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A sustainable blood supply chain model considering disruption using multi-objective fuzzy programming

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ABSTRACT

This study considers a blood logistics problem in natural and man-made disaster condition. For this purpose, a multi-objective mathematical model is proposed in order to minimize total cost, environmental impacts and optimize the social impacts. Because of in the disaster condition some facilities may be damaged, these predefined capacities may not be available. For more similarity to the real world, in this research disruptions in capacity of facilities are considered. Then, the multi-objective model solves as single-objective model applying LP-metric method. Finally, uncertainty analysis is done on imprecise parameters of the third objective function of the proposed model and the results are reported.

Keywords: blood supply chain, disaster, multi-objective, sustainable, LP-metric

1. INTRODUCTION

Supply chain network design (SCND) has a significant impact on supply chains performance. It communicates with many aspects of the network, affecting networks qualitative and quantitative performance such as numbers, locations and capacities of facilities as well as information and material flow allocations. Because of significant costs and the required time, the network configuration cannot be changed in short terms. In the supply chain management, the supply chain network design has effect on tactical and operational decisions (Devika et al.,2014; Fu and Fu, 2015; Amin et al., 2017) [1]. The companies forced to consider the impacts of sustainable supply chain (SSC) design on the environment and society because of increasing concerns to meet environmental, social, and legislative requirements (Govindan et al., 2014) [2]. Human blood is a vital and rare resource and currently there is nothing that can be replaced with it, because the blood is extracted only from the human body. Furthermore, among all blood units that donated, only a small amount is useable. There is a required time interval between everyone blood donation and the next turn that the body can regenerates lost blood in this time.

De et al. [3] presented a sustainable ship routing problem under uncertainty with environmental impacts caused by carbon emissions and fuel consumption. For maintaining a sustainable ship routing they restricted environmental impacts by defining some limitations and upper limits for the total fuel cost, fuel consumption, and carbon emission level. Gunpinar and Centeno [4] considered routing aspect in their research. They presented an integer programming model that determines the optimal routings for bloodmobiles. This model has two objectives that determines the number of bloodmobiles and minimize the total distance traveled by vehicles simultaneously.

Dillon et al. [5] proposed a two-stage stochastic programming model to optimize the periodic review course for managing red blood cells inventory while dealing with perishability and demand uncertainty. The model aims at minimizing the operational costs, blood shortage as well as wastage costs. Jabbarzadeh et al. [6] determining the optimal way of blood distribution to hospitals by minimizing the average delivery time from local and regional blood centers to demand points (hospitals) under disastrous conditions has been also taken into account as another objective.

Rajendran and Ravindran [7] developed stochastic models under demand uncertainty for a single hospital. Their models aim includes ordering policies to reduce shortage, wastage and purchasing for different cost settings. Puraman et al. [8] designed an inventory model for a hospital network. The authors developed an integer-programming model allowing blood delivered to the hospitals by distributing through a common blood bank. Their models' results showed that outdating and shortage could be reduced under hospital collaboration. The remainder of this paper is organized as follows: in section 2, we define the problem and present a mathematical model. Section 3, gives the experimental results. Finally, in section 4, a discussion and some suggestions for future works are offered.

2. Problem definition

In this study, a multi-objective and multi-period sustainable blood supply chain network during and after disaster is presented. Donor groups, blood collection facilities, distribution centers, and hospitals as the demand points are the components in this network and the flow among the network elements, shown in Figure (1). The first part includes donor activities, where blood units are collected from various groups of donors in permanent or temporary blood facilities. The operationalized fixed blood facilities and blood centers are selected among available potential locations. After the registration process, all donors who come to blood facilities are checked through a screening process to avoid transmitting diseases caused by blood transfusion. Then, collected blood units are tested to prevent a variety of blood diseases. Each blood center according hospitals demand send required blood to them. Each vehicle only can start from a blood center, navigates a specified route to serve designated hospitals, and returns to the same blood center.

