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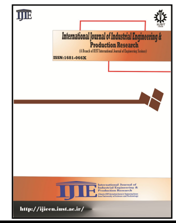

A Selective Covering-Inventory-Routing Problem to the Location of Bloodmobile to Supply Stochastic Demand of Blood

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KEYWORDS

Inventory-Routing; Covering problem; Selective Vehicle-Routing; Mobile Blood Collection

ABSTRACT

Supplying of blood and its products is one of the most challenging issues in the healthcare system since blood is a extremely perishable and vital good, and blood donation is a voluntary work. In this paper, a two-stage stochastic selective-covering-inventory-routing (SCIR) model was proposed to supply whole blood under uncertainty. Herein, a set of discrete scenarios was used to display uncertainty in stochastic parameters. Both of the fixed blood center and bloodmobile facilities were considered in this study. It was supposed that the number of bloodmobiles was indicated in the first stage before knowing which scenario occurred. To verify the validation of the presented SCIR model to supply the whole blood, the impact of parameters variation was examined on the model outputs and cost function using the CPLEX solver. In addition, the results of comparison between the stochastic approach and expected value approach were discussed.

1. Introduction

Whole blood and its products are vital for human lives while blood is a special product whose supply and demand is completely random. The blood supply chain includes the process of collection, production, storage, and distribution blood and its products from donor to recipient [1]. Since there is no alternative to human blood [2], it is critical to have a seamless process to collect and store this scarce resource. Collection and inventory management are two main activities in the blood supply chain, and several studies have been conducted in this field over the years. Figure 1 shows the general various scopes of the research studies regarding supply chain components and decision types (strategic, tactical, and operational), simultaneously. In most countries around the world, blood is mostly donated on a voluntary basis; therefore, the management of blood collection and blood inventory in the fixed or the mobile blood centers is highly important for preventing shortage in emergency situations.

Mainly, blood collection process is done in the fixed or mobile centers. It is notable that about 80% of all donations are made in bloodmobiles [3], and each bloodmobile represents an investment of $250,000 [4]. Additionally, effective use of bloodmobiles could be helpful in increasing the number of donations [5].

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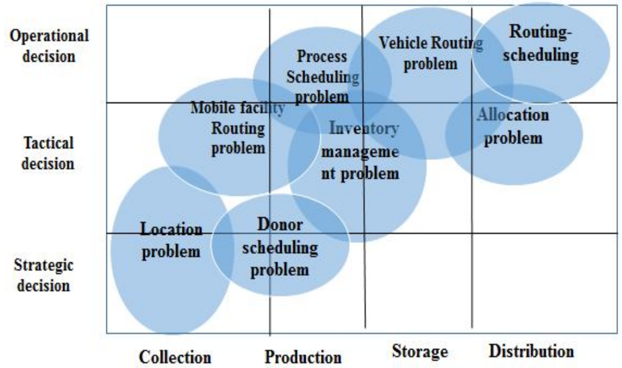
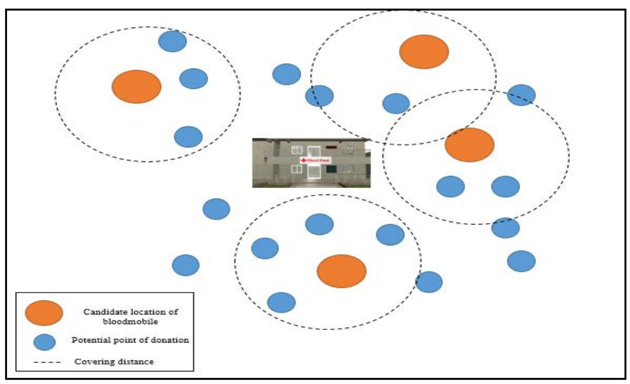


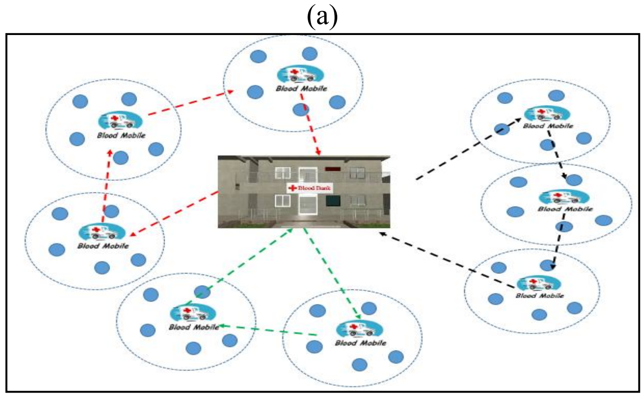
Fig. 1. Various scopes of researches in blood supply chain management

Thus, exact planning for the bloodmobile facilities is particularly important. Determining the right number of bloodmobiles to operate every day and strategic deployment of bloodmobiles to various locations to collect needed blood while minimizing the travelled distance have been discussed as important challenges in the literature [6]. In addition, due to the perishable nature of blood, an acceptable inventory policy seeks to maximize demand satisfaction and minimize the amount of blood units that expire [7].

