A distribution strategy using a two-step optimization to maximize blood services considering stochastic travel times

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Abstract. The blood service is a health service that utilizes human blood as basic material with humanitarian purposes, not for commercial one. Indonesian hospital ability in blood transfusions is generally still low, especially in terms of blood supply adequacy. In fact, there are still some provinces that experience excess blood supply while many other provinces experience a shortage of blood supply. The Blood Bank in Jakarta has the highest excess blood supply. Therefore, the blood can be transferred evenly from one province to another nearby province. The aim of this paper is to determine the allocation and the route of blood distribution to achieve the minimum travel times. Some variations in travel time are difficult to predict, so we take into account the stochastic properties of them. The effectiveness of blood distribution is very dependent on the accuracy of the target number of beneficiaries and the accuracy of the number of blood bags received in distribution activities. Meanwhile, the efficiency of blood bag distribution is measured by distribution routes that are directly related to transportation costs. This study uses a two-step optimization model to reach optimality. The first step is utilizing the transportation model to make sure the destination points are only the fastest to arrive. The second step is making use of the capacitated vehicle routing problem to ensure the routing is global optimal. This model successfully creates better blood demand fulfillment while minimizing transportation cost.

1. Introduction
Logistics management is part of supply chain management that plans, implements, and regulates the flow of products starting from the product is still in the form of raw materials to become finished products that are in the hands of consumers [1]. The focus of logistics activities is the efficiency of the distribution of goods from a supplier, through the manufacturing to be processed, to the point of consumption in a cost-effective manner, while still providing appropriate services for consumers [1]. In this context, efficient while effective supply chain planning and management of healthcare can result in human loss reduction [2], especially related to blood services.

Blood service is a health service that utilizes human blood as basic material with humanitarian purposes, not for commercial one [3]. Blood is a scarce, perishable and vital product, and no alternative has been found so far [2], [4]. Blood supply services in Indonesia are carried out by 421 Blood Banks throughout the country run by Indonesian Red Cross Society, and responsible to donor recruitment and collecting, securing, processing, storing, distributing and destroying blood
Componentizing Whole Blood (Life = 30 Days) Plasma (Life = 1 Year) Platelets (Life = 5 Days) Red Blood Cells (Life = 30 Days)

The demand for blood, commonly called the Whole Blood (WB) and blood components are satisfied by the donation of eligible individuals [5]. The process of componentizing of WB yields three major components, such as Red Blood Cells (RBCs), Platelets and Plasma as shown in Figure 1 [6]. Every component has a different life span, making the problem more complicated. Blood supply management is different from a typical supply chain problem in three aspects [5]. First, the number of donations, and thus, the amount of blood supply, changes over time [5]. Second, the WB and blood products have short life spans, and there has to be a certain amount of time between two consecutive donations of a donor to replace the donated blood [5]. Third, in order to extract platelets, one of the most important blood products, donated WB has to be processed within 6 hours of donation [5].

Indonesian hospital capability in blood transfusions is generally still low (average 55%), especially in terms of blood supply adequacy [7]. According to the World Health Organization (WHO) guidelines, the need for blood in an area is at least 2% of the population [3]. Unfortunately, Indonesia was only able to fulfill 81.2% of the blood demand in 2016 [3]. In other words, there is a shortage of 972,522 blood packages.

Table 1. Minimum Amount of Blood Needs and Blood Production in some Provinces in 2016 [3]

| No | Province            | Population | Minimal Blood Needs (Package) | Blood Production (Package) | Fulfillment (%) |
|----|---------------------|------------|--------------------------------|---------------------------|-----------------|
| 1  | Jakarta             | 10,277,628 | 205,553                        | 622,136                   | 302.7           |
| 2  | Yogyakarta          | 3,720,912  | 74,418                         | 113,390                   | 152.4           |
| 3  | Bali                | 4,200,069  | 84,001                         | 104,362                   | 124.2           |
| 4  | East Java           | 39,075,152 | 781,503                        | 901,658                   | 115.4           |
| 5  | East Kalimantan     | 3,501,232  | 70,025                         | 70,152                    | 100.2           |
| 6  | West Java           | 47,379,389 | 947,588                        | 589,999                   | 62.3            |
| 7  | Banten              | 12,203,148 | 244,063                        | 143,522                   | 58.8            |

The shortage and excess of blood supply in an area is a major problem. Inadequate number of
donations results in postponed surgeries, untreated patients and thus lost lives [2], [4], [5]. Having excess donations is not always better both because of donation/inventory related costs of outdated products and the ineligibility of the donor to donate for a certain amount of time [2], [5]. Excessive stock must be allocated appropriately to the needed regions to meet the blood demand. In addition, proper allocation and distribution can increase the effectiveness and efficiency of blood distribution [2]. Therefore, Blood Bank in Jakarta must be able to distribute blood effectively and efficiently so as to be able to help other areas that are lacking with low transportation costs.

