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Presenting a stochastic multi choice goal programming model for reducing wastages and shortages of blood products at hospitals

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Abstract

One of the most fundamental components of healthcare systems is the blood supply chain management. This chain has two significant components including collecting donor' bloods and supplying blood's products. The main purpose of this paper is to concentrate on supplying blood products and present a novel constrained bi-objective mathematical model for a two-echelon blood supply chain network (BSCN). The aims of the proposed model are: 1) minimize products' waste and shortage costs in hospitals and 2) to minimize the maximum unsatisfied demand of different products among hospital demands supplied by blood transfusion centers. Some techniques are used to linearize the model's nonlinear terms and decrease presented model's complexity. A multi-choice goal programming (MCGP) technique is used to convert bi-objective model into a single objective one. The model is solved by mathematical software under 3 different scenarios and 18 time periods in real-world BSCN. Computational results showed that hospitals are tended in accepting products' holding and waste costs to satisfy demands of patients who are highly need for receiving blood products.

Keywords: blood supply chain, packed red blood cells, MCGP, Blood transfusion center

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1- Introduction

Blood is a scarce source and has a limited life time. People can be required for receiving blood in both normal and crucial situations. Formal statistics published by Red Cross organization of United State reveals the fact that one person on each two seconds may be required for receiving blood. Similar statistics published in Iran show that one person on each three seconds may want to receive blood (Nagurney et al., 2012). Blood products are among the essential items needed to save the human life and the lack of them may lead to significant losses in human health (Kohneh et al., 2016).

The real world importance of the BSCN is unique, since human lives are at stake. The intricacy of the supply chain is perhaps less clear. According to Katsaliaki and Brailsford (2007), more than a hundred different products can be derived from blood, as well as products and sub-products, but red blood cells (RBC), plasma, platelets and cryoprecipitate are regarded as to be the most important. RBCs represent 63.4% of the total transfused products, followed by plasma at 17.8%, platelets at 13.6% and ultimately cryoprecipitate at 5% (Whitaker et al. 2016). Moreover, these products can be processed to obtain sub-products such as irradiated or washed products for particular treatments or as raw material for other products such as recombinant products. Components are used in different conditions: for instance, RBCs are needed in anaemia treatments, while platelets are needed for cancer patients and plasma is needed to treat patients with burns. This list represents one single instance of the use of each component; however, each component can have many uses in separate processes in health care. However, there are specific constraints and preferences in using them. Moreover, the shelf life of blood products is another important aspect to be considered; platelets, RBC, plasma and cryoprecipitate have unlike shelf lives. Platelets are the most significant component with a shelf life of just 5 days, followed by RBC with 42 days and ultimately plasma and cryoprecipitate with one year. This means that if a blood product has not been transfused before the end of its shelf life, it must be discarded. Finally, it is important to note that blood products are not produced independently. There are different primary fractionation alternatives that produce from one to four products, as well as different methods of collection(Osorio et al.,2015).

Hospitals are major consumers of blood products. They are committed to transfer blood to people who are injured in accidents, patients who will have a surgery, people who need for organ transplantation and people who are suffering from blood cancer or other diseases. People or hospitals are always tended in receiving blood products. It is always impossible to predict exact value of the demand for blood products in coming weeks or months. So, having a blood bank with enough available fresh blood inventories is one of the key components of the world's healthcare systems(Nagurney et al., 2012).

Iranian blood transfusion organization (IBTO) is Iran's only credible national structure that is committed to conduct and control all the activities involved in BSCN (Gharehbaghian et al., 2008). In other words, the main responsibility of IBTO organization is to collect bloods donated by volunteers and distribute them among different concerned centers. IBTO is established in 1974 as a central unified organization and is currently working as an inseparable component of Iran's healthcare system. A centralized system is involved in IBTO to perform all the activities like receiving donated bloods, storing, processing and collecting blood products among hospitals.(Cheraghali, 2012)

Blood and its products are produced, stored and processed in more than 90 blood transfusion centers to be distributed among various hospitals. 31 centers of these centers are located in state cities and their 34 centers are able to do specialized experiments. All the mentioned centers involve fixed and mobile blood Iran.(Omidkhoda et al. 2016)

According to the definitions of blood transfusion organization, blood transfusion center (BTC) is defined as a place that is responsible for selecting appropriate donors, collecting blood and its products, performing transmittable blood infections, producing blood products, storing and ultimately distributing them among different hospitals. Blood products can be used by hospitals for clinical applications or can be sent to the centers which are in contact with clinical centers. Blood can be collected by blood collection centers (BCCs) and blood collection processing centers (BCPCs). While BCCs only collect and freeze donated blood, BCPCs in addition to collecting and freezing blood also attempt to isolate blood products. In addition, blood collection centers have only blood collecting equipment and can only receive donors' bloods. Mobile blood collections teams (MT), comprised of a group of blood transfusion organization’s employees, and are located in predefined locations to collects volunteer donors’ blood. Details of the inbound process of blood donation and other steps involved in an Iranian blood supply chain are shown in Figure 1.

Hospitals demand for receiving blood d products associates with different problems. First of all, the blood volume requested by hospitals is always more their real need. Secondly, supply centers are not able to satisfy all the demand declared by different hospitals. So, they try to distribute their inventory based on hospitals’ real requirements.

