

A Model for Blood Bank Facility-Location Problem in Post-Disaster Area

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To cite this document:

Habibi, R., & Panjaitan, A. C. (2022). A Model for Blood Bank Facility-Location Problem at Post Disaster Area. ADI Journal on Recent Innovation, 4(2), 128–137.

DOI : <https://doi.org/10.34306/ajri.v4i2.849>



Author

Notification

13 December
2022

Final Revised

20 December
2022

Published

21 December
2022



Abstract

Effective handling of post-disaster victims is essential for the safety of humanity, both direct victims and those affected by the disaster. Especially the effectiveness, including a reliable network design for the distribution of essential commodities in the form of blood units, where a disaster can suddenly cause the demand for blood units to be high, but the supply in the hospital is not enough. The main objective of this research is to model and solve the problem of determining the location of post-disaster temporary blood bank facilities that are expected to serve hospitals that must be located in such a way with a minimum response time to be able to help hospital requests in the nearest area. Completing the model is done by making the distance to the hospital minimal and also expected to maximize the number of blood donors that can be reached. Heuristic Tabu Search (HTS) is proposed as a solution to solving the problem by taking the case of multi-facility-location with the mini-max model by calculating the distance using the euclidean distance. The number of temporary blood banks can be optimized by calculating the minimum total cost by considering various cost elements such as transportation costs, fixed costs, and maintenance costs. To demonstrate the proposed solution, a case study on hospitals and blood banks in Medan City was presented.

Keywords : Location-Facilities, Temporary Blood Facility, Heuristic Tabu Search, Minimax.



1. Introduction

Disasters are unexpected events that result in human suffering, loss of human life, ecological disruption, environmental destruction, and worsening of health due to the scale of the damage, which is sufficient to require a rapid and extraordinary response from non-affected areas and other communities[1]. The causes of disasters include natural anomalies (such as hurricanes, earthquakes, volcanic eruptions, tornadoes, floods, and forest fires) or human actions such as nuclear accidents, chemical spills, and terrorism, which have a significant impact on humans (in terms of injury) and causes a spike in increased demand for blood supply in the post-disaster area, requiring effective blood supply planning[2].

Disasters that have occurred before, such as the tsunami in 2004 in Aceh, the Bam earthquake in 2003 in Iran, the Great quake in 2011 in East Japan, the earthquake in 2008 in Sichuan, the flood in 2015 in Chennai or the big earthquake in 2015 in Nepal, it has been shown that the blood supply is vulnerable from the influence of external disturbances[3]. In almost all countries, proper and safe blood products and blood supply management has become a national interest because it involves the safety of human life[4]. A lesson from the Bam earthquake in Iran where the high death rate of disaster because of the ineffective design of the blood distribution network[5].

There needs to be more than the supply of blood units in hospitals in hospitals to supply needs or high demand for blood units in difficult disaster situations[6]. Provision of an adequate blood supply through the placement of several blood center facilities, namely places for reception, collection, testing, and processing, including distribution and storage of blood, may very well require high costs due to the occurrence of a disaster which is very difficult to predict[7]. Blood center facilities must collect blood from eligible donors and store it properly, as there can be severe death consequences when blood is needed but unavailable[8].

The blood center must also coordinate dynamic (temporary) blood collection facilities and accommodate static blood collection facilities[9]. When designing the blood supply chain, the blood product's quality, the blood's expiry date, and the storage period must be considered to avoid expiration. Balancing the demand and supply of blood in post-disaster areas is difficult because the market is stochastic, the collection is irregular, and blood products are easily damaged[10].

The design of the blood supply network has a primary goal to minimize costs incurred for blood supply by efficiently estimating demand and determining the capacity and optional location of blood facilities, so an approach is needed to determine the appropriate area of temporary facilities for blood supply after a disaster[11]. This study aims to create a model to find a brief blood bank that can serve the demand of the nearest hospital with a high response rate in a post-disaster area[12]. Completing the model is done by making the distance to the hospital minimal and also expected to maximize the number of blood donors that can be reached[13].

