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Blood products supply chain design considering disaster circumstances (Case study: earthquake disaster in Tehran)

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Abstract

Maintaining the health of people during and after a disaster is one of the most important issues in disaster management. 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. In this paper a comprehensive mathematical model of blood products supply chain is presented to respond the need for blood products in disaster situations. The proposed model is a bi objective mixed integer programming model and with respect to the unstable conditions during the disaster, uncertain parameters are modelled by fuzzy numbers. An interactive possibilistic programming approach is applied to handle the uncertainty. The developed model is implemented for the earthquake disaster case study in mega city of Tehran using blood transfusion network data. The results show the ability of the proposed model in generating effective solutions under earthquake conditions.

Keywords*:* Blood products supply chain, earthquake disaster, fuzzy mathematical programming, network design, multi-objective optimization.

1- Introduction

Since the beginning of creation, mankind have faced natural disasters which results in many fatal injuries and deaths, such that each year 200 million people experience natural disasters and hundreds of them died. Disaster-prone countries, suffer losses averaging 3% of their GDP per year (Green et al., 2003). Every day, many people around the world need blood and blood products, so that for every three people, one needs blood transfusion and blood products throughout life (IBTO). A huge challenge for governments' health systems all over the world is providing health and adequate blood during disaster. There is always a need for blood donors and blood products, while somewhat irregular supply by donors and the demand for blood products is often random. Matching the supply and demand in an efficient way is not easy. Due to the perishable nature of blood products, which makes it more complex, the shortage of blood products inflict many expenses to the community which could lead to increasing the rate of mortality (Beliën and Forcé, 2012).

Therefore, an important issue needing to be addressed is the design of a useful and efficient supply chain with real-world conditions to provide blood products in disaster conditions.

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Disaster in blood transfusion services indicates a situation in which the supply chain capability in receiving and supplying blood is lost temporarily or completely or a situation that causes sudden and more than usual demand for blood products in hospitals which causes problems in the blood collection system (AABB, 2008). One of the most important issues in blood supply chain is the required blood supply for hospitals that plays a key role in meeting the demand of hospitals in disaster conditions. As mentioned in the literature, in disaster conditions this becomes more sensitive. The need to make quick decisions and operations introduces disaster management. It should be noted that disaster management is not just a tactical response when disaster happens, but also it can be considered as preventive activities in the processes related to disaster prevention and preparedness through response to the disaster and improvement of the disaster situations (Mostafa et al., 2004).

Research on the supply chain management of perishable products particularly blood products first began by Van Zyl (1964). Nahmias (1982) in addition to focusing on blood products considered perishable inventory issues and conducted a brief review on the proposed issues in the blood bank management. Many researchers have used integer optimization models to design a blood supply chain. Jacobs et al. (1996) studied the relocation of blood donation centres in Norfak of Virginia using integer programming models and presented the conclusions of the scheduling method of blood products collection and distribution activities. Daskin et al. (2002) and Shen et al. (2003) presented non-linear integer programming models for a single period location-inventory problem of blood supply for hospitals. Pierskalla (2004) proposed a comprehensive review and examined a lot of problems in the areas of blood supply chain management.

Şahin et al. (2007) provided a mathematical model for regionalization of blood services on the part of the Turkish Red Crescent population using integer programming models to solve location-allocations problem for decision-making. Cetin and Sarul (2009) presented a multi-objective model for location of blood banks among hospitals or medical centres and they tried to minimize the total fixed costs and travel distances between blood banks and hospitals. Hemmelmayr et al. (2010) studied decision making in selecting hospitals which must be covered by blood transportation vehicles from blood donation canters every day considering uncertainty in blood demand of hospitals, determined required blood of each hospital. Ghandforoush and Sen (2010) presented a non-linear programming model to minimize the production costs of blood platelets for a regional blood transfusion centre. Also Nagurney et al. (2012), provided a blood supply chain model that includes collection centres, laboratory facilities, storage facilities and distribution canters. Beliën and Forcé (2012) presented a review of the blood supply chain and its products and considered issues such as inventory management, inventory allocation, schedule table, etc. Sha and Huang (2012) presented a multi-period location-allocation model to schedule blood supply after an earthquake in Beijing considering minimization costs such as transportation, inventory and penalty costs during a given time horizon. Jabbarzadeh et al. (2014) also considered a supply chain which included blood collection sites, blood canters and donors considering the uncertainty of the type of robust optimization and goal of minimization cost, decided about location and allocation of inventory during the disaster. Zendehdel et al. (2014) developed a mathematical model which is able to determine the optimum location for blood donation canters to deal with disaster while minimizing the total cost. Gunpinar and Centeno (2014) proposed a blood supply chain planning model for red blood cells and platelets. They considered supply chain includes donors, blood canters, mobile units, hospitals and patients. The objectives of this model are minimization of total cost, shortage and wastage levels of blood products at hospital. Arvan et al. (2015) presented a blood supply chain planning model with multiple products. Two objectives including the minimization of the total cost and the maximum time of blood transfusion are taken into account.

According to the previous researches, there is no comprehensive model which accommodates the entire blood products supply chain consisting of donor regions, permanent and temporary blood donation canters, blood banks, hospitals and blood recipient regions and three common blood products such as red blood cells, plasma and platelets in earthquake situations.

The aim of this paper is a comprehensive and integrated model for the supply chain of blood products at times of the occurrence of earthquake disaster which includes location of temporary blood donation canters, the amounts of donated blood in each region to permanent and temporary blood donation canters and the amounts of transported blood between different levels, the amount of blood products inventory in hospitals and blood banks and lost demand in recipient regions of blood products considering the disruption in permanent and temporary blood donation canters and hospitals. The objectives of the proposed model include minimization of various costs of blood products supply chain and maximization of coverage of blood donor regions by the temporary blood donation centres.

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

1. Presenting a bi-objective programming model of blood products supply chain considering the structure of the supply chain completely including blood donor regions, permanent and temporary blood donation canters, blood banks, hospitals and blood applicant regions.

2. To consider the problem in the real world condition, real data of blood transfusion network in Tehran and Japanese International Cooperation Agency (JICA, 2000) that have been used in relation to the Tehran earthquake.

3. This paper also considered earthquake disaster, which due to the existence of several faults in Tehran, different scenarios for the activation of each fault are considered. As well as how the time of the earthquake effects on the number of blood products applicant people is also considered.

4. Due to the uncertainty in the blood supply chain and as well as in disaster condition, the credibility-based fuzzy chance constrained programming is used.

The rest of this paper is organized as follows: The concerned problem is described in Section 2. The comprehensive model for the blood products supply chain in the earthquake disaster conditions is presented in Section 3. In Section 4, a case study on the earthquake disaster in Tehran and at the end in the fifth and sixth sections, the solution and conclusion are provided respectively.

2- Problem Description

The blood supply chain network begins with the donors who are from different regions donating blood at the most close permanent or temporary blood donation centres. Then due to the perishable nature of the blood, the donated blood is transferred immediately to blood banks and different processes are done in these banks such as blood purification and filtration and extraction of blood products including red cells, platelets and plasma. The blood products are then stored in blood banks and according to the needs of different regions, the requested amount of blood products are transferred from blood banks to corresponding hospitals. At the end of this chain, applicants of any blood product in each region receive the amount of needed blood products by referring to the hospitals. The supply chain of this problem is shown in Fig 1.

