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Research Article

A Robust Optimization Approach for Sustainable humanitarian supply chain management of blood products

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Abstract:
Background and objective:. Blood supply chain management aims to bridge the gap between blood donors and consumers. This results in no blood deficient, and minimization of, the corruption of blood products and lower costs. Humanitarian supply chain includes planning, managing activities related to materials, information, and finances when providing relief to affected people. The purpose of this study is to optimize the sustainable humanitarian supply chain of blood products in Tehran.
Method: In this study, a five-echelon blood supply chain network is presented that includes donors, mobile, fixed and regional blood collection centers, and hospitals. This study proposed a multi objective mixed integer linear programming optimization model considering economic, environment and social objectives. Due to the uncertain and random nature of blood supply and demand and cost parameters, the model develops into a robust optimization model. The ε-constraint method is used to transform the multi-objective problem into a single-objective mode. The model is coded in GAMS and solved by CPLEX solver.
Results: The model outputs include allocate blood donor to mobile and fixed blood collection centers, allocate fixed and mobile blood centers to regional blood centers, and allocate regional blood centers to hospitals. The application of the proposed model is investigated in a case problem in Tehran where real data is utilized to design a network for emergency supply of blood during potential disasters. The results indicate robust model is more efficient in controlling demand, supply and costs uncertainties. At $\omega = 100$ the supply chain cost reaches to $51746 and unmet blood demand is zero under any earthquake scenario and, the supply chain is robust in all scenarios.
Conclusion: To provide some managerial perspectives for the aforementioned problem, a sensitivity analysis has been performed. Important practical implications were drawn from the case study results. We showed how solution robustness (supply chain cost) can be balanced against model robustness (unmet demand). As the value of risk aversion weight, increases, the total cost indicating solution robustness increases, while the blood unmet demand indicating model robustness decreases. Finally results analysis, concluding remarks and directions for further research are presented.
Keywords: Sustainability, blood supply chain, humanitarian supply chain, robust optimization, uncertainty, multi objective optimization

Background and objective

Billions of people are affected by worldwide natural and man-made disasters each year. When a disaster occurs, there is usually a significantly elevated demand for blood and shortages in the blood[1]. Human blood is a rare and vital source that is produced only by human beings, and since there is currently no other product that can produce blood and also its uncertainty supply and demand side, keeping an adequate supply level is very important to fulfill demands[2]. Due to ineffective blood supply chain design and planning, from 108,985 donated blood units in devastating Bam earthquake in Iran in 2003, only 21,347 units (about 23%) were actually supplied to the affected residents[3]. The catastrophic earthquake in Kermanshah, which recently occurred in our country, once again highlighted the need for crisis management in the country and to deal with the crisis. Therefore, having a robust supply chain design is critical to improving the performance of blood supply chains in cases of disasters[1].

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Platelet (PLT), plasma and red blood cell are the most critical derivatives of whole blood in which, PLT has the least lifespan and expires between 5 and 7 days. Hence platelets have a high degree of perishability and are valuable resources. Shortage of PLT puts patient lives at risk and leads to high expenses for the supply chain. Platelets are drawn either from whole blood or through apheresis, which is the withdrawal of blood from a donor's body, separation of one or more components from the blood and transfusion of the remaining blood back into the donor[4,5].

The growing concerns to meet environmental, social, and legislative requirements are forcing companies to consider the impacts of sustainable supply chain management (SSCM) on the environment and society[6,7]. The area of humanitarian supply chain management (HSCM) has received growing attention from operations management researchers in the past few years. HSCM and logistics is important because it directly affects the success of the humanitarian aid effort[8,9]. HSCM is defined as "the activities of planning, implementing, and controlling the storage and flow of goods and information between the origin and consumption point for satisfying the needs of beneficiaries". The mission of Humanitarian Organizations is to rapidly provide and distribute aid to beneficiaries to minimize human death[10].

Generally, uncertain environments can be defined in three types namely stochastic, fuzzy and robust each of which are dealt with their corresponding modeling approaches. Data randomness can be captured by either stochastic or robust programming approaches[11]. It is noteworthy that the stochastic programming approach comes to the application when the adequate information about distribution functions of random data is available, or a repetitive action takes place during the planning horizon. However, the robust approach is applicable in the situation of little knowledge about the historical data and where, like the case under study, one cannot get sufficient information about the distribution functions of random variables[12,13] .

This paper develops a robust optimization model that aims to address the aforementioned concerns. The proposed model consists of blood donors, mobile blood facilities (such as blood donation vehicles), fixed blood centers, regional blood centers, disposal centers and hospitals. The model aims to determine the number and location of blood facilities (both permanent and temporary facilities), the service areas of blood facilities, the required blood collection at each facility, and inventory levels of blood at the end of each period and the amount of blood which should be delivered to hospitals. The objectives include minimize blood corruption, total cost and minimizes the blood shortage while ensuring that the network is robust to major disasters. To the best of our knowledge, a modeling effort for blood supply chain network design considering multi objective goals is non-existent.

The remainder of the paper is organized as follows. In section 2 the literature review of blood supply chain is presented. In section 3 gap analysis is discussed. Model formulation and robust formulation of the proposed model are shown in Section 4. Problem description is introduced in Section 5. Computational results and practical implications are given in Section 6. Conclusion, limitations and opportunities for future work are presented in Section 7.

Literature review

Blood supply chain

In recent years, blood supply chains have attracted increasing attention from researchers such as Yousefi Nejad et al., [14]; Yousefi Nejad[15]; Ghatreh Samani and

Hosseini-Motlagh[16]; Jokar and Hosseini-Motlagh[17]; Arani, et al., 2021[18] and Kazemi Matin, et al.[19]. Several authors presented review papers that provide a comprehensive review of blood supply chain research, including Belien and Force[20] and Osorio et al. [21]. The literature includes several studies that utilize a simulation approach to handle the high uncertainty in blood supply chain management. Jabbarzadeh et al.[3]. developed a model for the multi-period, single-product blood supply chain network in disaster situations considering the robust approach for the uncertainty of the demand parameter. The proposed model aims to minimize the total cost of the blood supply chain. Fahimnia et al.[22] proposed a new stochastic bi-objective model for a blood supply chain in a disaster condition. Their model minimizes the cost and minimizes the time simultaneously. They presented a hybrid solution approach using Lagrangian relaxation and ε-constraint methods. Ensafian and Yaghoubi[23] presented an integrated platelet supply chain where demand is age-differentiated according to the type of patient. At first, two mixed-integer programming models are developed based on FIFO and LIFO issuing policies. A bi- objective model has been then developed in which the first objective maximizes the freshness of the units delivered and the second minimizes the total cost. To cope with uncertain demand, a robust optimization approach is presented and the application of the proposed model is discussed in a case study. Eskandari-Khanghahi et al[5] developed a sustainable blood supply chain network in disaster situations with uncertain parameters. They considered some objectives as minimizing the costs, environmental effects of blood collection and wasted blood, maximizing the social impacts, such as the number of job opportunities created, and finally minimizing the cost of purchasing, lack of blood, maintenance, etc. The simulated annealing and harmony search algorithms were chosen and compared for the large-scale solution. Mohammadian- Behbahani, et al.[24] presented a multi-objective stochastic programming model for blood supply chain network design by considering the following objectives: minimizing total cost, minimizing delivery time and maximizing two important social measures (consumer's health and the rate of regular blood donors). A robust optimization approach is employed to incorporate different sources of uncertainties in demand and supply parameters. Ghatreh samani et. al.[25] proposed a novel multi objective mathematical model by incorporating both quantitative and qualitative factors to comprehensively model the investigated case study. In the proposed model, the quantitative factors aim to minimize the loss of product freshness and total cost of the network and maximize the number of collection facilities. Moreover, to cope with the uncertainty, a robust optimization approach is utilized, and an interactive fuzzy solution approach is applied to solve the proposed multi-objective model. Hamdan and Diabat,[1] proposed two-stage stochastic optimization model aims at minimizing the time and cost of delivering blood to hospitals after the occurrence of a disaster, while considering possible disruptions in blood facilities and transportation routes. A Lagrangian relaxation-based algorithm is developed that is capable of solving large-scale instances of the model. Haghjoo et al.[2] presented a dynamic robust location‑allocation model for designing a blood supply chain network under facility disruption risks and uncertainty in a disaster situation. A scenario-based robust approach is adapted to the model to tackle the inherent uncertainty of the problem. The usage of the model is implemented by a real-world case example that addresses the demand and disruption probability as uncertain parameters. Zhou et al.[26] presented an optimal model of blood transshipment problem with the goal of the shortest transshipment time and the maximum freshness of the transported blood. The effectiveness of the decision-making method and EWA inventory strategy are verified by numerical simulation. The results show that safety stock, target stock level and fluctuation range of demand have significant impacts on the control effect of blood inventory. Mousavi, et al. [27] introduces a bi-objective and sustainable blood supply chain network by considering both social and environmental factors of blood decomposition. the problem simultaneously considers optimizing the emission, balancing the flow of all utilized vehicles, penalty coefficient of non-visited centers, total costs of using all vehicles, and the social and environmental factors of blood decomposition. The findings of the study suggest that expecting more social factors convey more costs in most cases.