2. Literature review

2.1 Facility-Location Issues

Esmailikia et al. have confirmed that during the last thirty years, the development of academic research on-site facilities has been very rapid. Jabbarzadeh et al. revealed that the main facility-location problem is minimizing transportation costs by identifying the best geographical arrangement so that one or more facilities can be determined that need to be located. Facility-location problems can be distinguished as follows: (a) the number of new facilities that can be opened: single facility, multiple facilities; (b) location capacity: no capacity, capacity; (c) solution space: discrete, continuous; (d) distance measurements: euclidian, rectilinear, actual; and (e) objective function: maxi-min, mini-max, mini-sum.

The previous research literature on the facility-location problem, as An et al. raised the facility-location capacity problem and solved it with an algorithm based on linear programming. Tran et al. studied using a heuristic method: hypergraph multi-exchange to solve the location-facility problem with a single source capacity. Bilir et al. discussed a competitive facility location model for integrated multi-objective Supply chain networks and solved it by multi-objective optimization and mixed integer linear programming. Guo et al. studied a proposed solution with a hybrid evolution algorithm to solve the two-stage capacity location-facility problem. Meanwhile,

Maas et al. present a facility-location model with inventory by reducing hard capacity constraints and solving those problems using mixed integer programming. Many different methodologies and models have been developed and applied to formulate models and solve various facility-site problems. But, if we review most of the previous research on the topic of facility location, it still has not succeeded in solving the issue of the unique characteristics of emergencies with heavy damage impacts (whether it is an earthquake or a terrorist disaster) found while searching for the location of the facility in a crisis.

2.2 The Model of Facility-Location for Emergency Relief Distribution

In recent decades, there has been a trend of increasing the number of incidents of disasters and the number of victims affected by the damage caused by disasters. Many researchers have studied existing literature related to various disaster response operations techniques. Cheraghi & Hosseini-Motlagh looked at the problem of optimal blood transport in disaster relief and solved it with chance-constrained programming. Chen & Yu raised the issue of temporary location-location for emergency medical services and solved it with k-medoids, network-based clustering, and integer programming. Akgün et al. discussed the facility-location problem in the design of disaster relief distribution by considering the risks resolved using a fault tree analysis. Salman & Yücel studied disaster relief facility-location problems under network uncertainty and solved them with scenario generation algorithms and tabu search (HTS) heuristics. Ghezavati et al. researched the reliability of location facilities in disaster situations using robust optimization and chance-constrained programming with a settlement methodology.

Determining the location of temporary blood bank facilities to maintain adequate blood supplies, strategic decisions influence the success of disaster management operations in the form of the brief of blood supplies for post-disaster use. The response time for disaster aid distribution can be minimized if the facilities can be located at a point close to where the disaster occurred. This study had the main objective of placing a temporary blood bank facility that minimizes transportation time to hospitals within its reach. In addition, the request for blood supply to the nearest hospital after the disaster must also be fulfilled by obtaining as much blood supply as possible from people who meet the requirements to donate blood. Also, the search for the most efficient number of blood bank facilities to be deployed in areas close to the point of disaster.

2.3 Facility-location Problems using Tabu Search Heuristic (HTS) Approach

HTS is categorized into a group of meta-heuristic approaches after Glover (1989) introduced it with its power to search the solution space outside the local optimal solutions so that it does not get stuck in local optimality (Al-Sultan & Al-Fawzan). HTS has been successfully applied to various problem-solving, such as timetable problems (Lü & Hao), assignment problems (Diaz & Fernández), Job shop scheduling (Pezzella & Merelli), vehicle routes (Taillard et al.), as well as problems with location facilities (Sun). Methodological steps have been devised to determine potential sites for temporary blood bank locations. The steps for implementing HTS are as follows: (1) initial solution initialization; (2) all possible location rearrangements are explored; if the temporary solution is not better than the solution generated in the current step, then the resulting solution is used; otherwise, check the list of tabu solutions, select and execute another solution that is not listed in the list of tabu solutions. (3) then the temporary solution is updated; (4) get the final solution in the form of temporary blood bank facility coordinates.

