A NEW MODEL AND A MONTE CARLO BASED PARTICLE SWARM OPTIMIZATION ALGORITHM FOR THE STOCHASTIC BLOOD ASSIGNMENT PROBLEM

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Abstract. Blood and its products, in some cases, are the only vital and sanative medicine for the patients. Each donated blood unit is a valuable asset to protect the patients' lives, and it should be avoided waste and non-optimal consumption. The assignment of blood and its products to hospitals is one of assignment problems, in which finding the optimal solution can lead to a reduction in mortality and waste of expenditure. In this research, a new model for the assignment of blood products in a stochastic environment is presented. The goal of the model is to minimize the preparation, deficiency and waste cost of blood products, while considering the constraints of the problem. The stochastic model is implemented in a real case and is solved by the Monte Carlo simulation method. Then, a random model is settled in a real problem in Yazd city and it is solved *via* a Monte Carlo based Particle Swarm Optimization algorithm. The results reveal that the solution of the hybrid algorithm can significantly reduce the costs of preparation, deficiency and waste of blood products.

1. Introduction

Human blood is a rare source that is produced only by human, and there is currently no other chemical product or process used as a substitute for it [3]. Providing adequate and safe blood necessary for the hospitals and the related managers is a challenge in a normal and critical condition that government health care systems are always encountered it. The need for blood donors and their products is always present, while its supply by the donors is somewhat erratic and the demand for blood products is often stochastic [4]. Blood providers are the blood donors who are volunteers refer to a blood donation center voluntarily. Blood units are transmitted to the blood bank due to their corruptibility, and after that they are stored temporarily after necessary tests, and then they will be transfused the consumers (hospitals and health care centers) according to their need. A

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blood unit can be divided into the five blood products: blood red cells, plasma, white blood cells, serum and platelets. All blood elements are corruptible except the blood plasma. Usually, blood banks are encountering various problems. Two of these problems are the deficiency and waste of blood and its products.

The mean of the deficiency costs is the same cost of preparing or buying a blood unit that is not provided at the necessary time, and its deficiency will increase the mortality rate. On the other hand, when a blood unit is prepared, it will be corrupted, expired and discarded if it is not consumed, and it causes waste costs. Therefore, adoption of supply and demand in an efficient way is not easy task for this product.

The basic issue of this study is the optimal assignment of blood products from the Blood Transfusion Organization to hospitals and medical clinics. In the model presented in this paper, it is tried to minimize the cost of preparation, deficiency and waste of blood products. On the other hand, the demand of hospitals and health care centers is also considered as a random value and the problem is solved with Monte Carlo method and also with a hybrid method of Particle Swarm Optimization and Monte Carlo simulation. Moreover, we consider a real problem in Yazd blood organization and we apply the model and the algorithms to solve the problem.

2. Research background

The assignment problem is one of the basic problems in the operational research, which has been expanded since its presentation. In a study conducted by Sapountzis [15] in the field of blood assignment to hospitals in the UK, an integer programming model has been used to reduce expired blood. One of the constraints of the model is equality of the number of blood units sent to hospitals with the amount of their demands. Also blood units sent to hospitals are provided from the blood bank, and the hospital blood supply method is FIFO.

Angelis *et al.* [2] presented a multi-objective, multi-period, multi-product and multi-period linear programming model to better manage donation-transfer system in Italy. The aim of this study is to minimize the amount of imported blood from outside of the system. Some of the considered constrains in this study are limiting the amount of red blood cell assignment every day, the amount of red blood cells in the system and the amount of blood imported from outside of the system.

Tetteh [18] conducted a research on platelet optimal assignment in order to maximize the benefits, considering the social benefits, minus the cost of maintenance and the expense of expired units. Among the constraints of the model is the constraint of sending blood products with FIFO method and inventory constrains. In this research, a heuristic method and a linear programming model with rolling horizon approach have been used to solve the model.

Sha and Huang [16] conducted a research on the scheduling, location and assignment of blood in emergency systems (such as post-earthquake conditions) and proposed a multi-period dynamic model in order to minimize the operational costs. They considered several time periods in the model and have implemented their considered issue in a case study in Beijing.

Adewumi *et al.* [1] have conducted a study on optimizing blood assignment in the blood bank system in South Africa. In their research, they have presented a mathematical model to minimize the amount of blood unit imported from outside of the system. Several algorithms include Genetic Algorithm (GA), Adaptive Genetic Algorithm (AGA), Simulated Annealing Genetic Algorithm (SAGA), Adaptive Simulated Annealing Genetic Algorithm (ASAGA), and Hill Climbing (HC) Algorithm were provided to solve the problem, which ultimately HC algorithm has yielded the best results.