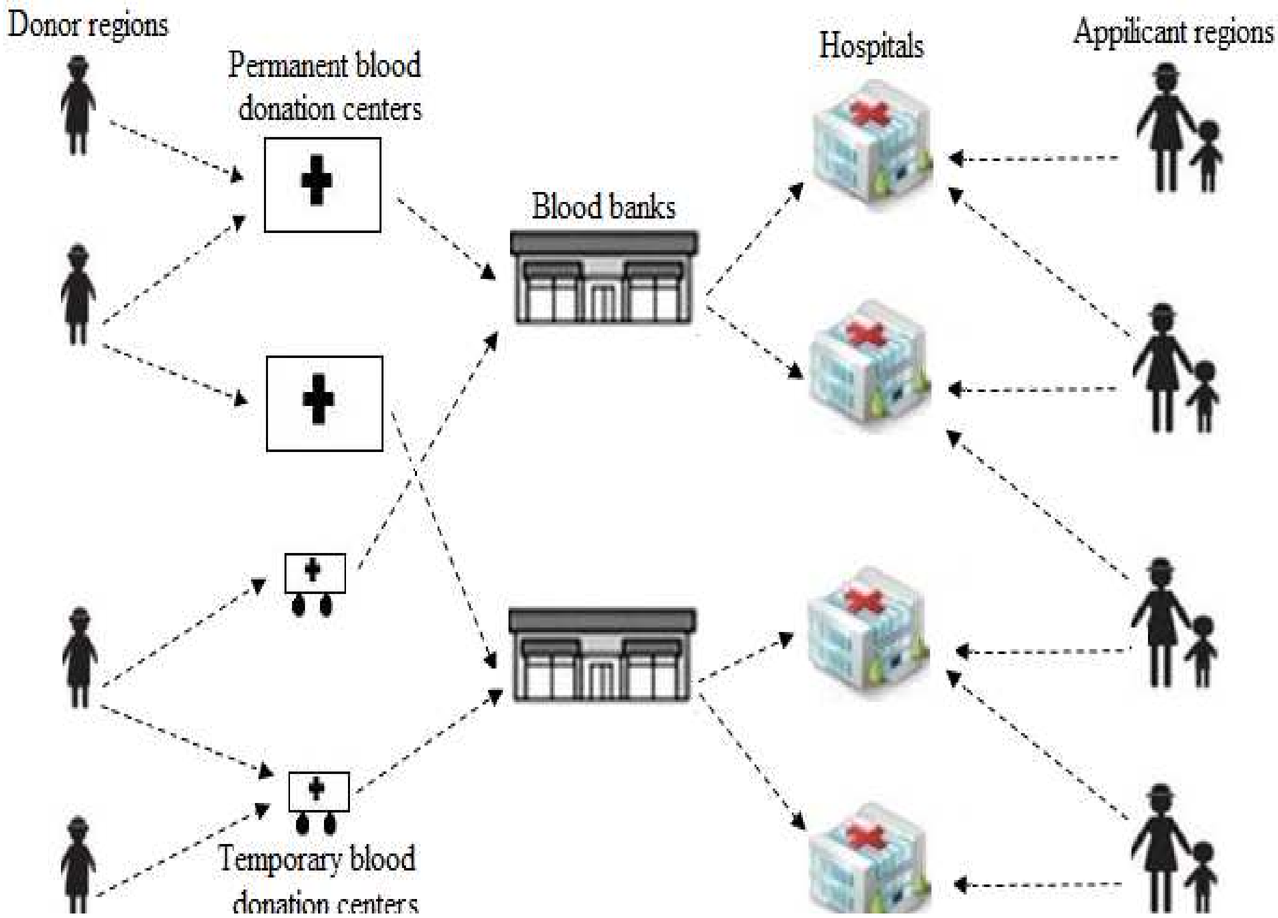

Figure 1. Blood products supply chain

2-1- Assumptions

Assumptions of the model are as follows:

1. Location problem for temporary blood donation centres is considered in short periods (e.g. a few days) operationally.

2. Request of applicants is divisible in each region so that demand can be met in a number of sectors and several hospitals.

3. Since blood in blood banks is refined and converted into its three components red cells, plasma and platelets, the entire chain has been considered as a single product before blood banks and then multi-product.

4. If a hospital is disrupted, the inventory will be lost completely.

5. Due to the perishable nature of blood and transferring it from permanent and temporary blood donation centres to blood banks as soon as possible, inventory holding in blood donation centres were not considered.

6. In each period, according to the budget, a limited number of temporary centres can be used.

7. Due to real world condition considerations, for storage of blood products at blood banks and hospitals, limited capacity has been considered.

8. Because of the uncertainty in the blood supply chain, according to viewpoints of experts in this field, some of the model parameters have been considered fuzzy.

3- Modelling

In this section, the complete supply chain of blood products for disaster conditions is modelled as multi-period and two-stage and scenario based. In the first stage, location of temporary blood donation centres and in the second stage, blood donation, transportation of blood products between different levels, the amount of received blood products by different regions from hospitals, the amount of holding of blood products in blood banks and hospitals and the amount of lost demand due to occurred destructions in the permanent and temporary blood donation centres and hospitals are determined.

Sets, parameters and variables of the problem are as follows.

Sets

I: Set of blood products indexed by i

J: Set of blood donor regions indexed by j

K: Set of permanent blood donation centres indexed by k

L: Set of temporary blood donation centres indexed by l

M: Set of blood banks indexed by m

N: Set of hospitals indexed by n

O: Set of blood applicant regions indexed by o

S: Set of earthquake disaster scenarios indexed by s

T: Set of time periods indexed by t

Parameters

$\tilde{f}_{lt}$: Activation cost of temporary blood donation centre l in period t

$\tilde{a}_{jk}$: Cost of blood donation by region j to permanent blood donation centre k

$\tilde{b}_{jl}$: Cost of blood donation by region j to temporary blood donation centre l

$\tilde{h}_{im}$: Holding cost of blood products i in blood bank m

$\tilde{g}_{in}$: Holding cost of blood products i in hospital n

$\tilde{c}_{io}$: Cost of lost demand at applicant region o from blood product i in period t

$\tilde{e}_{km}$: Transportation cost of blood from permanent blood donation centre at k to blood bank at m in period t

$\tilde{\rho}_{lm}$: Transportation cost of blood from temporary blood donation centre at l to blood bank at m in period t

$\tilde{r}_{mn}$: Transportation cost of blood product i from blood bank at m to hospital at n in period t

de_{km}: Distance between permanent blood donation centre k and blood bank m

df_{lm}: Distance between temporary blood donation centre l and blood bank m

dg_{mn}: Distance between blood bank m and hospital n

ϑ_{jk}: A binary parameter, equal to 1 if blood donor region j is covered by permanent blood donation centre k; 0, otherwise

ψ_{jl}: A binary parameter, equal to 1 if blood donor region j is covered by temporary blood donation centre l ; 0, otherwise

τ_{no}: A binary parameter, equal to 1 if blood applicant region o is covered by hospital n; 0, otherwise

δ_j^s: Potential population of blood donors in donor region j under scenario s

$\tilde{d}_{iot}^s$: Demand of applicant region o from blood product i in period t under scenario s

$\tilde{\sigma}_k$: Maximum of people who can donate blood at permanent blood donation centre k

$\tilde{\chi}_l$: Maximum of people who can donate blood at temporary blood donation centre l

π_{im} : Capacity of blood product i at blood bank m

$\tilde{\varphi}_i$: Capacity of blood product i at each of hospitals

ω^s_{kt} : A binary parameter, equal to 1 If don't happen earthquake at permanent blood donation centre k in period t under scenario s ; 0 , otherwise

ϖ^s_{lt} : A binary parameter, equal to 1 If don't happen earthquake at temporary blood donation centre l in period t under scenario s ; 0 , otherwise

β^s_{nt} : A binary parameter, equal to 1 If don't happen earthquake at hospital n in period t under scenario s ; 0 , otherwise

p_s : Probability of scenario s occurrence

Φ : Percentage of healthy and refined blood

P : Maximum number of temporary blood donation centre which can be active

M : A very large number

Decision variables

x^s_{jkt} : Quantity of blood donated from donor region j at permanent blood donation centre k in period t under scenario s

u^s_{jlt} : Quantity of blood donated from donor region j at temporary blood donation centre l in period t under scenario s

v^s_{kmt} : Quantity of blood delivered from permanent blood donation centre k to blood bank m in period t under scenario s

υ^s_{lmt} : Quantity of blood delivered from temporary blood donation centre l to blood bank m in period t under scenario s

γ^s_{imnt} : Quantity of blood product i delivered from blood bank m to hospital n in period t under scenario s

θ^s_{inot} : Quantity of blood product i received by applicant region o from hospital n in period t under scenario s

iv^s_{imt} : Inventory level of blood product i at blood bank m in period t under scenario s

q^s_{int} : Inventory level of blood product i at hospital n in period t under scenario s

ld^s_{iot} Quantity of lost demand at applicant region o from blood product i in period t under scenario s

Γ^s_{jt} : A binary variable, equal to 1 if donor region j is covered by temporary blood donation centre in period t under scenario s ; 0 , otherwise

y_{lt} : A binary variable, equal to 1 if temporary blood donation centre l is active in period t ; 0 , otherwise

3-1- Objective functions and constraints

One of the common methods to cope with objective function in scenario-based stochastic programming is to consider the expected value of the objective function. But one of the important problems of this type of modelling when arises that occurrence probability of one scenario is very low and the problem according to this scenario will provide the answer that there is such a pessimistic view. To remove this inefficiency, various approaches have been proposed, one of these approaches is provided by Aghezzaf et al. (2010). In this approach, moreover considering the pessimistic state that was explained above, as well as, minimizing the worst state or in other words the minimizing of the maximum regret is considered. In order to consider the above cases, each of them is multiplied to a coefficient which shows the importance of each case. In other words, in the objective function (1), if η is greater than λ, risk-taking will be more and realistic state for decision maker is good and if λ is greater than η, risk-taking will be low and pessimistic state for decision maker is good.

With respect to the importance of the first objective function, this approach has been used in this objective function. It should be noted that Z_s is the variable of objective function value for each scenario and Z_s^* is the parameter of objective function value for each scenario.