2.4 Application of Multi-Criteria Decision Making

Multi-criteria decision making (MCDM) was initially introduced in management science research, and later application of the methodology to facility-location problems has also been successful. Decision makers in implementing the MCDM methodology are carried out by selecting the best predetermined alternative solutions which are influenced by the tendencies of each criterion as well as the interaction and relationship between these criteria. MCDM methods that have been known to researchers include elimination and choice expressing reality (ELECTRE), hierarchical additive weighting, simple additive weighting (SAW), analytic network process (ANP), TOPSIS (Vafaei. & Oztaysi ; Roh et al.), and the analytic hierarchy process (AHP) (Bozorgi-Amiri & Asvadi).

3. Research Method

3.1 Model Formulation

Formulating the problem of temporary blood bank location facilities into a mathematical formula model is carried out by considering various constraints and costs that must be paid. The notation, assumptions and constraints used for the formulation of the mathematical model are as follows:

Notation:

In this model formulation, the notation used is:

i	Permanent Blood Facility, $i \in I = \{1, \dots, m\}$
j	Temporary Blood Bank Facility, $j \in J = \{1, \dots, n\}$
k	Hospital Facility, $k \in K = \{1, \dots, n\}$
C	Unit Cost
N	Total number of blood units
F	Fixed temporary blood facility cost
D	Distance from existing facilities
M	Maintenance costs
T_c	Transportation costs per blood unit
(a_i, b_i)	Permanent blood bank facility coordinates
(c_i, d_i)	The Hospital coordinates
(x_i, y_i)	Provisional Blood Center Coordinates

The formula of mathematics model can get by taking into account several assumptions, namely: (1) the location of the blood center and hospital is known, (2) using Euclidean distance calculations, and (3) the search for new facilities is carried out without obstacles. The main objective is to place a temporary blood bank facility that minimizes transportation time to hospitals within its reach in disaster condition. The model is obtained through the following steps: the first step is to collect the input data needed by the model. Meanwhile, the input data needed in this study are: coordinates of each candidates temporary blood bank, coordinates of each permanent blood center, number of units, fixed cost of opening a facility, distance from the hospital to the permanent facility, maintenance costs, transportation costs per unit, and unit costs. The second step is to set the objective function, where the aim of this research is to minimize the total cost required to build a temporary blood bank facility while at the same time determining the optimal number of these facilities.

First objective function, minimum total distance between facilities:

$$\min \left\{ \max \left(v_{jk} \left((X_j - X_k)^2 + (Y_j - Y_k)^2 \right)^{1/2}, u_{ij} \left((X_j - c_i)^2 + (Y_j - d_i)^2 \right)^{1/2} \right) \right\} \quad (1)$$

To get the optimal solution, it is necessary to minimize the total cost as the second objective function:

$$Z = \min \left\{ (j \times f) + (D \times T_c) + (j \times M) + \frac{(C \times N)}{j} \right\} \quad (2)$$

Objective functions include:

- Fixed costs ($j \times f$)
- Maintenance costs ($J \times M$)
- Transportation costs ($D \times Tc$)
- Part costs $\frac{(C \times N)}{j}$

To complete the objective function, the distance between each facility needs to be calculated. The objective function consists of the distance between each new facility and also the distance between the temporary blood bank facility and the hospital[14]. The limitations or constraints are as follows: (1) the distance between new facilities cannot be more than the objective function; (2) the distance between the permanent blood facility and the temporary blood bank is no more than the objective function[15].

3.2 Determine the Optimal Number of Temporary Blood Bank Facilities

Here, several different cost components are considered, including spare parts costs, facility fixed costs, maintenance costs, and transportation costs[16]. These different cost components are used to consider when determining the optimal number of temporary blood banks. The total cost due to placement of a number of temporary blood bank facilities allocated is calculated for each number of facilities[17]. Figure 1 shows the steps of the methodology for determining the optimal number of provisional blood banks[18].