Gap analysis

In this paper, some gaps in the blood supply chain are covered and the following contributions are categorized:

- Developing a new comprehensive blood platelet supply chain design model (including location, allocation) by integrating sustainability into the decision-making process.
- Apheresis and whole blood collection were both incorporated into the model. Apheresis method is used for extracting blood platelets as an efficient method.
- Examining the uncertainty in some parameters of the problem, such as supply, demand and moving cost of temporary and permanent facilities because of a disastrous occurrence.
- Modeling a humanitarian blood supply chain that is a new topic and a few papers deals with humanitarian blood supply chain
- Considering economic, environmental and social criteria for modeling humanitarian supply chain. A few paper considers all sustainable criteria for modeling humanitarian supply chain.
- Considering the perishability of blood products in blood supply chain model. Perishability are the concerns requiring attention, and thus, preserving the blood freshness is another critical aspect the concerned network has to deal with. Recent papers suggested considering perishability of blood products in future works. [22,28,29]
- Presenting a robust optimization formulation that incorporates uncertainties and different disaster scenarios for the design of supply chains in an emergency case.
- Using a real case study of Tehran in Iran to illustrate the applicability of the proposed model. Tehran is one of the largest cities in Western Asia which is composed of high-proportion of Iran population, and is located on earthquake faults and exposed to destructive earthquakes in recent years.

Method

Robust optimization

Robust optimization planning provides a risk aversion approach to handle uncertainty in optimization problems. Robust optimization techniques can be used with both single-objective and multi-objective optimization problems. The approach would then result in a series of solutions that are progressively less sensitive to realizations of the model data from a scenario set. Robust optimization explicitly incorporates the conflicting objectives of solution and model robustness by using a parameter reflecting the decision maker’s preference between the two. Mulvey et al. [30] demonstrated a description of scenario-based data and introduced solution robustness and model robustness contexts. The linear optimization model is as follows:

$$\text{Min } c^T x + d^T y \quad (1)$$
S.t.:
Ax = b
Bx+Cy = e
x, y ≥0

At this model, x and y define the vectors of decision and control variables, respectively. Control variables are subjected to frame once a specific realization of parameters, while design variables are specified before the realization of the uncertain parameters and are not dependent on the realization of them. A set of scenarios is introduced as $S = \{1, 2, 3,\ldots, s\}$. The robust optimization model can be formulated by:

$$\text{Min } \sigma(x, y_1, y_2, \ldots, y_{s'}) + \omega\rho(\delta_1, \delta_2, \ldots, \delta_s) \quad (2)$$
s.t.
Ax = b,
$B_s x + C_s y_s + \delta_s = e_s \; \forall s \in S$
$x \geq 0, y_s \geq 0 \; \forall s \in S$

Mulvey et al. [30] proposed that $\sigma(x, y_1, y_2, \ldots, y_{s'})$ can be written by:

$$\sigma(x, y_1, y_2, \ldots, y_{s'}) = \sum_{s\epsilon S} p_s \xi_s + \lambda \sum_{s\epsilon S} p_s \left(\xi_s - \sum_{\acute{s}\epsilon S} p_{\acute{s}} \xi_{\acute{s}}\right)^2$$

In the above suggestion, λ is a constant by which the objective function would be less sensitive to change under the scenarios. In brief, the final formulation of the robust optimization model based on the results of Yu and Li [31] is as follows:

$$\text{Min } \textstyle\sum_{s\epsilon S} p_s \xi_s + \lambda \sum_{s\epsilon S} p_s [(\xi_s - \sum_{\acute{s}\epsilon S} p_{\acute{s}} \xi_{\acute{s}}) + 2\theta_s] + \omega \sum_{s\epsilon S} p_s \delta_s \quad (3)$$
S.t.:

$$\xi_s - \sum_{s\epsilon S} p_s \xi_s + \theta_s \geq o \;\; \forall s \in S$$
$$\theta_s \geq o \;\; \forall s \in S$$

In this model, if a solution remains near to optimal for any realization of each scenario s, the mathematical programming model will be robust with regard to optimality that is defined as "solution robustness" and the solution feasibility is that if the solution remains almost feasible under almost all possible values for any realization of s that is defined as "model robustness". The weighting penalty ω is utilized to represent the trade-off between the two mentioned contents. With various scenarios, the objective function will become a random variable taking the value ξs and the θs is a variable, which is used to do the linearization of the model.

Mathematical model

In this section we present the multi-objective blood supply chain model that uses robust optimization techniques optimization to mitigate the effects of disasters, optimizing minimize blood travel time, total costs and the ratio of blood shortage to demand. The model has a periodic structure and we assume a time period 1 to 4 corresponding to 0–24 h, 24–72 h, 72–120 h and 120–168 h after each earthquake scenario occurs. Fig. 1 illustrates the blood supply chain structure considered in this work. The designed blood supply chain network in this paper is based on a real case study and it contains five echelons including blood donation points, blood collection facilities, regional blood centers, demand zones (hospitals) and disposal centers. A robust optimization modeling approach is proposed to mitigate the high uncertainty in the occurrence of disasters and their effects on the supply chain.

Assumptions of the model:
Capacity of temporary facilities is less than permanent ones.

Permanent facilities are established at the beginning of the planning horizon and exist until the end of planning horizon.
The location of temporary facilities can be changed over the planning horizon.
Establishing permanent facilities cost is more than temporary ones.
Mobile and permanent facilities, regional center and hospitals have limited capacities.
Platelets are drawn either from whole blood or through apheresis in this model. Apheresis method is used for extracting blood platelets as an efficient method.
Shortage is allowed, and the shortage cost is defined as the cost for demands which are not satisfied.
Blood wastages include wastes caused by blood diseases, expired blood in a blood center or a hospital, and lost blood in the testing process.
Vesal blood center is the only regional blood center in Tehran. The blood donation, laboratory, processing and storage are accomplished in this center.
Aradkooh is the only disposal center in Tehran.

