auxiliary) variable. This causes redundant iteration, so it may be bypassed, while no new Pareto-optimal solution is created.

Step 7: We determine the Pareto set due to the bypass coefficient and the number of grid points.

5.3. LP-Metric Method. The LP-metric method is a part of the first category of multiobjective decision-making problems, especially in cases where the decision-maker provides all the needed information before solving the problem [22]. This method minimizes the deviations of objectives in a multiobjective formulation compared to their ideal solution. In other words, LP-metric is applied to measure the proximity of an ideal solution, and its relationship is as follows:

$$\max\left[\sum_i \left(w_i \left|\frac{f_i^* - f_i}{f_i^*}\right|\right)^p\right]^{1/p}, \tag{36}$$

where w_i shows the degree of importance (weight) for the i^{th} objective function. The $1 \leq p \leq \infty$ represents the defining parameters of the LP family. The value of p specifies the degree of emphasis on existing deviations so that the larger p is, the more emphasis will be placed on the largest deviation. If $p = \infty$, it will mean that the largest deviation of the existing deviations is investigated for optimization. Here, in the process of single targeting by the LP-metric method, the value of $p = 1$ has been considered so that, as mentioned, each deviation has its own weight. Also, for each objective, the value of w_i is considered equal to 1.

6. Design of Numerical Instances and Results of Solving Them

In order to evaluate the developed mathematical formulation and solution methods, several numerical examples are examined and analyzed. For each example, the value of the objective functions and the duration of the formulation solution are determined by each method. The values for each numerical test example are listed in Table 2. At first, the indicators are defined. They include the values of the first and second objectives and the CPU time of the model by each method. By generating different numerical example problems in small dimensions, as represented in Table 2, the proposed methods are compared.

Other parameter values applied in numerical test examples are shown in Table 3, all of which are due to the uniform distribution. In addition, the needed weights for the methods of LP-metric and improved (modified) weighted Chebyshev for the first and second objectives are considered the same, and their value is 0.5.

To solve the mathematical formulation by proposed solution methods, GAMS software version 24.1.3 and CPLEX solver have been used in a system with the specifications of CPU = Cori7 6700 HQ and RAM = 16 GIG DDR4, and the results are compiled in Table 4.

7. Statistical Analysis

In order to analyze the results of three solution methods and compare them with each other, Tukey's method has been applied. This method is used when more than two samples are compared with each other, and it shows a suitable performance by comparing each pair of average results with each other [22]. Considering the confidence level of 95%, the statistical comparison test of the average results of the three proposed methods is performed for all three defined evaluation indicators. So that in each comparison, the null hypothesis (H_0) is equal to the equality of the averages of the results obtained from the three methods and the opposite hypothesis (H_1) seeks to reject this hypothesis. Using MINITAB version 21.1.1.0 software, the obtained results are shown in Tables 5–7 and Figure 2. Due to observational analysis, some technical remarks can be concluded as follows:

(i) As shown in Tables 5 and 6, considering that the P values for the indicators of the first and second objective function values are higher and lower than the significance level, respectively ($0.05 < 0.999$ for the indicator of the first objective function and $0.001 < 0.05$ for the indicator of the second objective function), so the null hypothesis is accepted for the first indicator and rejected for the second indicator. This means that based on the 95% confidence level, there is no significant difference between the answers obtained from the three proposed solution methods regarding the value indicator of the first objective. However, there is a difference in terms of the value indicator of the second objective function.

(ii) The null hypothesis is accepted concerning the CPU time indicator. According to the results of Table 7, the P value in this indicator is equal to 0.647, which is greater than 0.05, and as a result, it has led to the acceptance of the null hypothesis. In other words, there is no significant difference between the CPU times of the three proposed solution methods regarding the solution time indicator. It emphasizes that the computational efficiency of the methods is similar.

