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Calculating of the Optimal Number and Location of Blood Supply Centers in the Case of East Azerbaijan

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Abstract

Background and Objectives: One of the key issues in determining location for blood supply center is the design of blood supply chain. To minimize the cost of blood supply, the donors should be reached easily with appropriate distribution of blood and blood products to the hospital. The aim of this study was to calculate the optimal number and location of different types of blood supply centers.
Methods: This is a mathematical modeling study of potential donors in the East Azerbaijan province cities. The cost of construction and operation for each facility was calculated based on the activities and after adopting a mathematical model. Data were collected during March 2014 to September 2015. The mathematical model developed by software 24.1 GAMS.
Findings: The results showed that optimal locations for constructing of preparation and processing centers of East Azerbaijan province are cities of Maragheh, Mianeh and Marand. Establishing fixed blood supply centers in the cities of Ahar, Tabriz, Shabestar, Azarshahr, Ajab Shir, Bonab, Malekan, Bostanabad and Sarab had the lowest opening and transportation cost. Therefore, optimal situation for mobile teams (MTs) were Julfa, Varzaqan, Khodaafarin, Harris, Tabriz, Osku, Maragheh, Khoda Afarin, Hashtrud and Charuymaq.
Conclusions: The appropriate allocation of satellite, fixed centers and mobile teams for the cities of East Azerbaijan reduces the cost of supplying blood. Observing this can reduce transportation costs.
Key words: Blood supply chain, Blood supply centers, Blood transfusion center, Mobile team, Fixed centers

Background and Objectives

Blood supply chain establishment mainly includes 4 steps of supplying, processing, storage and distribution. In all steps, blood transfusion centers (BTCs) are faced with supplying blood and blood products against operational cost challenges.[1]

Economically, supplying blood and blood products bears the highest costs among all treatment services. This cost includes blood supply from healthy and low risk donors, screening and grouping tests, processing and preparation of blood products from whole blood, storage and transportation.[2,3]

Iranian National Blood Transfusion Organization (IBTO) is the only internationally recognized and authorized organization in Iran responsible for guiding and controlling the blood supply chain and responsible for distribution of the supplied blood from volunteer donors to the beneficiary centers.[4] IBTO, established in 1974, is a centralized and unified body in the country and an integral part of health system of the country. All activities such as volunteer blood donations, processing, storage and distribution of blood and blood products to hospitals as centers of consumption of blood is carried out under IBTO system.[5] Some countries are unable to meet their national requirements for blood and blood components in a timely manner. Since establishment of Iran Blood Transfusion Organization (IBTO,[6] Blood donations include hidden costs, for example for collecting, processing, storing and distributing blood. Most of the previous articles have focused on decreasing such costs.[7-13]

In Iran, there are more than 370 blood supply, preparation, processing, and BTCs[14] and more than 90 BTCs provide supply, storage and distribution of blood and blood products to hospitals. Across the country, among all the centers, 31 of them ensure BTC and in 34 centers specialized tests are being carried out. In general, these centers are fixed centers or mobile teams.

IBTO database or BTC are a place where occur all

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activities related to donor selection, blood products supply, infection tests, blood groups tests, storage and eventually distribution to the blood bank or hospital for clinical applications and distribution centers. Blood Supply and Processing Center (BSPC) in addition to blood apheresis treatment provide production and distribution of blood and blood products. In these centers samples of donors are screened for virus and then sent to BTC database. The Blood Supply Center (BSC) specifically serves as blood supply or apheresis and in these centers, after blood supply, blood bags and donor samples are sent for screening tests and determining blood groups to BSPC or BTC of the same province incompliance with Blood Transfusion Organization standards.[15]

Blood supplying mobile teams (MT) are formed of employees from BTC with blood sampling equipment positioned at predetermined locations and collect blood from volunteer donors.