Given the above interpretations, the considered supply chain of blood products can be formulated as follows:

$$
\begin{aligned}
\mathrm{Min} Z_1 = {} & \eta \cdot \left(\max\left(Z_s - Z_s^*\right)\right) \\
& + \lambda \Bigg(\sum_j \sum_k \sum_t \sum_s p_s \tilde{a}_{jk} x_{jkt}^s + \sum_j \sum_l \sum_t \sum_s p_s \tilde{b}_{jl} u_{jlt}^s + \sum_k \sum_m \sum_t \sum_s p_s \tilde{e}_{km} de_{km} v_{kmt}^s \\
& + \sum_l \sum_m \sum_t \sum_s p_s \tilde{\rho}_{lm} df_{lm} \upsilon_{lmt}^s + \sum_i \sum_m \sum_t \sum_s p_s \tilde{h}_{im} iv_{imt}^s + \sum_i \sum_m \sum_n \sum_t \sum_s p_s \tilde{r}_{mn} dg_{mn} \gamma_{imnt}^s \\
& + \sum_i \sum_n \sum_t \sum_s p_s \tilde{g}_{in} q_{int}^s + \sum_i \sum_o \sum_t \sum_s p_s \tilde{c}_{io} ld_{iot}^s + \sum_l \sum_t \tilde{f}_{lt} y_{lt} \Bigg)
\end{aligned} \tag{1}
$$

$$\mathrm{Max} Z_2 = \sum_j \sum_t \sum_s p_s \delta_j^s \Gamma_{jt}^s \tag{2}$$

$$
\begin{aligned}
Z_s = {} & \sum_j \sum_k \sum_t \tilde{a}_{jk} x_{jkt}^s + \sum_j \sum_l \sum_t \tilde{b}_{jl} u_{jlt}^s + \sum_k \sum_m \sum_t \tilde{e}_{km} de_{km} v_{kmt}^s + \sum_l \sum_m \sum_t \tilde{\rho}_{lm} df_{lm} \upsilon_{lmt}^s \\
& + \sum_i \sum_m \sum_t \tilde{h}_{im} iv_{imt}^s + \sum_i \sum_m \sum_n \sum_t \tilde{r}_{mn} dg_{mn} \gamma_{imnt}^s + \sum_i \sum_n \sum_t \tilde{g}_{in} q_{int}^s + \sum_i \sum_o \sum_t \tilde{c}_{io} ld_{iot}^s \\
& + \sum_l \sum_t \tilde{f}_{lt} y_{lt} \qquad \forall s
\end{aligned} \tag{3}
$$

$$x_{jkt}^s \le M\left(\omega_{kt}^s \cdot \vartheta_{jk}\right) \qquad \forall j,k,t,s \tag{4}$$

$$u_{jlt}^s \le M\left(\varpi_{lt}^s \cdot y_{lt} \cdot \Psi_{jl}\right) \qquad \forall j,l,t,s \tag{5}$$

$$\sum_j x_{jkt}^s \le \tilde{\sigma}_k \qquad \forall k,t,s \tag{6}$$

$$\sum_j u_{jlt}^s \le \tilde{\chi}_l \qquad \forall l,t,s \tag{7}$$

$$\sum_m v_{kmt}^s = \sum_j x_{jkt}^s \qquad \forall k,t,s \tag{8}$$

$$\sum_m \upsilon_{lmt}^s = \sum_j u_{jlt}^s \qquad \forall l,t,s \tag{9}$$

$$\sum_k v_{kmt}^s + \sum_l \upsilon_{lmt}^s \le \sum_i \pi_{im} \qquad \forall m,t,s \tag{10}$$

$$iv_{imt-1}^s + \sum_k v_{kmt}^s + \sum_l \upsilon_{lmt}^s - \Phi \sum_n \gamma_{imnt}^s = iv_{imt}^s \qquad \forall i,m,t,s \tag{11}$$

$$iv_{imt}^s \le \pi_{im} \qquad \forall i,m,t,s \tag{12}$$

$$\sum_m \gamma_{imnt}^s \le \tilde{\varphi}_i \cdot \beta_{nt}^s \qquad \forall i,n,t,s \tag{13}$$

$$q_{int-1}^s + \Phi \sum_m \gamma_{imnt}^s - \sum_o \theta_{inot}^s = q_{int}^s \qquad \forall i,n,t,s \tag{14}$$

$$q_{int}^s \le \tilde{\varphi}_i \cdot \beta_{nt}^s \qquad \forall i,n,t,s \tag{15}$$

$$\theta_{inot}^s \le M\left(\beta_{nt}^s \cdot \tau_{no}\right) \qquad \forall i,n,o,t,s \tag{16}$$

$$\tilde{d}_{iot}^s - \sum_n \theta_{inot}^s = ld_{iot}^s \qquad \forall i,o,t,s \tag{17}$$

$$\sum_l y_{lt} \le P \qquad \forall t \tag{18}$$

$$\Gamma_{jt}^{s} \le \sum_{l} \Psi_{jl} \cdot y_{lt} \cdot \varpi_{lt}^{s} \qquad \forall j, t, s \tag{19}$$

$$x_{jkt}^{s}, u_{jlt}^{s}, v_{kmt}^{s}, \upsilon_{lmt}^{s}, \gamma_{imnt}^{s}, \theta_{inot}^{s}, iv_{imt}^{s}, q_{int}^{s}, ls_{iot}^{s}, Z_{s} \ge 0 \tag{20}$$

$$\Gamma_{jt}^{s}, y_{lt} \in \{0,1\} \tag{21}$$

The objective function (1), as mentioned above is the minimizing sum of the maximum regret or the realistic state (first row) and the expected value of occurrence of scenarios or the pessimistic state (second row to the end). In the second row, the blood donation cost at permanent and temporary centres and the transportation cost of blood from permanent blood donation centres to blood banks according to the distances are observed respectively. In the third row, the transportation cost of blood from temporary blood donation centres to blood banks according to the distances, the holding cost of blood products inventory in blood banks and the transportation cost of blood products from blood banks to hospitals considering the distances are provided respectively. Also, holding cost of blood products inventory in hospitals, the cost of lost demand in applicant regions and the activation cost of temporary blood donation centres in each period are presented respectively in the fourth row. In the objective function (2) maximization of the coverage of blood donor regions by temporary blood donation centres is shown.

Constraint (3) shows the value of the objective function (1) for each scenario, which in this approach is considered as a variable. Constraints (4) and (5) respectively state that blood donor regions can donate blood to a permanent or actived temporary blood donation centre if they exist within the coverage radius of the centre, and that centre is not destroyed by an earthquake. Constraints (6) and (7) respectively show the blood donation capacity of donor regions to permanent and temporary blood donation centres, maximum equal to the reception capacity of blood in these centres. Constraints (8) and (9) represent equality between the input and output of blood flow in permanent and temporary blood donation centres respectively.

Constraint (10) states that the total inflow of blood to each blood bank from permanent and temporary blood donation centres should be less than the sum of blood products capacity in that blood bank. Constraints (11) and (12), respectively, indicating the balance of the inventory in the blood bank and the amount of inventory in each blood products is less than the holding capacity of its product in that blood bank. Constraint (13) also shows that the amount of transferred blood product to each hospital if the hospital is not destructed by the earthquake, must be less than that from the holding capacity of blood products in that hospital. Constraints (14) and (15) demonstrate the balance of the inventory at each hospital and the amount of inventory for each blood product at each hospital is less than the total holding capacity at that hospital if the hospital is not destructed by the earthquake. Constraint (16) also shows that the applicant region of blood products can get these products from a hospital if it exists within the coverage radius of that hospital and that hospital has not been destructed by the earthquake. Constraint (17) also represents the lost demand of applicant regions and constraint (18) indicates the maximum number of temporary blood donation centres that can be activated in each period. Constraint (19) states that the applicant region can be covered by a temporary blood donation centre which is located within the centre's coverage radius and the centre is activated and not destroyed by the earthquake. At the end, the non-negative and binary decision variables are presented in constraints (20) and (21) respectively.

3-2- Linearization and defuzzification of the model

Due to the nonlinearity of the first part of the objective function ($\max\left(Z_s - Z_s^*\right)$), considering the positive variable w, this term can be linearized as Eqn.(22).

$$w \ge Z_S - Z_S^* \qquad \forall s \tag{22}$$

Also in order to convert the uncertain model to the deterministic model, credibility-based fuzzy chance constrained programming is used.

In this paper, linear possibilistic distribution has been used as trapezoidal fuzzy number and the four prominent values of trapezoidal fuzzy numbers have been determined for each of the uncertainty parameters by experts' viewpoints which have been mentioned in the case study section.