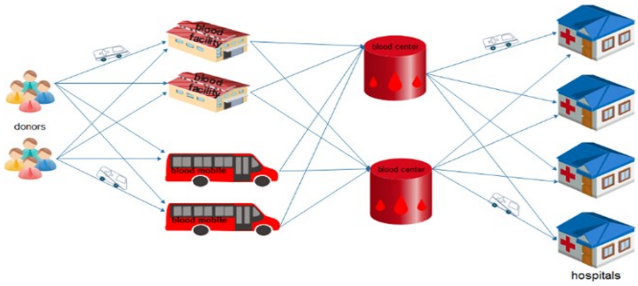

Figure 1. blood supply chain network

2.2. Sets

L Set of blood donors areas, $l \in L$

I Set of candidate sites to establish blood collecting facilities, $i, i_1 \in I$

J Set of candidate sites to establish blood centers, $j, j_1 \in J$

K Set of hospitals sites as demand points, $k, k_1 \in K$

V Set of vehicles, $v \in V$

C Set of blood centers' capacity, $c \in C$

R Set of blood age, $r \in R$

T Set of different planning periods, $t \in T$

F Merged set of hospitals and candidate distribution blood centers; i.e., $K \cup J$ and $f, f_1 \in F$

A Set of age group of blood, $a \in A$

S set of disruption scenario, $s \in S$

P set of products type, $p \in P$

2.3. Parameters

VC_V	Capacity of vehicle v.	MCT	Maximum capacity of each temporary blood facility.
CV_v	Set up cost of vehicle v.	MCH	Maximum capacity of each hospital.

FCa_{ij}	Fixed cost of transportation from blood facility i to blood center j.	MC_{ii_1t}	Transferring cost of each temporary blood facility from location i_1 to location i in planning period t.
FCa'_{ff_1}	Fixed cost of transportation from location f to location f_1.	FB_{jc}	Cost of establishing a blood center at candidate location j with size c.
TC_{il}	Transportation cost of donors from location l to I.	FP_i	Cost of establishing a permanent blood facility at candidate location i.
OC_{jt}	Operating cost of one-unit blood at blood center j in planning period t.	π_{jt}	Shortage cost of each blood unit at blood center j at planning period t.
CC_{it}	Operational cost of collecting each blood unit at location i in planning period t.	π'_{kt}	Shortage cost of each blood unit at hospital k at planning period t.
OCH_{kt}	Operating cost of one-unit blood at hospital k at planning period t.	HB_{jt}	Holding cost of blood unit at blood center j at planning period t.
MSC_c	Maximum storage capacity in each blood center with size c.	HH_{kt}	Holding cost of each unit blood at hospital k at planning period t.
MCF	Maximum capacity of each fixed blood facility.	U_l	maximum blood supply of allowed donor group l.
π_t^0	Penalty cost due to using 'old' blood for patients with 'young' blood demand in planning period t.	ρ	Penalty cost due to environmental effect of waste blood.
π_t^1	Penalty cost due to using 'young' blood for patients with 'any' blood demand in planning period t.	γ	Rate of lost blood in the production process.
EF_i	Environmental impacts of establishing permanent blood facility at location i.	η_1	Rate of lost blood in inspection after receipt blood by blood centers.
EB_{jc}	Environmental impacts of establishing blood center j with size c.	η_2	Rate of lost blood in inspection after receipt blood by hospitals.
ET_{ij}	Environmental impact of shipping each collected blood from location i to location j.	ω	Estimated percentage of blood related to five years old blood in inventory.
ET'_{ff_1}	Environmental impact of shipping each collected blood from location f to location f_1.	α^s_{jpt}	Percentage of decrease in capacity of blood center j for product p in period t under scenario s.
JO_{jc}	Total number of job opportunities available when a distribution center is opened at location j with size c.	β^s_{ipt}	Percentage of decrease in capacity of permanent blood facility i for product p in period t under scenario s.
JO'_i	Total number of job opportunities available when a permanent blood facility is opened at location i.	$\phi^s_{i_1pt}$	Percentage of decrease in capacity of temporary blood facility i_1 for product p in period t under scenario s.
D'_{0kt}	'Young' blood demand of hospital k in planning period t.	B	Total number of hospitals.
D'_{1kt}	'Any' blood demand of hospital k in planning period t.	M	A very large number.
DC	Unit disposal and transporting cost of waste blood.		