According to the mentioned reasons, managing blood collection and blood inventory with conflicting objectives, especially under stochastic and dynamic conditions, represent one of the problematic issues of the blood supply chain. In this paper, a new two-stage stochastic selective-covering-inventory-routing (SCIR) model is presented to supply whole blood in an uncertain environment and manage the inventory.



(a)



(b)

Fig. 2. Illustrative example of the proposed model

level of blood to reduce wastage and holding costs. A blood supply network is studied which includes blood center, bloodmobile facilities, and blood donation sites. The rest of the paper is organized as follows: Section 2 presents the related literature. Section 3 describes problem description, mathematical model, and linearization scheme. Computational results of applying the presented model on the generated data sets are discussed in section 4. Finally, the paper is concluded in Section 5.

2. Related Literature

Blood supply chain origin dates back to 1960s [8]. Figure 3 illustrates the distribution of the presented papers according to the blood supply chain stages.

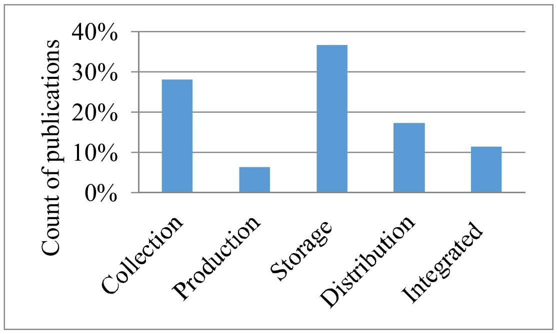


Fig. 3. Publications in blood supply chain (adopted from [1], [9])

According to the latest review studies, Osorio et al. [1], and Belien and Force [8], a wide range of the researches are dedicated to the collection and storage stages. Figures 4 and 5 indicate the trend of studies in the collection and storage according to publication date, respectively. Both Figures reveal the increasing popularity of this subject after the year 2000.

In the last decade, there are several comprehensive reviews which analyze the related paper from various aspects in the blood supply chain management such as Beliën and Forcé [9], Lowalekar and Ravichandran [10], and Osorio et al. [1]. The focus of this section is the conducted research related to the blood collection and blood inventory management problems associated with our study. Although mobile facilities are widely used for collection of blood donations in many countries including Iran, there are very few studies on bloodmobile operations in the literature. Şahin et al. [11] developed a location-allocation model for regionalization of blood services in a hierarchical network consisting of regional blood centers, blood stations, and mobile facilities. Alfonso et al. [12] addressed the blood collection problem considering both a fixed site and bloodmobile collection.

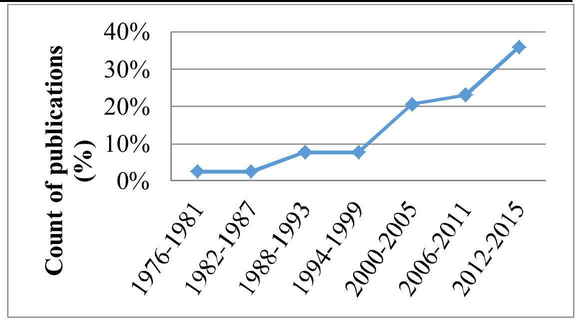


Fig. 4. Publications in blood collection (adopted from [1], [9])

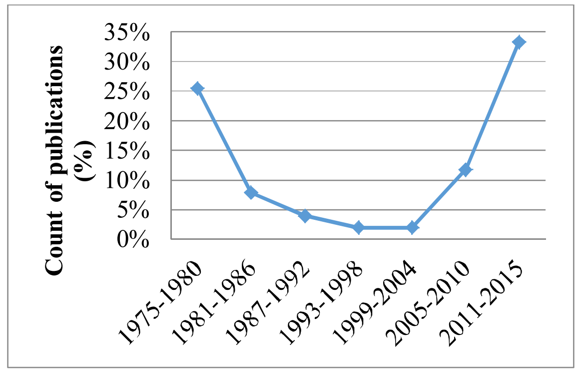


Fig. 5. Publications in blood inventory management (adopted from [1], [9])