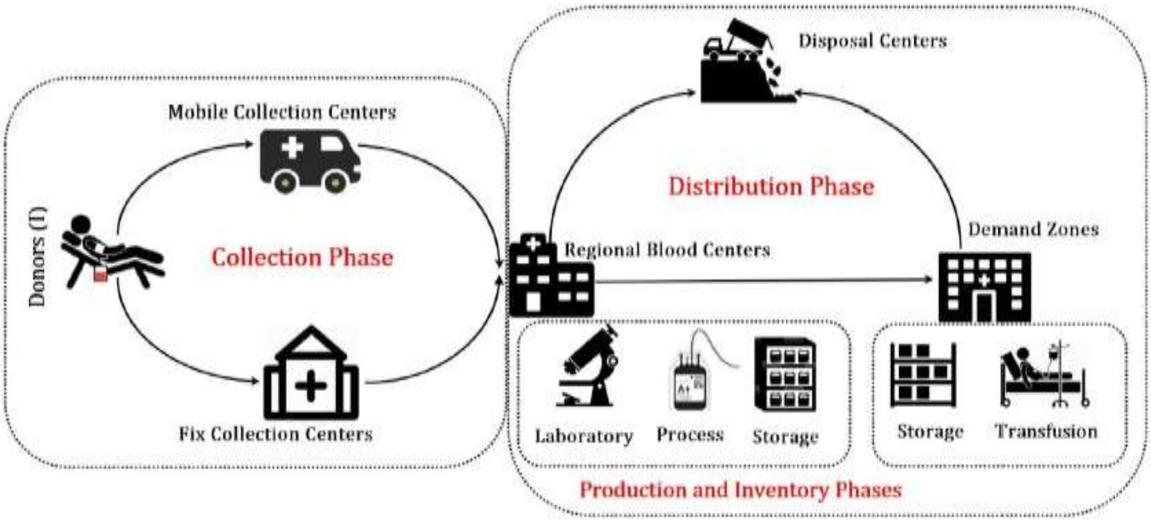

Figure.1. Blood supply chain network.

Sets

I set of donor groups indexed by i
J set of candidate locations for mobile blood facilities indexed by j and l
K Set of permanent blood centers indexed by k
R Set of regional blood centers indexed by r
D Set of disposal centers indexed by d
H Set of demand centers (hospitals) indexed by h
T Set of time periods indexed by t
S Set of disaster scenarios indexed by s

Certain Parameters

f_k Fixed cost of locating a permanent blood facility at location k
fm_j Fixed cost of locating a mobile blood facility at location k
or_{rt} Unit operational cost of processing blood at regional blood centers r in period t
hr_{rt} Unit operational cost of holding blood at regional blood centers r in period t
r_{ij}Distance between donor group i and mobile blood facility at location j
r_{ik} Distance between donor group i and permanent blood facility at location k
b_{jt} Capacity of temporary blood facility at location j in period t
C_{kt} Capacity of permanent blood facility at location k in period t

C_{rt} Capacity of regional blood facility at location r in period t

S_{ht} Blood shortage cost at hospital h in period t.

M a very large number

tb_{jr} Blood travel time from mobile blood center j to regional blood center r

tk_{kr} Blood travel time from permanent blood center k to regional blood center

tr_{rh} Blood travel time from regional blood center r to hospital h

R Coverage distance of blood mobile and permanent facilities

p_s Probability of scenario s occurrence

w_{rt} Cost of blood wastage at regional blood center r in period t

w_{rt} Cost of blood wastage at hospital h in period t

wl_{rt} Percentage of outdated blood at regional blood center r in period t

wl_{ht} Percentage of outdated blood at hospital h in period t

$l_{tt'}$ Equal to 1 if blood deteriorates between period t andt'; 0, otherwise.

ω Risk-aversion weight

λ Variability weight

O Blood product life time (1-5 day)

Uncertain parameters:

cap_{it}^{s} Max blood supply by donor group i in period t under scenario s

d_{ht}^{s} Blood demand at hospital h in period t under scenario s

v_{ljt}^{s}Cost of moving a mobile facility from location l to location j in period t under scenario s

ab_{ik}^{s} Unit blood transportation cost from mobile center j to regional center r under scenario s

ar_{jk}^{s}Unit blood transportation cost from permanent k to regional center r under scenario s

ah_{rh}^{s}Unit blood transportation cost from regional center k to hospital h under scenario s

ad_{rd}^{s}Unit wastage transportation cost from regional k to disposal center d under scenario s

ah_{hd}^{s} Unit wastage transportation cost from hospital h to disposal center d under scenario s

Decision variables

X_ka binary variable, equal to 1 if a permanent facility is opened at site k; 0, otherwise.

XO_ja binary variable, equal to 1 if a mobile facility is opened at site j; 0, otherwise.

Y_{ijt}^{s}A binary variable, equal to 1 if mobile facility I at location j is assigned to donor group i in period t d under scenario s; 0, otherwise.

U_{ikt}^{s} A binary variable, equal to 1 if permanent facility k at location j is assigned to donor group i in period t d under scenario s; 0, otherwise.

Z_{ljt}^{s}A binary variable, equal to 1 if a mobile facility is located at location l in period t-1, and moves to location j in period t; 0 otherwise

A_{krt}^{s} equal to 1 if permanent center k is assigned to regional center r in period t under scenario s; 0, otherwise

B_{jrt}^{s} equal to 1 if mobile center j is assigned to regional center r in period t under scenario s; 0, otherwise

FI_{oht}^{s}equal to 1 if o days blood is used at hospital h in period t under scenario s; 0, otherwise

Q_{ijrt}^{s} the amount of blood transportation to regional center r from mobile center j and donor group I in period t under scenario s

Q_{ikrt}^{s} the amount of blood transportation to regional center r from permanent center k and donor group I in period t under scenario s

Q_{rht}^{s} the amount of blood transportation to hospital h from regional center r in period t under scenario s

$d_{htt'}^{s}$ Quantity of blood consumption at hospital h from regional center r between period t and t' under scenario s

$F_{rdtt'}^{s}$ the amount of wastage blood transportation from regional center r to disposal center d between period t and t' under scenario s

$N^{s}_{dhtt'}$ the amount of wastage blood transportation from regional center r to disposal center d between period t and t' under scenario s

I^{s}_{rt} Blood inventory level at regional blood center r at the end of period t under scenario s

$I^{s}_{rtt'}$ Blood inventory level at regional blood center r between period t and t'under scenario s

b^{s}_{ht} blood wastage at hospital h in period t under scenario s

$d^{s}_{htt'}$ Quantity of blood consumption at hospital h between period t and t' under scenario s

ID^{s}_{ht} the amount of blood consumption at hospital h in period t under scenario s

$ID^{s}_{htt'}$ Blood inventory level at hospital h between period t and t' under scenario s

Objective functions

One of the main contributions of this work is the consideration of a multi-objective formulation to design a robust blood supply chain. Three objectives are as following:

First objective contributes to environmental issues. It aims to minimize outdated blood and provides disposal center. This objective minimizes blood travel time from mobile and permanent centers to regional center and from to regional center to hospitals. Also, environmental goal emphasizes on minimizing disposal costs which is considered at second objective.

$$\min G1 = \sum_s \sum_i \sum_k \sum_r \sum_t p_s Q^{s}_{ikrt} tk_{kr} + \sum_s \sum_i \sum_j \sum_r \sum_t p_s Q^{s}_{ijrt} tb_{jr} + \sum_s \sum_r \sum_h \sum_t p_s Q^{s}_{rht} tr_{rh} \quad (1)$$

Second objective contributes to cost issues. It aims to minimize total cost of blood supply chain including cost of locating a mobile blood facility, cost of locating a mobile blood facility, cost of moving mobile blood facility, cost of blood transportation from mobile and permanent facilities to regional centers and hospitals, blood operational cost, blood holding cost, blood shortage cost, blood wastage cost at regional center and hospitals, transportation cost of wastage blood from regional center to disposal center and transportation cost of wastage blood from hospitals to disposal center.

