Calculating of the optimal number and location of blood supply centers in the case of East Azerbaijan

Mahdi Yousefi Nejad Attari
1Department of Industrial Engineering, Bonab branch, Islamic Azad University, Bonab, Iran

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 calculating of the optimal number and location of different various types blood supply centers

Methods:
This was 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 which a mathematical model has been used. Blood supply centers was included fixed centers and mobile teams. Data collection for this study was obtained in March 2014 to September 2015. The mathematical model developed by software 24.1 GAMS

Results:
The location of Blood Transfusion Centers in the city of Tabriz in East Azerbaijan province were showed that optimal location 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 were Julfa, Varzaqan, Khodaafarin, Harris, Tabriz, Osku, Maragheh, Khoda Afarin, Hashtrud and Charuymaq.

Conclusion:
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. Therefore, the blood transfusion organization should choose the places to set up the blood supply centers to reduce its costs.

Key words:
Blood supply chain, Blood supply centers, Blood transfusion center, Mobile team, Fixed centers
Background and Objectives:

Blood supply chain has been established mainly consisting of four steps includes of supplying, processing, storage and distribution. In all steps, Two basic challenges faced by Blood transfusion centers (BTC) in the world are supply of blood and blood products and on other hand to maintain the operational cost (1).

Economically, supplying blood and blood products have high cost, therefore supplying safe blood and blood products is highest cost bearing 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).

National Iranian Blood Transfusion Organization(IBTO) is the only internationally recognized and authorized organization in Iran which is responsible for guiding and controlling the blood supply chains from beginning to the end which means it is responsible for distribution of the supplied blood from volunteer donors to the beneficiary centers(4). Iranian Blood Transfusion Organization, which was established in 1974, as a centralized and unified body in the country which is now 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 a centralized system in IBTO (5-6)

Since blood donations are carried out voluntarily in Iran, collecting, processing, storing and distributing blood has become a hidden cost. Most of the previous articles have also focused on decreasing costs.(19-25)

In Iran, more than 90 blood transfusion or processing centers 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 completely separate in 34 centers specialized tests are carried out. In general, to supply blood all the centers that have been mentioned are fixed centers or mobile teams. There are more than 370 blood supply, preparation, processing, and BTC in the country (7).
IBTO database or BTC can be defined as a place where all activities related to donor selection, blood supply and its products including whole blood or aphaeresis, testing of infections transmitted through blood and blood products, tests to determine blood groups, the production of blood products, storage and eventually distribution to the blood bank or hospital for clinical applications and distribution centers that are associated with clinical services. 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 sent to BTC database. The Blood supply Center (BSC) is specific only for blood supply or apheresis. 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 in compliance with Blood Transfusion Organization standards.

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.

Mobile teams have different types based on fixed or rotating work in places such as factories, offices, universities or villages and to facilitate access to regular donors or with a history blood donation, blood supply will randomly done in exhibitions, towns or large villages. Mobile teams as well as fixed BSC collect blood and blood bags are 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.

Optimal location for establishment of fixed centers and mobile teams blood supply and processing can have significant reduction in overall cost. It has also been mentioned in numerous published articles that the blood supply chain design emphasis on determining the optimal location of blood supply centers.

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. Also in this paper considers flow between facilities in multi-period context, which is more realistic than single period statement
because the decisions made in each period change the subsequent decisions in the next periods; this assumption is seldom considered in the literature (32-37).

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 team blood supply. Moreover, there are two more mobile teams and blood preparation centers in the cities Maragheh and Mianeh to carry the task of supplying, BSPC for East Azerbaijan province.

Purpose of this research was to choose the right location for BSC (mobile teams, fixed BSC and BSPC) and a novel mathematical model is used for this problem

Methods:
In mathematical models, parameters are values that have been taken from completed studies whereas decision variables were values that have been 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 mobile teams (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.

Blood supply chain Cost in this study were based on calculations of published article, blood supply which includes equipment investment, overload cost of capital equipment, supply expense, cost of overhead consumption, building depreciation expense, amortization expense of automobiles and miscellaneous and also taking into consideration inflation rate in the from 2009 to 2018 as well taking into considerations the calculations of Gharehbaghi et.al paper (16),(17), (18),(23), (25).