Studies regarding the distribution effectiveness and efficiency have been carried out with various methods, including descriptive analytical methods, simulations, Genetic Algorithms (GA), Fuzzy Genetic Algorithms (FGA) and Simulated Annealing. The earlier study was conducted to measure the effectiveness and efficiency of distribution routes using analytical descriptive methods [8]. The simulation model was applied in previous work to improve the sustainability of the distribution network performance in British logistics companies by paying attention to exhaust emissions [9]. Another research tried to optimize costs for the distribution of fresh food products using GA, FGA, and Simulated Annealing [10]. Respectfully, the above studies did not solve the problem while ensuring the optimality as this paper did.

Previous research used the CVRP model to determine distribution routes while minimizing transportation costs. The integration of the transportation model and CVRP in this study aims to minimize the travel times of the blood distribution route from Jakarta which experiences an abundance of blood supply to the surrounding areas that are experiencing shortages. Travel times may be dynamic [11] and vary exogenously due to traffic congestion, weather conditions, moving targets or mobile obstacles, affecting the efficiency and even feasibility of a delivery route [12], [13]. By minimizing the travel times of the distribution route, operational costs are assumed to be minimal as well in order to achieve distribution effectiveness and efficiency. In this study, there were 2 (two) types of locations considered, namely the source and the distribution points. The source point for distribution is defined as Blood Bank in Jakarta. Blood production distribution activities are carried out at Blood Bank in Jakarta that is overstocked with the closest Blood Banks in provinces that are experiencing shortages.

This study uses two-step optimization to reach out the distribution effectiveness and efficiency simultaneously. The first step is utilizing the transportation model to make sure the destination points are only the fastest to arrive. The second step is making use of the capacitated vehicle routing problem (CVRP) to ensure the routing is globally optimal.

2. Problem Formulation
The scope of this study is the blood distribution route in the Jakarta and its surrounding. Figure 2 shows one single source and 20 destination points, which is divided into two regions, West Java (shown in orange) and Banten (shown in blue). Some variations in travel time are difficult to predict, like traffic accidents, which cause congestion of which both the occurrence and delay are difficult to foresee [13]. Therefore, when it comes to the travel times we follow the assumption that they are continuous [12] and normally distributed, as demonstrated in the previous research in terms of speed of the vehicle [14]. We take the mean value as the input in the first and second step of the following optimization. The previous study takes into account the travel times from \( i \) to \( j \) and the other way around was equal [15], and successfully improved in this paper as in fact they are not.

Jakarta can distribute 416,583 blood packages while West Java and Banten need 357,589 and 100,541 blood packages respectively. The blood packages are assumed to be 450 ml each and are stored in a 35-liters cool box. In the distribution process, each cool box can store 77 blood packages and transports in a vehicle with capacity 22 cool box per trip. Therefore, each trip can transport 1694 blood packages and the trip is done once a week.
3. Model

3.1. Transportation Model

Transportation is the movement of products from one location to another, starting from the product still in the form of raw goods to finished goods distributed to customers in a supply chain system [16]. Transportation has the following characteristics, namely:

a. There are a number of specific sources and destinations. In this study, we use one single source and 20 destinations.

b. The number of goods to be distributed from each source and requested by each destination is varied. In this case, we consider the shortage of blood as the demand.

c. Goods are distributed from one source to a particular destination, considering the demand and capacity of the source.

d. The cost of shipping commodities from each source to each destination is different. This research contemplates the shipping cost as the travel times from the source to the destination.

The following shows the transportation model [16], [17].