- $\sum f_k X_k$ = cost of locating a mobile blood facility
- $\sum fm_j XO_j$ = cost of locating a mobile blood facility
- $\sum_s \sum_j \sum_l \sum_t p_s v^{s}_{ljt} Z^{s}_{ljt}$ = cost of moving mobile blood facility
- $\sum_s \sum_i \sum_j \sum_k \sum_r \sum_t p_s (ab^{s}_{ikt} Q^{s}_{ijrt} + ar^{s}_{jkt} Q^{s}_{ikrt} + ah^{s}_{rht} Q^{s}_{rht})$ = cost of blood transportation from mobile and permanent facilities to regional centers and hospitals
- $\sum_s \sum_i \sum_j \sum_k \sum_r \sum_t p_s or_{rt} (Q^{s}_{ijrt} + Q^{s}_{ikrt})$ = blood operational cost
- $\sum_r \sum_t hr_{rt} I^{s}_{rt}$= blood holding cost
- $\sum_s \sum_r \sum_t p_s S_{ht} b^{s}_{ht}$ = blood shortage cost
- $\sum_s \sum_h \sum_t p_s w_{ht} wl^{s}_{ht} + \sum_s \sum_r \sum_t p_s w_{rt} wl^{s}_{rt}$ = blood wastage cost at regional center and hospitals
- $\sum_s \sum_r \sum_d \sum_t p_s ad_{rdt} wl^{s}_{rt} I^{s}_{rt}$ = transportation cost of wastage blood from regional center to disposal center
- $\sum_s \sum_h \sum_d \sum_t p_s ad_{hdt} wl^{s}_{ht} ID^{s}_{ht}$ = transportation cost of wastage blood from hospitals to disposal center

$$\min G2 = \sum f_k X_k + \sum fm_j XO_j + \sum_s \sum_j \sum_l \sum_t p_s v^{s}_{ljt} Z^{s}_{ljt} + \sum_s \sum_i \sum_j \sum_k \sum_r \sum_t p_s (ab^{s}_{ikt} Q^{s}_{ijrt} + ar^{s}_{jkt} Q^{s}_{ikrt} + ah^{s}_{rht} Q^{s}_{rht}) + \sum_s \sum_i \sum_j \sum_k \sum_r \sum_t p_s or_{rt} (Q^{s}_{ijrt} + Q^{s}_{ikrt}) + \sum_r \sum_t hr_{rt} I^{s}_{rt} + \sum_s \sum_r \sum_t p_s S_{ht} b^{s}_{ht} + \sum_s \sum_h \sum_t p_s w_{ht} wl^{s}_{ht} +$$

$$\sum_s \sum_r \sum_t p_s w_{rt}\, wl_{rt}^s + \sum_s \sum_r \sum_d \sum_t p_s ad_{rdt}\, wl_{rt}^s I_{rt}^s + \sum_s \sum_h \sum_d \sum_t p_s ad_{hdt}\, wl_{ht}^s ID_{ht}^s \qquad (2)$$

Third objective reflects the social goal. It aims to minimize the ratio of blood shortage to demand.

$$\text{Min G3} = \sum_s \sum_h \sum_t p_s \, {b_{ht}^s}/{d_{ht}^s} \qquad (3)$$

4.2.6. Constraints

$$I_{rt-1}^s + \sum_i \sum_j \sum_k (Q_{ijrt}^s + Q_{ikrt}^s) - \sum_h \sum_{t'=1}^{t} Q_{rhtt'}^s - \sum_d \sum_{t'=1}^{t} F_{rdtt'}^s = I_{rt}^s \quad \forall r,t,s \qquad (4)$$

Constraint 4 is a control constraint that determines the inventory level at blood centers and the unmet blood demand.

$$\sum_d F_{rdtt'}^s \le l_{tt'} I_{rtt'}^s \qquad \forall r,t,s,t' \in \{1,\dots,t\} \qquad (5)$$

Constraint 5 mentions the amount of regional center wastage blood that send to disposal center is not more than safe blood in regional center.

$$\sum_h N_{dhtt'}^s \le (1 - l_{tt'}) I_{rtt'}^s \qquad \forall r,t,s,t' \in \{1,\dots,t\} \qquad (6)$$

Constraint 6 indicates the amount of hospital wastage blood that send to disposal center is not more than safe blood in hospitals.

$$FI_{oht}^s \le FI_{(o-1)ht}^s \qquad \forall h,t,s,o \in \{1,\dots,5\} \qquad (7)$$

Constraint 7 represents the blood products consumption method as first in first out policy.

$$XO_j + \sum_l Z_{ljt}^s \le 1 \quad \forall j,t,s \qquad (8)$$

Constraint (8) aims to avoid locating more than one mobile facility at each site.

$$\sum_l Z_{ljt}^s \le \sum_l Z_{ljt-1}^s \quad \forall j,t,s \qquad (9)$$

Constraint (9) enforces that mobile facilities cannot move from a location where no facility has been located.

$$Y_{ijt}^s \le XO_j + \sum_l Z_{ljt}^s \quad \forall i,j,t,s \qquad (10)$$

Constraint (10) ensures that donors can only be assigned to open mobile and permanent facilities.

$$r_{ij} Y_{ijt}^s \le r \quad \forall i,j,t,s \qquad (11)$$

$$r_{ik} U_{ikt}^s \le r \quad \forall i,k,t,s \qquad (12)$$

Constraints (11-12) guarantee that donors are covered within a distance r of blood facilities to which they are assigned

$$Q_{ijrt}^s \le M * Y_{ijt}^s \quad \forall i,j,t,r,s \qquad (13)$$

Constraint (13) ensures the blood given by a donor cannot be transported from a facility not assigned to that donor.

$$\sum_i \sum_j \sum_k \sum_r \sum_t (Q_{ijrt}^s + Q_{ikrt}^s) \le c_{kt} X_k + b_{jt} \sum_l Z_{ljt}^s \quad \forall j,t,s \qquad (14)$$

Constraint (14) limits the capacity of blood collection at each facility.

$$\sum_d N_{dhtt'}^s \le l_{tt'} ID_{htt'}^s \qquad \forall h,t,s,t' \in \{1,\dots,t\} \qquad (15)$$

Constraint (15) ensures that the amount of hospitals wastage blood that send to disposal center is not more than safe blood which sent to hospitals.

$$d_{htt'}^s \le (1 - l_{tt'}) ID_{htt'}^s \qquad \forall h,t,s,t' \in \{1,\dots,t\} \qquad (16)$$

Constraint (16) ensures that the amount of hospitals' blood consumption is not more than hospitals' safe blood.

$$I_{rt}^s \le C_{rt} \; \forall r,t,s \qquad (17)$$

Constraint (17) expresses the capacity of blood holding at regional blood center.

$$\sum_j \sum_k \sum_r (Q^s_{ijrt} + Q^s_{ikrt}) \le cap^s_{it} \quad \forall\, i,t,s \qquad (18)$$

Constraint (18) expresses the blood donated by donors i to mobile and permanent facilities is lower than the maximum blood supply by donors i.