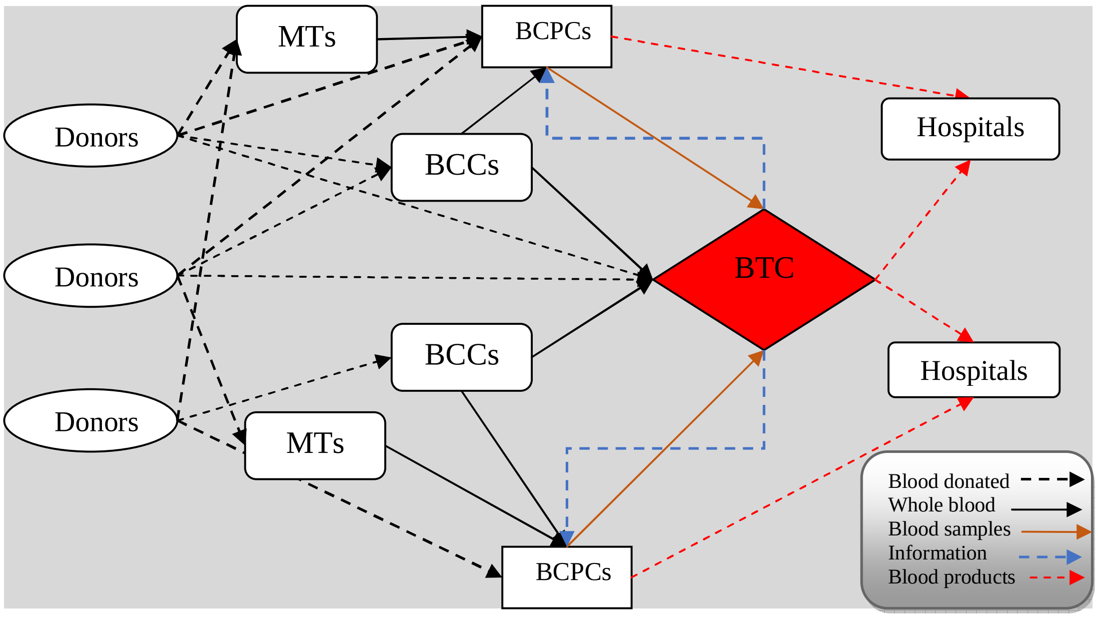


Figure 1. Iran’s blood supply chain network

The Rest of this paper is organized as follow. Literature review of BSCN and MCGP approach is discussed in section 2. Section 3 is divided into three different subsections. The first subsection is devoted to presenting a mixed integer nonlinear programming formulation for a two echelon blood supply chain network. The second subsection is devoted to linearizing the model’s nonlinear terms. The third subsection is devoted to formulating proposed model in context of MCGP approach. Section 4 is devoted to implementing a real case study of Iran’s blood supply chain network. Finally, the paper’s conclusion and some recommendations for future works are discussed in section 5.

2- Literature review

The research works presented in literature are investigated in two different parts including papers related to BSCN and MCGP approach.

2-1- Blood Supply Chain Network (BSCN)

In the subject of BSCN, Beliën and Forcé (2012) and Osorio et al (2015) presented a comprehensive review on the BSCN to support different decision-making issues and determine required future researches. Pierskalla and Brailer (1994) and Pierskalla (2004) focused on both strategic and tactical topics related to BSCN including blood-banking functions, coordination between supply and demand, blood collection, setting inventory levels, etc.

It can be inferred from Table 1 that all the studies performed in field of blood supply chain networks can be categorized by following research areas:

- Modeling approaches. Different types of decision variables including continuous, binary and integer variables can be used for defining various mathematical models for BSCNs. Binary nonlinear goal programming (BNGP) approaches have been used more than other approaches for modeling mixed integer programming (MIP) models.
- Uncertainty approaches. Different approaches like fuzzy set theory (FS), stochastic programming (SP) and robust optimization (RO) techniques have been used in literature for modeling parameters' uncertainty.
- Time periods. Most of the formulations considered for modeling BSCNs are presented in form of multi-period models.
- Objective functions. Different mathematical formulation developed in literature for modeling BCSNs are presented in context of single objective and multi-objective models.
- Solution techniques. The methods used for solving various mathematical models can be categorized in four different groups including exact methods (E), heuristic algorithms (H) and simulation techniques(S).
- Research scopes. Most of the scopes have been considered in literature for designing a BSCN were restricted to collecting and distributing blood and blood products. And other researchers have been focused on distribution (Dis) or collection (Co) of blood.
- Performance measure. The two most general categories of performance measures are those considering the number of outdated units and the number of units short of demand. So we divide inventory costs to Wastage (Wa), Shortage (Sh) and holding (Ho) costs.
- Demand points. Most of the formulations considered for modeling BSCNs have single demand point. But so far only one paper considers multiple demand points.
- Shortage costs. In none of the past researches patient (NDi) demand are not divided. But it can be divided (Di).
- Blood products. In real world, Hospitals order the package of various products but Most of the formulations considered for modeling BSCNs have single blood product.

Table 1. Pervious researches

References	Model	Uncertainty				Time period		Objective function		Solution techniques			Research scopes			Performance measure			Demand points		Shortage costs		Blood products		Case study
		D	FS	SP	RO	Single	Multi	single	multi	E	S	H	BSCN	Dis	Co	Sh	wa	ho	single	Multi	Di	NDi	single	Multi	
(Rytilä and Spens, 2006)	-	-	-	-	-	-	-	●	-	-	●	-	●	-	-	●	-	-	●	-	-	●	●	-	Canadian
(Van Dijk et al., 2009)	MDP[1]	●	-	-	-	-	●	-	-	-	●	-	-	●	-	●	●	●	-	-	-	●	●	-	Dutch blood bank
(Grant , 2010)	-	-	-	-	-	-	-	●	-	-	-	-	●	-	-	-	-	-	●	-	-	-	●	-	-
(Cetin and Sarul ,2009)	GNLP	●	-	-	-	●	-	●	-	●	-	-	-	●	-	-	-	-	-	●	-		●	-	-
(Zhou et al., 2011)	SDP[2]	-	-	●	-	-	●	●	-	●	●	-	-	●	-	●	●	●	●	-	-	-	●	-	-
(Seifried et al. 2011)	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	●	-
(Sha and Huang 2012)	MINLP	●	-	-	-	-	●	●	-	-	-	●	-	-	●	-	-	-	●	-	-	-	●	-	Beijing
(Stanger et al. 2012)	-	-	-	-	-	-	●	-	-	-	-	-	●	-	-	-	●	-	-	-	-	-	-	-	-
(Blake and Hardy, 2013)	-	-	-	-	-	-	-	●	-	-	●	-	-	-	●	-	-	-	-	●	-	-	●	-	Canada
(B. Zahiri et al., 2015)	MIP	-	-	●	-	-	●	●	-	●	-	-	-	-	●	-	-	-	-	-	-	-	●	-	Mazandaran
(Jabbarzadeh, et al., 2014)	MIP	-	-	-	●	-	●	●	-	●	-	-	-	-	●	-	-	-	-	●	-	-	●	-	Tehran
(Fahimnia et al. , 2015)	MIP	-	-	●	-	-	●	-	●	●	-	-	-	-	●	-	-	-	-	●	-		●	-	Unclear
(Osorio et al., 2016)	MIP	●	-	-	-	-	●	●	-	-	●	-	-	●	●	-	-	-	●	-	-	-	●	-	Colombia
(Gunpinar and Centeno, 2015)	MIP	-	-	●	-	-	●	●	-	●	-	-	-	●	-	●	●	●	●	-	-	●	●	-	Unclear
(Behzad Zahiri and Pishvaee, 2016)	MIP	-	●	●	-	●	-	-	●	●	-	-	●	-	-	-	-	-	-	●	-	-	-	●	Mazandaran
(Puranam et al., 2017)	DP[3]	-	-	●	-	-	●	●	-	-	-	●	●	-	-	-	●	●	-	-	-	-	●	-	Unclear
(Yates et al., 2017)	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	●	-	●	-	-	-	-	-	-
(Kazemi et al., 2017)	MIP	-	●	-	-	-	●	●	-	●	-	-	-	●	-	-	-	●	●	-	-	-	●	-	Mazandaran
This article	MIP	-	-	●	-	-	●	-	●	●	-	-	-	●	-	●	●	●	-	●	●	-	-	●	Tabriz