They presented the modeling and simulation of blood collection systems in France. Blood collection through mobile facilities has been taken into consideration in recent years. Ghandforoush and Sen [13] presented a nonlinear integer programming model for platelet production and bloodmobile scheduling for a regional blood center to meet daily demand. Fahiminia et al. [14] investigated the emergency supply of blood in disasters. They considered a supply network which includes fixed and mobile blood center, donation sites, and hospitals with stochastic demands. Although they determined the inventory constrains in their models, they did not forecast the condition where demand exceeded capacity of fixed and blood center (as considered in this study). Sahinyazan et al. [5] presented a selective vehicle routing problem suggested by Chao et al. [15] with integrated tours. They optimized the route of bloodmobiles which collect blood and shuttles which transfer collected blood by bloodmobiles to the blood center. They only focused on the optimizing the route of mobile facility with no consideration about blood inventory. Based on Sahinyazan et al. [5] study, Rabbani et al. [16]

investigated the mobile blood collection system for platelet production and optimized the location of bloodmobiles and their routes in two separate models. Gunpinar and Centeno [6] proposed an integer programming approach to the bloodmobile routing problem. They considered uncertainty in blood potentials and applied robust optimization. They also determined minimum and maximum levels of blood inventory in each period.

A wide number of papers have reported important approaches to reducing the cost of waste and shortage of blood products [7]. The results of a study conducted in Transfusion Services at Stanford University Medical Center indicated that it was possible to reduce the loss of blood products by 50% if supply chain tools were implemented [17]. Although most of integrated researches studied storage stage in combination with distribution stage (such as Hemmelmayr et al. [18]; Baesler et al. [7] or production stage (such as Haijema et al. [19]; Lang and Christian [20]; Rytilä and Spens, [21]), there is a few study in the field of collection and storage, simultaneously. Nahmias [22] studied the inventory ordering policies for perishables including blood bank management. A review paper was reported in Prastacos [23] on the theory and practice of blood inventory management. Baesler et al. [7] created a discrete event simulation model to analyze and propose inventory policies in a blood center. Gunpinar and Centeno [6] focused on reducing wastages and shortages of red blood cells and platelet components of whole blood units at a hospital.

Table 1 illustrates some of the characteristics of related studies according to collection, inventory, and general characteristics. The last row in table 1 indicates the present study. As Table 1 shows, most of researches in the collection stage are focused on the planning of mobile and fixed blood collection facilities; however, the combination of inventory management with a collection stage has been considered in few studies.

The aim of this study is to present a new SCIR model to whole blood collection and its inventory management under uncertainty. To the best of author's knowledge, a modeling effort for blood supply similar to the present study is non-existent.

This paper contributes to the area of blood supply in the following ways:

- A new selective covering inventory-routing problem is designed for blood supply for the first time in the literature.
- This study considers that the blood demand and blood donation in the fixed or mobile facilities is stochastic.
- The inventory level constraints and blood campaigns are considered when the inventory levels in blood center are critical in order to manage the shortage in each period.
- A two-stage stochastic programming approach is presented for blood SCIR problem.

3. The Proposed SCIR Model

3-1. Problem description

A new SCIR model is designed for whole blood collection and its inventory management in a blood center during the planning horizon, simultaneously. Periodic stochastic demands could be supplied through collected blood by blood center or bloodmobiles. The bloodmobiles start their tours at the beginning of the planning horizon from blood centers and do not need to return to the blood center at the end of each period. In this study, it is supposed that a vehicle transfers collected blood by each bloodmobile to the blood center. The stop points for bloodmobiles are selected based on the level of stochastic blood donation in candidate location and also the amount of stochastic blood potential in donation sites in its coverage distance. Each bloodmobile visits only one location in each period and collects blood only from donation sites located within its coverage radius. An illustration of the proposed model is shown in Figure 2. Figure 2a depicts the blood center, donation sites, and potential stops of the bloodmobiles and their coverage areas; figure 2b shows the covering tours of three bloodmobiles as an illustrative example. In the proposed model, a policy is considered for inventory management of whole blood under the rules of Iranian.

Tab. 1. Summery of the related literature in blood collection and inventory management

Authors	Year	Collection characteristics						Inventory characteristics				General characteristics									
		Collection facility		Model structure				Shortage		Inventory level		Quality of information			Stochastic parameter			Stochastic programming approach		Solution approach	
		Fixed	Mobile	Location	Allocation	Routing	Other	Yes	No	Yes	No	Deterministic	Stochastic	Other	Demand	Donation	Other	Two- stage	Other	Exact	heuristic
Şahin et al. [11]	2007	*	*	*	*				*		*	*									
Ghandforoush and Sen [13]	2010		*	*	*				*		*	*									*
Alfonso et al. [12]	2012	*	*	*	*				*		*	*									*
Fahiminia et al. [14]	2014	*	*		*	*			*		*		*		*			*			*
Sahinyazan et al. [5]	2015					*			*		*	*									*
Gunpinar and Centeno [6]	2016					*			*	*			*		*					*	
Rabbani et al. [16]	2017		*			*			*		*			*		*					*
This study	-	*	*		*	*		*		*			*		*	*		*		*	