In another study by Igwe *et al.* [9] in the field of blood products assignment in order to reduce blood losses and provide the patient's needs, the researchers have modeled the issue of blood assignment using multiple knapsack problem. They have used two methods of dynamic programming and GRASP algorithm to solve the model. The constraint of the studied model was included the limited capacity of the blood center, constrains associated with using the FIFO method for blood supply, the constraint of the blood products lifetime and the constraint of the waiting time to receive blood units. The results from this model indicate that the GRASP algorithm is more efficient than the dynamic programming.

TABLE 1. Comparison of the researches carried out on blood assignment and its products with the current research.

Reference	Objective function					Constrains						Type of demand	Method of solution
	To maximize the general benefits	To minimize the operational	To minimize blood deficiency	To minimize blood loss	To minimize the amount of imported blood	Limited capacity of the blood	Assignment ≥ Demand	Assignment = Demand	Limited longevity of blood	Using the FIFO method in the delivery of blood	The possibility of blood supply from outside of the organization		
Sapountzis [15]				✓							✓	Deterministic	Exact solution based on the mathematical programming model
Angelis et al. [2]				✓			✓				✓	Deterministic	Exact solution based on multi-objective programming model
Tetteh [18]	✓			✓					✓	✓		Deterministic	Heuristic method
Sha and Huang [16]		✓				✓		✓				Deterministic	Heuristic method
Adewumi et al. [1]				✓	✓						✓	Deterministic	Genetic algorithm
Igwe et al. [9]				✓					✓	✓		Deterministic	Grasp algorithm
Olusanya et al. [14]				✓	✓	✓			✓		✓	Deterministic	Queue model & knapsack algorithm and pso- based approach
Olusanya and Adewumi [13]					✓	✓					✓	Deterministic	Tabu Search algorithm
Current research			✓	✓	✓		✓		✓*	✓*	✓	Stochastic	Monte Carlo simulation and hybrid algorithm

Olusanya et al. [14], have used the Queuing theory and Knapsack problem in a study on the assignment of blood to the blood-bank system, to minimize blood and blood product imports and minimize blood loss. The constraints of the presented model are that the volume of blood assigned per day should not be more than the available total blood volume. Also, any blood unit should not be stored for more than 30 days because it will be expired and must be burned. In this research, a simulation based on the sets of randomly generated data has been used to solve the problem and the results indicate a considerable decrease in blood type imports. They presented a Particle Swarm Optimization algorithm to solve the problem.

Olusanya and Adewumi [13], have applied the mathematical programming models in a study on optimizing the assignment of blood, to minimize imported blood from outside of the system. Also, they have used Metaheuristic techniques to solve the model. The considered constraint in this model is the equality of the total amount of the supplied blood units with the total amount obtained from inside and outside of the system. Researchers have modeled the problem as a knapsack problem and have solved the problem by two Tabu Search (TS) and Simulated Annealing (SA) Algorithms. Also, a hybrid method based TS and SA algorithms has been developed that provided better results.

Except the issue of assignment of blood and its products, some researches have been carried out in blood supply chain. Some studies have been done by Katsaliaki and Brailsford [11], Ghandforoush and Sen [6], Beliën and Forcé [3], Nagurney *et al.* [12], Silva Filho *et al.* [17], Jabbarzadeh *et al.* [10], Vananya *et al.* [19], Zahraee *et al.* [20], Gunpinar and Centeno [7], Heidari and Pasandideh [8], and Eskandari-Khanghahi *et al.* [5], but since the purpose of this paper is the optimal assignment of blood and its products from the Blood Transfusion Organization to hospitals and health care centers, so reviewing these articles is avoided here.

Table 1 shows the difference between some of researches that have been done in the field of assignment of blood and its products and the present study.

3. Mathematical modelling

Suppose that there is a Blood Transfusion Organization that assigns blood to the n hospitals in the form of a complete blood unit and its separated products (k types), based on their daily demand. On the other hand, the Blood Transfusion Organization receives blood from blood donors for free each day, and if additional blood is needed to assign blood to hospitals, it will receive the required amount from outside of the Blood Transfusion Organization for free, but there is a shipping charge. The donated blood needs 2 days to be tested and separated to the blood products, and as a result, the newest blood product has longevity of 3 days.