If it is assumed that $\tilde{\xi}$ is a fuzzy parameter and r is a real number, then according to the Liu and Liu (2002) we have:

$$E\left[\tilde{\xi}\right]=\int_0^{\infty} Cr\left\{\tilde{\xi}\geq r\right\} dr-\int_{-\infty}^{0} Cr\left\{\tilde{\xi}\leq r\right\} dr \tag{23}$$

Now assume that $\tilde{\xi}$ is a trapezoidal fuzzy parameter with values $\xi^{(1)},\xi^{(2)},\xi^{(3)},\xi^{(4)}$ and according to Eqn.(23) expected value of $\tilde{\xi}$ is shown as $\left(\xi^{(1)}+\xi^{(2)}+\xi^{(3)}+\xi^{(4)}\right)/4$ and its credibility measure will be Eqns.(24) and (25):

$$Cr\left\{\tilde{\xi}\leq r\right\}=\begin{cases} 0 & r\in\left(-\infty,\xi^{(1)}\right] \\ \dfrac{r-\xi^{(1)}}{2\left(\xi^{(2)}-\xi^{(1)}\right)} & r\in\left(\xi^{(1)},\xi^{(2)}\right] \\ \dfrac{1}{2} & r\in\left(\xi^{(2)},\xi^{(3)}\right] \\ \dfrac{r-2\xi^{(3)}+\xi^{(4)}}{2\left(\xi^{(4)}-\xi^{(3)}\right)} & r\in\left(\xi^{(3)},\xi^{(4)}\right] \\ 1 & r\in\left(\xi^{(4)},+\infty\right] \end{cases} \tag{24}$$

$$Cr\left\{\tilde{\xi}\geq r\right\}=\begin{cases} 1 & r\in\left(-\infty,\xi^{(1)}\right] \\ \dfrac{2\xi^{(2)}-\xi^{(1)}-r}{2\left(\xi^{(2)}-\xi^{(1)}\right)} & r\in\left(\xi^{(1)},\xi^{(2)}\right] \\ \dfrac{1}{2} & r\in\left(\xi^{(2)},\xi^{(3)}\right] \\ \dfrac{\xi^{(4)}-r}{2\left(\xi^{(4)}-\xi^{(3)}\right)} & r\in\left(\xi^{(3)},\xi^{(4)}\right] \\ 0 & r\in\left(\xi^{(4)},+\infty\right] \end{cases} \tag{25}$$

Based on Eqns.(24) and (25) if $\alpha \succ 0.5$, according to the Pishvaee et al. (2012) can be shown that:

$$Cr\left\{\tilde{\xi}\leq r\right\}\geq\alpha \Leftrightarrow r\geq(2-2\alpha)\xi^{(3)}+(2\alpha-1)\xi^{(4)} \tag{26}$$

$$Cr\left\{\tilde{\xi}\geq r\right\}\geq\alpha \Leftrightarrow r\leq(2\alpha-1)\xi^{(1)}+(2-2\alpha)\xi^{(2)} \tag{27}$$

Also according to Pishvaee et al. (2014) for the equality constraints we have:

$$Cr\left\{\tilde{\xi}=r\right\}\geq\alpha \Leftrightarrow \xi^{(2)}\leq r\leq\xi^{(3)} \tag{28}$$

Given the above states, fuzzy equations such as objective function (1) and constraints (3), (6), (7), (13), (15) and (17) as deterministic equations such as objective function (29) and constraints (30)-(37) are written respectively. According to the above descriptions it should be noted that equality constraint (17) is converted to the two inequality constraints. Due to the lack of fuzzy parameters, the objective function (2) remains unchanged. Also due to space saving, other deterministic constraints are not provided again.

$$\begin{aligned} Min Z_1 &= \eta \cdot w \\ &+\lambda \left(\sum_{j,k,t,s} p_s \left[\frac{a_{jk}^{(1)} + a_{jk}^{(2)} + a_{jk}^{(3)} + a_{jk}^{(4)}}{4} \right] x_{jkt}^s + \sum_{j,l,t,s} p_s \left[\frac{b_{jl}^{(1)} + b_{jl}^{(2)} + b_{jl}^{(3)} + b_{jl}^{(4)}}{4} \right] u_{jlt}^s \right. \\ &+ \sum_{k,m,t,s} p_s \left[\frac{e_{km}^{(1)} + e_{km}^{(2)} + e_{km}^{(3)} + e_{km}^{(4)}}{4} \right] de_{km} v_{kmt}^s + \sum_{l,m,t,s} p_s \left[\frac{\rho_{lm}^{(1)} + \rho_{lm}^{(2)} + \rho_{lm}^{(3)} + \rho_{lm}^{(4)}}{4} \right] df_{lm} \upsilon_{lmt}^s \\ &+ \sum_{i,m,t,s} p_s \left[\frac{h_{im}^{(1)} + h_{im}^{(2)} + h_{im}^{(3)} + h_{im}^{(4)}}{4} \right] iv_{imt}^s + \sum_{i,m,n,t,s} p_s \left[\frac{r_{mn}^{(1)} + r_{mn}^{(2)} + r_{mn}^{(3)} + r_{mn}^{(4)}}{4} \right] dg_{mn} \gamma_{imnt}^s \\ &+ \sum_{i,n,t,s} p_s \left[\frac{g_{in}^{(1)} + g_{in}^{(2)} + g_{in}^{(3)} + g_{in}^{(4)}}{4} \right] q_{int}^s + \sum_{i,o,t,s} p_s \left[\frac{c_{io}^{(1)} + c_{io}^{(2)} + c_{io}^{(3)} + c_{io}^{(4)}}{4} \right] ld_{iot}^s \\ &\left. + \sum_{l,t} \left[\frac{f_{lt}^{(1)} + f_{lt}^{(2)} + f_{lt}^{(3)} + f_{lt}^{(4)}}{4} \right] y_{lt} \right) \end{aligned} \quad (29)$$

$$\begin{aligned} Z_s \le & \sum_j \sum_k \sum_t a_{jk}^{(3)} x_{jkt}^s + \sum_j \sum_l \sum_t b_{jl}^{(3)} u_{jlt}^s + \sum_k \sum_m \sum_t e_{km}^{(3)} de_{km} v_{kmt}^s + \sum_l \sum_m \sum_t \rho_{lm}^{(3)} df_{lm} \upsilon_{lmt}^s \\ & + \sum_i \sum_m \sum_t h_{im}^{(3)} iv_{imt}^s + \sum_i \sum_m \sum_n \sum_t r_{mn}^{(3)} dg_{mn} \gamma_{imnt}^s + \sum_i \sum_n \sum_t g_{in}^{(3)} q_{int}^s + \sum_i \sum_o \sum_t c_{io}^{(3)} ld_{iot}^s \\ & + \sum_l \sum_t f_{lt}^{(3)} y_{lt} \qquad \forall s \end{aligned} \quad (30)$$

$$\begin{aligned} Z_s \ge & \sum_j \sum_k \sum_t a_{jk}^{(2)} x_{jkt}^s + \sum_j \sum_l \sum_t b_{jl}^{(2)} u_{jlt}^s + \sum_k \sum_m \sum_t e_{km}^{(2)} de_{km} v_{kmt}^s + \sum_l \sum_m \sum_t \rho_{lm}^{(2)} df_{lm} \upsilon_{lmt}^s \\ & + \sum_i \sum_m \sum_t h_{im}^{(2)} iv_{imt}^s + \sum_i \sum_m \sum_n \sum_t r_{mn}^{(2)} dg_{mn} \gamma_{imnt}^s + \sum_i \sum_n \sum_t g_{in}^{(2)} q_{int}^s + \sum_i \sum_o \sum_t c_{io}^{(2)} ld_{iot}^s \\ & + \sum_l \sum_t f_{lt}^{(2)} y_{lt} \qquad \forall s \end{aligned} \quad (31)$$

$$\sum_j x_{jkt}^s \le (2\alpha - 1)\sigma_k^{(1)} + (2 - 2\alpha)\sigma_k^{(2)} \qquad \forall k,t,s \quad (32)$$

$$\sum_j u_{jlt}^s \le (2\alpha - 1)\chi_l^{(1)} + (2 - 2\alpha)\chi_l^{(2)} \qquad \forall l,t,s \quad (33)$$

$$\sum_m \gamma_{imnt}^s \le \left((2\alpha - 1)\varphi_i^{(1)} + (2 - 2\alpha)\varphi_i^{(2)} \right) \cdot \beta_{nt}^s \qquad \forall i,n,t,s \quad (34)$$

$$q_{int}^s \le \left((2\alpha - 1)\varphi_i^{(1)} + (2\alpha - 1)\varphi_i^{(2)} \right) \cdot \beta_{nt}^s \qquad \forall i,n,t,s \quad (35)$$

$$d_{iot}^{(2)s} \le \sum \theta_{inot}^s + ld_{iot}^s \qquad \forall i,o,t,s \quad (36)$$

$$\sum \theta_{inot}^s + ld_{iot}^s \le d_{iot}^{(3)s} \qquad \forall i,o,t,s \quad (37)$$

Objective function (2) and other constraints (4), (5), (8)-(12), (14), (16), (18)-(12)

4- Case Study

According to the UN report in 2005, Iran is among the countries in the world that ranks top in the number of earthquakes with an intensity greater than 5.5 on the Richter scale and one of the highest ranking in the field of earthquake vulnerability and the number of dead people as a result of this disaster (Pelling et al., 2004). The Iranian capital, as the most populous city in the country, with a population of about 8,154,051 people, according to Census of 2011 is vulnerable. Because of the large number of faults and historical records of faults' activity, it can be said that in the near future, Tehran will face massive earthquakes. Among the faults of Tehran, three faults such as Mosha fault, North-Tehran fault and Ray fault are very prominent (JICA, 2000).