Blood Transfusion Organization (IBTO). Based on these rules, at least three days of safety stock must be carried, and if the inventory level in each day is less than five days of demand, a special campaign for extra donations begins. To avoid blood spoilage and reduce the cost of inventory holding, it is supposed that blood center may transfer the extra blood inventory to the other blood centers regarding their requirements if and only if its inventory level is more than seven days of demand. To the best of our knowledge, such modeling with these inventory rules considerations in combination of collection process has not been considered in the literatures. Generally, in this paper, the following decisions are determined:

- The stopping location of bloodmobiles among candidate locations;
- The covering tour of bloodmobiles;
- The quantity of collected blood by blood center and bloodmobiles;
- The quantity of collected blood by blood campaign;
- The quantity of transferred blood to the other centers.

3-2. Mathematical model

Let graph G (V, E) be a geographical network where V is the node of considered network and E represents roads between nodes. In this study, $V = \{0\} \cup I \cup L$. 0 is the blood center; I= {1, ..., n} is the set of candidate locations for bloodmobiles; L= {1, …, m} is the set of potential donor points that must be covered. Note that blood from donors is collected in both of location indexed by {0}, I, and L; however, bloodmobile facilities could settle only in special places such as universities or industrial complexes where indexed by I and donors move blood center or bloodmobile location based on their distances to donation (i.e., based on or coverage distance of each blood collection facility: fixed or mobile). Assumption, indices, parameters, and decision variables as well as mathematical formulation of the proposed model are described in the following.

Assumptions:

The framework under study considers the following assumptions**:**

- We use a homogenous fleet of bloodmobiles and do not consider the required capacity for them.
- The inventory level of blood in the blood center is checked at the end of each period.
- The shortage is not allowed in each period.
- The demand level of whole blood and donated blood (the number of people who are willing to donate blood) in each period is considered stochastic.
- The operation cost of collecting blood in bloodmobile and blood center is not considered in the proposed model.

The indices, parameters, and decision variables to the mathematical model formulation are describes as below.

Indices:

I: Set of candidate locations for bloodmobile indexed by *i*

L: Set of potential blood donation sites indexed by *l*

T: set of time period indexed by *t*

S: set of scenario indexed by *s*

Parameters:

h**:** Inventory holding cost

λ : Cost of call for extra donation

α : Cost of transferring blood unit to the other center

c_{ij} : Distance between bloodmobile locations *i* and *j*

r_{li} : Distance between bloodmobile location *i* and donation sites *l*

d_t^s : Demand of blood center in period *t* under scenario *s*

β : Percentage of collected units discarded due to a disease detected after testing

b_l^s : Blood potential of blood donation site *l* under scenario *s*.

b_j^s : Blood potential of blood donation in bloodmobile location *j* under scenario *s*.

τ : Coverage distance

fb : Fixed cost of establishing a bloodmobile facility

M: A very large number

π_s : Probability of scenario *s* occurrence

Decision variables:

I_t^s **:** Inventory level of the whole blood at the end of period *t* under scenario *s*.

x_{ijt}^{s} : Equals 1 if bloodmobile *k* be sent to *j* after *i* in period t under scenario *s;* 0 otherwise.

y : Number of bloodmobiles.

Q_t^s : Total unit of received blood to the blood center in period *t* under scenario *s*.

BQ_t^s **:** Total unit of collected blood from donors in the blood center in period *t* under scenario *s*.

CQ_t^s : Total unit of received blood to the blood center by bloodmobiles in period *t* under scenario *s*.

Q'^{s}_{t} : Total unit of received blood through campaign of blood extra donation to the blood center in period *t* under scenario *s*.

RQ_t^s : Amount unit of extra blood sent to the other blood centers in period *t* under scenario *s*.

q'^{s}_{t} *:* Quantity of collected blood through campaign in period *t* under scenario *s*.

q_t^s : Quantity of collected blood by bloodmobiles in period *t* under scenario *s*.

qq_t^s : Quantity of collected blood units in the blood center in period *t* under scenario *s*.

p'^{s}_{lt} : Equals 1 if the donor located in site *l* refers to blood center for blood donation in period *t* under scenario s.

p^s_{ljt} : Equals 1 if the donor located in site l refers to bloodmobile k located in site j for blood donation in period t under scenario s.