Hospital demand value for every type of blood products is routinely reported to the Blood Transfusion Organization by the hospitals at the beginning of each day. If the hospitals are faced with an unexpected deficiency of blood during the day they announce it to the Blood Transfusion Organization and the Blood Transfusion Organization is responsible to compensate for the blood deficiency of hospitals. So, let's assume that if the requested amount of hospitals demand exceeds the inventory of the Blood Transfusion Organization at the beginning of the morning, the organization will compensate for the deficiency by ordering blood outside of the organization to satisfy the demand. But if the deficiency is occurred during the day, the Blood Transfusion Organization will announce this deficiency to the blood center outside of the organization, and then the center will send the necessary blood or its products to the related hospital. Thus, this type of problem doesn't enter directly in the model. But since retransmission of blood takes some times and endangers the patients' life, the cost of blood deficiency is high. On the other hand, the amount of excess blood assigned to the hospitals is stored in the blood bank of the hospitals and after the expiration and non-use, it is returned to the Blood Transfusion Organization, then the organization removes them, so it leads to the waste cost for the organization. Therefore, the organization can reduce the accumulated blood products in their blood banks by minimizing the amount of extra assigned blood in hospitals on a daily basis, so it can minimize waste amount. In fact, the goal of the proposed model is to minimize the costs of supply, shortage and loss of blood products, so that the constraints of the problem are observed. For a more precise definition of the under consideration problem, the following assumptions are defined.

3.1. Hypotheses of the model

(1) At the end of the day, the amount of donated blood is known for the Blood Transfusion Organization.
(2) At the end of the day, the deficiency of hospitals blood products is known according to the amount of their sudden order to the organization.
(3) At the end of the day, the extra value of hospitals blood products is known based on the recorded actual amount of their consumption.

(4) Testing and separating the blood components requires 2 days. As a result, all types of blood products have longevity of 3 days, while this lifetime is limited to a maximum threshold for each blood product.

(5) The blood which is prepared outside of the Blood Transfusion Organization is ready and tested.

3.2. Model parameters

Table 2 describes the parameters used in the model.

TABLE 2. Model parameters.

Parameters	Symbol	Related index of the set
Blood products set	J	$j \in J = \{1, 2, \ldots, k\}$
Number of blood products	k	
Maximum longevity of jth type blood product	L_j	
Longevity of jth type blood product	l_j	
Hospitals set	I	$i \in I = \{0, 1, \ldots, n\}$
Total number of hospitals	n	
The transfusion cost of each blood unit	C	
The shortage cost of jth type blood product	sh_j	
The waste cost of jth type blood product	w_j	
Approximated demand of ith hospital for the jth type blood product at the beginning of the day	d_{ij}	
The actual demand of ith hospital for the jth type blood product at the end of the day	d'^s_{ij}	
The amount of jth type blood products available with the longevity of the l days in the blood bank of the Blood Transfusion Center	β_{lj}	
The set of scenarios	S	$s \in S = \{1, \ldots, \varepsilon\}$
Number of scenarios	ε	
The occurrence probability of each scenario	p^s	

3.3. Model variables

Since the demand value for blood and its products is a stochastic parameter, and it can be varied depending on the conditions and the number of patients, etc, so in reality we deal with a stochastic problem. Here, we suggest a two stage stochastic programming model to formulate the problem. To model the problem in this case, let's assume that the set S contains different scenarios for the actual demand value of hospitals for blood products, represents a scenario and is the probability related to the event of the sth scenario. In this case, the decision variables of the first and second stages are as follows:

– *Decision variables of the first stage*:

x_j: jth type blood products ordered from outside of the Blood Transfusion Organization.

y_{ijl}: The amount of jth type blood products with longevity of l days that is assigned to the ith hospital from the Blood Transfusion Organization.

– *Decision variables of the second stage*:

z^s_{ij}: The total deficiency amount of jth type blood product at the end of the day in the ith hospital at sth scenario.

r^s_{ij}: The total extra amount of jth type blood product at the end of the day in ith hospital at sth scenario.

3.4. The proposed model

Considering defined parameters (Tab. 2) and variables, we propose the following two stage stochastic model. This model considers the supply, deficiency and surplus cost in the objective and involves different related constraints.

$$\min \sum_{s \in S} p^s \left(\sum_{j \in J} cx_j + \sum_{i \in I} \sum_{j \in J} sh_j z_{ij}^s + \sum_{i \in I} \sum_{j \in J} w_j r_{ij}^s \right)$$

$$x_j + \sum_{l=3}^{Lj} \beta_{jl} \geq \sum_{i \in I} d_{ij} \qquad \forall j \in J \tag{3.1}$$

$$\sum_{l=3}^{Lj} y_{ijl} \geq d_{ij} \qquad \forall i \in I, \forall j \in J \tag{3.2}$$

$$y_{ijl} \geq y_{ij(l-1)} \qquad \forall i \in I, \forall j \in J, \forall l \in \{4, \ldots, L_j\} \tag{3.3}$$