2.4. Decision variables

x_{ijt}	Amount of blood traveling from blood facility i to blood center j in planning period t.	HP_t	Total amount of waste blood in planning period t.
y_{rkvt}	Amount of blood age r traveling to hospital k by vehicle v in planning period t.	W_i	A binary variable, which is equal to 1 if a permanent facility is opened at site i; 0, otherwise.
b_{rjt}	Number of blood age r shortage at blood center j at the end of planning period t.	O_{jc}	A binary variable, which is equal to 1 if a blood center with size c is opened at site j; 0, otherwise.
bb'_{akt}	Number of blood group a shortage at hospital k at the end of planning period t.	G_{ii_1t}	A binary variable, which is equal to 1 if a temporary facility is located at location i_1 in period $t-1$, and moves to location i in planning period t; 0 otherwise.
b'_{akt}	A binary variable, which is equal to 1 if blood facility at location i is assigned to blood center j in planning period t; otherwise 0.	VH_{vt}	A binary variable, which is equal to 1 if a vehicle v is used in planning period t; 0, otherwise.
E_{ilt}	A binary variable, which is equal to 1 if blood facility at location i is assigned to donor group l in planning period t; otherwise 0.	R_{ff_1vt}	If f precedes f_1 in the route of vehicle v in planning period t.
I'_{akt}	Blood group a inventory level at hospital k at the end of planning period t.	V_{jkt}	A binary variable, which is equal to 1 if hospital at location k is assigned to blood center j in planning period t; 0, otherwise.

I_{rjt} The r days old blood inventory level at blood center j at the end of planning period t.

HP_t Total amount of waste blood in planning period t.

W_i A binary variable, which is equal to 1 if a permanent facility is opened at site i; 0, otherwise.

M_{kvt} Auxiliary variable defined for hospital k for sub-tour elimination in route of vehicle v in planning period t.

2.5. Model formulation

$$MinZ_1 = \sum_{j}^{J}\sum_{c}^{C} EB_{jc} O_{jc} + \sum_{i}^{I} EFW_i + \sum_{i}^{I}\sum_{j}^{J}\sum_{t}^{T} ET_{ij} M_{ijt} + \sum_{f}^{F}\sum_{f_1}^{F}\sum_{v}^{V}\sum_{t}^{T} ET'_{ff_1} R_{ff_1vt} + \sum_{t}^{T} \rho HP_t \quad (1)$$

$$MaxZ_2 = \sum_{j}^{J}\sum_{c}^{C} JO_{jc} \times O_{jc} + \sum_{i}^{I} JO'_i \times W_i \quad (2)$$