The objective function and constraints for the proposed model are as in (1)-(23):

$$\min z = \mathrm{fb} * y + \sum_{s=1}^{S} \pi_s * (\sum_{t=1}^{T} (I^s_t * \mathrm{h} + Q'^s_t * \lambda + RQ^s_t * \alpha + \sum_{i=0}^{n} \sum_{j=0}^{n} c_{ij} * x^s_{ijt})) \quad (1)$$

Subject to:

$$I^s_t = I^s_{t-1} + Q^s_t + Q'^s_{t-1} - d^s_t - RQ^s_{t-1} \quad \forall s, \forall t \quad (2)$$

$$Q'^s_t = (1-\beta) q'^s_t \quad \forall s, \forall t \quad (3)$$

$$q'^s_t = \max(0, 5d^s_t - I^s_t) \quad \forall s, \forall t \quad (4)$$

$$Q^s_t = CQ^s_t + BQ^s_t \quad \forall s, \forall t \quad (5)$$

$$CQ^s_t = (1-\beta) qq^s_t \quad \forall s, \forall t \quad (6)$$

$$qq^s_t \le \sum_{l=1}^{m} b^s_l * p'^s_{lt} \quad \forall s, \forall t \quad (7)$$

$$BQ^s_t = (1-\beta) q^s_t \quad \forall s, \forall t \quad (8)$$

$$q^s_t = \sum_{j=1}^{n} (\sum_{i=0}^{n} b^s_j * x^s_{ijt} + \sum_{l=1}^{m} b^s_l * p^s_{ljt} * x^s_{ijt}) \quad \forall s, \forall t \quad (9)$$

$$I^s_t \ge 3d^s_t \quad \forall s, \forall t \quad (10)$$

$$RQ^s_t = \max\{(I^s_t - 7d^s_t), 0\} \quad \forall s, \forall t \quad (11)$$

$$r_{lj} * p^s_{ljt} \le \tau \quad \forall s, \forall t, \forall l, \forall j \quad (12)$$

$$r_{l0} * p'^s_{lt} \le \tau \quad \forall s, \forall t, \forall l \quad (13)$$

$$\sum_{j=1}^{n} p^s_{ljt} + p'^s_{lt} \le 1 \quad \forall s, \forall t, \forall l \quad (14)$$

$$\sum_{i=0}^{n} x^s_{ijt} = \sum_{i=0}^{n} x^s_{jit+1} \quad \forall s, \forall t \le |T| - 1, \forall j \ne 0 \quad (15)$$

$$\sum_{i=0}^{n} \sum_{t=1}^{T} x^s_{ijt} \le 1 \quad \forall s, \forall j \ne 0 \quad (16)$$

$$\sum_{j=0}^{n} \sum_{t=1}^{T} x^s_{jit} \le 1 \quad \forall s, \forall i \ne 0 \quad (17)$$

$$\sum_{i=1}^{n} x^s_{i0|T|} = \sum_{i=1}^{n} x^s_{0i1} \quad \forall s \quad (18)$$

$$\sum_{i=1}^{n} \sum_{j=0}^{n} x^s_{ij1} = 0 \quad \forall s \quad (19)$$

$$\sum_{i=0}^{n} \sum_{j=0}^{n} x^s_{ijt} \le y \quad \forall s, \forall t \quad (20)$$

$$I^s_t, Q^s_t, BQ^s_t, CQ^s_t, Q'^s_t, RQ^s_t, q'^s_t \ge 0 \quad \forall s, \forall t \quad (21)$$

$$x^s_{ijt}, p^s_{ljt}, p'^s_{lt} \in \{0,1\} \quad \forall s, \forall t \quad (22)$$