$$\sum_{l=3}^{Lj} y_{ijl} + z_{ij}^s - r_{ij}^s = d_{ij}^{'s} \qquad \forall i \in I, \forall j \in J, \forall s \in S \tag{3.4}$$

$$\sum_{i=1}^{n} y_{ijl} \leq x_j + \beta_{jl} \qquad \forall j \in J, l = 3 \tag{3.5}$$

$$\sum_{i=1}^{n} y_{ijl} \leq \beta_{jl} \qquad \forall j \in J, \forall l \in \{4, \ldots, \ L_j\} \tag{3.6}$$

$$x_j \geq 0 \,\&\, \text{int} \qquad \forall j \in J \tag{3.7}$$

$$y_{ijl} \geq 0 \,\&\, \text{int} \qquad \forall i \in I, \forall j \in J, \forall l = 3, \ldots, L_j \tag{3.8}$$

$$z_{ij}^s \geq 0 \,\&\, \text{int} \qquad \forall i \in I, \forall j \in J, \forall s \in S \tag{3.9}$$

$$r_{ij}^s \geq 0 \,\&\, \text{int} \qquad \forall i \in I, \forall j \in J, \forall s \in S. \tag{3.10}$$

The objective function is to minimize the mathematical expectation of total supply, deficiency and surplus cost of various types of blood products in the Blood Transfusion Organization for different scenarios. The first constraint indicates that the amount of jth type blood products received from outside of the organization together with the amount of jth type blood products in the Blood Transfusion Organization should be greater than or equal to the total approximated hospital demand. The second constraint indicates that the total amount of jth type blood products assigned to the ith hospital should be greater than or equal to the approximated need of the hospital for this product at the beginning of the day. The third constraint indicates the assignment of blood to hospitals with FIFO strategy. The fourth constraint calculates the amount of blood deficiency and surplus in each scenario in the form of a goal constraint. Constraints (3.5) and (3.6) show the availability limitation of blood products for allocation. It should be note that only the fresh products are considered to be supplied from outside. Seventh to tenth constraints define the variables.

4. SOLUTION APPROACH

Problems that are involved with uncertainty in the objective function or constraints are located in the category of stochastic programming models. In the past decades, various algorithms have been proposed in the form of exact and approximate methods to solve stochastic models. In this paper, a Monte Carlo simulation algorithm, which is an approximate method, and a hybrid method of Particle Swarm Optimization (PSO)

algorithm with Monte Carlo simulation are applied to solve the model. Since the assignment of blood involves some complexities and the demand is stochastic, so the problem can be seen as NP-Hard [14]. Therefore, applying inexact approaches like metaheuristics to solve the problem is a common way. The details of the methods are given in the following.

4.1. Monte Carlo simulation

Here, we introduce the details of Monte Carlo simulation algorithm to solve the blood assignment problem. The steps are as follows:

(1) For each hospital $i \in I$ and for each blood product $j \in J$, we produce Q scenarios for the demand.
(2) We solve the stochastic model (presented in Sect. 3.4). Suppose that $x*$ is the best feasible solution of the model. We fix the value of $x*$ and we compute the true value of objective function of $x*$ with the following steps.
(3) For each hospital $i \in I$ and for each blood product $j \in J$, we produce Q' scenarios (in which Q' is much larger than Q) for the demand.
(4) The value of the mathematical expectation of the objective function is estimated using the following equation.

$$\frac{\sum_{s \in S} \left(\sum_{j \in J} cx_j + \sum_{i \in I} \sum_{j \in J} sh_j z_{ij}^s + \sum_{i \in I} \sum_{j \in J} w_j r_{ij}^s \right)}{Q'}.$$

As Q' increases, the values of the mathematical expectation of the objective function tends to the real mathematical expectation with probability one.

4.2. Simulation based Particle Swarm Optimization

Here, we apply the Particle Swarm Optimization technique to solve the blood assignment problem. The idea of PSO is based on studying about some crowds such as bird's flight or fishes' swim. This metaheuristic has recently attracted many researchers attention because it can produce high quality solutions with low calculation. But, the studied blood assignment problem is stochastic, so we apply a hybrid of the PSO algorithm with Monte Carlo simulation. The framework of the algorithm are described in the following (Figs. 1 and 2).

5. Computational results

Here, first, a real problem is introduced, and then the results obtained from the model will be presented based on the gathered data.

5.1. The real problem

To implement the model, Blood Transfusion Organization of Yazd city which is one of the Iranian cities with 19 hospitals in this city are considered. Also, two blood products, *i.e.* platelets and red blood cells, have been studied due to their high degree of corruptibility and high demand. The demand for blood units has been extracted from the available data of these hospitals, while Easyfit software has been used to extract demand distribution functions. This software approximates the data with different probability functions and runs the Kolmogorov–Smirnov test for them. Then, it arranges the functions according to the proximity of the estimated function with the data, and the best functions can be used.