According to studies of the JICA (2000) on the earthquake in Tehran, the intensity of the earthquake induced activation of Mosha and North-Tehran faults will be roughly 7.2 on the Richter scale and the Rey fault will be roughly 6.7 on the Richter scale and due to these intensities, on average in case of activation of Mosha, North-Tehran and Ray faults the destruction degree of buildings in Tehran will be 12.9 %, 35.7% and 55.2% respectively (JICA, 2000). To validate this case study and also for accurate planning in Tehran, the JICA (2000) is used, which is the agreement in 2000 between Japan International Cooperation Agency and the government of Iran, a group of Japanese researchers came to Tehran and conducted a series of tests on Tehran and provided a comprehensive report entitled seismic micro-zoning of the Greater Tehran, this serves as our authority and is very authentic and citable. Tehran has 22 regions and if an earthquake occurs in the night, the human casualties increase, but the number of destructed buildings at night or during day will be the same (JICA, 2000).

Because the JICA report is for 2000, planning according to the results of this report is associated with relatively large error. According to the many researcher's opinions, such as Zangiabadi and Tabrizi (2006), Motamedi et al. (2012), and Mohamadi et al. (2015) since, the number of structures in Tehran have improved today, but like many of the old ones were not built with international standards and thus, making their vulnerability to destruction during earthquakes very high. Therefore, the content of the JICA (2000) is stringent little and needs to be updated with present realities; the extension of the results of this authentic study to the present has been used according to the census of 2011. Based on the domain experts' viewpoints considering the parameter of the number of injured people and demand of some of these injured people from blood products in the form of fuzzy, these data have been considered close to the present greatly. In the following items, about the number of injured people and blood applicants, further discussion will be presented.

In this case study, assumptions are as follows:

1. Due to the existence of 22 regions in Tehran, all regions have been considered as blood donors and applicants in which the amounts of donation and reception of blood are different based on existence of different scenarios or in other words, activation of any fault.

2. According to the existing statistics of Tehran Blood Transfusion Organization, There are 13 permanent blood donation centers and 7 potential locations to establish temporary ones in the city of Tehran. It should be noted that at these temporary and permanent centers, the occurrence possibility of an earthquake and thus, the destruction of centers have been considered (IBTO).

3. Also there is only one blood bank in Tehran, i.e., the Vesal centre, in addition to, blood donation, filtering and refining and holding of blood are performed perfectly in this centre. If a high magnitude earthquake occurs and destroys the centre, Tehran will face a serious blood crisis. There exist also the option of retrofitting this centre against the earthquake and according to the domain experts' viewpoints, the possibility of the centre's destruction by an earthquake has not been considered.

4. Moreover, the activities of the three faults of Mosha, North-Tehran and Ray are considered as the first, second and third scenarios respectively.

5. Each permanent and temporary blood donation centres and hospitals in each region can cover their respective regions and around regions which has common border with them.

6. According to the high rate of damage and causalities of the earthquake if it occurs at night and just in time aid to the affected region is not possible, then the highest rate of causality is experienced and otherwise this rate will be less. The same can be applied for earthquakes during the day time, though the rate of casualties will be lower than that of the night time, but also depends on the just in time aiding and without aiding which in the state of without aiding the number of causalities will be more than the state of aiding. Therefore, the number of injured people will be a trapezoidal fuzzy number. In the JICA (2000) the number of casualties is given and according to Nateghi (2001) the number of injured people is triple the number of victims. Therefore, according to the above mentioned facts and the number of non-injured people, the number of applicants of blood products based on the specific type of fault activation will be discussed in the item No. 13.

7. In this paper, three types of blood products namely red blood cells, platelets and plasma are considered. The whole blood is the main product that is received from donors and the different constituent components of blood have been separated. Patients who suffer from chronic anemia for example those diagnosed with renal failure and cancer enjoy the highest result of red blood cells. Platelets are prescribed for patients with platelet deficiency or dysfunction and plasma is typically used when there is one or more coagulation factor deficiency or a blood replacement is required (IBTO).

Due to different holding temperatures for these three products, there are different refrigerators for storage of blood products. Holding capacity of these products in Vesal blood bank is deterministic and is given in table 1. Also, due to different holding capacities for these products at different hospitals in the city of Tehran, this capacity according to the domain experts' viewpoints, has been considered as fuzzy numbers and shown in the table 2.

Table 1. Capacity of blood products in Tehran blood bank (π_{im})

Type of blood products	Capacity	Type of blood products	Capacity	Type of blood products	Capacity
Red blood cell $(i = 1)$	32000	Platelet $(i = 2)$	750	Plasma $(i = 3)$	38000

Table 2. Capacity of blood products in Tehran hospitals ($\tilde{\varphi}_{in}$)

Type of blood products	Capacity
Red blood cell $(i = 1)$	(1000,1250,1500,1750)
Platelet $(i = 2)$	(250,500,750,1000)
Plasma $(i = 3)$	(750,1000,1250,1500)

8. Also in normal conditions, a minimum of 2.2% of Iranians donate blood and according to the past statistics at time of earthquake more people donate blood. The average number of potential donors is obtained by subtracting the average number of injured people from the total population in each region for each scenario and multiplying it by 2.2% for three scenarios.

9. The Permanent blood donation centers and the potential locations of temporary blood donation centers and blood bank are shown on the map of the Tehran city in Fig 2.

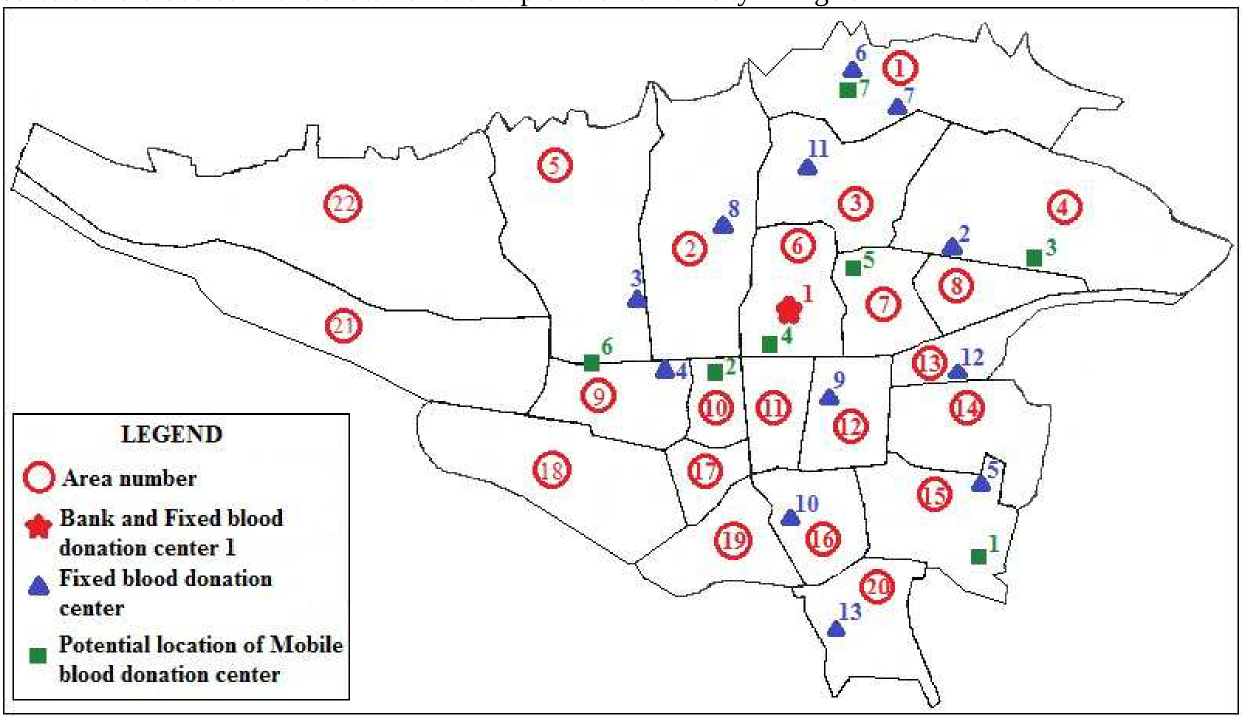

Figure 2. Tehran Map containing the blood bank, permanent blood donation centers and the potential locations of temporary blood donation centers

10. Due to lack of accurate information about costs, uncertainty has been considered as fuzzy and by using opinions of experts in each field close to the real world. About activation cost of temporary blood donation centres ($\tilde{f}_{lt}$) regarding the fact that most places such as mosques, organizations, universities have been established previously as make shift temporary blood donation centers disaster, the cost here relates to transportation of beds and blood donation equipment to these centers and deploying them there. As well as, in the cost of blood donation in permanent and temporary centers, also considered in

this cost something such as give the cake and juice to blood donors for per unit of blood donation. About the lost demand cost, if the need of the applicant for blood product is not met, this will result maiming or even death, average cost has been considered for each unit of blood products. About transportation cost according to these costs in objective function multiply to distances among different levels of the chain and thus, the cost of fuel and vehicle depreciation have been considered for each meter per blood or blood product unit. It should be noted that the unit of cost is Tomans. The fuzzy values of existent costs in the blood supply chain are given in the table 3.