$$y, q^s_t, qq^s_t \in \mathbb{Z}^+ \quad \forall s, \forall t \quad (23)$$

Equation (1) minimizes the total cost function, which includes establishing bloodmobiles, holding cost, cost of blood collection campaign, and transportation cost. Constraint (2) shows the blood inventory level in period *t* under scenario *s*. This level is equal to the inventory level in period *t-1*, plus total unit of blood collected by blood center and bloodmobiles in period t under scenario s, plus total unit of received blood through campaign of blood extra donation to the blood center in period *t-1* under scenario *s*, minus the stochastic demand in period *t*, minus amount unit of extra blood sent to the other blood centers in period *t-1* under scenario *s* (the inventory level in the end of each period is checked and, after that, the amount of sending extra blood or supplying shortage blood is determined). Constraint (3) indicates the total units of received blood through blood campaign to the blood center in period *t* under scenario *s,* regarding reduction coefficient *β*. Constraint (4) indicates that the campaign for blood collection must be done when the blood inventory level is less than five times the demand. Constraint (5) computes the total unit of received blood to the blood center by itself or through bloodmobiles in period t under scenario s. Constraint (6) defines the total unit of received blood to the blood center by all of bloodmobiles in period *t* under scenario *s*. Constraint (7) calculates the quantity of collected blood units in the blood center in period *t* under scenario *s*. Constraint (8) is the total unit of collected blood from donors in the blood center in period t under scenario s regarding reduction coefficient *β*. Constraint (9) determines the quantity of collected blood by bloodmobiles in period *t* under scenario *s*. Constraint (10) guarantees that, at least, three periods (days) of safety stock are considered in blood center. Constraint (11) makes sure that blood transfer to the other centers is possible if only and if the blood inventory level in blood center be more than seven times the demand in each period under each scenario. Constraints (12) and (13) ensure that bloodmobiles and blood center only accept donors within their coverage distance. Constraint (14) imposes that each donor site is served by only blood center or a bloodmobile. Constraint (15) specifies that if there is a bloodmobile coming to node *j* in period t, there should be also an outgoing one from node *j* in period *t+1*. Constraints (16) and (17) force that each potential location of bloodmobile under each scenario will be visited utmost one in planning period. Constraint (18) determines that each bloodmobile, which starts its tour from center, must go back to it in the end of its tour. Constraint (19) prevents tours starting from any site other than the blood center. Constraint (20) ensures that the number of used bloodmobiles does not exceed the number of established bloodmobiles. In this model, it is supposed that variable *y* determines the number of requirement bloodmobiles independent of each period and each scenario. It is noteworthy that Constraints (3), (16), and (17) altogether prevent sub-tours of bloodmobiles. Constraints (21)-(23) define the eligible domains of the decisions variables.

3-3. Model linearization

The proposed mathematical model is nonlinear in the present form because of constraints (4), (9), and (11). The linearization scheme is based on the method introduced in [24] to linearize constraint (4), and new binary variables are introduced as $lv1_t^s, lv2_t^s$; constraint (4) should be replaced by constraints (24)-(30).

$$q_t^s \le M * lv1_t^s \qquad \forall t, \forall s \tag{24}$$

$$q_t^s \ge -M * lv1_t^s \qquad \forall t, \forall s \tag{25}$$

$$q_t^s - \left(5d_t^s - I_t^s\right) \le M * lv2_t^s \qquad \forall t, \forall s \tag{26}$$

$$q_t^s - \left(5d_t^s - I_t^s\right) \ge -M * lv2_t^s \qquad \forall t, \forall s \tag{27}$$

$$5d_t^s - I_t^s \le M * \left(1 - lv2_t^s\right) \qquad \forall t, \forall s \tag{28}$$

$$5d_t^s - I_t^s \ge -M * \left(1 - lv2_t^s\right) \qquad \forall t, \forall s \tag{29}$$

$$lv1_t^s + lv2_t^s = 1 \qquad \forall t, \forall s \tag{30}$$

In addition, variable $lv3_{ijlt}^s$ is used instead of multiplication of two binary variables x_{ijt}^s, p_{ljt}^s in constraint (9); therefore, this constraint is replaced by equation (31), and additional constraints (32)-(35) should be added to the model.

$$q_t^s = \sum_{j=1}^{n} \left(\sum_{i=0}^{n} b_j^s * x_{ijt}^s + \sum_{l=1}^{m} b_l^s * \text{lv}3_{ijlt}^s \right) \quad \forall s, \forall t \tag{31}$$

$$lv3_{ijlt}^s \le p_{ljt}^s \qquad \forall t, \forall s, \forall i, \forall j, \forall l \tag{32}$$

$$lv3_{ijlt}^s \le x_{ijt}^s \qquad \forall t, \forall s, \forall i, \forall j, \forall l \tag{33}$$

$$lv3_{ijlt}^s \ge x_{ijt}^s + p_{ljt}^s - 1 \quad \forall t, \forall s, \forall i, \forall j, \forall l \tag{34}$$

$$lv3_{ijlt}^s \ge 0 \quad \forall t, \forall s, \forall i, \forall j, \forall l \tag{35}$$

Finally, to linearize the proposed model, binary variables $lv4_t^s, lv5_t^s$ are defined and (11) should be replaced with the following additional constraints.