[1] Markov dynamic programming
[2] stochastic dynamic programming
[3] Dynamic Programming

The motivation behind this study that differentiates this paper from the existing ones in the related literature can be summarized as follows:

- BSCN presented by Gunpinar & Centeno (2015) includes one hospital. Here, we develop their network to a network with multiple hospitals.
- The presented model, aimed to minimize total waste and shortage costs of blood products. Here, we extend their model to a bi-objective mathematical model. To do so, another objetcive is added to the model to minimize deviations between hospitals demand and supply of blood tranfussion centers. This issue can be used for establishing a trade off between supply and demand of blood products.
- Shortage costs of preparing patients' required blood products is divided in two parts of shortage in satisfying demand of ordinary and highly required patients for blood products. This subject is not considered in none of the studies.
- A MCGP approach is employed in this paper for solving bi-objective mathematical model. Because this method has more flexibility in sensitivity analysis.
- A real case study is employed in this paper for testing and evaluating performance of developed model.
- Due to the uncertainty in the BSCNs and as well as in demand hospitals, the credibility-based stochastic programming is used.
- In real world, Hospitals order the package of various products, For this reason BTCs or BCPCs supply offer various products. But Most of the studies considered for modeling BSCNs have single blood product. So we have considered multi-blood products whit different expiration times.

2-2- Goal programming approach

Goal programming (GP) has been used extensively in literature for solving different multi-objective optimization problems. This method was firstly introduced by Charnes and Cooper (1957) for solving various types of multi-objective problems. This method has been used successfully for solving different real life multi-objective decision making problems. In addition, different versions of this technique were developed in literature for solving decision making problems. All the GP based techniques can be classified in two main groups including fuzzy goal programming models and crisp making problems. The techniques of the first group can be used for solving multi-objective models dealing with uncertainty mean while the second group's techniques should be used for solving deterministic constrained multi-objective problems. This method is mainly designed to minimize positive and negative deviations of objectives involved in the model. In other words, this technique aims at minimizing the gap existed between objectives and their aspiration level. This method uses two different types of the constraints including goal constraints and system constraints. System constraints are designed to consider the linear programming concepts meanwhile goal constraints including auxiliary variables are used to identify optimal solutions by considering a set of predefined goals. The major structure of GP techniques used for solving multi-objective optimization problems is:

Minimize $\sum_{i=1}^{n} d_i^{+}+d_i^{-}$

Subject to

$$h_k(x)=(\leq \text{ or } \geq)0 \quad ; \forall \ k=1,2,\dots,q$$

$$f_i(x)+d_i^{+}+d_i^{-}=g_i \quad ; \forall \ i=1,2,\dots,n$$

$$x\in X$$

$$d_i^{+},d_i^{-}\geq 0 \qquad ; \forall \ i=1,2,\dots,n$$

Where the k^{th} system constraint, the i^{th} goal constraint, the i^{th} goal's aspirant level and variables indicating positive and negative deviation from i^{th} goal's target value are respectively depicted by $h_k(x)$, $f_i(x)$, g_i, d_i^+ and d_i^-. Additionally, corresponding value of d_i^+ and d_i^- can be calculated as follow:

$$d_i^+ = \begin{cases} f_i(x)-g_i & ;\text{if } \ f_i(x)>g_i \\ 0 & \text{otherwise} \end{cases}$$

$$d_i^- = \begin{cases} g_i-f_i(x) & ;\text{if} f_i(x)<g_i \\ 0 & \text{otherwise} \end{cases}$$

Different objectives like weighted, preemptive and min-max goals can be defined for GP techniques. The main structure of weighted goal programming technique is defined as:

Minimize $\sum_{i=1}^{n} W_i(d_i^+ + d_i^-)$

Subject to

$$h_k(x) = (\leq \text{or} \geq) 0 \qquad ; \forall k=1,2,\ldots,q$$

$$f_i(x) + d_i^- - d_i^+ = g_i \qquad ; \forall i=1,2,\ldots,n$$

$$x \in X$$

$$d_i^+, d_i^- \geq 0 \qquad ; \forall i=1,2,\ldots,n$$

Where, positive weight defined for both negative and positive deviations of the i^{th} goal form its predefined target value is shown by W_i.

Most of decision makers are interested in selecting lower values for aspiration level. Consequently, multi-choice version of GP technique (MCGP) was firstly introduced by Chang (2007) was firstly developed to tackle with this problem. The main reasons behind using this technique is to consider different aspiration levels for the goals and avoid assigning lower values to each goal's aspiration level. This technique is mainly designed to consider single and multiple aspiration levels for local and global areas in order to find global optimal solution. Overall structure of this technique is presented as follow:

Minimize $\sum_{i=1}^{n} W_i(d_i^+ + d_i^-)$

Subject to

$$h_k(x) = (\leq \text{or} \geq) 0 \ ; \qquad \forall k=1,2,\ldots,q$$

$$f_i(x) + d_i^- - d_i^+ = \sum_{j=1}^{m} b_{ij} S_{ij}(B); \qquad \forall i=1,2,\ldots,n$$

$$x \in X$$

$$d_i^+, d_i^- \geq 0; \qquad \forall i=1,2,\ldots,n$$

$$S_{ij}(B) \in R_i(x); \qquad \forall i=1,2,\ldots,n$$

Where, i^{th} goal's j^{th} aspiration level, function of binary serial number and function of resource boundaries are respectively shown by b_{ij}, $S_{ij}(B)$ and $R_i(x)$.

Moreover, overall structure of two other MCGP based mathematical models proposed by Chang (2008) is:

The less is better

$$\text{Min}\sum_{i=1}^{n}[W_i(d_i^{+}+d_i^{-})+\alpha_i(e_i^{+}+e_i^{-})]$$

Subject to:

$$h_k(x)=(\leq \text{or} \geq)0; \quad \forall k=1,2,\ldots,q$$

$$f_i(x)+d_i^{-}-d_i^{+}=y_i; \quad \forall i=1,2,\ldots,n$$

$$y_i+e_i^{-}-e_i^{+}=b_{i.min}; \quad \forall i=1,2,\ldots,n$$
$$b_{i.min}\leq y_i\leq b_{i.max}; \quad \forall i=1,2,\ldots,n$$
$$d_i^{+},d_i^{-},e_i^{+},\ e_i^{-}\geq 0; \quad \forall i=1,2,\ldots,n$$