$$\frac{\sum_j \sum_i Q^s_{ijrt}}{(1-wl_{rt})} \le \sum_s \sum_j \sum_i \sum_t cap^s_{it} Y^s_{ijt}\, B^s_{jrt} \quad \forall\, r,t,s \qquad (19)$$

$$\frac{\sum_j \sum_i Q^s_{ikrt}}{(1-wl_{rt})} \le \sum_s \sum_j \sum_i \sum_t cap^s_{it} U^s_{ikt} A^s_{krt} \quad \forall\, r,t,s \qquad (20)$$

Constraint (19-20) expresses the maximum blood that transfer from blood facilities is lower than blood supply by donors i.

$$Y^s_{ijt}, Z^s_{ljt}, U^s_{ikt}, A^s_{krt}, X_j, B^s_{jrt}, l_{tt'}, XO_j, FI^s_{oht} \in \{0,1\}$$

$$Q^s_{ijrt}, Q^s_{ikrt}, Q^s_{rht}, D_{kt}, a_{ijt}, Q^s_{rhtt'}, F^s_{rdtt'}, N^s_{dhtt'}, I^s_{rtt'}, b^s_{ht}, d^s_{htt'}, Z^s_{ph}, ID^s_{ht}, ID^s_{htt'} \quad \forall\, i,j,k,r,t \ge 0 \qquad (21)$$

Constraint (21) defines the domains of the decision variables

4.2.7: The robust model formulation

In This section, the deterministic model is extended to robust optimization in which demand, supply and Cost of moving a mobile facility, blood transportation cost from mobile and permanent centers to regional center, wastage transportation cost from regional center and hospitals to disposal center are considered uncertain.

$$\text{Min} \sum_{s\epsilon S} p_s G_{1s} + \lambda \sum_{s\epsilon S} p_s [(G_{1s} - \sum_{\acute{s}\in S} p_{\acute{s}}\, G_{1\acute{s}}) + 2\theta_s] \qquad (22)$$

$$\text{Min} \sum_{s\epsilon S} p_s G_{2s} + \lambda \sum_{s\epsilon S} p_s [(G_{2s} - \sum_{\acute{s}\in S} p_{\acute{s}}\, G_{2\acute{s}}) + 2\theta_s] + \omega \sum_h \sum_t \sum_{s\epsilon S} p_s b_{hts} \qquad (23)$$

$$\text{Min} \sum_{s\epsilon S} p_s G_{3s} + \lambda \sum_{s\epsilon S} p_s [(G_{3s} - \sum_{\acute{s}\in S} p_{\acute{s}}\, G_{3\acute{s}}) + \theta_s] \qquad (24)$$

Constraint (4-21)

$$G_{1S} - \sum_{s\epsilon S} p_s G_{1s} + \theta_s \ge o \quad \forall s \in S \qquad (25)$$

$$G_{2S} - \sum_{s\epsilon S} p_s G_{2s} + \theta_s \ge o \quad \forall s \in S \qquad (26)$$

$$G_{3S} - \sum_{s\epsilon S} p_s G_{3s} + \theta_s \ge o \quad \forall s \in S \qquad (27)$$

$$\theta_s \ge o \quad \forall s \in S \qquad (28)$$

ε-constraint method

There are many methods for solving multi-objective models such as weighted sum approach and epsilon constraint method. The ε-constraint method is employed to solve the multi-objective problems. According to this method, there are main and secondary objective functions. The purpose is to optimize main objective function and limit the secondary function by some allowable amount (ε). In this method, multi-objective model is transformed into a single-objective model. A detailed introduction to the ε-constraint method and its advantages over other methods for solving multi-objective problems can be founded in the literature.[32] in the proposed model, the first objective is considered as main objective function and the second and third objectives are converted to constraints. The advantages of ε -constraint method in comparison with other methods are as following:

- Weighting approach results in only efficient extreme solutions for linear models whereas non-extreme solutions can be created through applying ε -constraint method.
- Weighting approach highly depends on objective functions scale while this subject is not important in the ε -constraint method.
- The controlled number of efficient solutions can be produced in ε -constraint method by effectively tuning the number of grid points in the range of each objective.[33]
-

Problem description

Case problem and decision scenarios

In this section an example from a real word platelet supply chain is presented to illustrate the practicality of the proposed models and solution approach to account for the uncertain environment. Iran is one of the most earthquake-prone countries in the world and has faced many devastating earthquakes during the past few years.[3] Iranian Blood Transfusion Organization (IBTO) is responsible for the blood provision during both non-emergency and emergency situations. IBTO was established in 1974 to centralize all blood transfusion activities including defining standards for transfusion services, conducting donation screening tests, developing blood supply network throughout country, preparing blood components and distributing them to health centers. Tehran's blood demand is collected through mobile blood facilities such as blood donation buses and permanent facilities established in different metropolitan areas.[34] The donor groups are allocated based on the number of municipal districts as defined by Tehran Municipality. 22 donor groups corresponding to 22 geographically dispersed districts in Tehran. Since it is not practically possible to plan for each donor, a group of donors is considered as donation point in the center of each district. The center of each district is also considered as a potential site for establishing a blood facility. The cost of moving a temporary facility from one site to another during the second period and the transportation cost between potential facilities and the blood center are assumed to be proportional to the traveling distances.[3] The supply chain consisting of five echelons including 22 blood donation points, 12 mobile centers, 12 permanent centers, 1 regional center, 1 disposal center and 22 demand zones (hospitals).

We adopted the approach proposed by Tabatabaie et al. [35] to develop a set of earthquake scenarios and estimate the blood demand for each scenario. First, Injury to Death Ratio (IDR) data is collected to obtain the number of injured people in an earthquake. Second, the Hospital Admission Rate (HAR) is estimated; that is the proportion of the injured admitted to hospitals. Third, Blood Transfusion Rate (BTR) is estimated which the proportion is of hospitalized injured people in need of blood transfusion. We assume that all scenarios occur with an equal probability $p_s = {}^{1}/_{18}$. According to Tabatabaie et al.[35] Data from earthquakes with the highest mortality in Iran over the past 20 years is used to estimate the IDR. We use three ranges, 1,2, 3, for the IDR. Using the in recent earthquakes, for each IDR range, we define two HAR values of 0.2 and 0.3 and for each HAR we define three BTR values of 0.05, 0.1 and 0.15. Given these values for IDR, HAR and BTR, we can develop 18 earthquake scenarios. Table 1 shows the estimated blood demand for time period 1 to 4 corresponding to 0–24 h, 24–72 h, 72-120 h and 120-168 h after each earthquake scenario occurs. The potential blood supply in each donation point is calculated based on population and blood donation rate of each district as presented in Table 2. According to IBTO data, unit holding cost of blood is assumed to be set at $1. Unit operational cost of blood collecting is assumed to be set at $0.5-unit blood wastage cost including blood production, holding and processing is assumed to be set at $50. Capacities of regional, permanent and temporary facilities are 1500, 300 and 100 units per day, respectively. Cost of moving a mobile facility, blood transportation cost from mobile and permanent centers to regional center, wastage transportation cost from regional center and hospitals to disposal center are uncertain and depends on earthquake severity and are presented in table 3. A standard blood unit is about 450 mm. the percentage of blood wastage is assumed to be 10%.