$$MinZ_3 = \sum_{i}^{I}\sum_{j}^{J}\sum_{t}^{T} M_{ijt} FCa_{ij} + \sum_{f}^{F}\sum_{f_1}^{F}\sum_{v}^{V}\sum_{t}^{T} R_{ff_1vt} FCa'_{ff_1} + \sum_{i}^{I}\sum_{i_1}^{I}\sum_{t}^{T} Mc_{ii_1} G_{ii_1t} + \sum_{i}^{I}\sum_{l}^{L}\sum_{t}^{T} TC_{il} E_{ilt} + \sum_{r}^{R}\sum_{j}^{J}\sum_{t}^{T} HB_{jt} I_{rjt} +$$
$$\sum_{a}^{A}\sum_{k}^{K}\sum_{t}^{T} HH_{kt} I'_{akt} + \sum_{r}^{R}\sum_{j}^{J}\sum_{t}^{T} \pi_j b_{rjt} + \sum_{a}^{A}\sum_{k}^{K}\sum_{t}^{T} \pi'_k b'_{akt} + \sum_{k}^{K}\sum_{t}^{T} \pi_i^0 \delta_{kt}^0 + \sum_{k}^{K}\sum_{t}^{T} \pi_i^1 \delta_{kt}^1 + \sum_{c}^{C}\sum_{j}^{J} FB_{jc} O_{jc} + \sum_{i}^{I} FP_i \omega_i \quad (3)$$
$$+\sum_{i}^{I}\sum_{j}^{J}\sum_{t}^{T} OC_{jt} X_{ijt} + \sum_{r}^{R}\sum_{k}^{K}\sum_{v}^{V}\sum_{t}^{T} OCH_{kt} y_{rkvt} + \sum_{i}^{I}\sum_{j}^{J}\sum_{t}^{T} CC_{it} x_{ijt} \left(\frac{1}{1-\gamma}\right) + \sum_{t}^{T} DCHP_t + \sum_{v}^{V}\sum_{t}^{T} VH_{vt} CV_v$$

St:

$$\sum_{r\geq 2} I_{rjt} \leq \sum_{c} (1-\alpha'_{jpt}) MSC_c O_{jc} \qquad t=2,3,\dots,T,\ \forall j \quad (4)$$

$$I'_{1kt} + I'_{0kt} \leq MCH \qquad t=3,\dots,T,\ \forall k \quad (5)$$

$$\sum_{j} [illegible] \qquad t=2,3,\dots,T,\ \forall i \quad (6)$$
$$+\sum_{i_1}^{I} (1-\phi'_{i_1pt}) G_{ii_1t} MCT$$

$$b'_{0kt} \times I'_{0kt} = 0 \qquad t=3,\dots,T,\ \forall k \quad (25)$$

$$X_{ijt} \leq M \times M_{ijt} \qquad t=2,3,\dots,T,\ \forall i,j \quad (7)$$

$$b'_{1kt} \times I'_{1kt} = 0 \qquad t=3,\dots,T,\ \forall k \quad (26)$$

$$W_i + \sum_{i_1} G_{ii_1t} \leq 1 \qquad t=3,\dots,T,\ \forall i \quad (8)$$

$$I'_{0kt-1} + (1-\eta_2)\sum_{v}\sum_{r\geq 4} y_{rkvt} - \delta_{0kt} - D'_{kt} \geq 0 \qquad t=3,\dots,T,\ \forall k \quad (27)$$

$$\sum_{i_1} G_{ii_1t} \leq \sum_{i_1} G_{ii_1t-1} \qquad t=3,\dots,T,\ \forall i \quad (9)$$

$$[illegible] \sum_{k} [illegible] \sum_{i}\sum_{j} [illegible] \frac{[illegible]}{1-\gamma} [illegible] \qquad \forall k,t \quad (28)$$
$$+\sum_{i}^{I}\sum_{j}^{J} \eta_1 x_{ijt} + \sum_{j}^{J} I_{5jt}$$

$$\sum_{c} O_{jc} \leq 1 \qquad \forall j \quad (10)$$

$$I_{rjt} = I_{(r-1)j(t-1)} - \sum_{k}\sum_{v} V_{jkt} y_{rkvt} + b_{rjt} \qquad t=3,\dots,T,\ r=3,\dots,R,\ \forall j \quad (29)$$

$$\sum_{k}\sum_{a} D'_{kat} V_{jkt} \leq \sum_{c} (1-\alpha'_{jpt}) MSC_c O_{jc} \qquad t=3,\dots,T,\ \forall j,k \quad (11)$$

$$I_{2jt} = \sum_{i} (1-\eta_1) x_{ij(t-1)} \qquad t=2,\dots,T,\ \forall j \quad (30)$$