MTs have different types based on fixed or rotating work in places such as factories, offices, universities or villages and are set up to facilitate access to regular donors or those with a blood donation history.[16]

MTs as well as fixed BSC collect blood and blood bags to be sent to BSPC or BTC of same province for screening blood tests and determining blood groups in compliance with IBTO standards. Screening test results are made available in shortest time possible and sent to the related centers, which gives possibility of registering blood and blood products at treatment centers.[16]

Optimal location for establishment of fixed centers and mobile can have significant reduction in overall cost.[17] Numerous articles have emphasized on the role of blood supply chain design in determining the optimal location of blood supply centers.[18-22]

To this regard, several authors have used integer optimization models such as facility location, allocation, set covering, and routing to deal with the optimization/design of supply chains of blood or other perishable critical products.[23-28] Also, they have considered the flow between facilities in multi-period context, which is more realistic than single period statement since the decisions made in each period change the subsequent decisions in the next periods.[29-34]

Currently, there is a BTC in the city of Tabriz in East Azerbaijan province, Iran with two fixed centers (includes of BSC and BSPC) and mobile blood supply team. Moreover, there are two more MTs and blood preparation centers in the cities Maragheh and Mianeh to carry the task of supplying, and BSPC for East Azerbaijan province. Purpose of this research was to choose the right locations for BSC (MTs, fixed BSC and BSPC) using a novel mathematical model.

Methods

In mathematical models, parameters are values that have been taken from completed studies whereas decision variables are values obtained in response to suitable location of blood supply centers.

In order to provide the model, we assume that the proposed sites of blood supply centers are pre-determined and will not change over time. We also assume that there is no limit to human resources, and post-site centers can be managed without human resource problems.

Parameters are as follows: Individual donors (i), Proposed locations for MTs (j), Location of fixed location blood supply centers (k), and Suggested locations for the BSCP (l); index (t) is considered to show different time intervals.

In this study, calculating the blood supply chain cost was based on the data obtained from published articles, blood supply cost, which includes equipment investment, overload cost of capital equipment, supply expense, cost of overhead consumption, building depreciation expense, amortization expense of automobiles and also taking into account the inflation rate from 2009 to 2018 as well taking into account the calculations of Gharehbaghian et al study.[35,36]

Parameters

$Cl1_{j}$: The cost of using MTs (j)

$Cl2_{k}$: The construction costs of fixed blood supply center (k)

$Cl3_{l}$: Construction costs of preparing and processing center (l)

$O1_{jt}$: Operating costs of MTs (j) in period time (t)

$O2_{kt}$: Operating costs of fixed centers (k) in period time (t)

$O3_{lt}$: Operating costs of preparation and processing center (l) in time period (t)

$O4_{t}$: Operating costs BTC in time period (t)

$D1_{jl}$: The cost of moving the MTs (l) and preparation and processing center (j)

$D2_{kl}$: Transportation cost between fixed Blood supply Center (k) and preparing and processing center (l).

$D3_{j}$: Cost of moving between the MTs (j) and BTC.

$D4_{k}$: Cost of moving between fixed blood supply centers (k) and BTCs.

Bd_{it}: Amount of blood donated by donors (i) in time period (t)

Td_{t}: The total demand for blood in the period (t)

M: A very large number.

The decision variables

$X1_{jt}$: A variable of zero and one, its value is one if in time period (t) the MTs in place (j) are stable, otherwise is zero.

$X2_{\mathrm{k}}$: A variable of zero and one, its value is one if the fixed blood supply center in place (k) are build, otherwise is zero.

$X3_{\mathrm{l}}$: A variable of zero and one, its value is one if BSPC in place (l) are build, otherwise is zero.

$B1_{ijt}$: The amount of blood donated by donors (i) in time period (t) which is referring to MT (j).

$B2_{ikt}$: The amount of blood donated by donors (i) in time period (t) which is referring to fixed BSC center(k).

$B3_{iLt}$: The amount of blood donated by donors (i) in time period (t) which is referring to preparing and processing center (l).

$B4_{it}$:The amount of blood donated by donors (i) in time period (t) which is referring to BTC.

$B5_{jlt}$ :: The amount of blood which MT (j) in time period (t) after blood supply delivered to preparing and processing center (l).

$B6_{klt}$: The amount of blood which fixed BSC (k) in time period (t) after blood supply delivered to preparing and processing center (l)

$B7_{jt}$: The amount of blood which MT (j) in time period (t) after blood supply delivered to BTC.

$B8_{kt}$: The amount of blood which fixed BSC (k) in time period (t) after blood supply delivered to BTC.

$\mathrm{Y1_{ij}}$: A variable of zero and one, its value is one if group of donors (i) referring to MT (j) otherwise is zero.

$\mathrm{Y2_{ik}}$:A variable of zero and one, its value is one if group of donors (i) referring to BSC (k) otherwise is zero.