Table 1. Earthquake scenarios and the associated blood demands

Scenarios	IDR	HAR	BTR	First period demand	Second period demand	third period demand	fourth period demand
S1	1	0.2	0.05	810	567	688	405
S2	1	0.2	0.1	1140	798	969	570
S3	1	0.2	0.15	1650	1155	1402	825
S4	1	0.3	0.05	1140	798	969	570
S5	1	0.3	0.1	1590	1113	1351	795
S6	1	0.3	0.15	2310	1620	1965	1155
S7	2	0.2	0.05	1630	1142	1386	815
S8	2	0.2	0.1	2280	1596	1938	1140
S9	2	0.2	0.15	3255	2278	2766	1627
S10	2	0.3	0.05	2280	1596	1938	1140
S11	2	0.3	0.1	3195	2236	2715	1597
S12	2	0.3	0.15	4560	3192	3876	2280
S13	3	0.2	0.05	2445	1711	2078	1222
S14	3	0.2	0.1	3420	2394	2907	1710
S15	3	0.2	0.15	4890	3423	4156	2445
S16	3	0.3	0.05	3420	2394	2907	1710
S17	3	0.3	0.1	4785	3349	4067	2392
S18	3	0.3	0.15	6840	4788	5814	3420

Table 2. Maximum blood supply and geographic coordinates of each blood donor

donors	latitude	longitude	S1-S6	S7-S12	S13-S18
D1	35.8025	51.4597	277	521	719
D2	35.7575	51.3622	398	749	1043
D3	35.7544	51.4481	188	354	488
D4	35.7419	51.4920	522	983	1356
D5	35.7489	51.3003	449	847	1169
D6	35.7372	51.4059	295	557	768
D7	35.7219	51.4466	176	332	459
D8	35.7244	51.4983	241	454	627
D9	35.6836	51.3172	99	186	256
D10	35.6840	51.3667	186	350	482
D11	35.6794	51.3959	164	309	426
D12	35.6800	51.4264	137	257	355
D13	35.7078	51.5142	156	305	406
D14	35.6744	51.4703	274	517	714
D15	35.6309	51.4737	362	682	941
D16	35.6394	51.4092	163	308	424
D17	35.6539	51.3631	197	373	512
D18	35.6517	51.2928	222	418	577
D19	35.6205	51.3670	139	262	360
D20	35.5903	51.4409	193	364	502
D21	35.6906	51.2579	92	174	241
D22	35.7472	51.2042	74	139	191

Table 3..Cost of blood transportation and cost of mobile center transportation between candidate facilities and donors ($ per KM)

Scenarios	Injury to Death Ratio (IDR)	Blood transportation cost	Cost of mobile center transportation
S1	1	1	1
S2	1	1	1
S3	1	1	1
S4	1	1	1
S5	1	1	1
S6	1	1	1
S7	2	1.25	1.25
S8	2	1.25	1.25
S9	2	1.25	1.25
S10	2	1.25	1.25
S11	2	1.25	1.25
S12	2	1.25	1.25
S13	3	1.5	1.5
S14	3	1.5	1.5
S15	3	1.5	1.5
S16	3	1.5	1.5
S17	3	1.5	1.5
S18	3	1.5	1.5

Results and practical implications

We implement the proposed robust optimization model to determine optimal location and allocation for the blood supply chain problem. All computational experiments are conducted using GAMZ 24.8.3 on a laptop with Intel Core i7 CPU, 2.4 GHz and 8 GB of RAM. Fig. 2 and Tables 4–7 summarize the numerical results at ω = 100, λ = 1, r = 10. Table 4 shows the temporary facilities located under each scenario at each period. Fig. 2 shows that the permanent blood facilities tend to be located more towards the center of the metropolitan area and closer to the blood center. This is due to the ease of access to the blood supplies and a lower cost of blood transportation from permanent to regional center.

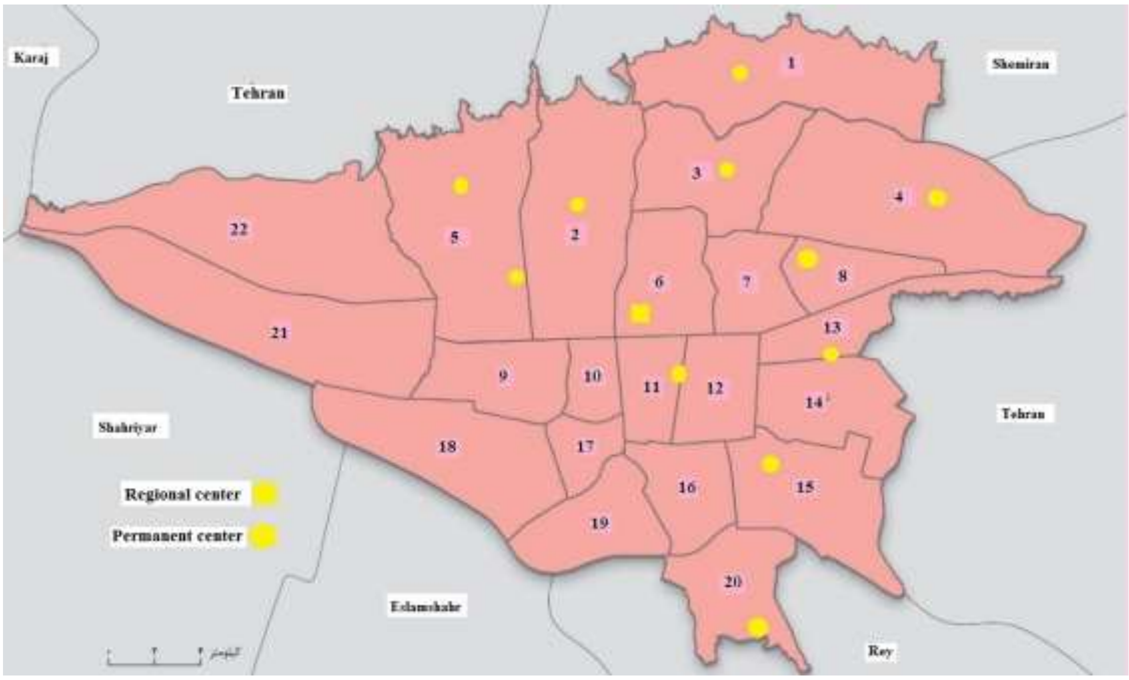

Figure 2. Geographical dispersion of districts and location of the permanent and regional blood centers in Tehran

Table 4 indicates that temporary facilities are only opened in more severe earthquake scenarios, such as scenario 16, 17 and 18, with tendency to be located in more distant areas from the center and areas without permanent centers. Another observation is that the permanent facilities are using more than mobile facilities in all scenarios evidenced by the higher number of permanent facilities selected compared to the mobile facilities selected at optimal solutions of all scenarios. Tables 5 provide the assignment of donor groups to the blood facilities in the first period under each scenario indicating which facilities would cover a blood donor group under each earthquake scenario. Optimal allocation of mobile and permanent blood centers indicate that a donor group may be assigned to multiple facilities in some earthquake scenarios. In most scenarios, the number of assignments is higher during the first period after an earthquake occurrence in most scenarios because of high blood demands during 24 hours after earthquake. Also, in most allocations donors assigned to closer mobile and permanent facilities for time, distance and transportation cost reduction. According to allocation results all permanent centers which are closer to regional center are active in most scenarios and period times. The reason is short distance between these permanent centers and regional center cause lower transportation cost. In some district such as 18 and 22 donors may allocated to mobile centers instead of permanent centers cause of long distance between donors and permanent centers. Also, 19, 20 and 21 districts are assigned to only one permanent centers cause of donors far from permanent facilities and mobile centers are active in these districts. Table 6 presented the quantity of blood (Blood Unit) collected from mobile and permanent facilities in the first period under each scenario. The last column of these tables sums the supply values for each blood facility in different scenarios, indicates how much each facility satisfies the overall blood demand. For example, the permanent centers located in 2, 5 and 7 districts have the largest summation value and provide highest blood supply capacity in all scenarios of earthquakes. Table7 presented the amount of blood transportation from regional center to hospitals in all periods under each scenario.