Parameters:

- **C1j:** The cost of using mobile teams (j)
- **C2k:** The construction costs of fixed blood supply center (k)
- **C3l:** Construction costs of preparing and processing center (l)
- **O1jt:** Operating costs of mobile teams (j) in period time (t)
- **O2kt:** Operating costs of fixed centers (k) in period time (t)
- **O3lt:** Operating costs of preparation and processing center (l) in time period (t)
- **O4t:** Operating costs BTC in time period (t)
- **D1lj:** The cost of moving the mobile teams (l) and preparation and processing center (j)
- **D2kl:** Transportation cost between fixed Blood supply Center (k) and preparing and processing center (l).
- **D3j:** Cost of moving between the mobile teams (j) and BTC.
- **D4k:** Cost of moving between fixed blood supply centers (k) and BTC.
- **Bdi:** Amount of blood donated by donors (i) in time period (t)
- **Td:** The total demand for blood in the period (t)

M: a very large number.

The decision variables
$X_1_{jt}$: A variable of zero and one, its value is one if in time period (t) the mobile teams in place (j) are stable, otherwise is zero.

$X_{2k}$: A variable of zero and one, its value is one if the fixed blood supply center in place (k) are build, otherwise is zero.

$X_{3l}$: A variable of zero and one, its value is one if BSPC in place (l) are build, otherwise is zero.

$B_{1_{ijt}}$: The amount of blood donated by donors (i) in time period (t) which is referring to mobile team (j).

$B_{2_{ikt}}$: The amount of blood donated by donors (i) in time period (t) which is referring to fixed BSC center (k).

$B_{3_{ilt}}$: The amount of blood donated by donors (i) in time period (t) which is referring to preparing and processing center (l).

$B_{4_{it}}$: The amount of blood donated by donors (i) in time period (t) which is referring to BTC.

$B_{5_{jit}}$: The amount of blood which mobile team (j) in time period (t) after blood supply delivered to preparing and processing center (l).

$B_{6_{klt}}$: The amount of blood which fixed BSC (k) in time period (t) after blood supply delivered to preparing and processing center (l)

$B_{7_{jt}}$: The amount of blood which mobile team (j) in time period (t) after blood supply delivered to BTC.

$B_{8_{kt}}$: The amount of blood which fixed BSC (k) in time period (t) after blood supply delivered to BTC.

$Y_{1_{i}}$: A variable of zero and one, its value is one if group of donors (i) referring to mobile team (j) otherwise is zero.

$Y_{2_{ik}}$: A variable of zero and one, its value is one if group of donors (i) referring to BSC (k) otherwise is zero.

$Y_{3_{il}}$: 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.

$Y_{4_{i}}$: A variable of zero and one, its value is one if group of donors (i) referring to BTC otherwise is zero.

$Y_{5_{j}}$: A variable of zero and one, its value is one if the mobile team (j) delivers the supplied blood to preparing and processing center (l) otherwise is zero.

$Y_{6_{kl}}$: 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.

$Y_{7_{j}}$: A variable of zero and one, its value is one if the mobile team(j) deliver the supplied blood to BTC otherwise is zero.

$Y_{8_{k}}$: 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 four values) and the cost of moving between centers (last four values) corresponds to:
Min \[ Z = \sum_{j} C1_{ij} X1_{ij} + \sum_{k} C12_{ik} X2_{ik} + \sum_{j} C13_{ij} X3_{ij} + \sum_{i,j} O1_{ji} B1_{ji} + \]
\[ \sum_{i,j} O2_{ki} B2_{ki} + \sum_{i,j} O3_{ij} B3_{ij} + \sum_{i,j} O4_{ij} B4_{ij} + \sum_{j} D1_{ji} Y5_{ji} + \sum_{j} D2_{ki} Y6_{ki} + \]
\[ \sum_{j} D3_{ji} Y7_{ji} + \sum_{k} D4_{k} Y8_{k} \]

**Constraints:**

**Constraint 1:**
This restriction indicates that group of donors’ to donate blood refers to one of the mobile teams or fixed BSC or preparation and processing center or to BTC:
\[ \sum_{j} Y1_{ij} + \sum_{k} Y2_{ik} + \sum_{i} Y3_{ii} + Y4_{i} \leq 1 \quad \forall i \]

**Constraint 2:**
This limitation shows that a mobile team can collect blood donations only when it is stable in location:
\[ B1_{ji} \leq M \cdot X1_{ij} \quad \forall i, j, t \]