The more is better

$$\text{Min}\sum_{i=1}^{n}[W_i(d_i^{+}+d_i^{-})+\alpha_i(e_i^{+}+e_i^{-})]$$

Subject to:

$$h_k(x)=(\leq \text{or} \geq)0; \quad \forall k=1,2,\ldots,q$$

$$f_i(x)+d_i^{-}-d_i^{+}=y_i; \quad \forall i=1,2,\ldots,n$$

$$y_i+e_i^{-}-e_i^{+}=b_{i.max}; \quad \forall i=1,2,\ldots,n$$
$$b_{i.min}\leq y_i\leq b_{i.max}; \quad \forall i=1,2,\ldots,n$$
$$d_i^{+},d_i^{-},e_i^{+},\ e_i^{-}\geq 0; \quad \forall i=1,2,\ldots,n$$

Where, continuous variable, lower and upper bound of i^{th} aspiration level, positive and negative deviations defined as $|y_i-b_{i.min}|$ in less is better model and $|y_i-b_{i.max}|$ in more is better formulations and weight of sum of positive and negative deviations are respectively presented by y_i, $b_{i.min}$, $b_{i.max}$, e_i^{+}, e_i^{-} and α_i.

MCGP technique has been used in literature for modeling different real world multi-objective problems. Ustun (2012) developed a conic scalarizing based MCGP model. The model had two main contributions including reducing auxiliary constraints and additional variables and ensuring obtaining global optimal solution that can guaranty feasibility of obtained solutions. They presented some examples and test problems to show usefulness of the proposed model. Paksoy and Chang (2010) developed a MCGP model for multi-period multi- stage supply chain problem. The proposed mixed integer programming formulation aimed to minimize three different goals including transportation costs, setup costs and inventory costs. They used mathematical software to solve proposed model. Bankian-Tabrizi et al (2012) developed a new formulation for fuzzy MCGP technique. The proposed formulation can be used both for modeling real world problems and giving understanding about the solutions of the recently developed fuzzy MCGP problems. Pal and Kumar (2013) developed a revised MCGP technique for modeling and solving economic environmental power generation and dispatch problems. They converted proposed nonlinear model into a linear model and used GP technique for solving the developed linear model. Patro, et al (2015) used two methods of Vandermonde's interpolating polynomial binary variables and the least square approximation method to develop a novel mathematical formulation of MCGP problem. They used mathematical software to solve proposed model and find the model's global optimal solutions.

3- Mathematical modeling

Mathematical formulations can be used for generating blood's collection and distribution network to optimize BSCN (Duan & Liao, 2014). In this section, a novel mathematical model is presented for a two echelon BSCN with one distribution center and multiple hospitals. The BTC or BCPCs will supply hospitals' requested demand by investigating its available inventory. Scope of paper is shown in Figure 2. So, it's very necessary for hospitals to identify optimal level of their blood inventory on different periods. The amount of blood required for hospitals on different periods cannot be predicated exactly. So, they always face with uncertainty on satisfying patients' need for receiving blood. As a result, demand uncertainty should be considered in presenting a new model to make it closer to real conditions of the hospitals.

Transportation costs are the only external costs that Iran's hospitals are paying for receiving blood products. But these have different internal costs such as wastage, shortage and holding costs. So we minimize sum of these costs. It is mentioned that holding cost of blood products is different because these store in dissimilar condition.

On the other hand, the demand values declared by hospitals on different time periods are always more than their real needs. This fact has been iteratively experienced by IBTO. As a result, BTCs or BCPCs are not always supplying all the declared demand of hospitals. So, we try presenting a mathematical model to make a reasonable and fair balance between hospital demands, but also we minimize the maximum unsatisfied demand of different products among hospital demands throughout the planning horizon.

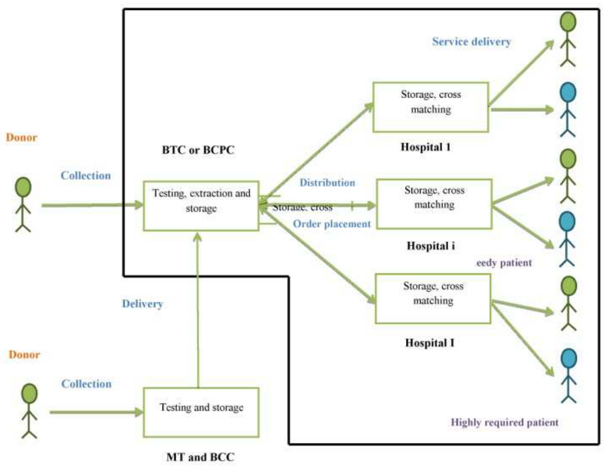


Figure 2. Scope of research

Paper outputs can be expressed as follows:

- BTC or BCPCs Distribute blood products between hospitals fairly, and Number of blood product units is determined for each hospital and every period.
- In optimal condition and various scenarios, hospitals save determined inventory to minimize wastage, shortage and holding costs.

3-1- model's assumptions

- The real capacity of BTC or BCPCs for storing blood and supplying hospitals' demand for consuming blood products is limited.
- Life time of blood products supplied by BTC or BCPCs is known and may change during time.

- Shortage costs can be occurred when all the demand requested by hospitals are not completely supplied by BTCs or BCPCs. Happening shortages may have harmful effects on patients' healthiness that urgently needs for consuming blood products.
- The time required for transporting and delivering blood products for hospitals is ignorable.
- FIFO policy is used by hospitals for consuming blood products.
- Disposal costs will be paid by hospitals for the bloods that their useful life time is passed.
- Number of highly required patients equal to needy patients.
- Firstly, hospitals satisfy highly required patient demands then remaining blood products are used for needy patients.

3-2- Indices

i	Index of hospitals ($i=1,\dots,I$)
k	Index of blood product types ($k=1,\dots,k$)
j_k	Index of product k life time $j_k=1,\dots,Et_k$
t	Index of different time periods ($t=1,\dots,T$)
s	Index of different scenarios ($s=1,\dots,S$)

3-3- Parameters

π_s	Probability of occurring scenario *s*
$CS1_k$	Hospitals' shortage costs to prepare blood product k for highly required patients
$CS2_k$	Hospitals' shortage costs to prepare blood product k for needy patients
h_k	holding costs of keeping blood product k on hospitals
Ca^t	Capacity of BTC or BCPCs on distributing blood products among hospitals on time period t.
$d1_{ik}^{ts}$	highly required patients demand of hospital i for receiving blood product k on time period t under scenario s
$d2_{ik}^{ts}$	needy patients demand of hospital i for receiving blood product k on time period t under scenario s
Cw	Costs of wasting one unit of blood products on hospitals
Ct_i	Costs of transporting each unit of blood products from BTC or BCPCs to hospital i
$\theta_{ij_kk}^t$	Ratio of blood product k with j days life time from BTC or BCPCs center to hospital i on period t, $0\le\theta_{ij_kk}^t\le 1\ \forall\ i, j_k, k, t$ and $\sum_j \theta_{ij_kk}^t=1\ \forall\ i,k,t$
Et_k	Expiration time of blood product k
M	A big number