$\mathrm{Y3_{il}}$:A variable of zero and one, its value is one if group of donors (i) referring to preparing and processing center (l) otherwise is zero.

$\mathrm{Y4_{i}}$:A variable of zero and one, its value is one if group of donors (i) referring to BTC otherwise is zero.

$\mathrm{Y5_{jl}}$: A variable of zero and one, its value is one if the MT (j) delivers the supplied blood to preparing and processing center (l) otherwise is zero.

$\mathrm{Y6_{kl}}$:A variable of zero and one, its value is one if the BSC(k) deliver the supplied blood to preparing and processing center (l) otherwise is zero.

$\mathrm{Y7_{j}}$:A variable of zero and one, its value is one if the MT(j) deliver the supplied blood to BTC otherwise is zero.

$\mathrm{Y8_{k}}$: A variable of zero and one, its value is one if the BSC(k) deliver the supplied blood to BTC otherwise is zero.

The Functional Objective

The functional objective value of total construction cost of fixed centers and institution building (first three values), operational (next 4 values) and the cost of moving between centers (last 4 values) corresponds to (1):

$$Min\,Z = \sum_{j}\mathrm{Cl1_j}\,X1_{\mathrm{j}} + \sum_{k}\mathrm{Cl2_k}\,X2_{\mathrm{k}} + \sum_{l}\mathrm{Cl3_l}\,X3_{\mathrm{l}} + \sum_{i,j,t}\mathrm{O1_{jt}}\,B1_{ijt} + \sum_{i,j,t}\mathrm{O2_{kt}}\,B2_{ikt} + \sum_{i,l,t}\mathrm{O3_{lt}}\,B3_{iLt} + \sum_{\mathrm{i,t}}\mathrm{O4_t}\,B4_{it} + + \sum_{j,l}\mathrm{D1_{jl}}\,\mathrm{Y5_{jl}} + \sum_{j,l}\mathrm{D2_{kl}} + \sum_{i}\mathrm{D3_j}\,\mathrm{Y7_j} + \sum_{k}\mathrm{D4_k}\,\mathrm{Y8_k} \quad (1)$$

Constraints

Constraint 1 in relation to (2):

This restriction indicates that group of donors to donate blood refers to one of the MTs or fixed BSC or preparation and processing center or to BTC:

$$\sum_{\mathrm{j}}\mathrm{Y1_{ij}} + \sum_{\mathrm{k}}\mathrm{Y2_{ik}} + \sum_{\mathrm{l}}\mathrm{Y3_{il}} + \mathrm{Y4_i} \le 1 \qquad \forall i \qquad (2)$$

Constraint 2 in relation to (3):

This limitation shows that a MT can collect blood donations only when it is stable in location:

$$B1_{ijt} \le M.X1_{jt} \qquad \forall i,j,t \qquad (3)$$

Constraint 3 in relation to (4):

This limitation shows that a fixed BSC can collect blood from voluntary donors only when built at their location:

$$B2_{ikt} \le M.X2_{\mathrm{k}} \quad \forall i,k,t \qquad (4)$$

Constraint 4 in relation to (5):

This limitation shows that the preparation and processing centers can collect blood donations only when built at a location:

$$B3_{iLt} \le M.X3_{\mathrm{l}} \quad \forall i,l,t \qquad (5)$$

Constraint 5 in relation to (6):

States that at any given time the total blood donated by different groups of blood donors must be equal to supplied blood by BSC:

$$\sum_{i,j}B1_{ijt} + \sum_{\mathrm{i,k}}B2_{ikt} + \sum_{i,l}B3_{iLt} + \sum_{i}B4_{it} \le \sum_{\mathrm{i}} \qquad (6)$$

Constraint 6 in relation to (7):

Shows that all the supplied blood in BTC and BSPC must not exceed the total demand of health centers in that period:

$$\sum_{\mathrm{i},l}B3_{iLt} + \sum_{\mathrm{j,l}}B5_{jlt} + \sum_{k,l}B6_{klt} + \sum_{i}B4_{it} + \sum_{j}B7_{jt} + \sum_{k}B8_{kt} \ge \mathrm{Td_t} \ \forall t \qquad (7)$$