The "Tukey simultaneous control limits" is a graph that shows the control limits of the difference of the averages of all the examined samples for all pairs in multiple comparisons. If the difference interval of at least one of the examined pairwise comparisons does not include the zero line, it means a significant difference in the average results of the two methods and finally rejects the null hypothesis. The graphs displayed in parts (A) and (C) of Figure 3 are related to the indicators of the value of the first objective and the CPU time of three proposed solution methods, respectively. It is considered that for the CPU time and the first objective function, all pairwise comparisons include the zero line, and the null assumption is accepted for two indicators. No significant difference is observed between the results of the three proposed solution methods in producing the values of the objective functions. Considering the graph in part (B) of Figure 3 and regarding the indicators of the value of the second objective function, there is a significant difference between the results of the AUGMECON2 and LP-metric methods, as well as the AUGMECON2 and improved weighted Chebyshev methods. It causes the null hypothesis to be rejected.

8. The Best-Proposed Solution Method

In order to choose the best method among the three proposed solution methods, TOPSIS has been applied. TOPSIS stands for technique for order preference by similarity to the

Table 2: Numerical example problems generated in small dimensions.

No.	I	L	M	R	P	K	H	A	T
1	8	5	6	4	5	3	5	2	4
2	10	6	7	5	5	4	6	2	3
3	12	8	9	6	5	4	5	2	5
4	15	10	5	7	5	2	3	2	7
5	9	13	8	4	5	5	4	2	3
6	11	12	15	7	5	3	7	2	6
7	9	11	9	8	5	3	6	2	8
8	7	5	12	7	5	5	7	2	2
9	10	4	5	6	5	2	4	2	3
10	8	7	9	4	5	4	5	2	7
11	12	4	5	6	5	5	3	2	4
12	14	8	13	5	5	4	5	2	6
13	9	10	7	6	5	5	6	2	3
14	8	7	11	5	5	5	2	2	7
15	10	9	5	6	5	4	3	2	2
16	12	11	15	4	5	3	3	2	6
17	15	20	10	7	5	4	5	2	5
18	6	11	14	6	5	5	3	2	6
19	12	6	9	3	5	2	4	2	5
20	20	14	18	5	5	5	7	2	2

Table 3: Values of the parameters applied in the numerical examples.

Parameter	Value range
Fa_l	$\sim U$ (100, 150)
Fb_r	$\sim U$ (150, 300)
$Fc_{m'm''t}$	$\sim U$ (1, 3)
Ta_{pt}	$\sim U$ (0.03, 0.035)
Oa_{ipt}	$\sim U$ (0.01, 0.015)
Pa_{pt}	$\sim U$ (0.03, 0.06)
Hc_{pt}	$\sim U$ (0.02, 0.03)
Sa_{lp_1t}	$\sim U$ (132, 180)
Sb_{pt}	$\sim U$ (84, 108)
Sc_{rpat}	$\sim U$ (480, 600)
Se_{rpat}	$\sim U$ (120, 144)
Sk_{hpat}	$\sim U$ (50, 80)
Da_{im}	$\sim U$ (2, 15)
α_t	$\sim U$ (0.02, 0.03)
$Db_{i'l}$	$\sim U$ (2, 15)
Dc_{ir}	$\sim U$ (2, 15)
Dd_{mr}	$\sim U$ (2, 15)
De_{lr}	$\sim U$ (2, 15)
Dh_{rh}	$\sim U$ (300, 1000)
Ra_m	10
Rb_l	10
Rc_r	10
Po_p	1.3
Ea_{hpat}	10
Dm^s_{hpat}	$\sim U$ (40, 60)
π^s	$\sim U$ (0.3, 0.4)
St	0.5

ideal solution. It, as proposed by Huang and Yun [23], is a suitable technique for ranking options. It evaluates m options by identifying negative and positive ideal solutions and using n evaluation criteria. Finally, the option that has the largest distance from the negative ideal solution and the smallest distance from the positive ideal solution is known as the best option. The main steps of the TOPSIS are detailed in [23].

Due to the results of the numerical test example to implement the TOPSIS, the improved weighted Chebyshev was selected as the most efficient method among the three proposed solution methods. It can be represented in Table 8.