Here, we first concentrate on the results of Monte Carlo simulation algorithm. Then we present the hybrid algorithm results and we compare the methods.

In order to simulate the Monte Carlo, first, the optimal answer to the stochastic programming model is obtained using the steps mentioned in Section 4.1 (steps 1 and 2) for different Q values. It should be noted

For $k = 1, \ldots, n$
Produce Sol_k as an initial particle randomly
Check the feasibility of Sol_k and repair it if it is necessary
End
Do
$t = 1$
For $k = 1, \ldots, n$
Calculate the fitness value (Sol_k) with Obj-Simulation function (Sol_k)
If $t = 1$ **Then** $\text{PBest}_k = fitnessvalue(Sol_k)$ **ElseIf** fitness value $(Sol_k) < PBest_k$
Then $\text{PBest}_k = fitnessvalue(Sol_k)$ **End** Choose the particle with the best fitness value among all the solutions as the GBest **For** $k=1,\ldots, n$ Calculate particle velocity according to equation below
$v_k(t) = v_k(t\text{-}1) + (c_1 * rand(t)(\text{PBest}_k - Sol_k(t-1))) + (c_2 * rand(t)(\text{GBest} - Sol_k(t-1)))$
Update particle position according to equation below
$Sol_k = Sol_k(t-1) + v_k(t)$
Check the feasibility of Sol_k and repair it if it is necessary
End
t= t+1**While** $t < maxiter$ (or the best solution has not been changed in α iterative cycles)

FIGURE 1. The framework of the hybrid algorithm.

TABLE 3. Results of estimated objective functions.

Number of stochastic scenarios (Q)	Minimum objective function	Average objective function	Maximum objective function	Maximum running time (s)
5	5 521 000	5 554 700	5 589 000	1.88
10	5 539 000	5 579 250	5 600 000	1.05
20	5 536 750	5 562 025	5 593 125	1.77
30	5 526 750	5 562 066	5 588 833	1.48
40	5 544 500	5 559 687	5 581 062	2.9
50	5 536 250	5 554 385	5 574 000	3.84
60	5 539 292	5 557 966	5 567 708	3.12
70	5 555 964	5 561 249	5 564 135	3.12
80	5 539 906	5 559 840	5 570 531	3.98
90	5 549 165	5 557 291	5 569 250	6.08
100	5 552 825	5 563 502	5 575 975	16.71
200	5 554 537	5 565 044	5 583 176	21.74
500	5 557 000	5 560 495	5 563 880	37.25

that for each Q, ten independent runs of the program were implemented, in which the minimum value of the objective function, the average objective function and the maximum objective function are recorded in Table 3. In this table, the first column is the number of stochastic scenarios, the second to fourth columns indicate the
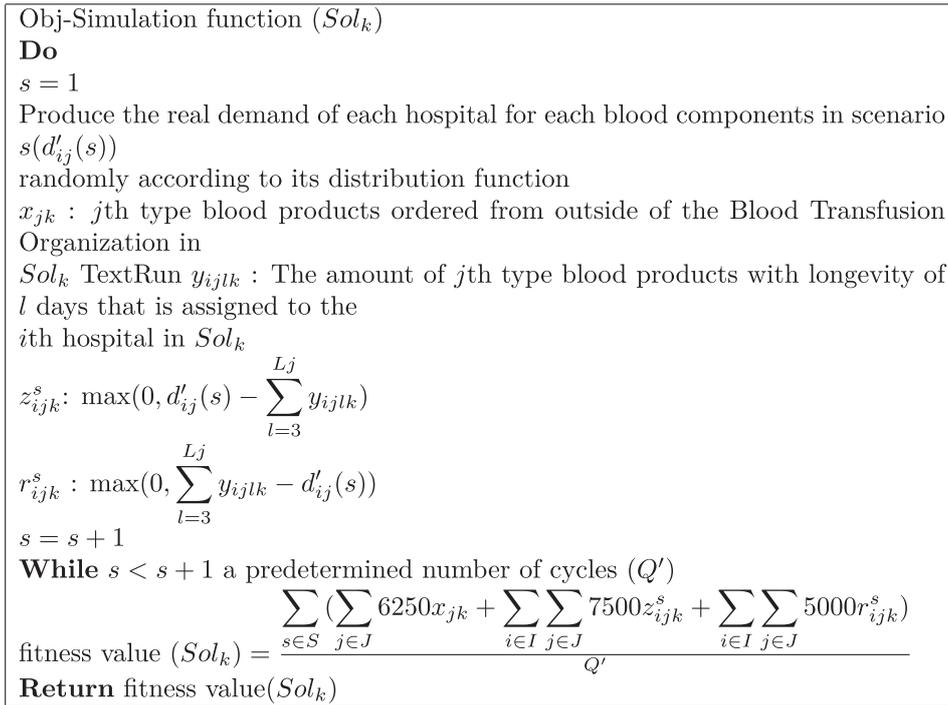
Obj-Simulation function (Sol_k)
Do
$s = 1$
Produce the real demand of each hospital for each blood components in scenario
$s(d'_{ij}(s))$
randomly according to its distribution function
x_{jk} : jth type blood products ordered from outside of the Blood Transfusion Organization in
Sol_k TextRun y_{ijlk} : The amount of jth type blood products with longevity of l days that is assigned to the
ith hospital in Sol_k