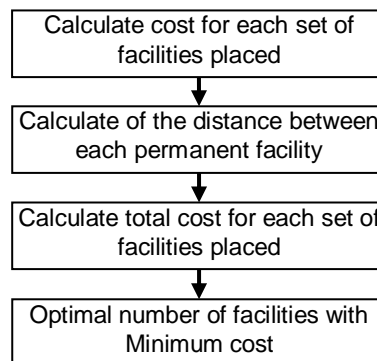


Figure 1: Procedures for Allocating Temporary Blood Bank Locations

4. Case Study

4.1 Data collection

Given the nature of this research, it is essential to obtain real-value data[19]. For this reason, by exploring Google Maps and websites, several methods have been attempted to receive sufficient actual data, including data on the locations of permanent blood centers and significant hospitals[20]. Table.1 shows a complete list of the location coordinates of each major hospital in the city of Medan, and an overview of Google maps for the locations of the major hospitals recorded is presented in Figure.2.

4.2 Tabu Search for Searching Temporary blood banks

Completion of the model that has been shown in the previous section will be explained in this section using HTS. All computational experiments were carried out using the Matlab

2016a application on a laptop with Intel Core i5 2.3 GHz 8 GB RAM specifications. The decision on allocating the temporary location of the blood bank was taken by considering each of the assumptions shown in section 3. The input data for the model consists of: (1) the coordinates of the permanent blood bank location; (2) the coordinates of the hospital location; (3) temporary blood bank spacing; (4) the distance between the Hospital and the temporary blood bank; and (5) the distance between the permanent blood bank and the temporary blood bank.

Table 1: The Coordinates of The Location of The Medan City Hospital

No	Hospital Name	Coordinate	
		Latitude	Longitude
0	Pusat Darah Permanen	3,601648259	98,68375635
1	RSUP Adam Malik	3,518633478	98,60859508
2	RSUD Dr. Pirngadi	3,598061913	98,68839753
3	RS Bhayangkara	3,572529381	98,65845707
4	RS Bina Kasih	3,578482589	98,61294597
5	RS Columbia Asia	3,585748413	98,67685363
6	RS Herna Medan	3,579570689	98,66580195
7	RS Martha Friska	3,575913429	98,68291024
8	RS Mitra Sejati	3,541056473	98,67986531
9	RS Murni Teguh	3,590806144	98,68151544
10	RS Permata Bunda	3,580785447	98,68577044
11	RS Putri Hijau	3,599910643	98,67267874
12	RS Royal Prima	3,598238182	98,65427795
13	RS Santa Elisabeth	3,574909997	98,67681666
15	RSU Haji Medan	3,618519679	98,71318582

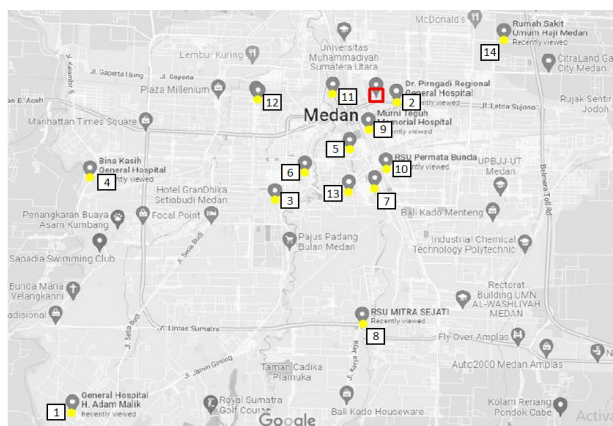


Figure 2: Location of Hospital and Permanent Blood Facility in Medan City

In this study, HTS was applied to find a temporary blood bank by considering the following assumptions: (1) the location of the blood bank and the hospital is known, (2) using the Euclidean distance calculation, (3) the search for a new facility is carried out without a hitch. From the calculation results, it was found that there were seven temporary blood bank facilities utilizing HTS. The coordinates of quick blood banks that can be used during and post-disaster in Medan city are shown in Table 2. The red marker in Figure 3 indicates the location of the temporary blood bank, while the other feature is the hospital. Arrows indicate hospital allocation to quick blood banks.