9. Sensitivity Analysis

In order to evaluate the impact of changes in the main parameters of the mathematical formulation on the results of the objectives, sensitivity analysis has been used. Considering that due to the results of the TOPSIS technique, the improved weighted Chebyshev was chosen as the best method, and the sensitivity analysis has been carried out on the mathematical formulation using the improved weighted Chebyshev method. The results of the sensitivity analysis are represented in Figure 4.

Here, the sensitivity analysis has been carried out only according to the changes in parameter α. First, only the cost parameter has been added to the mathematical model. Therefore, its effect has been investigated by increasing it from 0.02 to 0.03 (in 11 cases). As can be concluded, with the growth of parameter α, the first objective has remained constant in all values and has not changed. This means that increasing the parameter α does not affect the values of the first objective. On the other hand, since the first objective is related to costs, it is logical to remain constant for several values of parameter α.

Nevertheless, the results for the second objective function are not similar. More precisely, the α had a significant impact on the second objective function. According to Figure 4, with the increase of parameter α, the values of the second objective have increased. This means that the higher

Table 4: The results of solving the numerical instances.

No.	LP-metric Z_1 (MU)	LP-metric Z_2 (%)	LP-metric CPU time (s)	AUGMECON2 Z_1 (MU)	AUGMECON2 Z_2 (%)	AUGMECON2 CPU time (s)	Modified weighted Chebyshev Z_1 (MU)	Modified weighted Chebyshev Z_2 (%)	Modified weighted Chebyshev CPU time (s)
1	1486	720	105	1386	1594	101	986	406	150
2	2722	361	225	2628	1121	170	1720	371	105
3	3688	320	310	2888	1078	600	2540	369	108
4	4629	306	1012	3521	976	303	3828	351	1011
5	5161	300	147	6043	916	958	6040	306	147
6	5163	271	116	6170	745	168	6160	300	116
7	5501	269	1030	6468	690	455	7065	290	1029
8	7241	262	183	6605	676	107	7469	247	183
9	8469	251	704	7040	624	600	7521	247	205
10	8822	204	180	8420	549	580	10650	232	182
11	9664	170	808	10822	538	807	10820	216	338
12	11163	160	288	11620	504	246	11912	204	287
13	11737	152	1028	12160	499	576	12055	171	1029
14	12626	147	1022	12434	470	1130	12160	162	1023
15	13050	124	1038	14052	412	240	12740	152	1038
16	18004	121	1021	18213	305	634	16151	121	1022
17	18132	120	1016	19004	250	1025	17145	119	1017
18	19243	109	1034	19140	218	964	17270	107	1035
19	22707	107	246	23507	149	151	24708	107	1247
20	26235	101	1014	24272	102	558	25214	101	1015
Average	10772.2	228.75	626.35	10819.70	620.8	518.65	10707.70	228.95	614.35

Table 5: Statistical hypothesis test results for the first objective function.

Source	Degree of freedom	SS	MS	F value	P value
Behavior	2	126286	63143	0.00	0.999
Error	57	2739535821	48062032	—	—
Total	59	2739662107	—	—	—

Table 6: Statistical hypothesis test results for the second objective function.

Source	Degree of freedom	SS	MS	F value	P value
Behavior	2	126286	1024166	18.18	≤0.001
Error	57	3211244	56338	—	—
Total	59	5259575	—	—	—

Table 7: Statistical hypothesis test results for the CPU time.

Source	Degree of freedom	SS	MS	F value	P value
Behavior	2	139345	69673	0.44	0.647
Error	57	9042056	158633	—	—
Total	59	9181401	—	—	—