z^s_{ijk}: $\max(0, d'_{ij}(s) - \sum\limits_{l=3}^{Lj} y_{ijlk})$

r^s_{ijk} : $\max(0, \sum\limits_{l=3}^{Lj} y_{ijlk} - d'_{ij}(s))$

$s = s + 1$
While $s < s + 1$ a predetermined number of cycles (Q')

fitness value $(Sol_k) = \dfrac{\sum\limits_{s\in S}(\sum\limits_{j\in J} 6250 x_{jk} + \sum\limits_{i\in I}\sum\limits_{j\in J} 7500 z^s_{ijk} + \sum\limits_{i\in I}\sum\limits_{j\in J} 5000 r^s_{ijk})}{Q'}$

Return fitness value(Sol_k)

FIGURE 2. The Obj-Simulation function.

TABLE 4. Results of true objective function.

Number of stochastic scenarios (Q)	Minimum objective function	Average objective function	Maximum objective function	Maximum running time (s)
5	5 616 500	5 653 000	5 704 500	5.33
10	5 570 000	5 601 650	5 651 250	5.2
20	5 569 000	5 590 262	5 607 750	5.35
30	5 564 500	5 576 725	5 600 000	5.13
40	5 551 375	5 570 043	5 590 062	5.01
50	5 557 350	5 572 603	5 593 450	4.72
60	5 559 208	5 574 104	5 589 625	4.91
70	5 555 964	5 564 028	5 575 000	5.35
80	5 559 625	5 571 453	5 584 937	4.96
90	5 550 750	5 565 788	5 585 000	4.77
100	5 535 550	5 560 635	5 571 750	5.16
200	5 556 987	5 567 564	5 595 475	5.63
500	5 555 865	5 560 996	5 565 130	6.75

values of the objective function (minimum, average and maximum), the fifth column is the calculation time (in seconds). It should be noted that for each Q, ten independent data is generated randomly for simulation using the demand distribution functions.