**Constraint 3:**
This limitation shows that a fixed BSC can collect blood from voluntary donors only when built at their location:
\[ B2_{ik} \leq M \cdot X2_{ik} \quad \forall i, k, t \]

**Constraint 4:**
This limitation shows that the preparation and processing centers can collect blood donations only when built at a location:
\[ B3_{ik} \leq M \cdot X3_{i} \quad \forall i, l, t \]

**Constraint 5:**
States that at any given time the total blood donated by different groups of blood donors must be equal to supplied blood by BSC:
\[ \sum_{i,j} B1_{ij} + \sum_{i,k} B2_{ki} + \sum_{i,j} B3_{ij} + \sum_{j} B4_{ji} \leq \sum_{i} Bd_{i} \quad \forall t \]

**Constraint 6:**
Shows that all the supplied blood in BTC and BSPC must not exceed the total demand of health centers in that period:
\[ \sum_{i,j} B3_{il} + \sum_{j,k} B5_{jk} + \sum_{k,l} B6_{kl} + \sum_{i} B4_{i} + \sum_{j} B7_{ji} + \sum_{k} B8_{ki} \geq Td_{i} \quad \forall t \]

In Table 1 Total number of Suggested BSC centers, preparation and processing centers, fixed centers and mobile teams of blood supply was determined through the modeling and optimal locations of which were noted through calculation. Meanwhile, as the provincial capital Tabriz was considered as center of BTC in the calculations with fixed determinates. Also In figure 1 is shown proposed BSC for the cities of East Azerbaijan.

**Table 1: number of proposed BSC for the cities of East Azerbaijan**

<table>
<thead>
<tr>
<th>ID of City</th>
<th>Name of City</th>
<th>Current population (thousands)</th>
<th>Number of mobile teams</th>
<th>Number of BSC</th>
<th>Number of BSPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Marand</td>
<td>240</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C2</td>
<td>Julfa</td>
<td>55</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C3</td>
<td>Varzaqan</td>
<td>49</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C4</td>
<td>Khoda Afarin</td>
<td>34</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
In Appendix 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 mobile teams in various cities can be calculated. The distance had been considered in kilometers which cost an average of 0.5$ for each kilometer displacement.

In Table 2, for high frequency usage of packed red blood cells (PRBC) 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.

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

Table 2: whole blood distribution centers in East Azerbaijan province
Results:
Purpose of this research was to choose the right location for BSC (mobile teams, fixed BSC and BSPC) and a novel mathematical model is used for this problem.
The result in this study showed in Table 3 that if these centers were established in different cities of east Azerbaijan province by using mathematical model calculations the cost of blood supply will be effectively minimized. Because of Minimization model, all amounts of variables are optimized. In following table 4 shows optimal cost in all blood supply facilities.

Table 3: The number of BSC for the cities of East Azerbaijan in the lowest cost based on mathematical modeling

<table>
<thead>
<tr>
<th>City Name</th>
<th>current population (thousands)</th>
<th>Number of mobile teams</th>
<th>number of fixed BSC</th>
<th>number of BSPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marand</td>
<td>240</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Julfa</td>
<td>55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Varzaqan</td>
<td>49</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Khoda Afarin</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kalibar</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hurand</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ahar</td>
<td>155</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Heris</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tabriz</td>
<td>1652</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shahrestar</td>
<td>127</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oskou</td>
<td>77</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Azarshahr</td>
<td>104</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ajab Shir</td>
<td>86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bonab</td>
<td>132</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malekan</td>
<td>105</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maragheh</td>
<td>245</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hashtrud</td>
<td>68</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bostanabad</td>
<td>101</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sarab</td>
<td>138</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mianeh</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charuymaq</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4: optimal cost of blood supply facilities

<table>
<thead>
<tr>
<th>Blood supply facilities</th>
<th>Cost with considering inflation (Rials)</th>
<th>Cost calculated in Davoudi-kia golpayeh et al. (2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCC</td>
<td>159,974,787</td>
<td>391,316,570</td>
</tr>
<tr>
<td>BSPC</td>
<td>889,500,810</td>
<td>2,558,274,770</td>
</tr>
<tr>
<td>Mobile teams</td>
<td>524,193,465</td>
<td>1,535,281,500</td>
</tr>
<tr>
<td>BTC</td>
<td>524,193,465</td>
<td>1,535,281,500</td>
</tr>
</tbody>
</table>
Results summarized in Table 3 showed that suitable preparation and processing centers in the cities of Maragheh and Mianeh, fixed centers in the cities of Tabriz and Ahar. Also recommended to collect blood by squads travel to cities of Marand, Tabriz, Ajab Shir, Malekan, Maragheh and Hashtrud.