$$\sum_{j} V_{jkt} \leq 1 \qquad t=3,\dots,T,\ \forall k \quad (12)$$

$$I_{rjt} \times b_{rjt} = 0 \qquad t=2,\dots,T,\ \forall j \quad (31)$$

$$\sum_{j} M_{ijt} \leq W_i + \sum_{i_1} G_{ii_1t} \qquad \forall i,t \quad (13)$$

$$\sum_{v}\sum_{j} R_{jkvt} \leq \sum_{j} V_{jkt} \qquad t=3,\dots,T,\ \forall k \quad (32)$$

$$M_{ijt} \leq \sum_{c} O_{jc} \qquad t=2,\dots,T,\ \forall i,j \quad (14)$$

$$\sum_{v}\sum_{k} R_{jkvt} \leq \sum_{k} V_{jkt} \qquad t=3,\dots,T,\ \forall j \quad (33)$$

$$\sum_{i} E_{ilt} \leq 1 \qquad \forall l,t \quad (15)$$

$$\sum_{j}\sum_{k}\sum_{a} D'_{kat} R_{jkvt} \leq VC_v \qquad t=3,\dots,T,\ \forall v \quad (34)$$

$$E_{ilt} \leq W_i + \sum_{i_1} G_{ii_1t} \qquad \forall i,l,t \quad (16)$$

$$M_{kvt} - M_{k_1vt} + B\sum_{k}\sum_{k_1} R_{kk_1vt} \leq B-1 \qquad t=3,\dots,T,\ \forall k,v \quad (35)$$

$$\sum_{j} \frac{x_{ijt}}{(1-\gamma)} \leq \sum_{l} U_l E_{ilt} \qquad \forall i,t \quad (17)$$

$$M_{kvt} \leq B \qquad t=3,\dots,T,\ \forall k,v \quad (36)$$

$$\sum_{r\geq 3} y_{rkvt} \leq VC_v \sum_{j} R_{jkvt} \qquad t=3,\dots,T,\ \forall k,v \quad (18)$$

$$\sum_{f_1} R_{ff_1vt} = \sum_{f_1} R_{f_1fvt} \qquad t=3,\dots,T,\ \forall k,v \quad (37)$$

$$\sum_{k}\sum_{v} y_{4kvt} = 0 \qquad t=1,2,3 \quad (19)$$

$$\sum_{j}\sum_{k} R_{jkvt} = VH_{vt} \qquad t=3,\dots,T,\ \forall v \quad (38)$$

$$\sum_k \sum_v y_{5kvt} = 0 \quad t = 1,2,3,4 \quad (20)$$

$$I_{0kt} = (1-\eta_2)\sum_v y_{3kvt} + \delta_{0kt} - \delta_{1kt} - D'_{k0t} + b'_{0kt} \quad t = 3,\dots,T,\ \forall k \quad (21)$$

$$\delta_{0kt} = 0 \quad t = 3,\ \forall k \quad (22)$$

$$(1-\eta_2)\sum_v y_{3kvt} - \delta_{1kt} - D'_{k0t} \geq 0 \quad t = 3,\dots,T,\ \forall k \quad (23)$$

$$I_{1kt} = I_{0kt-1} + (1-\eta_2)\sum_{r\geq 4} y_{rkvt} + \delta_{1kt} - \delta_{0kt} - D'_{k1t} + b'_{1kt} \quad t = 3,\dots,T,\ \forall k \quad (24)$$

$$\sum_l R_{lkvt} + \sum_l R_{jlvt} - V_{jkt} \leq 1 \quad t = 2,\dots,T,\ \forall j,k,v \quad (39)$$

$$R_{jjvt} = R_{jj_1vt} = 0 \quad \forall j, j_1, v, t, t \quad (40)$$

$$x_{ijt}, y_{rkvt}, b'_{0kt}, b'_{1kt}, I'_{0kt}, I'_{1kt}, I_{rjt}, b_{rjt} \in Z^+ \quad \forall i, j, r, k, v, t \quad (41)$$