3-4- Decision variables

x_{ik}^t	Number of units of blood product k determined by BTC or BCPCs to be sent to hospital i on period t
$y_{ij_kk}^t$	Number of units of blood product k with j_k days life time received by hospital i at the beginning of period t
u_{ik}^{ts}	Number of units of blood product k wasted by hospital i at the end of period t under scenario s
$v_{ij_kk}^{ts}$	Inventory volume of i^{th} hospital's blood product k with j_k days life time at the end of period t under scenario s
$r1_{ik}^{ts}$	Number of shortage units of blood product k for highly required patients at hospital i in the end of period t under scenario s
$r2_{ik}^{ts}$	Number of shortage units of blood product k for needy patients at hospital i at the end of period t under scenario s
$l_{ij_kk}^{ts}$	An auxiliary variable associated with life time j in time t that captures the number of blood product k units in life time left to be utilized for the subsequent period if all available blood in this life time is not completely used to meet the demand of present period.

B_{ik}^{ts} Number of Remaining units of blood product k highly required patients at hospital i in the end of period t under scenario s

$z_{ij_k k}^{ts}$ 1 if demand of hospital i for receiving j_k days blood product k at period t under scenario s is completely satisfied , 0 otherwise

3-5- mathematical model

$$\text{Min } Z1=\sum_{k=1}^{K}\sum_{i=1}^{I}\sum_{t=1}^{T} Ct_i\, x_{ik}^{t} + \pi_s\Big(\sum_{i=1}^{I}\sum_{j_k=3}^{Et_k}\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{k=1}^{K} h_k.v_{ij_k k}^{ts} + \sum_{i=1}^{I}\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{k=1}^{K} Cw\, u_{ik}^{ts} + \sum_{i=1}^{I}\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{k=1}^{K} CS1_k r1_{ik}^{ts} + + \sum_{i=1}^{I}\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{k=1}^{K} CS2_k r2_{ik}^{ts}\Big) \tag{1}$$

$$\text{Min } Z2=\underset{i,k,t,s}{\text{Max}}\,(d1_{ik}^{ts} + d2_{ik}^{ts}\text{-}x_{ik}^{t}) \tag{2}$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K} x_{ik}^{t} \le Ca^{t} \qquad \forall t \tag{3}$$

$$y_{ij_k k}^{t}=0 \qquad \forall j_k=1,2,\ldots,Et_k, \forall\ i,k,t \tag{4}$$

$$y_{ij_k k}^{t}= x_{ik}^{t}\theta_{ij_k k}^{t} \qquad \forall j_k=3,4,\ldots,Et_k, \forall\ i,k,t \tag{5}$$

$$z_{ij_k k}^{ts} \ge z_{i(j_k\text{-}1)k}^{ts} \qquad \forall j_k=3,4,\ldots,Et_k, \forall\ i,k,t,s \tag{6}$$

$$v_{ij_k k}^{ts}=0 \qquad \forall j_k=1,2,\ldots,Et_k, \forall\ i,k,t,s \tag{7}$$

$$z_{i2k}^{ts}=0 \qquad \forall\ i,t,k,s \tag{8}$$

$$u_{ik}^{ts}=v_{ij_k k}^{ts} \qquad \forall j_k=Et_k, \forall\ i,k,t,s \tag{9}$$

$$d1_{ik}^{ts}+B_{ik}^{ts}=\sum_{j_k=3}^{Et_k}((v_{i(j_k\text{-}1)k}^{(t\text{-}1)s}+y_{ij_k k}^{t})(z_{ij_k k}^{ts})\text{-}l_{ij_k k}^{ts})+r1_{ik}^{ts} \qquad \forall\ i,k,t,s \tag{10}$$

$$d2_{ik}^{ts}=B_{ik}^{ts}+r2_{ik}^{ts} \qquad \forall\ i,k,t,s \tag{11}$$

$$(z_{ij_k k}^{ts}\text{-}z_{i(j_k\text{-}1)k}^{ts})\left((v_{i(j_k\text{-}1)k}^{(t\text{-}1)s}+y_{ij_k k}^{t}\right) \ge l_{ij_k k}^{ts} \qquad \forall j_k=3,4,\ldots,Et_k, \forall\ i,k,t,s \tag{12}$$

$$d1_{ik}^{ts}+d2_{ik}^{ts}\text{-}\sum_{j_k=3}^{Et_k}((v_{i(j_k\text{-}1)k}^{(t\text{-}1)s}+y_{ij_k k}^{t})\le r1_{ik}^{ts}+r2_{ik}^{ts} \qquad \forall\ i,k,t,s \tag{13}$$

$$v_{ij_k k}^{ts}=(1\text{-}z_{ij_k k}^{ts})\left((v_{i(j_k\text{-}1)k}^{(t\text{-}1)s}+y_{ij_k k}^{t}\right)+(z_{ij_k k}^{ts}\text{-}z_{i(j_k\text{-}1)k}^{ts})l_{ij_k k}^{ts} \qquad \forall j_k=3,4,\ldots,Et_k, \forall\ i,k,t,s \tag{14}$$

$$x_{ik}^{t}, y_{ij_k k}^{t}, u_{ik}^{ts}, v_{ij_k k}^{ts}, r1_{ik}^{ts}, r2_{ik}^{ts}, l_{ij_k k}^{ts} \ge 0 \text{ , Integer} \qquad \forall j_k, i,k,t,s \tag{15}$$

$$z_{ij_k k}^{ts}=0,1 \qquad \forall j_k, i,k,t,s \tag{16}$$

Objective function (1) is mainly designed to minimize total costs of transporting blood products between BTC or BCPCs and hospitals, holding costs of blood products, wasting costs of out dated products and shortage costs. The second objective function (2) seeks to minimize the maximum unsatisfied demand of different products among hospital demands throughout the planning horizon to make a reasonable and fair balance between hospital demands. (3) Ensures that all the bloods supplied by BTC or BCPC to various hospitals on each period should not be greater than their total holding capacity. Constraint (4) guaranties that blood products are not delivered to hospital on the first two days of their life time. In fact, specialized tests and experiments are performed on blood products at the first two days their life to ensure their healthiness. Constraint (5) is mainly imposed to the model to assign products to different age groups at each hospital and on each period. Constraint (6) enforces the model to perform FIFO policy of delivering products to patients in hospitals on each period. Constraint (7) ensures that all the hospitals are committed to refuse deliverance of one and two days products. Constraint (8) implies that BTC or BCPC is committed to refuse satisfaction of hospitals demand for receiving products with two days life time. Constraint (9) implies that hospitals are committed to dispose out dated products. Constraint (10) Firstly, hospitals satisfy highly required patient demands. Constraint (11) implies that remaining blood products are used for needy patients. Constraint (12) shows that the amount of blood products transported to the next period at each hospital should not be greater than inventory volume of the products' pertinent age group. Constraint (13) guaranties that shortage volume of the products consumed by both needy and highly required patients at each hospital should be greater or equal to the gap between hospitals' demand and inventory level. Constraint (14) calculates inventory level of the products with known life time on each time period. Finally, integer and binary variables used in proposed model are respectively shown in constraints (15) and (16).