Considering that the supplied blood by the fixed centers and mobile teams should be delivered to one of the BSPC or to database BTCs. It is shown in Table 5 how it can be covered.

### Table 5: Coverage of fixed BSC and mobile teams

<table>
<thead>
<tr>
<th>Mobile teams</th>
<th>Delivery location</th>
<th>Fixed BSC</th>
<th>Delivery location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hashtrud, Ajab Shir, BONAB and Malekan of mobile teams</td>
<td>BSC of Maragheh</td>
<td>Ahar of BSC</td>
<td>BTC of Tabriz</td>
</tr>
<tr>
<td>Marand of BSC</td>
<td>BTC of Tabriz</td>
<td>Tabriz of BSC</td>
<td>BTC of Tabriz</td>
</tr>
<tr>
<td>Tabriz of BSC</td>
<td>BTC of Tabriz</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Discussion:**
Blood supply chain has several of expenses as process of supply, storage and distribution of blood. Therefore, in developed countries BTCs if struggling with high costs, they compensate by selling, but 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 is used to calculate the optimal number and location of blood supply centers with goal of minimizing total cost. BSCs, BSPCs and mobile teams locations are determined.

**Findings:**
Table 6 and figure 2 is the comparison between current states of BSC with findings from the study.
Following is the presentation of current status and research findings:

- Considering that none of the towns in the north have established preparation and processing center or fixed BSC. Therefore, building fixed BSC in Marand can reduce the costs of relocation and as a result minimizing the total cost of blood supply in the Eastern Azerbaijani province and the mathematical model results also confirms this.

- Mobile teams has been suggested for the cities of Maragheh, Hashtrud, AjabShir, Bonab, Malekan, Tabriz and Marand which is at different time zones due to the distances between the cities, devoted two mobile teams for the blood supply is enough. Mobile teams schedule circulation in these cities could be examined in future research.

But another issue that can be discussed and evaluated is the outcome of covering the location of fixed BSC and mobile teams by BSPC and BTC.

Considering that the supplied blood by fixed BSC and mobile teams 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.

**Conclusion**
Blood collection facilities in the IBTO play a major role in providing blood to the health centers, but due to the cost of constructing this facility, construction and utilization of this facility in all cities of a province is not cost-effective and should be oriented toward the correct location of the facility. Optimal location of different BSPC covers BSC and mobile teams can greatly reduce the blood supply chain cost and provide medical centers of their needs. Therefore, it is appropriate nationwide usage mathematical technique to determine the appropriate number and optimal location of BSC. Finally, the management suggestions point to the results:
1-Blood supply facilities in the IBTO play a major role in supplying blood to the health centers, but due to the cost of constructing this facility, construction and utilization of this facility in all cities of a province is not cost-effective and should be oriented toward the suitable location of 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 is charitable. Indeed location change of BSCs and BSPCs is profitable.

Abbreviations:
BSC: Blood supply center
PRBC: packed red blood cells
BSPC: blood supply and processing center
BTC: Blood transfusion center

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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References:


### Appendix 1: The distance between the East Azerbaijan Province in terms of kilometers

<table>
<thead>
<tr>
<th>City Name</th>
<th>Tabriz</th>
<th>Chirvani</th>
<th>Marvdasht</th>
<th>Varzaneh</th>
<th>Kalibrir</th>
<th>Khoda Afarin</th>
<th>Varamin</th>
<th>Jerd</th>
<th>Mardasht</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marvdasht</td>
<td>73</td>
<td>235</td>
<td>252</td>
<td>214</td>
<td>112</td>
<td>180</td>
<td>180</td>
<td>180</td>
<td>73</td>
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<tr>
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<td>138</td>
<td>290</td>
<td>324</td>
<td>286</td>
<td>211</td>
<td>279</td>
<td>295</td>
<td>279</td>
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<tr>
<td>Varzaneh</td>
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<td>235</td>
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<td>140</td>
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<td>0</td>
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<td>205</td>
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<tr>
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