$$V_{jkt}, VH_{vt}, M_{ijt}, W_i, O_{jc}, G_{ii_1t}, R_{jj_1vt} \in \{0,1\} \quad \forall i, i_1, j, k, v, t, t, t_1, c \quad (42)$$

$$M_{kvt}, HP_i \geq 0 \quad \forall k, v, t \quad (43)$$

Equation (1) shows the first objective function that minimizes the total environmental impacts caused by establishing blood centers and permanent blood facilities in each potential location, shipping the collected blood units from blood facilities to blood centers and blood centers to hospitals in the routing path and the penalty cost resulted from disposal of wasted blood units. Expression (2) is the second objective function that maximizes the total social impacts. Social impacts including fixed jobs (positions such as managers independent of the capacity of the blood facilities), and variable jobs. Variable jobs are those jobs that totally rely on the capacity of the facility. For instance, a blood facility with greater size needs more workers or staffs than the smaller facility. Equation (3) is the third objective function that minimizes the total variable and fixed costs in the network. Total costs including transportation costs, blood holding costs in blood banks, blood shortage cost, dismatching cost, fixed cost of establishing the blood centers and blood facilities, blood operating or production costs, costs of removal or disposal process of wasted blood and vehicle set up costs.

Constraint set (4) shows that the inventory level of a blood center must be appropriate for its capacity with disruption in capacity. Constraint (5) impose that the inventory level of a hospital must be appropriate for its capacity. Constraint (6) limits the amount of blood that sent to the blood centers at each blood facility with disruption in their capacity. Constraint (7) requires that if a blood facility is not allocated to any blood center, any blood is sent from this blood facility to that blood center. Constraint (8) enforces in each location at most one blood facility can be located. Constraint (9) shows that only if one facility is located in one place, the temporary blood facilities can move from that place. Constraint (10) guarantees that only one blood center with one size can be established in each location j. constraint (11) enforces the risk in capacity limitation with assigning each hospital to a single established blood center. Constraint (12) enforces that each hospital at most can be assigned one blood center. Constraint (13) ensures that if a blood facility is located in location i, each blood facility can be assigned to one blood center. Constraint (14) requires that if a blood center is closed, no blood facility is assigned to it. Constraint (15) ensures that each donor group can be assigned to at most one blood facility. Constraint (16) enforces that blood donors can be allocated to established blood facilities. Constraint (17) limits the maximum blood that comes out from each blood facility that can be maximum permissible blood supply of the allocated donor group l. constraint (18) shows that the blood delivered to each hospital depends on vehicle type allocated to its relevant tour. Constraints (19) and (20) consider the required time to prepare blood for delivering to each hospital. Constraint (21) imposes inventory balance of 'young' blood at each hospital. Constraint (22) shows there is no 'old' blood for dismatching blood. Constraint (23) illustrates that if patients' Kind 2 use young blood, it does not lead to a shortage of ''young'' bloods' inventory. Constraint (24) imposes inventory balance of 'old' blood at each hospital. Constraints (25) and (26) show that at most one variable can be positive. Constraint (27) illustrates that if patients' Kind 1 use old blood, it does not lead to a shortage of ''old'' bloods' inventory. Constraint (28) calculates the total non-usable blood or lost blood throughout the

supply chain. Constraints (29) and (30) are related to end-period blood inventory levels at blood centers.
Constraint (31) ensures that at most one variable can be positive. Constraint (32) and (33) show that each hospital and blood center can be visited at most once. Constraint (34) requires that the capacity of each vehicle should be respected. Constraint (35) is sub-tour elimination and guarantees that each customer is visited once in each period, and they cannot return. Constraint (36) shows the maximum value of Auxiliary variable M_{kvt}. Constraint (37) imposes the flow conservation on each hospital in each time period and guarantees that a vehicle returns to its distribution center of origin. Constraint (38) shows that each vehicle leaves, at the most, one blood center. Constraint (39) imposes that blood center j serves hospital k, if there is one vehicle v leaving j and arriving at k, and also V_{jkt} can be equal to 1 even if no vehicle travels from j to k. Constraint (40) ensures that there is no connection between blood centers, and there is no connection between each blood center or hospital by itself. Constraints (41) to (43) define the domains of the decisions variables.