As it can be seen in the above table, the calculation time is increased as the number of scenarios is increased, and the deviation of the values obtained for the objective function is reduced. This convergence of the objective
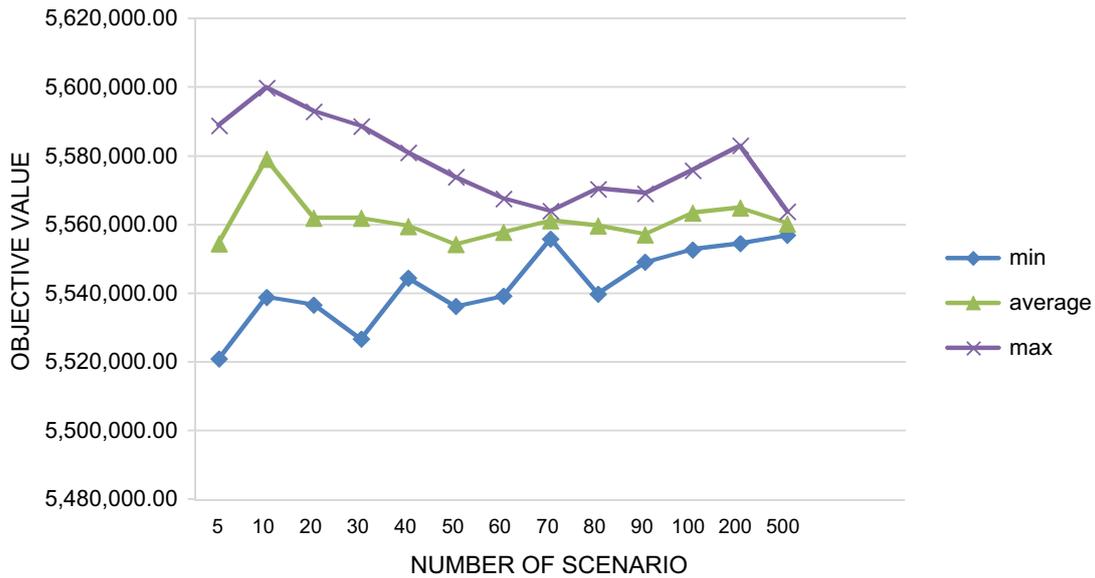
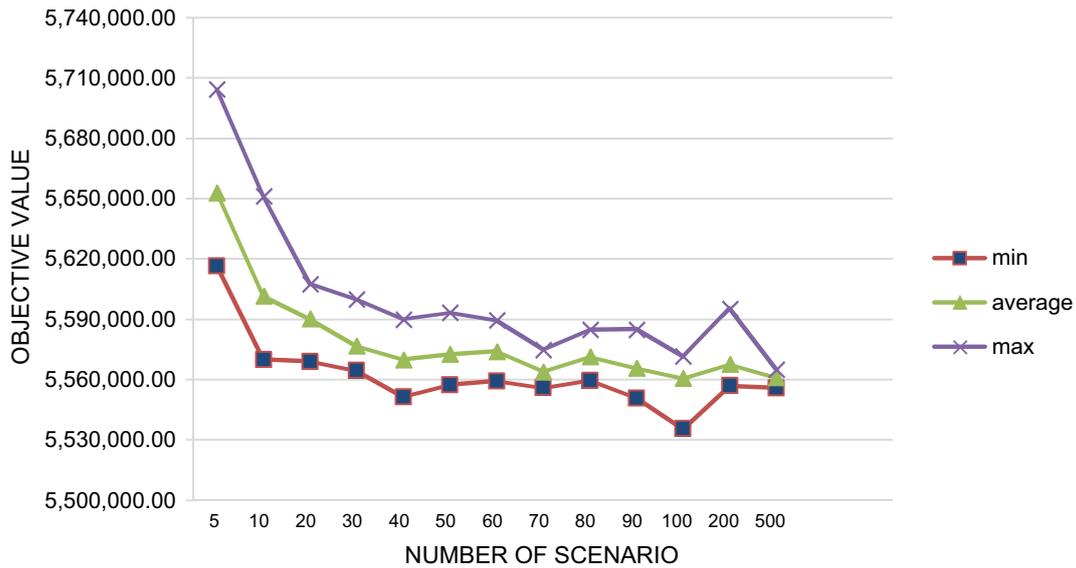FIGURE 3. Estimated values of objective function.

FIGURE 4. The true values of objective function.

function can be seen in the minimum value of the objective function in the incremental trend, and in the maximum value of the objective function in decreasing trend. In the next step, the true values of the objective function (the final results of Monte Carlo algorithm using $Q' = 500$ scenarios) are presented in Table 4.

The convergence of the objective function can be seen in Figures 3 and 4 as well.

To test the performance of the hybrid algorithm we should first justify the parameters. 200 repetitions of the algorithm has been considered as the stopping criteria while different values of other parameters has been tested.

TABLE 5. Hybrid algorithm parameters.

Parameters	Teste values	Best value
Q'	$50, 100$	100
N	$10, 20, 30$	20
C_{1s}	$1, 2, 3$	1
C_{1e}	$1, 2, 3$	1
C_{2s}	$1, 2, 3$	1
C_{2e}	$1, 2, 3$	1
Max_iteration	1000 repetition, the lack of improvement in 10 repetition	1000 repetition

TABLE 6. Comparing the results of different algorithms.

Method	Objective function	Time to reach the best answer (s)	The total running time (s)
Hybrid algorithm	4285750	1.65	2.03
Monte Carlo method	5560966	6.75	6.75
Particle Swarm Optimization	5165420	2.31	3.25

Finally the best amount of parameters were selected. Also we tested the sensitivity of the best parameters to the number of repetitions. We changed the stopping criteria to 1000 repetitions but the best values of parameters have not been changed.

The results of the tested values and the best values of the parameters are given in Table 5.

It should be mentioned that, the linear reduction criterion in the acceleration coefficients is as follows:

$$c_1 = [c_{1E} - c_{1S}] \left[\frac{t}{\text{maxiter}} \right] + c_{1S}$$

$$c_2 = [c_{2E} - c_{2S}] \left[\frac{t}{\text{maxiter}} \right] + c_{2S}$$

After implementing the hybrid algorithm, the quality of the answer during various iterations has been shown in Figure 5.