Notation

\[ n = \text{number of source locations} \]
\[ m = \text{number of demand points} \]
\[ c_{ij} = \text{the cost of shipping one unit from } i \text{ to } j. \]
\[ x_{ij} = \text{quantity shipped from source } i \text{ to destination } j \]
\[ a_i = \text{the total amount to be shipped out of source } i \]
\[ b_j = \text{the total amount to be shipped into destination } j \]

Objective function

\[ \text{Minimize } z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}x_{ij} \]  \hspace{1cm} (1)
Subject to

\[ \sum_{j=1}^{n} x_{ij} \leq a_i, \ i = 1,2, \ldots, m \] (2)

\[ \sum_{i=1}^{m} x_{ij} \geq b_j, j = 1,2, \ldots, n \] (3)

\[ x_{ij} \geq 0, \forall i \forall j \] (4)

Equation (1) minimizes the total cost (approximated by travel times) of shipping all units from \( i \) to \( j \). Equation (2) ensures the quantity shipped cannot exceed the supply availability. Equation (3) makes sure the demand in destination \( i \) is met. Equation (4) ensures the non-negativity constraints.

3.2. Capacitated Vehicle Routing Problem (CVRP)[18]

Determination of distribution routes is the operational decision of each company with the ultimate goal is to minimize transportation costs which are approached by the length of the route [19]. CVRP has become the research material for combinatorial optimization. This research utilizing CVRP to minimize the total traveled times by the \( m \) vehicles, subject to [18]:

- Each route of a solution must to starts and ends at the depot, in this case depot means Blood Bank in Jakarta
- Each customer of a route is visited exactly once by exactly one vehicle.
- The total demand of each route does not exceed the capacity of vehicle.

Objective function

\[ \text{Minimize } z = \sum_{i=0}^{m} \sum_{j=0}^{n} c_{ij}x_{ij} \] (5)

Subject to

\[ \sum_{j=0}^{m} x_{0j} = m \] (6)

\[ \sum_{j=0}^{m} x_{i0} = m \] (7)

\[ \sum_{j=1}^{i} x_{ij} = 1 \] (8)

\[ \sum_{i=1}^{m} x_{ij} = 1 \] (9)

\[ m \geq 1 \] (10)

The objective function in equation (5) is to minimize total costs. The constraint (6) represents the number of modes of transportation used \( m \). The constraint (7) guarantees that all modes of transportation departing from the distribution source return to the same place. Equations (8) and (9) guarantee that all distribution points will be visited.

4. Discussion

The blood is not distributed to all destinations, and only to 19 destination points instead, due to the demand is higher than the supply availability as shown in Figure 3. The destination point (node) 4
partially meets the demand since the capacity of supply while node number 6 is not supplied at all.

![Map showing distribution routes](image)

**Figure 3. Visualization According to Transportation Model Results**

The second model is CVRP which generates five trips from Jakarta to several distribution points every week, as shown in Table 2. With the determination of routes like this, it can be obtained the total travel times is 2,272.70 minutes.

| Distribution Route                           | Times Traveled (min) | Blood Packages (per week) |
|----------------------------------------------|----------------------|---------------------------|
| Jakarta – 1 – 11 – 5 – Jakarta               | 434.90               | 1587                      |
| Jakarta – 2 – 8 – 9 – Jakarta                | 207.80               | 1587                      |
| Jakarta – 3 – 4 – 7 – 18 – Jakarta           | 810.96               | 1593                      |
| Jakarta – 13 – 12 – 10 – Jakarta             | 449.60               | 1587                      |
| Jakarta – 16 – 14 – 20 – 15 – 19 – 17 – Jakarta | 369.44             | 1657                      |
| **Total**                                    | **2,272.70**         | **8011**                  |

**5. Conclusion**

The results obtained from the two-step optimization with the transportation model and CVRP sequentially create better blood demand fulfillment. Blood Bank in Jakarta can distribute the blood to its surrounding, which is West Java and Banten, while minimizing the transportation cost. Figure 4 shows the better condition of blood demand fulfillment. This model escalates the demand fulfillment in Banten to 100%, while still maintaining the demand fulfillment in Jakarta also 100%. The performance in West Java is clearly satisfying enough since demand fulfillment is improved from 62.26% to 95.62%. Further research can use this model to determine the distribution routes of other regions that have excess blood supply to the surrounding area.
Further research can consider multi product perishable inventory decisions [6] as there is a relationship between storage duration and the length of stay in hospital and organ failure [20]. The next study may lead to minimize an objective function combining fuel consumption (or CO2 emissions) and total route duration [12].

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