As shown in Table 1, the total number of suggested

Table 1. Number of Proposed BSC for the Cities of East Azerbaijan

ID of City	Name of City	Current Population (thousands)	Number of MTs	Number of BSC	Number of BSPC
C1	Marand	240	2	1	1
C2	Julfa	55	1	0	0
C3	Varzaqan	49	1	0	0
C4	Khoda Afarin	34	1	0	0
C5	Kalibar	92	1	0	0
C6	Hurand	4	1	0	0
C7	Ahar	155	2	1	0
C8	Heris	71	1	0	0
C9	Tabriz	1652	8	4	2
C10	Shabestar	127	2	1	0
C11	Oskou	77	1	0	0
C12	Azarshahr	104	2	1	0
C13	Ajab Shir	86	1	0	0
C14	Bonab	132	2	1	0
C15	Malekan	105	2	1	0
C16	Maragheh	245	2	2	1
C17	Hashtrud	68	1	0	0
C18	Bostanabad	101	1	1	0
C19	Sarab	138	2	1	0
C20	Mianeh	200	2	2	1
C21	Charuymaq	36	1	0	0

BSC centers, preparation and processing centers, fixed centers and MTs of blood supply was determined through the modeling and optimal locations of which were noted through calculation. Meanwhile, the provincial capital Tabriz was considered as center of BTC in the calculations with fixed determinates. Also, Figure 1 shows the proposed BSCs for the cities of East Azerbaijan.

n online Table S1 (see Supplementary file 1), the distance between different cities of East Azerbaijan were presented. By using these numbers, the distance between the preparing and processing centers and fixed BSC proposed stationing of MTs in various cities can be calculated.

The distance had been considered in kilometers which cost an average of US$0.5 for each kilometer displacement.

In Table 2, the high frequency usage of packed red blood cells is considered as the most important and most widely used product in treatment centers and as the product distributed in the first and second semester of 2014 and first semester of 2015 and other products are not taken into consideration such as platelet and whole blood.

Table 2. Whole Blood Distribution Centers in East Azerbaijan Province

Time Frame	First 6 Months of 93 (t=1)	Second Half of 93 (t=2)	First 6 Months of 94 (t=3)
The amount of distributed blood	40600	42061	43575
The amount of blood demand	42700	43800	44200

The following results are calculated by GAMS 22.9 using CPLEX solver on a laptop with a core i5 2.5 GHz CPU and 4.0 GB of RAM.

Results

Purpose of this research was to choose the right location

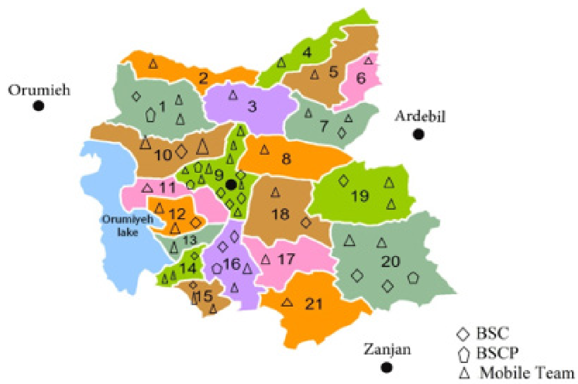

Figure 1. Proposed BSC for the Cities of East Azerbaijan.

Table 3. The number of BSC for the Cities of East Azerbaijan in the Lowest Cost Based on Mathematical Modeling

City Name	Current Population (thousands)	Number of MTs	Number of fixed BSC	Number of BSPC
Marand	240	1	0	0
Julfa	55	0	0	0
Varzaqan	49	0	0	0
Khoda Afarin	34	0	0	0
Kalibar	92	0	0	0
Hurand	4	0	0	0
Ahar	155	0	1	0
Heris	71	0	0	0
Tabriz	1652	1	1	0
Shabestar	127	0	0	0
Oskou	77	0	0	0
Azarshahr	104	0	0	0
Ajab Shir	86	1	0	0
Bonab	132	1	0	0
Malekan	105	1	0	0
Maragheh	245	1	0	1
Hashtrud	68	1	0	0
Bostanabad	101	0	0	0
Sarab	138	0	0	0
Mianeh	200	0	0	1
Charuymaq	36	0	0	0

Table 4. Optimal Cost of Blood Supply Facilities

Blood supply facilities	Cost with considering inflation (Rial)	Cost calculated in (Davoudi-kiakalayeh et al (2012
BCC	1592971073	461374553
BSPC	8895008107	2576274270
Mobile teams	530080882	153528105
BTC	52419346542	15182292374

for BSC (MTs, fixed BSC and BSPC) and a novel mathematical model is used for this problem.