3-6- linearization scheme

Linearization schemes are used in this paper to linearize the model's nonlinear terms. It can be inferred that second objective along with constraints (10), (12) and (14) are nonlinear. So, following procedures are used in this section to linearize their nonlinear components.

3-6-1- Step 1.Second objective's linearization scheme

Due to the min-max structure of the second objective function, a positive variable φ is defined to facilitate the linearization of the concerned objective function. Accordingly, the model can be rewritten as follows:

$$\text{Min } Z3=\varphi \qquad (17)$$

$$\varphi \geq d1_{ik}^{ts} + d2_{ik}^{ts} - x_{ik}^{t} \qquad \forall i,k,t,s \qquad (18)$$

$$\varphi \geq 0 \qquad (19)$$

3-6-2- Step2. Constraints linear equivalent

The technique employed by (Gunpinar and Centeno, 2015) is used in this section to linearize constraints (10), (12) and (14). So, constraints (A-1)-(A-19) should be imposed to the model to linearize the model's nonlinear constraints. The details of this formulation are given in Appendix A.

3-6-3- Step3. Constraints linear equivalent

Finally, following constraints can be replaced with constraints (10), (11) and (14).

$$d1_{ik}^{ts}+B_{ik}^{ts}=\sum_{j_k=3}^{J}(\alpha_{ij_kk}^{ts}+\beta_{ij_kk}^{ts}-l_{ij_kk}^{ts})+r1_{ik}^{ts} \qquad \forall i,t,s \qquad (20)$$

$$\alpha_{ij_kk}^{ts}+\beta_{ij_kk}^{ts}-\rho_{i(j_k-1)k}^{ts}-\sigma_{ij_kk}^{ts}\geq l_{ij_kk}^{ts} \qquad \forall j_k=3,4,\ldots,Et_k,\forall\, i,k,t,s \qquad (21)$$

$$v_{ij_kk}^{ts}=v_{i(j_k-1)k}^{(t-1)s}+y_{ij_kk}^{t}-\alpha_{ij_kk}^{ts}-\beta_{ij_kk}^{ts}+\gamma_{ij_kk}^{ts}-\delta_{ij_kk}^{ts} \qquad \forall j_k=3,4,\ldots,Et_k,\forall\, i,k,t,s \qquad (22)$$

3-7- Converting model to a single objective one

A MCGP approach is used in this section to convert proposed model into a single objective one. The main purpose of this technique is to minimize positive deviations of the model's objectives. Single objective version of linearized model is presented as follow:

$$\text{Min } Z_4= W_1(d_1^+)+\alpha_1(e_1^+)+W_2(d_2^+)+\alpha_2(e_2^+) \qquad (23)$$

$$Z_1-d_1^+=yy_1 \qquad (24)$$

$Z_3\text{-}d_2^+=yy_2$ (25)
$yy_1\text{-}e_1^+=b_{1.min}$ (26)
$yy_2\text{-}e_2^+=b_{2.min}$ (27)
$b_{1.min}\le yy_1\le b_{1.max}$ (28)
$b_{2.min}\le yy_2\le b_{2.max}$ (29)
Constraints (3) to (9),(11),(13),(15),(16),(18),(19),(20) to (22), (A-1)-(A-19)
$d_1^+,d_2^+,e_1^+, e_2^+\ge 0$ (30)

4- Computational results

We design a set of test experiments to (1) validate the performance of the proposed model, (2) investigate various coefficients in MCGP technique. Two data sets are generated with different sizes as shown in Table 2. A mathematical software is used for problem modeling and optimization.

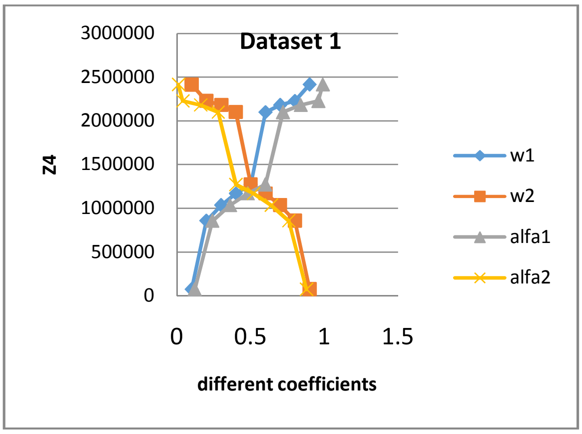
Table 2. Details of the three datasets used in all experiments

	$\|I\|$	$\|K\|$	$\|J\|=\|Et_k\|$	$\|T\|$	$\|S\|$
Dataset 1	6	1	$Et_1=30$	1	1
Dataset 2	12	2	$Et_1=30, Et_2=5$	2	2

For the three datasets, Table 3 presents the numerical results gained using the exact solution method at different coefficients $(w_1, w_2, \alpha_1, \alpha_2)$. Model runtime is given in the other column. GAMS software was able to provide feasible solutions for datasets 1 and 2. These results show that importance of first objective function is higher. Also Figure 3 shows that we must distinguish to first objective function.