In order to test the efficiency of the hybrid algorithm, we compare the results of the hybrid algorithm with Monte Carlo simulation and PSO (in deterministic version), separately. We first pay attention to their final solutions. The best objective function found *via* hybrid algorithm is 4285750, while it is 5560966 for the Monte Carlo simulation and 5165420 for the PSO algorithm. Moreover, the total running time of the hybrid algorithm is 2.03 s, while it is 6.75 for Monte Carlo and 3.25 s for the PSO. The details of this comparison have been shown in Table 6.

In Table 7 the value of deficiency, surplus and the values of blood products ordered from out of organization are compared in the final answers of two stochastic algorithms *i.e.* Monte Carlo simulation and hybrid algorithm.

6. CONCLUSION

In this study, a two-stage stochastic programming model has been proposed to assign the blood products from the Blood Transfusion Organization to hospitals. This model has been designed considering stochastic amount of blood products demand (platelet and red blood cells), while the goals of the model are minimizing
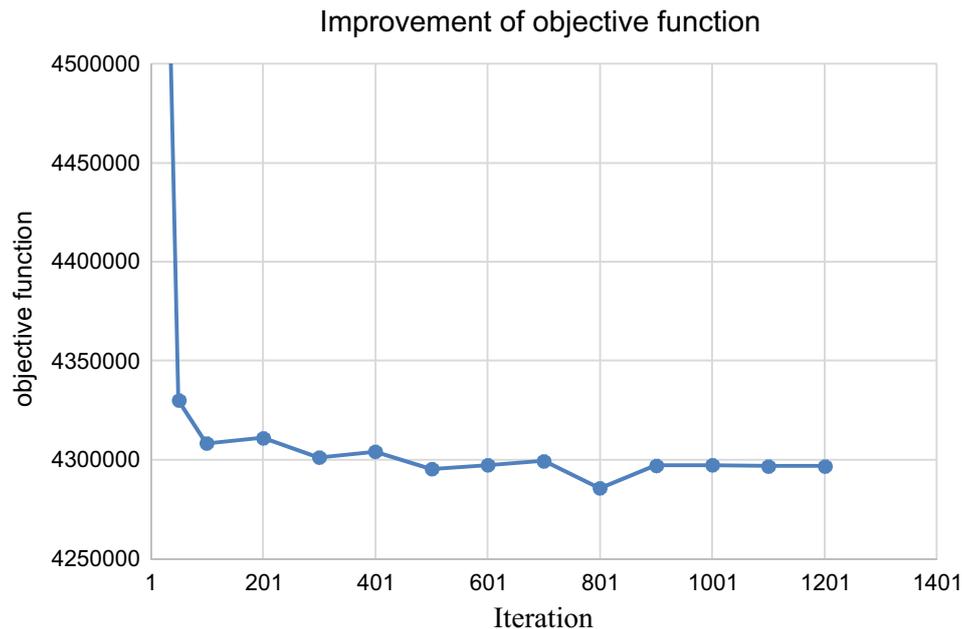
FIGURE 5. Improvement of the objective function values in different iterations.

TABLE 7. Comparing the values of deficiency, surplus and blood products ordered from out of the organization in Monte Carlo simulation and hybrid algorithm.

The values obtained	Monte Carlo simulation method	Hybrid algorithm
Total shortage value in platelet blood products	90	0
Total shortage value in red blood cell product	2	0
Total wastage value in platelet product	95	17
Total wastage value in red blood cell product	235	63
Total blood values ordered from out of organization	32	2

the supply, loss and surplus cost of blood products. The constraints of the proposed model are using FIFO strategy in the blood delivery, the limited longevity of blood products, the possibility of blood supply from outside of the organization and covering approximated demand. The proposed model was implemented on an actual problem in Yazd city and it was solved using Monte Carlo simulation and hybrid algorithm of Particle Swarm optimization and Monte Carlo simulation.

The final answer obtained from solving the model *via* hybrid algorithm indicates that this method overcome Monte Carlo simulation and PSO method. Moreover, it could decrease the shortage and the wastage of the blood products significantly. Also the amount of ordered blood products in hybrid method is much smaller than the Monte Carlo algorithm. Adding planning for the particular days of a year (like holy days) in which the number of the grantor is decreased can be considered in the future researches. The lack of proper strategy to reserve blood for high consumer sections and the lack of observation of cold chain by the hospital personnel out of hospital blood bank (while transportation of blood units between blood bank and the consumer sections and/or in the operation room and consumer section) and impossible return of unused blood to the blood bank have made the problem necessary for further investigation. This study was conducted generally without investigating different sections of the hospitals separately. Therefore, this study can be conducted in different departments

of hospitals and the causes can be searched in these sections in order to investigate the main causes of loss and eliminating them.

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