Table 3. The fuzzy values of existent costs in the blood supply chain

Cost	First fuzzy number	Second fuzzy number	Third fuzzy number	Fourth fuzzy number	Cost	First fuzzy number	Second fuzzy number	Third fuzzy number	Fourth fuzzy number
$\tilde{f}_{lt}$	30000	35000	40000	45000	$\tilde{c}_{iot}$	10000000	15000000	20000000	25000000
$\tilde{a}_{jk}$	1500	2000	2500	3000	$\tilde{e}_{kmt}$	0.08	0.085	0.09	0.095
$\tilde{b}_{jl}$	1500	2000	2500	3000	$\tilde{\rho}_{lmt}$	0.08	0.085	0.09	0.095
$\tilde{h}_{im}$	200	250	300	350	$\tilde{r}_{imnt}$	0.08	0.085	0.09	0.095
$\tilde{g}_{int}$	200	250	300	350					

11. According to JICA (2000) in time of earthquake, narrow alleys have high probability of being blocked and on the other hand, the possibility of blockages on the highways and main streets due to the existence of several exits on these ways is very low. To calculate the distances with respect to the use of an ambulance vehicle or similar vehicle, the shortest distance in the main routes (highways and main streets) is considered and the Tehran navigation system (2015) is used for this purpose.

12. There exist 144 hospitals which require blood products for surgery, thalassemia patients, etc. Also according to the map of Tehran Faults in Fig 3 and according to the domain experts' viewpoints, it is assumed that if the hospital or permanent or temporary blood donation centre exists on the relevant fault and active fault, this facility will be completely destroyed. Thus, according to JICA (2000) in case of activation of the Mosha fault, the hospitals and permanent and temporary blood donation centers in regions 4 and 12 and in case of activation of the North-Tehran fault these mentioned facilities in regions 1, 2, 4 and 5 and if the Ray fault is also activated, these facilities in regions 11, 12, 15, 18 and 20 will have been considered destroyed completely. It should be noted that the destruction of the regions can be due to inappropriate structures of buildings or existence of a fault on the region.

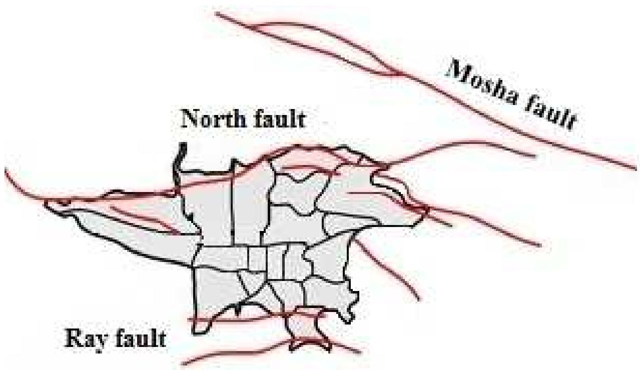

Figure 3. Map of Tehran faults

13. According to statistics of Tehran Blood Transfusion Organization in the past years, the demand for red blood cells, platelets and plasma has been 53.5%, 15.5% and 31% respectively. Given that, according to the domain experts' viewpoints, Tehran metropolis during the day by people from other surrounding cities due to factors such as employment, health and other cases is filling and emptying and the demand for blood products during the day is more than the night. Also, with respect to the fact that most of the injured people reside in Tehran and due to the destruction of their home or workplace are

injured and thus, when the earthquake is happened, it is assumed that 1.2% of injured people and 0.3% of non-injured people need blood products every 4 days. Hence, according to the above explanations, the demand for blood products of affected and healthy regions will be obtained considering the occurrence time of the earthquake and the relief type. With regard to the greater number of non-injured people compared to injured people in the time of earthquake, in each scenario, for the first and second fuzzy numbers, night situation with aid and without aid and for the third and fourth fuzzy numbers the day with aid and without aid have been considered respectively.

In other hand, there has been chosen 16 days and has been considered as four 4-day periods. As the demand of injured people a few days after the earthquake is high and then gradually decreases, hence, the time of the earthquake the demand in the first, second, third and fourth periods will be 40%, 30%, 20% and 10% of the total demand respectively. Due to the large volume of information, the demand of each applicant region has been removed which to obtain this demand in each period and under each scenario can be used from above information.

14. Also the blood donation process takes 20 to 30 minutes, based on the domain experts' viewpoints, it is assumed that this process lasts approximately maximum 30 minutes and by taking into account the 12-hour activity of permanent and temporary blood donation centers from 8 am to 8 pm and the number of beds and facilities at each centre, the maximum number of people who can donate blood in permanent and temporary blood donation centers will be achieved and due to the uncertainty of beds and facilities number are considered as fuzzy numbers in the table 4. It should be noted that since Vesal blood donation centre is also a blood bank, it has double beds and facilities rather than other centers and thus, more people are able to donate blood. Also the coefficients Φ for the percent of healthy blood after filtration is considered and according to the statistics of Tehran Blood Transfusion Organization it is considered as 80%.

Table 4. The maximum number of people that can donate blood in permanent and temporary blood donation centers ($\tilde{\sigma}_k, \tilde{\chi}_l$)

Center name	First fuzzy number	Second fuzzy number	Third fuzzy number	Fourth fuzzy number
Permanent center 1 (Vesal center)	144	192	240	288
Other permanent and temporary centers	72	96	120	144

5- Solution Approach

With regards to the concerned bi-objective problem, an interactive possibilistic programming approach is used to solve the proposed model. This method is provided by Torabi and Hassini (2008) and it is one of the well-known approaches to deal with multi-objective problems. In this approach, the coefficients in the objective function can be considered as realistic and pessimistic cases or state of between them by the decision maker. Therefore, according to the case study and the importance of the decision maker’s opinions, this method has been used.

If the objective functions (1) and (2), are shown with Z_1 and Z_2 respectively, then the steps of the interactive possibilistic programming approach for this problem is as follows:

1. First appropriate trapezoidal probability distributions for the ambiguous parameters is specified and then the problem is modelled in the form of fuzzy (Eqns.(1)-(21)).

2. The objective function (1), which is fuzzy is converted to a certain objective function (Eqn.(29))

3. The minimum acceptable possibility level (α) is determined for ambiguous parameters and the fuzzy problem is converted to deterministic problem (Eqns.(29)-(38), the objective function (2) and other constraints (4), (5), (8)-(12), (14), (16) and (18)-(21).

4. The positive ideal solution (PIS) and the negative ideal solution (NIS) will be obtained for each of the objective functions by solving the fuzzy problem that is converted to the deterministic problem as follows:

$$Z_1^{PIS} = \min Z_1 \quad , \quad Z_1^{NIS} = \max Z_1 \qquad (38)$$
$$Z_2^{PIS} = \max Z_2 \quad , \quad Z_2^{NIS} = \min Z_2$$

s.t.
Eqns. (30)–(37) and other constraints (4), (5), (8)-(12), (14), (16) and (18)-(21)

It should be noted that to obtain Z_1^{PIS} it is sufficient that the deterministic problem with minimum cost objective function (29) and constraints are written on Eqn.(38) is solved, and to obtain Z_2^{PIS} as well as, the problem with maximal covering objective function (2) with the constraints listed in Eqn.(38) is solved. It is enough to determine Z_1^{NIS} after obtaining Z_2^{PIS}, the common variable in two the objective functions, i.e., the location variable of the temporary blood donation centers (y_{lt}) as the parameter in problem Z_1^{PIS} is considered and the problem is solved with the same constraints. Also it is enough to determine Z_2^{NIS} after obtaining Z_1^{PIS}, the common variable mentioned above (y_{lt}) as the parameter in problem Z_2^{PIS} is considered and the problem is solved with the same constraints.

5. For each objective function a linear membership function is defined as follows:

$$\mu_1(\nu) = \begin{cases} 1 & \text{if } Z_1 < Z_1^{PIS} \\ \dfrac{Z_1^{NIS} - Z_1}{Z_1^{NIS} - Z_1^{PIS}} & \text{if } Z_1^{PIS} \le Z_1 \le Z_1^{NIS} \\ 0 & \text{if } Z_1 > Z_1^{PIS} \end{cases} \tag{39}$$

$$\mu_2(\nu) = \begin{cases} 1 & \text{if } Z_2 > Z_2^{PIS} \\ \dfrac{Z_2 - Z_2^{NIS}}{Z_2^{PIS} - Z_2^{NIS}} & \text{if } Z_2^{NIS} \le Z_2 \le Z_2^{PIS} \\ 0 & \text{if } Z_2 < Z_2^{NIS} \end{cases} \tag{40}$$

In the above equations $\mu_h(\nu)$ is the satisfaction degree of the *h*th objective function for the given solution vector ν.