Table4. The temporary blood facilities selected in different scenarios at each period.

	first period (T1)	First period (T2)	first period (T3)	first period(T4)
J1	S17-S18			
J2	S17-S18			
J3	S17-S18			
J4	S17-S18	S18		
J5	S16-S17-S18	S18	S18	
J6	S16-S17-S18	S18	S18	
J7	S16-S17-S18	S17-S18	S18	
J8	S15-S16-S17-S18	S17-S18	S17-S18	
J9	S13-S14-S15-S16-S17-S18	S16-S17-S18	S17-S18	
J10	S13-S14-S15-S16-S17-S18	S16-S17-S18	S17-S18	
J11	S13-S14-S15-S16-S17-S18	S16-S17-S18	S17-S18	
J12	S13-S14-S15-S16-S17-S18	S16-S17-S18	S17-S18	

Table 5. The assignment of donor groups to blood facilities in the first period under each scenario

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18
I1						1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3
I2	2-5[1]	2-5	2-5	2-5	2-5	2-5	2-5-6	2-5-6	2-5-6	2-5-6	2-5-6	2-5-6	2-5-6-7	2-5-6-7	2-5-6-7	2-5-6-7	2-5-6-7	2-5-6-7
I3	3	3	3	3	3	2-3	2-3	2-3	2-3	1-2-3	1-2-3-4	1-2-3-4	1-2-3-4-7	1-2-3-4-7	1-2-3-4-7	1-2-3-4-7	1-2-3-4-7	1-2-3-4-7
I4						4	4-8	4-8	4-8	4-8	4-8	4-8	4-8	4-8-10	4-8-10	4-8-10	4-8-10	4-8-10
I5	5	5	5	5	5	5	5-6	5-6	2-5-6	2-5-6	2-5-6	2-5-6	2-5-6	2-5-6	2-5-6	2-5-6	2-5-6	2-5-6
I6	2-7	2-7	2-7	2-7	2-7	2-7	2-5-7	2-5-7	2-5-6-7	2-5-6-7	2-5-6-7	2-3-5-6-7	2-3-5-6-7	2-3-5-6-7-9	2-3-5-6-7-9	2-3-5-6-7-9	2-3-5-6-7-9	2-3-5-6-7-9
I7							4-7	4-7	4-7	4-7-9	4-7-9	4-7-9	4-7-9-10	4-7-9-10	4-7-9-10-11	4-7-9-10-11	4-7-9-10-11	4-7-9-10-11
I8						8	8-10	8-10	8-10	8-10	4-8-10	4-8-10	4-8-10	4-7-8-10	4-7-8-10	4-7-8-10	4-7-8-10	4-7-8-10
I9						5	5	5	5	5	5	5	5	5	5	5	5	5
I10						7	5-7	5-7	5-7-9	5-7-9	5-7-9	5-7-9	5-7-9	5-7-9-11	5-7-9-11	5-7-9-11	5-7-9-11	5-7-9-11
I11							5-7	5-7	5-7	5-7-9	5-7-9	5-7-9	5-7-9-10	5-7-9-10	5-7-9-10-11	5-7-9-10-11	5-7-9-10-11	5-7-9-10-11
I12						9	7-9	7-9	7-9-10	7-9-10	7-9-10	7-9-10	7-9-10	7-9-10-11	7-9-10-11	7-9-10-11	7-9-10-11	7-9-10-11
I13							4-8	4-8	4-8	4-8	4-8	4-8	4-8-10	4-8-10	4-8-10	4-8-10	4-8-10	4-8-10
I14							10	10	4-9-10	4-9-10	4-9-10	4-9-10	4-9-10	4-9-10-11	4-9-10-11	4-9-10-11	4-9-10-11	4-9-10-11
I15						10-11	10-11	10-11	10-11	10-11	10-11	10-11	10-11	10-11-12	10-11-12	10-11-12	10-11-12	10-11-12
I16						9	9	9-11	9-11	9-11	9-11	9-11	9-11-12	9-11-12	9-11-12	9-11-12	9-11-12	9-11-12
I17						7-9	7-9	7-9	5-7-9	5-7-9	5-7-9	5-7-9	5-7-9	5-7-9	5-7-9	5-7-9	5-7-9	5-7-9
I18																		
I19										9	9	9	9	9	9	9	9	9
I20											12	12	12	12	12	12	12	12
I21													5	5	5	5	5	5
I22																		

[1] It means donor groups 2 allocate to permanent center 2 and 5 in the first scenario and first period time.

Table 6. The quantity of blood (Blood Unit) collected from mobile and permanent facilities in the first period under each scenario

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	total
K1						110	110	180	200	200	200	200	200	200	200	200	200	200	2400
K2	200	180	300	300	300	300	200	200	200	200	250	300	300	300	300	300	300	300	4730
K3			10	150	280	300	100	150	150	200	200	200	240	240	240	240	240	250	3190
K4							100	150	150	200	200	200	200	200	250	250	250	250	2400
K5	150	300	300	300	300	300	200	250	250	280	300	300	300	300	300	300	300	300	5230
K6							300	300	300	300	300	300	300	300	300	300	300	300	3600
K7	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	5400
K8							100	150	200	200	200	200	250	250	250	250	250	250	2550
K9							100	150	200	200	210	250	250	300	300	300	300	300	2860
K10									100	150	200	260	300	300	300	300	300	300	2510
K11									100	150	200	200	200	200	200	200	200	200	1850
K12													100	120	170	200	200	200	990
J1																	40	100	140
J2																	50	100	150
J3																	50	100	150
J4																	50	100	150
J5																50	50	100	200
J6																50	50	100	200
J7																50	50	100	200
J8															50	50	50	100	250
J9														50	100	100	100	100	450
J10														50	100	100	100	100	450
J11														50	100	100	100	100	450
J12														50	100	100	100	100	450
supply	650	780	910	1050	1180	1310	1510	1830	2150	2380	2560	2710	2940	3210	3560	3740	3930	4350	
demand	650	780	910	1050	1180	1310	1510	1830	2150	2380	2560	2710	2940	3210	3560	3740	3930	4350	

Table 7. The amount of blood transportation from regional center to hospitals in all periods under each scenario

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18
T1	30	35	41	48	58	60	69	83	98	108	116	123	134	146	162	170	179	198
T2	25	30	35	41	49	51	58	71	83	92	99	105	114	124	138	145	152	168
T3	21	25	29	33	40	42	48	58	68	76	81	86	94	102	113	119	125	138
T4	16	20	23	26	32	33	38	46	54	60	64	68	74	80	89	94	98	109