As shown in Table 3, if these centers were established in different cities of east Azerbaijan province using mathematical model calculations the cost of blood supply will be effectively minimized. Because of minimization model, all amounts of variables are optimized. Table 4 shows the optimal cost in all blood supply facilities.

Results summarized in Table 3 shows the suitable preparation and processing centers in the cities of Maragheh and Mianeh, and the fixed centers in the cities of Tabriz and Ahar. Also, it recommends to send squads to cities of Marand, Tabriz, Ajab Shir, Malekan, Maragheh and Hashtrud considering that the supplied blood by the fixed centers and MTs should be delivered to one of the BSPC or to BTCs database. Table 5 shows how it can be covered.

Blood supply chain has several expenses such as

Table 5. Coverage of Fixed BSC and MTs

MTs		Fixed BSC	
MT	Delivery Location	BSC	Delivery Location
Hashtrud, Ajab Shir, Bonab and Malekan of MTs	BSPC of Maragheh	Ahar of BSC	BTC of Tabriz
Marand of BSC	BTC of Tabriz	Tabriz of BSC	BTC of Tabriz
Tabriz of BSC	BTC of Tabriz		

process of supply, storage and distribution of blood. Therefore, in developed countries BTCs if struggling with high costs, they compensate for it by selling blood products. Nevertheless, a very important approach to adopt is selecting the optimal supplying locations. In Iran, due to blood and blood products are provided free of charge to treatment centers on the one hand and with regard to use of government resources for the construction and management of BTCs on the other hand, it is necessary to adopt measures to reduce costs and to establish effective supply chain for blood transfusion and distribution.

Therefore, in current research, a novel mathematical model was used to calculate the optimal number and location of blood supply centers to minimize the total cost. BSCs, BSPCs and MTs' locations are then determined.

Table 6 and Figure 2 show comparisons between current states of BSC and findings from current study.

Table 6. Comparison of the Current State With Research Findings

Current Situation	Suggested Situation	
Maragheh, Mianeh	Maragheh, Mianeh	BSCP
Tabriz	Tabriz, Marand	BSC
Maragheh, Tabriz	Maragheh, Hashtrud, Ajab Shir, Bonab Malekan, Tabriz, Marand	MTs

Following is the presentation of current status and research findings:

- None of the towns in the north have established preparation and processing center or fixed BSC. Therefore, establishing a fixed BSC in Marand can reduce the costs of relocation and as a result minimize the total cost of blood supply in the Eastern Azerbaijani province; the mathematical model confirms this.
- MTs are suggested for the cities of Maragheh, Hashtrud, AjabShir, Bonab, Malekan, Tabriz and Marand at different time zones, and due to the distances between the cities devoting two MTs for the blood supply is enough. MTs scheduled circulation in these cities could be examined in future research.

Another issue that can be evaluated is the outcome of covering the location of fixed BSC and MTs by BSPC and BTC. The supplied blood by fixed BSC and MTs must be able to provide coverage to one of the BSPC or a BTC by calculated mathematical model.

It should be mentioned that minor changes take place in order to compensate change in amount of blood donation and demand of blood treatment centers.

Conclusions

Blood collection facilities in the IBTO play a major role in providing blood to the health centers, but due to the high costs of construction and utilization, establishing the facility in all cities of a province is not cost-effective and should be oriented toward finding the correct locations of the facility.

Optimal location of different BSPC covering BSC and MTs can greatly reduce the blood supply chain cost up to medical centers' needs.

Therefore, it is an appropriate mathematical technique to determine the appropriate number and optimal location of BSCs.

The study suggests that:

1. Blood supply facilities in the IBTO play a major role in supplying blood to the health centers, but due to the high costs, construction and utilization of this facility in all cities of a province is not cost-effective and should be oriented toward finding suitable set up locations for the facility.
2. Regarding the gained results for changing of BCCs, a technical and economic feasibility study seems necessary. In Iran, building and land of BTC, BCCs and BCPCs are charitable. Indeed, BSCs and BSPCs location change is profitable.

Competing Interests

The authors declare no competing interests

Authors' Contributions

A novel mixed-integer linear program is presented for the blood supply chain problem to integrate both strategic and tactical decisions with flexibility to cover varying proportions of demands and blood donors in the IBTO.

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Supplementary Materials

Supplementary file 1 contains Table S1.

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