2.6. LP-metric method

Since MILP model is a multi-objective, mixed integer Linear programming model whose objective functions are completely inconsistent, we used the LP-metrics method which is one of the famous Multi-Criteria Decision Making methods for solving multi-objective problems with conflicting objectives simultaneously. According to this method, a multi-objective problem is solved by considering each objective function separately and then a single objective is reformulated which aims to minimize the summation of normalized differences between each objective and the optimal values of them. In our proposed model, just you can assume that three objective functions are named as Z_1, Z_2, Z_3. Based on LP-metrics method, MILP should be solved for each one of these three objectives separately Assume that the optimal values for these three problems are Z_1^*, Z_2^*, Z_3^*. Now the LP-metrics objective functions can be formulated as follows:

$$MinZ = W_1\left[\frac{Z_1 - Z_1^*}{Z_1^*}\right] + W_2\left[\frac{Z_2 - Z_2^*}{Z_2^*}\right] + W_3\left[\frac{Z_3 - Z_3^*}{Z_3^*}\right] \quad (44)$$

3. Numerical examples

The results of solving problem in different sizes are given in Table 1. This table includes 5 test problem that solved by using LP-metric method and applying Lingo software. The first column denotes the number of test problem. second column shows size of problem. F, S and T denote the first, second and third objective function values, respectively. The sixth column shows the value of LP-metric function and the last column shows computational times of solving model. The CPU times illustrated in Figure 2. and Figure 3. shows the value of LP-metric function. As can be seen in Figure 2. and Figure 3. the CPU time and LP-metric function value of solving the model increased with increasing in size of the problem.

Table 1. results of experiments

T.P	|l|×|i|×|j|×|k|×|v|×|c|×|r|×|t|×|f|×|a|×|s|×|p|	F	S	T	LP-metric function	C.P.U Time(s)
1	|1|×|1|×|1|×|1|×|1|×|2|×|2|×|2|×|2|×|1|×|2|×|1|	1640	250	35567800	0.08	1.5
2	|2|×|1|×|1|×|2|×|2|×|3|×|2|×|3|×|3|×|2|×|3|×|2|	1780	278	46723500	0.25	7.8
3	|2|×|2|×|2|×|3|×|3|×|3|×|4|×|4|×|4|×|3|×|3|×|2|	1890	305	56100043	0.29	15.3
4	|3|×|3|×|2|×|4|×|3|×|4|×|4|×|4|×|5|×|4|×|5|×|3|	2100	347	65098120	0.3	22.6
5	|4|×|4|×|3|×|5|×|4|×|5|×|5|×|6|×|6|×|5|×|6|×|4|	2530	412	78325000	0.4	25