$$RQ_t^s \le M * lv\,4_t^s \qquad \forall t, \forall s \tag{36}$$

$$RQ_t^s \ge -M * lv\,4_t^s \qquad \forall t, \forall s \tag{37}$$

$$RQ_t^s - \left(I_t^s - 7d_t^s\right) \le M * lv\,5_t^s \qquad \forall t, \forall \tag{38}$$

$$RQ_t^s - \left(I_t^s - 7d_t^s\right) \ge -M * lv\,5_t^s \qquad \forall t, \tag{39}$$

$$I_t^s - 7d_t^s \le M * \left(1 - lv\,5_t^s\right) \qquad \forall t, \forall s \tag{40}$$

$$I_t^s - 7d_t^s \ge -M * \left(1 - lv\,5_t^s\right) \qquad \forall t, \forall s \tag{41}$$

$$lv\,4_t^s + lv\,5_t^s = 1 \qquad \forall t, \forall s \tag{42}$$

4. Computational Results

Since the problem described in this paper has not been studied before, no benchmark instances are available in the literature. We therefore generate a set of three numerical examples with small and medium sizes according to the real situation in blood center in Isfahan Blood Transfusion Center. Characteristics of the generated datasets are shown in Table 2. In the present study, after linearizing the model, the GAMS (23.5)– with CPLEX solver is used for optimization. Table 3 shows the numerical results obtained by using GAMS for all of data sets at different reduction percentage (β). In Table 3, "Absolute gap" column represents the difference between MIP solution and the best solution obtained using GAMS; also, the model runtime is given in the last column.

Number of determined bloodmobiles, Average quantity of collected blood by bloodmobiles, blood center, and blood campaign under each scenario are presented for three datasets and varying β. The value of β between is changed 0.1 and 0.9 in increments of 0.1. By increasing β, we observe that the number of bloodmobiles as well as cost function increase in three datasets.

At a constant level of bloodmobiles in each dataset, first, quantity of collected blood by blood center increases; after that, the level of collected blood by bloodmobiles increases.

Tab. 2. Characteristics of the generated datasets

characteristics	Data set 1	Data set 2	Data set 3
Number of candidate bloodmobile locations	4	7	9
Number of blood donation sites	10	15	20
Time period horizon	3	3	4
Number of scenario	2	4	5

Finally, if the amounts of periodic demands exceed capacity of blood center and blood mobiles, the needed blood will be collected by blood campaign and high costs. The results indicate that the proposed SCIR model produces the expected output correctly. For some instances in which the absolute gap is large, a solution approach to solving them would be more useful. In this study, the benefit of the two- stage stochastic programming approach is examined by comparing its performance against that of an expected value approach. In this paper, we used stochastic parameters under discrete scenarios for demand and amount of potential blood in donation sites and bloodmobiles locations in each period. There are several measures to evaluate the benefit of scenario-based approaches. Value of the Stochastic Solution (*VSS*) introduced by Birge [25] is one of the common criteria to investigate the benefits of the two-stage stochastic programming approach.

VSS can be formulated as follows:

$$VSS = z_{EEV} - z_{HN} \tag{43}$$

where z_{EEV} and z_{HN} indicate the objective values under expected value and stochastic programming approaches, respectively. z_{HN} is the optimal objective value presented in section 3. To compute z_{EEV}, the presented model is solved by replacing the values of the stochastic parameters with their expected values. The solution obtained from solving this model provides the optimal number of bloodmobiles (y) for the expected value approach. In the final step, initial model is solved based on each scenario, separately while the number of bloodmobiles is fixed to the optimal number of bloodmobiles (y) obtained in the previous step.

Based on the computed results, *VSS* for data set 1 for all of β values is equal to 0, since there are only 2 scenarios in data set 1 and occurrence of scenarios is equal; there is no difference between stochastic and expected value approaches. Figures (6) and (7) indicate the trend of *VSS* over a range of β for datasets 1 and 2, respectively. The results show that trend of *VSS* completely depends on value of β and is not regular regarding increasing β. In dataset 1, for β values more than 0.7, not only the stochastic programming approach is not useful, but also *VSS* value is negative. Note that, in higher level of β, the majority of blood demand supply by blood campaigns; therefore, considering stochastic value for blood potential in donation sites could not improve cost function. No difference observed between stochastic or deterministic approaches when β equals 0.1 or 0.2. In the range of 0.3 to 0.7 for β values, the proposed stochastic programming approach has a higher priority than the expected value approach. The obtained results show that trend of *VSS* for dataset 2 follows a similar pattern to those of dataset 1 with some of the differences.

Generally, the stochastic programming approach does not show a clear preference over an expected value approach and depends directly on β value in both datasets.