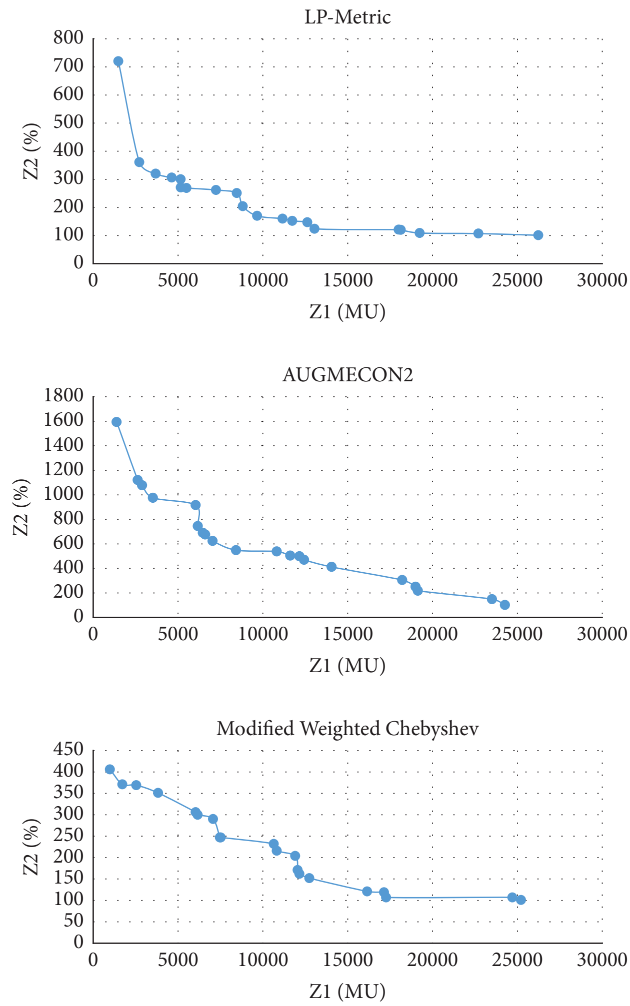
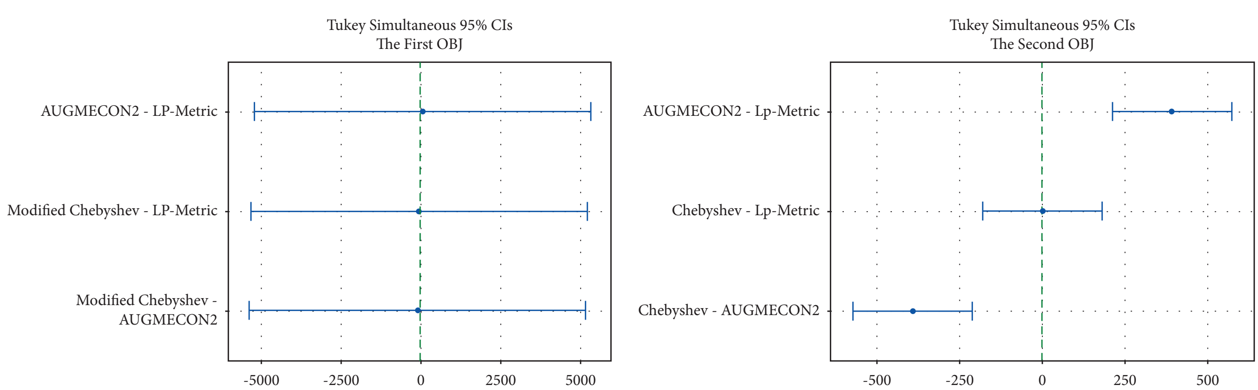
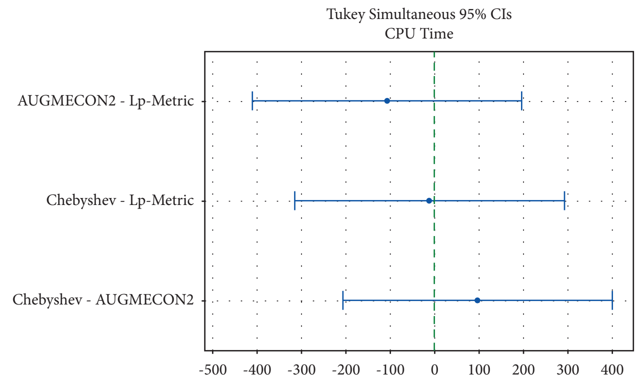


Figure 2: Pareto diagram (trade-off between objectives) of the proposed solution methods.