6. The deterministic linear multi-objective problem is converted to the crisp single objective problem by using Eqn.(41).

$$\max \ \lambda(\nu) = \Omega\lambda_0 + (1-\Omega)\sum_h \ell_h \mu_h(\nu) \tag{41}$$

$$\text{s.t.} \quad \lambda_0 \le \mu_h(\nu), \quad h = 1,2$$
$$\nu \in F(\nu), \lambda_0$$
$$\gamma \in [0,1]$$

Where $\lambda_0 = \min_h \{\mu_h(\nu)\}$ is the minimum satisfaction degree of objective functions. This approach is a convex combination of the lower bound for the satisfaction degree of goals (λ_0) and the weighted sum of these obtained degrees ($\mu_h(\nu)$) to ensure a tunably moderate conciliation solution.

In addition to ℓ_h and Ω are the relative importance of the *h*th objective function and the coefficient of compensation, respectively. In other words, If Ω is more, compensation is more difficult and if it is less, compensation is more possible. ℓ_h is defined by the decision maker, according to his/her preference, such that $\sum_h \ell_h = 1, \ell_h > 0$.

7. Considering the compensation coefficient Ω and the relative importance of fuzzy goals (vector ℓ), the deterministic single-objective model in Eqn.(41) with the same constraints (30)-(37) and other constraints (4), (5), (8)-(12), (14), (16) and (18)-(21) is solved. If the decision maker is consented with the current effective solution, the approach is stopped. Otherwise, some controllable parameters such as Ω, α are changed and Steps 3-7 are repeated, and another effective solution will be obtained (Torabi and Hassini, 2008).

5-1- Computational results and sensitivity analysis

Now, the problem by using CPLEX 24.1 in GAMS software in various aspects has been solved in a computer with a Core i3 processor. In the case study section the values of the parameters were discussed. According to the domain experts' viewpoints, the activation probability for each fault and the probability of no earthquake are considered as 0.2 and 0.4, respectively. Now for various α, η, λ, Ω, ℓ_1 and ℓ_2 the model has been solved and the values of the first, second and total objective functions (Obj_1, Obj_2 and Total Obj) as well as established temporary blood donation centers and establishment periods are shown in table 5.

Table 5. The values of objective functions and established temporary centers for α, η, λ, Ω, ℓ_1 and ℓ_2

Case	α	η	λ	Ω	ℓ_1	ℓ_2	Obj_1	Obj_2	Total Obj	Stablished Temporary centers (Established facility number (Stablishment periods))
1	0.6	0.2	0.8	0.2	0.2	0.8	4826951237	560086	5306	1(1-4), 2(1-4), 3(1), 4(1-4), 5(1-4), 6(1-2,4),7(1-4)
2					0.5	0.5	4783256495	554792	3322	1(1-4), 2(1-4), 3(1), 4(1-4), 5(1-4), 6(1-2,4),7(1-4)
3					0.8	0.2	4747060661	549918	1938	1(1-4), 2(1-4), 3(1), 4(1-4), 5(1-4), 6(1-2,4),7(1-4)
4				0.8	0.2	0.8	5046573270	521887	1596	1(1-4), 2(1-4), 3(1), 4(1-4), 5(1-4), 6(1-2,4),7(1-4)
5					0.5	0.5	4964523782	513610	1272	1(1-4), 2(1-4), 3(1), 4(1-4), 5(1-4), 6(1-2,4),7(1-4)
6					0.8	0.2	4877412367	502199	646	1(1-4), 2(1-4), 3(1), 4(1-4), 5(1-4), 6(1-2,4),7(1-4)
7		0.5	0.5	0.2	0.2	0.8	3074258912	560086	5681	1(1-4), 2(1-3), 3(1), 4(1-4), 5(1-4), 6(1-2,4),7(1-4)
8					0.5	0.5	3015492146	554792	3948	1(1-4), 2(1-3), 3(1), 4(1-4), 5(1-4), 6(1-2,4),7(1-4)
9					0.8	0.2	2966912913	549918	2214	1(1-4), 2(1-3), 3(1), 4(1-4), 5(1-4), 6(1-2,4),7(1-4)
10				0.8	0.2	0.8	3358413267	521887	1845	1(1-4), 2(1-3), 3(1), 4(1-4), 5(1-4), 6(1-2,4),7(1-4)
11					0.5	0.5	3287451278	513610	1645	1(1-4), 2(1-3), 3(1), 4(1-4), 5(1-4), 6(1-2,4),7(1-4)
12					0.8	0.2	3205412894	502199	1182	1(1-4), 2(1-3), 3(1), 4(1-4), 5(1-4), 6(1-2,4),7(1-4)
13		0.8	0.2	0.2	0.2	0.8	1324587516	560086	5733	1(1-4), 2(1-3), 3(1), 4(1-4), 5(1-4), 6(1-2),7(1-4)
14					0.5	0.5	1258469172	554792	4034	1(1-4), 2(1-3), 3(1), 4(1-4), 5(1-4), 6(1-2),7(1-4)
15					0.8	0.2	1186765165	549918	2355	1(1-4), 2(1-3), 3(1), 4(1-4), 5(1-4), 6(1-2),7(1-4)
16				0.8	0.2	0.8	1594515487	521887	2021	1(1-4), 2(1-3), 3(1), 4(1-4), 5(1-4), 6(1-2),7(1-4)
17					0.5	0.5	1527125534	513610	1821	1(1-4), 2(1-3), 3(1), 4(1-4), 5(1-4), 6(1-2),7(1-4)
18					0.8	0.2	1442834958	502199	1485	1(1-4), 2(1-3), 3(1), 4(1-4), 5(1-4), 6(1-2),7(1-4)
19	0.8	0.2	0.8	0.2	0.2	0.8	6512149325	560086	4485	1(1-4), 2(1-4), 3(1-3), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
20					0.5	0.5	6448566938	554792	2805	1(1-4), 2(1-4), 3(1-3), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
21					0.8	0.2	6354851880	549918	1594	1(1-4), 2(1-4), 3(1-3), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
22				0.8	0.2	0.8	6732273958	521887	1296	1(1-4), 2(1-4), 3(1-3), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
23					0.5	0.5	6682891726	513610	957	1(1-4), 2(1-4), 3(1-3), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
24					0.8	0.2	6605184173	502199	486	1(1-4), 2(1-4), 3(1-3), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
25		0.5	0.5	0.2	0.2	0.8	4097952704	560086	4646	1(1-4), 2(1-4), 3(1,3), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
26					0.5	0.5	4018125046	554792	2956	1(1-4), 2(1-4), 3(1,3), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
27					0.8	0.2	3959282425	549918	1421	1(1-4), 2(1-4), 3(1,3), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
28				0.8	0.2	0.8	4329357296	521887	1336	1(1-4), 2(1-4), 3(1,3), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
29					0.5	0.5	4261535781	513610	1078	1(1-4), 2(1-4), 3(1,3), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
30					0.8	0.2	4185933029	502199	715	1(1-4), 2(1-4), 3(1,3), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
31		0.8	0.2	0.2	0.2	0.8	2125274015	560086	4831	1(1-4), 2(1-4), 3(1), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
32					0.5	0.5	2035514579	554792	3073	1(1-4), 2(1-4), 3(1), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
33					0.8	0.2	1883712970	549918	1501	1(1-4), 2(1-4), 3(1), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
34				0.8	0.2	0.8	2357544188	521887	1411	1(1-4), 2(1-4), 3(1), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
35					0.5	0.5	2274919962	513610	1108	1(1-4), 2(1-4), 3(1), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)
36					0.8	0.2	2209830176	502199	854	1(1-4), 2(1-4), 3(1), 4(1-4), 5(1-4), 6(1-2,3),7(1-4)

According to Table 5 it is observed that whenever coefficient α is increased, the degree of strictness and the value of objective function 1 (i.e. the optimized total cost) is also increased; but the value of aggregated objective function is decreased. Also if the pessimistic degree of objective function 1 (λ) is increased, the risk of decision maker is reduced and the value of objective function 1 is also increased. However, the value of aggregated objective function is decreased and as a result, more temporary blood donation centres is established to respond the applicants of blood products. For example, various facilities such as permanent and temporary blood donation centers and blood bank in Tehran in the case of $\alpha = 0.6$ for $\eta = 0.8$, $\lambda = 0.2$ $\Omega = 0.8$, $\ell_1 = 0.8$ and $\ell_2 = 0.2$ in $t = 4$, are shown in Fig 4.