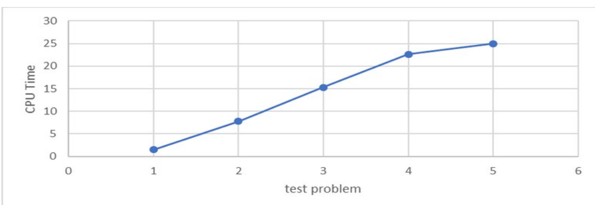

Figure 2. CPU Time of the problem

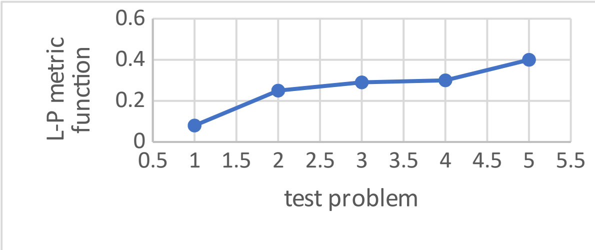

Figure 3. LP-metric function of the problem

4. Uncertainty Analysis on cost

As can be seen in table 2. first column shows the number of test problem. Second and third columns show deterministic value and fuzzy value of third objective of the model, respectively. In this problem the price of uncertainty is obtained by difference between fuzzy and deterministic value. Uncertainty price (UP) that shown in last column. Figure 4. shows fuzzy and deterministic value and red boxes in this figure shows the difference between them (UP).

Table 2. uncertainty price

T.P	Deterministic	Fuzzy	UP
1	35000256	35567800	567544
2	42011100	46723500	4712400
3	49023477	56100043	7076566
4	58934560	65098120	6163560
5	70006521	78325000	8318479

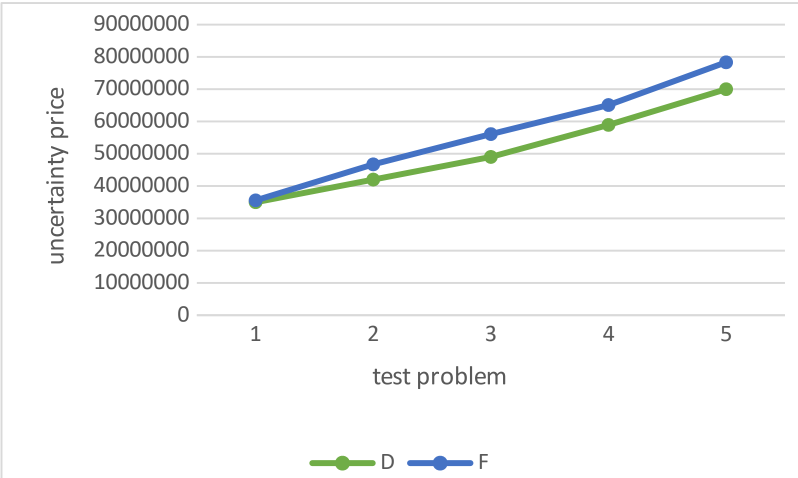

Figure 4. uncertainty price (UP)

5. Sensitivity Analysis

In this section the sensitivity of the third objective function on capacity of blood center and demand are examined. In table 3. the values of third objective function in five different modes for capacity of blood center (Base case, -20%, -10%, +10% and +20%) are obtained and the sensitivity analysis results are illustrated. As can be seen in table 3. with increasing the capacity of blood center the value of third objective function decreased.

Table 3. sensitivity analysis on capacity parameter

Capacity of blood center	Third objective function value
-20%	65000000
-10%	60000000
base case	55000000
+10%	50000000

+20%	45000000

Table 4. sensitivity analysis on demand parameter

Demand	Third objective function value
-20%	25000000
-10%	30000000
base case	35000000
+10%	40000000
+20%	45000000

In table 4. the values of third objective function in five different modes for blood demand (Based case, 20%, -10%, +10% and +20%) are examined and the sensitivity analysis results are illustrated. According to table 4. with increasing the quantity of demand the value of third objective function increased.

9. Conclusions

In this study, we have provided a mixed-integer programming formulation to design and optimize the supply chain network design (SCND) related to the blood products with three objective functions. We have developed a model under uncertainty because of existence of some inexact input parameters in the supply chain network. In this regard, a fuzzy programming method has been utilized. In addition, L-P metric method is developed for solving problem. In this paper, we have presented a model that human relief activities integrated with sustainable operations are considered in this model. In this study, it is aimed to draw international community and local actors' attention to the point that even under uncertain situations, sustainable operations should not be omitted. One future research direction is prioritizing patients based on their needs for blood. In addition, it is possible to consider the total time traveled in the network as one of the objective functions, and minimize the number of delays regarding the delivery date.

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