Table 3. The numerical results for all datasets

	w_1	w_2	α_1	α_2	Z_4	Runtime(second)
Dataset 1	0.1	0.9	0.1	0.9	113594.8	27.196417
	0.2	0.8	0.2	0.8	139219	27.65239
	0.3	0.7	0.3	0.7	148702	27.597413
	0.4	0.6	0.4	0.6	936726	27.063464
	0.5	0.5	0.5	0.5	1135936	27.663422
	0.6	0.4	0.6	0.4	1384445	27.694553
	0.7	0.3	0.7	0.3	2085581	27.431653
	0.8	0.2	0.8	0.2	2139253	27.042407
	0.9	0.1	0.9	0.1	2158277	27.381087
Dataset 2	0.1	0.9	0.1	0.9	73025.22	53.9795
	0.2	0.8	0.2	0.8	857806.3	53.32165
	0.3	0.7	0.3	0.7	1035022	53.50884
	0.4	0.6	0.4	0.6	1169840	53.72639
	0.5	0.5	0.5	0.5	1271166	53.48809
	0.6	0.4	0.6	0.4	2098770	53.96574
	0.7	0.3	0.7	0.3	2180605	53.68156
	0.8	0.2	0.8	0.2	2227418	53.98347
	0.9	0.1	0.9	0.1	2415215	53.92959



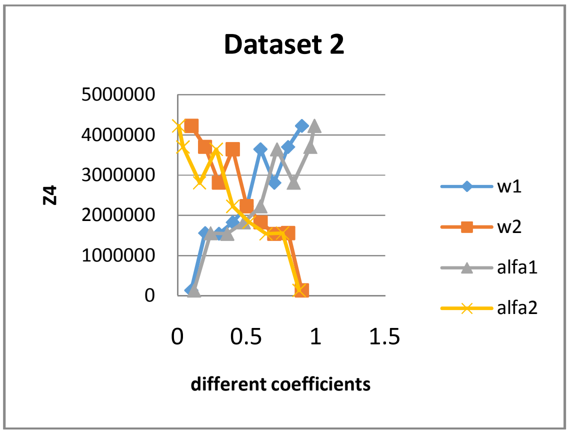


Figure 3. Computational results with various coefficients

5- Case study

5-1- Total position of BSCN

The only BTC of Eastern Azerbaijan province (EAP) is located in Tabriz. The main responsibility of this center is to perform all the activities of collecting blood and its products among different hospitals. In addition, two BCPCs located in Mianeh and Maragheh cities of this province can collect blood and distribute its products among different hospitals. Number of clinical centers and hospitals covered by EAP's BTC and BCPCs is shown in Table 4.

Table 4. Position of blood supply chain network

Tabriz's BTC	35
Mianeh's BCPC	3
Maragheh's BCPC	6
Sum of centers located in EAP	44

The real demand and supply values of hospitals and EAP's BTC and BCPCs is shown in Table 5 to prove the fact that hospitals' demand for blood products is more than their real need. Therefore, there should be balance hospital demands.

Table 5. Distribution centers of EAP

Distribution center	Demand values	Supply values
Tabriz's BTC	203650	172912
Mianeh's BCPC	15464	15510
Maragheh's BCPC	17929	17570
Sum of centers located in EAP	237043	205992

5-2- data collection and implementation

Tabriz's BTC is able to cover demands of 35 various hospitals and clinical centers. Note BCPCs located in Mianeh and Maragheh are not investigated.

Hospitals are mainly interested in receiving packed red blood cells, platelet concentration, Cryoprecipitate, whole blood, Washed Red Blood cells and Fresh Frozen Plasma (Maramazi Ghaflez et al., 2014). The model and real data investigated in this paper is restricted to pack cells (PCs), Fresh Frozen Plasma (FFP) and platelets (PLTs). Although the real life time of these products accompanies with

type of its injected holder material, we assume that these products life time equals to 30, 300, 5 days respectively. Demand values of hospitals and clinical centers for this product for the years 1393 and 1392 under various assumptions are mentioned in appendix 1. Shortage costs for each unit of this products for needy and highly required patients is respectively equal to 800 and 2000 million Rials (Zhou et al., 2011).In addition, waste cost for each unit of this product is assumed to be equal to 0.6 million Rials (Haijema et al., 2007).
A mathematical software is used in this paper to solve the model presented in previous section under real data of Tabriz's BSCN and find the model's global optimal solutions. The result of solving proposed model under various scenarios in presented as follow:

- Optimal values of objective function based on different values of coefficients of the MCGP model's objective function under various scenarios are presented in Table 6. The results shows that selecting lower coefficients for the first objective will meaningfully decrease total costs of MCGP formulation.

Table 6. Objective function's optimal values under different scenarios and coefficients

Scenarios	[illegible]	[illegible]	[illegible]	[illegible]	**Objective function**	**Time solution (second)**
	0.05	**0.95**	**0.05**	**0.95**	**662636.3**	**160.79**
s1	**0.5**	**0.5**	**0.5**	**0.5**	**6626291**	**141.03**
	0.95	**0.05**	**0.95**	**0.05**	**12589950**	**154.33**
	0.05	**0.95**	**0.05**	**0.95**	**643024.9**	**335.67**
s2	**0.5**	**0.5**	**0.5**	**0.5**	**6430191**	**342.55**
	0.95	**0.05**	**0.95**	**0.05**	**12217360**	**440.3**
	0.05	**0.95**	**0.05**	**0.95**	**672253.3**	**1024.58**
s3	**0.5**	**0.5**	**0.5**	**0.5**	**6722443**	**832.42**
	0.95	**0.05**	**0.95**	**0.05**	**12772630**	**890.14**

The result of solving proposed model on GAMS software showed that optimal value of slack variable equals to zero. It shows that hospitals were able to satisfy patient's need for receiving blood products. So, shortage costs imposed to hospitals on different periods equals to zero. For example, optimal values of the blood products delivered hospital 9, 25 (x_{9k}^{t}, x_{25k}^{t}) on different periods under the third scenario are shown in Table 7.

Table 7. Amount of blood products delivered to hospital 9, 25

	Hospital 9			Hospital 25		
period	PCs	FFP	PLTs	PCs	FFP	PLTs
1	211	82	98	24	9	11
2	212	83	99	25	10	12
3	141	55	66	16	6	7
4	282	110	131	32	12	15
5	352	137	164	40	15	19
6	351	136	163	40	16	19
7	280	109	131	32	12	15
8	281	109	131	35	13	16
9	276	107	128	30	12	14
10	211	82	98	23	9	11
11	215	84	100	24	9	11
12	141	55	66	16	6	7
13	219	85	102	25	10	12
14	222	86	103	28	11	13
15	146	57	68	17	6	8
16	292	114	136	33	13	15
17	367	143	171	43	17	20
18	365	142	170	41	16	19

5-3- Sensitivity analysis shortage costs

We now complete a sensitivity analysis to examine whether adjustments in wastage and shortage costs can be used as a strategy to improve BSCN and service level in EAP. Figure 4 illustrates changes in BSCN over a range of shortage costs of highly requested patient. A general observation is that increased CS1 in cost function results in supply chain cost constantly.