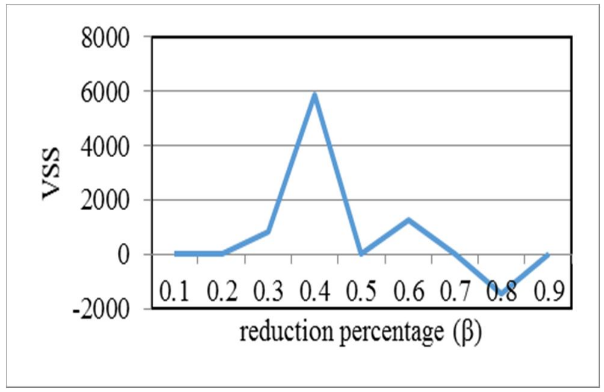


Fig. 6. VSS results for data set 2

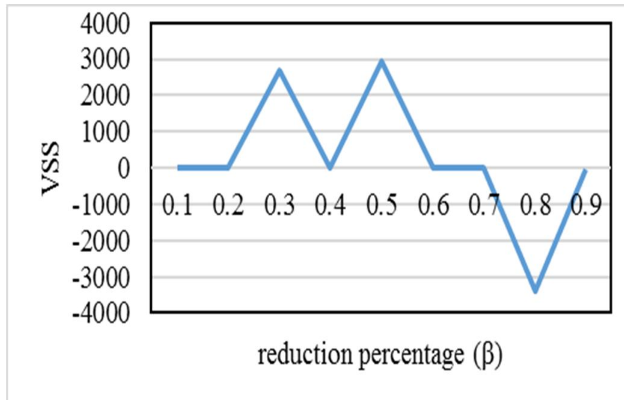


Fig. 7. VSS results for data set 3

Tab. 3. The impact of varying reduction percentage (β) on cost function and optimal number of blood facilities, collected blood by bloodmobiles, centers, and campaign

Data set	B	Cost function (MIP solution)	Number of used blood mobile	verage quantity of collected blood by bloodmobiles in each scenario	verage quantity of collected blood by blood center in each scenario	verage quantity of collected blood by blood campaign in each scenario	Absolute gap	Solution time (S)
Data set 1	0.9	112811	2	193	49	98.8	0	13.949
	0.8	77142	2	193	49	74.5	312	13.594
	0.7	53184	2	193	49	49.5	117.93	12.187
	0.6	29128	2	193	49	26.2	17.997	11.646
	0.5	7636	2	188	49	3	0.15	12.355
	0.4	3184	2	156	49	0	106.4	13.758
	0.3	3184.5	2	127	49	0	172.58	12.517
	0.2	3182.5	2	105	49	0	232.36	12.841
	0.1	3138.5	1	88	49	0	216.3	12.769
Data set 2	0.9	109120.750	3	264.75	47	106.725	7490.1	39.373
	0.8	70958.500	3	264.75	47	68.15	1470	26.124
	0.7	38580.750	3	264.75	47	35.475	1971.5	24.046
	0.6	13806.000	3	249.25	47	10.5	0	18.742
	0.5	4623.250	3	208.5	47	1.25	0.01	18.247
	0.4	3387.750	3	186.25	47	0	98.24	21.418

	0.3	3387.000	3	137.75	47	0	167.75	19.409
	0.2	3335.25	2	114.5	47	0	0	19.633
	0.1	3341.5	2	96.75	47	0	0.19181	21.352
Data set 3	0.9	109856.6	4	329	47	110.8	10.96	450.132
	0.8	61833.6	4	344	46	57.68	3544.2	178.532
	0.7	22518.8	4	334	46	18	0	95.611
	0.6	7028.8	4	273.8	46	2.4	287.6	27.867
	0.5	4620	4	218	46	0	46.777	74.966
	0.4	4564	3	174	46	0	18.204	46.930
	0.3	4566.8	3	143	46	0	8.5832	25.580
	0.2	4513.6	2	125	46	0	239.25	24.874
	0.1	4517.8	2	101	46	0	31.043	41.294

5. Conclusion

The timely supply of safe blood is a challenging issue in the healthcare problems. This work presented a selective-covering-inventory-routing (SCIR) model for supply stochastic demand of whole blood under uncertainty conditions. In the presented two-stage stochastic approach, the number of the needed bloodmobiles was determined in the first stage before knowing information about occurrence of the scenarios and other decisions were made in the second stage. This proposed model considered inventory management rules of Iranian Blood Transfusion Organization (IBTO) as well as the bloodmobile routing problem. Three randomized datasets were generated and sensitivity analysis was done based on model parameters.

Numerical results showed that the small instances of the problem could be solved to optimality using GAMS in reasonable amount of time; however, a solution approach to solving the big instances was needed. Results showed the collected blood by blood center, bloodmobiles and campaign increase, respectively, when demand and reduction percentage of blood increases. In addition, the benefit of stochastic value approach versus expected value approach by using VSS criteria was investigated. Results showed that the stochastic programming approach does not show a clear preference over an expected value approach and depends directly on the β value in each dataset.

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