Sensitivity analysis

To investigate sensitivity of the objective function to variation in uncertain parameters, sensitivity analysis is performed. In this section we discuss how the supply chain costs (solution robustness) and unmet demand (model robustness) can be balanced at different risk-aversion weights. As mentioned in section 3.2. ω (Risk-aversion weight for unmet of blood demand), is used to consider a tradeoff between the solution robustness and the model robustness. Model robustness is defined as being close to a feasible solution while solution robustness means being close to an optimal solution. A risk averse decision maker who strictly avoids shortage of blood demand chooses higher values for. A more risk-taker, on the other hand, may assign smaller values to ω placing more focus on the cost minimization objective. Hence, variations in the values of risk-aversion weight can help in finding a proper risk-aversion weight and tradeoffs between cost and unmet demand. For different risk-aversion weights, Fig. 3 illustrates the tradeoff between the solution robustness and the model robustness. According to Fig. 3, as the value of ω, increases, the total cost indicating solution robustness increases, while the blood unmet demand indicating model robustness decreases. This implies that at larger risk-aversion weights, there is a tendency towards 'almost' feasible solutions in all earthquake scenarios, at the expense of an increased total cost. The expected unmet demand will eventually reach the zero line at larger risk-aversion weights. This tradeoff can assist in determining an appropriate value for risk-aversion weight. Unmet blood demand can be completely avoided by assigning a large risk-aversion weight. On the other hand, when facing budgetary constraints, a smaller risk-aversion weight results in reduced overall costs while ensuring that the supply chain is robust to most of the scenarios. At ω = 100 the supply chain cost reaches to $51746 and unmet blood demand is zero under any earthquake scenario and, the supply chain is robust in all earthquake scenarios. For this reason, we set ω equal to 100 in the remaining test experiments. Since variability weight (λ) may also take different values, we investigate their impact on the solution robustness and the model robustness. The variations in variability weight are illustrated in Fig. 4. According to Fig.4 the total cost may not necessarily increase at larger λ values and larger value for λ does not necessarily decrease model robustness. At λ = 2 the model robustness reaches its minimum ensuring the lowest unmet blood demand. It is also evident in Fig. 4 that both model robustness and solution robustness are insensitive to further changes in variability weight after λ = 5. As the λ equal to 2 provide maximum demand satisfaction we choose λ = 2 in test experiments.

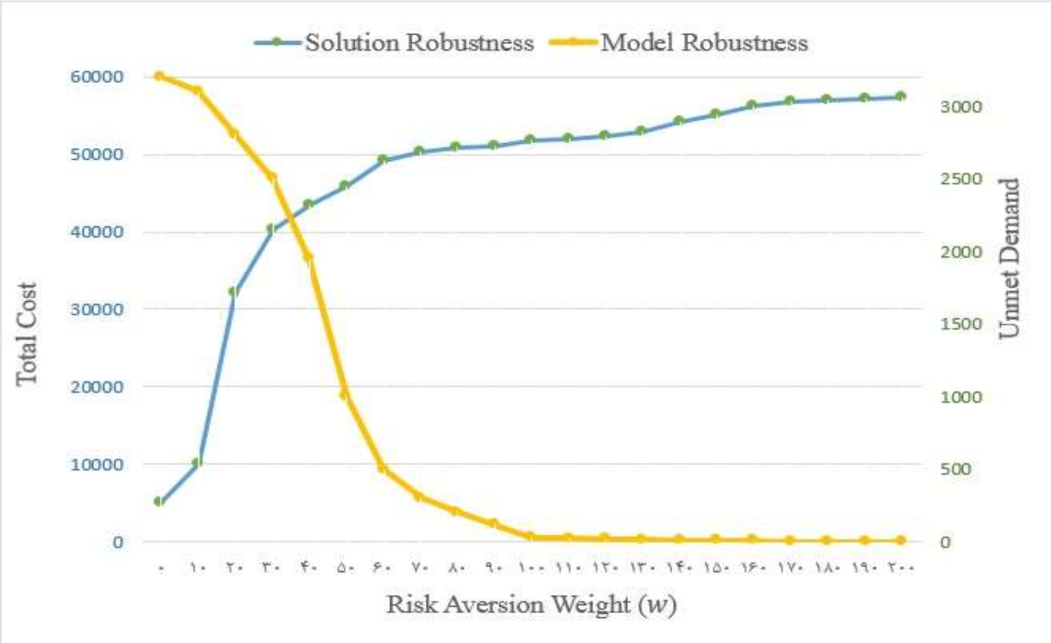

Figure3. Tradeoff between solution robustness and model robustness

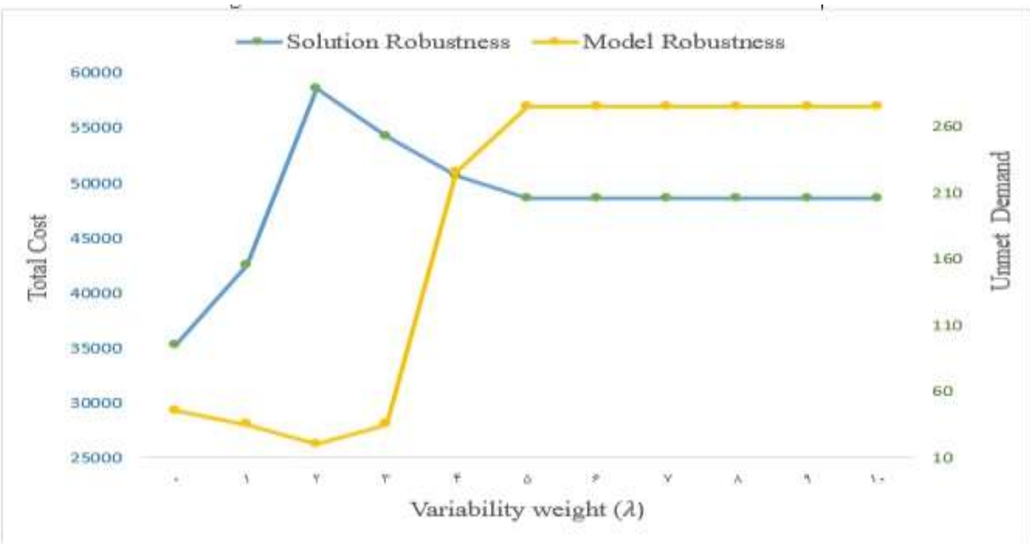

Figure 4. The impact of varying variability weight (λ) on solution robustness and model robustness

Conclusions

Because of increasing attention paid to the health care area in recent years particularly in the emergencies, this paper presented a robust optimization model for the design of an emergency platelet blood supply chain facing supply, demand and costs uncertainties. The proposed model considers economic, environment and social objectives and determines both location and allocation decisions for multiple post-disaster. The proposed model is a multi-echelon supply chain model that consists of blood donors, mobile blood facilities, permanent blood centers, regional blood centers, disposal centers and hospitals. The multi objective model aims to minimize blood corruption, minimize total cost and minimize the blood shortage while ensuring that the network is robust to major disasters. The location decisions involve the number and location of permanent and mobile blood facilities and allocation decisions concern the assignment of facilities to blood donors as well as determining blood inventory levels at each period. To boost the practicality and applicability of our case study, real data from Tehran area was considered. Important practical implications were drawn from the case study. For example, we showed how solution robustness (supply chain cost) can be balanced against model robustness (demand unmet level). The results of the paper are consistent with those obtained by Haghjoo, et al., [2] and Jabbarzadeh, et al., [3]. Despite the above contributions, this study is not without limitations. This model assumed that a blood center remains unaffected in all disaster scenarios. Future research can study a situation where blood centers may also be affected by disasters. Expressing the risk-aversion weight for unmet blood demand as a fuzzy parameter may also result in additional insights and practical implications. We suggest other new and effective methods to face uncertainty (e.g., stochastic programming or fuzzy programming). Also, the study could be also developed by solving the problem with heuristic or meta-heuristic methods in large-scale. The model considered location and allocation decisions, future works can study location, allocation and routing problems in a model. This model assumed whole blood will be supplied by Tehran's donors. The study can expand by considering blood supply from other cities in severe earthquake that blood demand is very high. A few researches evaluated social issue as an important factor for promoting blood supply chain and to motivate people for donating blood. Future works can present social announcements in collection facilities to promote the number of available donors.

Competing Interests
The authors declare no competing interests
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No support.
Authors' contributions

The authors are the same

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