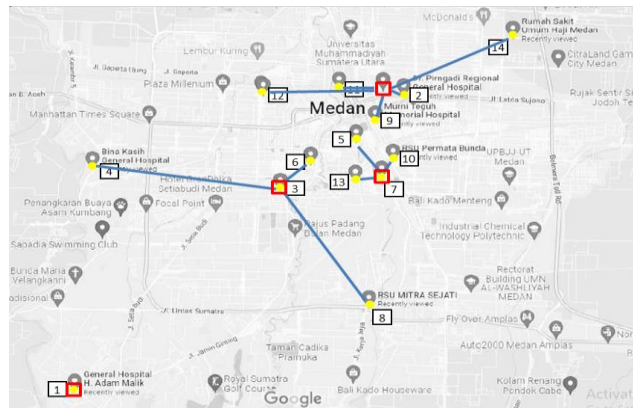


Figure 3: Temporary Blood Facility Allocations

Table 2: Determination of The Location of The Temporary Blood Bank Using HTS

Hospital Name	Coordinate	
	Latitude	Longitude
Temporary Blood Facility-1	3,601648259	98,68375635
Temporary Blood Facility -2	3,518633478	98,60859508
Temporary Blood Facility -3	3,572529381	98,65845707
Temporary Blood Facility -4	3,575913429	98,68291024

4.3 Determining the Optimal Blood Bank Count

The optimal number of temporary blood banks in Medan city during and after the disaster was determined by carrying out the step-by-step methodology as discussed in Figure 1. The fixed facility cost used in the calculation was IDR 10,000,000.00; the maintenance cost was IDR 500,000.00, and the transportation cost was charged as IDR 12,000.00 per km. The optimal number of temporary blood banks during a disaster and in the post-disaster area was determined based on the minimum total costs. Different location-allocation decisions are presented in figures 4(a) through 4(c) for other numbers of temporary blood banks. Table 3 shows the minimum total cost calculated due to the number of temporary blood bank facilities. From several different total costs, as shown in Table 3, it can be concluded that the test results recommend an optimal decision that four temporary blood banks need to be placed in the city of Medan.

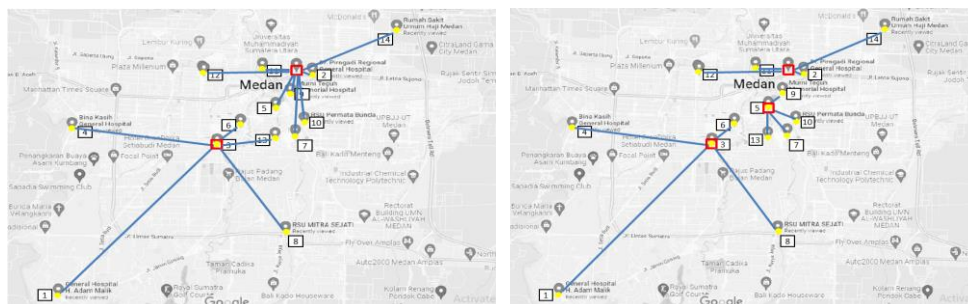


Figure 4(a): Location-allocation Decisions for Two and Three Temporary Blood Banks

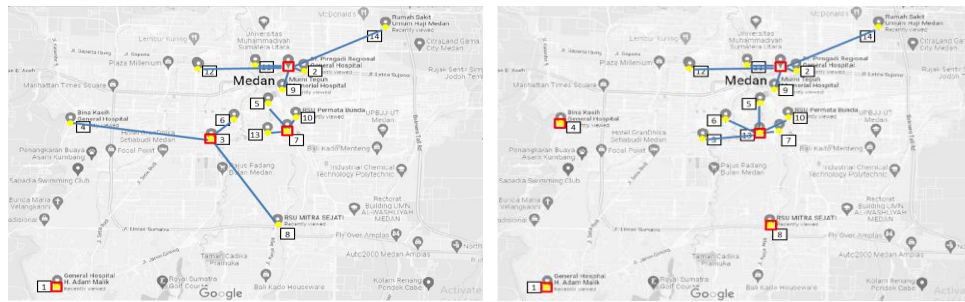


Figure 4(b): Location-allocation Decisions for Four and Five Temporary Blood Banks