(a) (b)

Figure 3: Continued.



(c)

Figure 3: Simultaneous control graph of Tukey limits. (a) The (pairwise comparison) indicator of the first objective. (b) The (pairwise comparison) indicator of the second objective. (c) The (pairwise comparison) indicator of CPU time.

Table 8: The final results of the TOPSIS technique.

Solution method	Proximity coefficient
LP-metric	0.513
AUGMECON2	0.537
Improved weighted Chebyshev	0.570

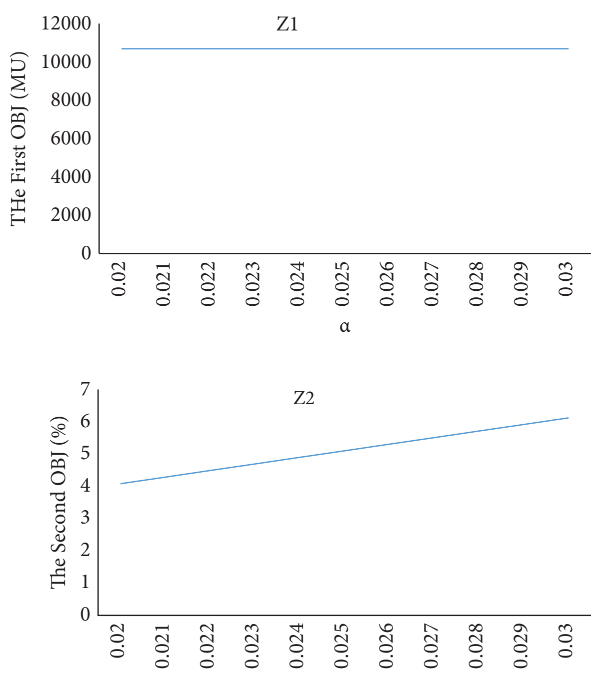


Figure 4: The sensitivity analysis of parameter α on the objective functions.

the α, the higher the probability of disease transmission from a corona patient to a healthy person. Therefore, the α has a significant effect on the values of the second objective, so a change in this parameter can cause many changes in the second objective.

10. Conclusions

The conditions of the coronavirus epidemic have put much pressure on the healthcare system. This epidemic has harmed the impact on the blood supply by reducing blood donation and reducing access to proper collection facilities due to dysfunction. Considering the importance of the subject, in the current study, the network of the multilevel dual-purpose BSC was investigated.

In the present study, for the first time, the objective of minimizing the spread of the coronavirus through increasing the supply of plasma from recovered people or reducing the shortage of this product at demand points, along with the objective function of minimizing the costs of the entire network, has been studied. In the proposed mathematical formulation, the percentage of the spread of the coronavirus is also minimized along with the costs of the entire network. The main goal is to minimize the spread of the Coronavirus at the location of blood donors in mobile, regional, and local blood centers in the proposed supply chain. Games software was used to exact solve the mathematical model by the proposed solution methods. In order to analyze the results of the three methods and compare them with each other, Tukey's test was used. The P value in this indicator is equal to 0.647, which is greater than 0.05, and as a result, it led to the acceptance of the null hypothesis. In other words, a significant difference between the results specified from the AUGMECON2, the LP-metric, and the improved weighted Chebyshev methods means a significant superiority of one of the proposed methods. By applying the TOPSIS technique, it is clear that the improved weighted Chebyshev can be chosen as the most efficient method among the three proposed solution methods.

The analytical results of the present study represent that improving the performance of the BSC can lead to a reduction in BSC costs and improved service to patients. Also, the adaptation of several components of the BSC and regular coordination between them play an influential role in controlling and improving this disease and reducing the costs of the BSC. Also, receiving the plasma product of recovered people from donors' type (II) can play a critical role in reducing the percentage of disease transmission.

Data Availability

The data supporting the current study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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