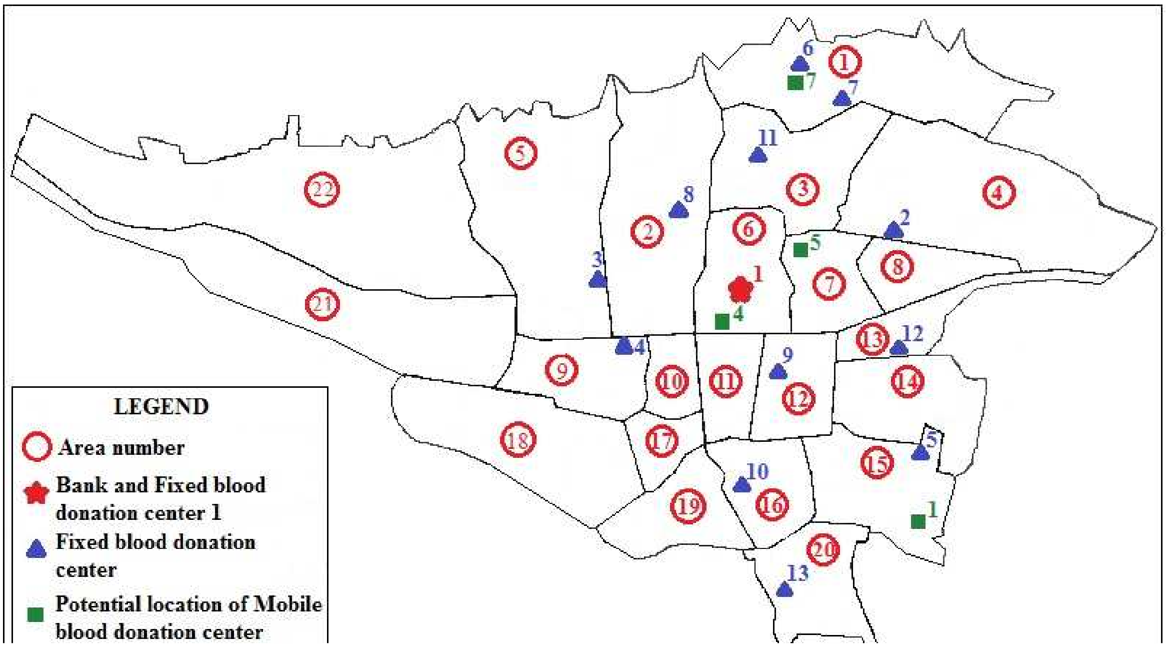

Figure 4. Various facilities in case of $\alpha = 0.6$ for $\eta = 0.8,\ \lambda = 0.2,\ \Omega = 0.8,\ \ell_1 = 0.8$ and $\ell_2 = 0.2$ in $t = 4$

Table 5 shows that the increase in ℓ_1, improves the value of objective function 1 and also reduces the values of objective function 2 and the aggregated objective function. Conversely, increase in ℓ_2, results in increase of the value of objective function 1 and improvement in the values of objective function 2 and the aggregated objective function.

Due to considering of the holding costs, the model in the normal state is not willing to hold inventory, this causes a reduction in total cost, but when demand increases suddenly, in order to avoid the lost demand which is costly, blood banks and hospitals (by comparing the costs of holding and lost demand) will keep inventory in order to be cost-effective.

5-2- Validation of the model

In this section, the model validation is performed. Therefore, both the deterministic model that considers the fuzzy parameters as mean and the fuzzy model in the case of $\alpha = 0.6$ for $\eta = 0.2,\ \lambda = 0.8,\ \Omega = 0.8,\ \ell_1 = 0.8$ and $\ell_2 = 0.2$ are solved and the solutions for both models will be achieved. Now, the obtained variables from the two models are considered as parameter in the one deterministic model in the above case which this model is similar to the first deterministic model, with the difference that fuzzy parameters are considered in the form of uniform distribution between the first and fourth fuzzy numbers and given in table 6.

Table 6. The uniform distribution for generation the fuzzy parameters

Fuzzy parameter	Uniform distribution for parameter production	Fuzzy parameter	Uniform distribution for parameter production
$\tilde{f}_{lt}$	$U[35000, 40000]$	$\tilde{e}_{kmt}$	$U[0.08, 0.095]$
$\tilde{a}_{jk}$	$U[1500, 3000]$	$\tilde{\rho}_{lmt}$	$U[0.08, 0.095]$
$\tilde{b}_{jl}$	$U[1500, 3000]$	$\tilde{r}_{imnt}$	$U[0.08, 0.095]$
$\tilde{h}_{im}$	$U[200, 350]$	$\tilde{\sigma}_1$ (For permanent center 1)	$U[144, 384]$
$\tilde{g}_{in}$	$U[200, 350]$	$\tilde{\sigma}_k$ (For other centers) and $\tilde{\chi}_l$	$U[72,192]$
$\tilde{c}_{iot}$	$U[10000000, 25000000]$	$\tilde{\varphi}_n$	$U[500,1250]$

Thus, the mentioned deterministic model for the obtained variables from the solution of the two previous models which were considered as parameter and these parameters generated by uniform distribution, for each generation of different value for both models is solved. The results are given in Fig 5.

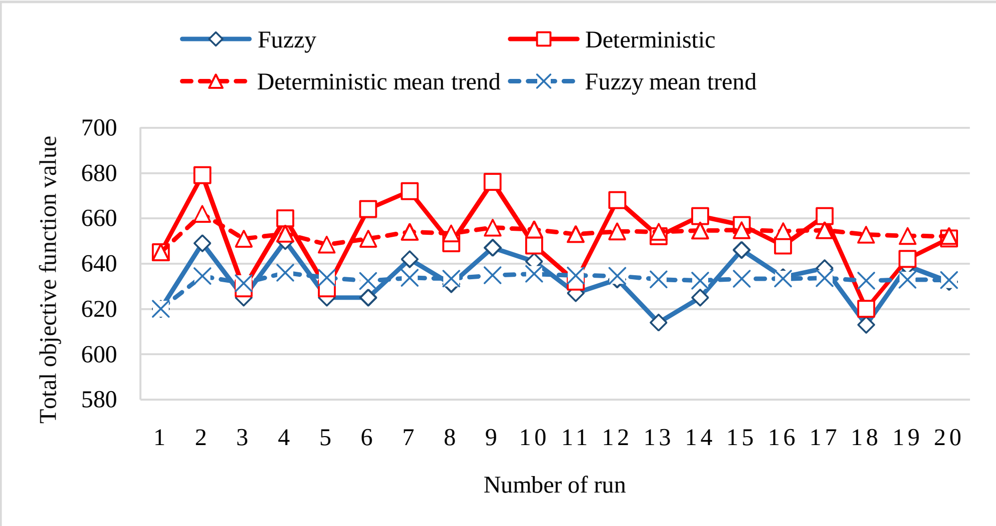

Figure 5. Results of validation

As it can be seen in Fig 5, the values of objective function for the solution of the model with fuzzy parameters is less than the solution of model with deterministic parameters which is natural, because in the fuzzy state, uncertain conditions are also considered which causes it to increase the first objective function and decrease the total objective function. As well as, the average value of the total objective function in the fuzzy state is less than the deterministic state and the standard deviation in the fuzzy state (11.105) is less than the standard deviation in the deterministic state (16.268), which indicates less variability of the objective function values in the fuzzy state compared to the deterministic state, that the validity of the model shows.

6- Discussion

Since the opinions of Senior Decision Makers (SDMs) are very important and have significant impact on the planning of the blood supply chain, the preferences of SDMs are precisely taken in to account. Also, with respect to importance of blood products in saving the human life, particularly in times of disaster, it would be reasonable to select a more risk-averse approach; therefore, the higher values of α and λ is required.

It should be noted that currently only permanent blood donation centers are used and temporary blood donation centers have been used in the past. But to meet the demand for blood products from applicants, it is essential to consider a variety of locations for temporary blood donation centers and based on the demand in each period, these centers will become active. Therefore, it can be concluded that the existing conditions are not sufficient to satisfy demand of disaster conditions and in this problem considering temporary blood donation centers have responded to a lot of demands.

Also, according to the obtained information, Vesal blood bank is the only blood bank in Tehran and must be strengthened against earthquakes. This becomes necessary because if the blood bank be destroyed, the city will be at great risk. Therefore, it is necessary that different locations for establishing other blood banks in this city are considered by experts, so that many costs such as transportation are reduced and the coverage level of blood products for applicants is increased.

7- Conclusions

In this paper, the complete structure of the blood products supply chain under earthquake disaster is presented. The purpose of the proposed model is minimizing common costs of blood supply chain and maximizing the covering of blood donors so that, the decisions related to the amount of blood donated to permanent and temporary blood donation centres, the amounts of blood products transported between different levels of the chain, received blood products by blood applicant regions from hospitals, holding blood products in hospitals and blood banks and lost demands in blood applicant regions and the locations of activated temporary blood donation centres at times of the occurrence of earthquake disaster are decided to the most optimum state.

Also, to make the model closer to reality, the data and information of the blood transfusion network of Tehran and JICA for earthquake disaster is used to verify the proposed model. To handle the uncertainty of input parameters a credibility-based fuzzy chance constrained programming method is used. Moreover, an interactive multi-objective fuzzy solution approach is employed to solve the proposed model and the corresponding results are reported in order to show the usefulness of the developed model.

The opportunities for future research are in the two following areas:

(1) Considering backup plans for disrupted routes in times of disaster.

(2) Routing of blood transfusion vehicles and transportation of blood products from other provinces in times of disaster.

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