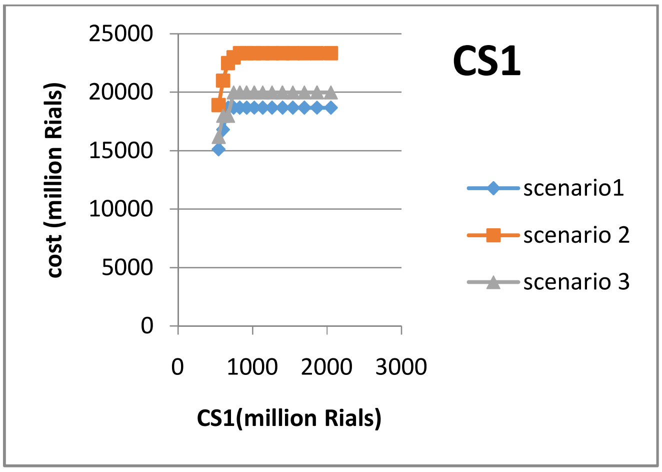


Figure 4. Sensitivity analysis for shortage costs of highly requested patient

Figure 5 shows changes in BSCN over a range of shortage costs of needy patient. A general analysis is that increased CS2 in cost function results in supply chain cost constantly.

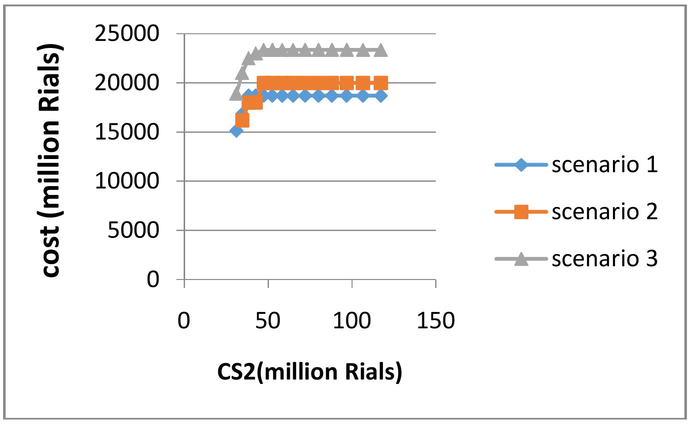


Figure5 . Sensitivity analysis for shortage costs of needy patient

6- Computational results and future suggestions

A novel mathematical model was presented in this paper for BSCN of EAP. The main purpose of developing bi-objective mixed integer nonlinear formulation was to 1) minimize total costs including transportation costs, holding costs, shortage costs and waste costs and 2) minimize total gap between hospitals' declared demand and supplying volume of blood transfusion center. Some linearization techniques presented in literature was employed to linearize the model's nonlinear terms and reduce its complexity. In addition, MCGP approach was used in this paper to convert the model into a single objective formulation. In addition, BSCN of Eastern Azerbaijan province with one blood transfusion center and 35 various hospitals was used as a real case study to evaluate accuracy and performance of proposed model. The model's real benchmark problems were implemented on a mathematical software to obtain optimal solutions of benchmark problems and analyze effects of objective's coefficient's values on quality of the solutions obtained by the software. All the results of solving benchmark problems on the software can be summarized as follows:

- Hospitals' holding, transportation and waste costs compared to their shortage costs are very low. So, their declared demand is always higher than their real needs.
- Blood transfusion center knows that hospitals and clinical centers are not able to pay high monies for preparing blood products. So, he attempts to manage his supply volume and sell blood products based on his real inventory capabilities.

Following suggestions can be considered for extending this paper is as follow:

- The model presented in this paper was tested on a supply chain network with one product type. So, the model can be implemented and tested on a benchmark problems or supply chain networks with a multiple blood products.
- Patients' needs for consuming fresh blood can be considered in future works.

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Appendix A:

$v^{(t-1)s}_{i(j_k-1)k} z^{ts}_{ij_kk} = \alpha^{ts}_{ij_kk}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$

$\alpha^{ts}_{ij_kk} \le z^{ts}_{ij_kk}.M$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-1)

$\alpha^{ts}_{ij_kk} \le v^{(t-1)s}_{i(j_k-1)k}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-2)

$\alpha^{ts}_{ij_kk} \ge M.\left(z^{ts}_{ij_kk}-1\right)+v^{(t-1)s}_{i(j_k-1)k}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-3)

$y^{t}_{ij_kk} z^{ts}_{ij_kk} = \beta^{ts}_{ij_kk}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$

$\beta^{ts}_{ij_kk} \le z^{ts}_{ij_kk}.M$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-4)

$\beta^{ts}_{ij_kk} \le y^{t}_{ij_kk}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-5)

$\beta^{ts}_{ij_kk} \ge M.\left(z^{ts}_{ij_kk}-1\right)+y^{t}_{ij_kk}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-6)

$z^{ts}_{ij_kk} l^{ts}_{ijk} = \gamma^{ts}_{ij_kk}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$

$\gamma^{ts}_{ij_kk} \le z^{ts}_{ij_kk}.M$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-7)

$\gamma^{ts}_{ij_kk} \le l^{ts}_{ij_kk}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-8)

$\gamma^{ts}_{ij_kk} \ge M.\left(z^{ts}_{ij_kk}-1\right)+l^{ts}_{ij_kk}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-9)

$z^{ts}_{i(j_k-1)k} l^{ts}_{ij_kk} = \delta^{ts}_{ij_kk}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$

$\delta^{ts}_{ij_kk} \le z^{ts}_{i(j_k-1)k}.M$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-10)

$\delta^{ts}_{ij_kk} \le l^{ts}_{ij_kk}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-11)

$\delta^{ts}_{ij_kk} \ge M.\left(z^{ts}_{i(j_k-1)k}-1\right)+l^{ts}_{ij_kk}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-12)

$z^{ts}_{i(j_k-1)k} y^{t}_{ij_kk} = \sigma^{ts}_{ij_kk}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$

$\sigma^{ts}_{ij_kk} \le z^{ts}_{i(j_k-1)k}.M$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-13)

$\sigma^{ts}_{ij_kk} \le y^{t}_{ij_kk}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-14)

$\sigma^{ts}_{ij_kk} \ge M.\left(z^{ts}_{i(j_k-1)k}-1\right)+y^{t}_{ij_kk}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-15)

$z^{ts}_{i(j_k-1)k} v^{(t-1)s}_{i(j_k-1)k} = \rho^{ts}_{i(j_k-1)k}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$

$\rho^{ts}_{i(j_k-1)k} \le z^{ts}_{i(j_k-1)k}.M$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-16)

$\rho^{ts}_{i(j_k-1)k} \le v^{(t-1)s}_{i(j_k-1)k}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-17)

$\rho^{ts}_{i(j_k-1)k} \ge M.\left(z^{ts}_{i(j_k-1)k}-1\right)+v^{(t-1)s}_{i(j_k-1)k}$ $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-18)

$\rho^{ts}_{i(j_k-1)k}, \sigma^{ts}_{ij_kk}, \gamma^{ts}_{ij_kk}, \beta^{ts}_{ij_kk}, \alpha^{ts}_{ij_kk} \ge 0$, Integer $\forall i,k,t,s, j_k=3,4,\ldots,Et_k$ (A-19)