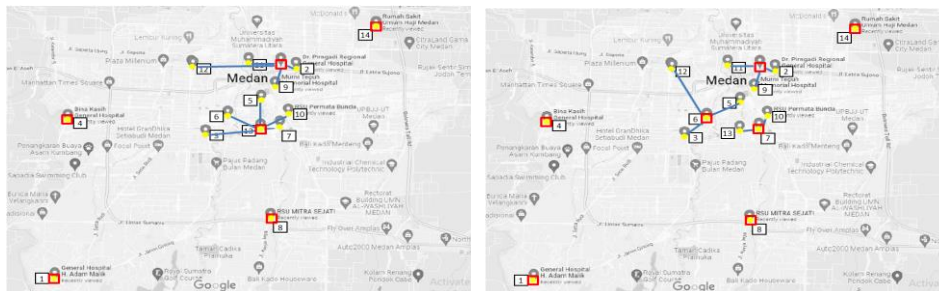


Figure 4(c): Location-allocation Decisions for Six and Seven Temporary Blood Banks

Table 3: Cost of Temporary blood bank Location

No	Number of Temporary Blood Bank Facility	Total Cost
1	Two	IDR 48,038,087.68
2	Three	IDR 34,622,574.80
3	Four	IDR 33,406,072.13
4	Five	IDR 33,882,751.23
5	Six	IDR 35,917,360.86
6	Seven	IDR 38,653,790.21

5. Results and Discussion

In the previous section, it was stated that this study presents a decision-making technique from a dynamic location-allocation model and produces an almost optimal decision on the number of temporary blood banks needed during and after a disaster in Medan[21]. The proposed model and methodology produce exciting results based on the empirical test studies in section 4.

This study recommends the optimal number of temporary blood bank facilities that need to be placed during and after the disaster in the city of Medan based on the calculated minimum total costs shown in Table 3[22]. The calculation results in the case study show that placing four temporary blood bank facilities impacts the full price of IDR 33,406,072.13. If we increase the facilities from 4 to 5, the total cost rises to IDR 33,882,751.23. Likewise, if the number of temporary blood bank facilities is reduced from 4 to 3, the total cost will also increase from IDR 33,406,072.13 to IDR 34,622,574.80. These calculations show that at least four temporary blood bank facilities must be in place to meet demand during and after-disaster periods[23]. The

difference in the location-allocation decision for each number of quick blood banks can be seen in Figures 4(a) to 4(c).

This study has provided an overview of how to meet the need for blood during or after a disaster by determining how many temporary blood bank facilities need to be placed[24]. This information will provide knowledge that will significantly assist agencies that manage blood banks to find out how many temporary blood bank facilities are required and where the facilities are located to address the need for blood supply during a disaster and in the post-disaster area[25].

6. Conclusion

The main contribution of the blood supply facility location problem-solving framework has been proposed in this study, in which the problem is modeled as a mini-max facility location model and solved by HTS to derive optimal temporary blood facility location-allocation decisions during and post-disaster period. Through a review of previous literature, it is possible to identify the factors needed to decide on the allocation of temporary blood facilities that can be used to meet the needs of blood distribution during and in post-disaster areas. Thus a model can be built. In this research, the problem has been modeled as a mini-max facility location model to obtain optimal temporary blood facility location-allocation decisions by solving it using the HTS and Euclidean approaches as the distance calculation method. Improvements can be made to the model by developing case studies based on conditions in other locations or adding survey activities directly to the field.

Acknowledgments

This work was supported by National Funding from DRTPM Kemdikbudristek, Indonesia, under project: 123/SPK/D4/PPK.01.APTV/VI/2022. The authors would like to thank the anonymous reviewers for their detailed comments and insights on our work, leading to better manuscripts.

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