Platelet Inventory Management System Using Monte Carlo Simulation

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Abstract. Improper blood management will lead to wastage due to the nature of blood that is not durable and easily damaged, so if the blood is stored too much and not used until the expired date, the blood will be damaged. Platelet components have a limited lifetime for 5 days. With a short blood age, every month there will be two possibilities, one is shortage of blood inventory (stockout) or two, over blood inventory (overstock) in the storage area. From the data obtained, the expired rate in 2017 reached 743 blood bags. Until now Indonesian Red Cross has not been able to predict the level of blood demand because of the uncertain level of demand. In this study, simulation will use Monte Carlo to develop a number of policies that can optimize inventory levels and minimize inventory costs.

1. Background
The uncertainty in blood availability caused by unpredictable blood demand and supply. In other word supply and demand in blood supply chain have stochastics or uncertainty characteristics [1]. According to the World Health Organization (WHO) recommendation that the minimum number of donor in one community is around 2% from the total population. However, the facts of the blood supply have decreased in the current decade, whereas the blood demand has increasing tendency [2]. In other word, currently donors are rare assets in society [3].

Improper blood management will create wastage because of the blood characteristics that are not durable and can be damaged easily, so if the blood inventory is in a big number of amount and not be used until the expiration date, then the blood will be broken. As specified by the annual report of a
blood bank in Kabupaten Sleman in 2017, there are 743 blood bags that should be annihilated due to its expiration date. The expired rate in 2017 is explained in Figure 1.

![Expired Blood Rate in 2017](image)

**Figure 1. Expired Blood Rate in 2017**

In accordance with the limited blood age that is 5 days for the TC component (Platelet), it needs a complex blood inventory management [5]. With a short age of blood, then there will be 2 possibilities that are stockout or overstock in each month in the inventory. If stockout, then the worst possibility is death. While if overstock happens, it will make the blood wasted if the saving time is exceeding its expiration date. Blood demand has uncertainty characteristics and the supply of blood also not constant. The demand pattern from the blood bag is different from another general product. In compliance with [4], blood product demand will be equal with the population growth rate, but the number of donors will be reduced. Blood demand across Indonesia could be classified into two; normal condition demand and special condition demand. The normal condition is a condition when there is no extraordinary situation that could cause a sudden spike in blood demand. A special condition is a certain condition that affects blood demand and directly spiked the blood demand, in example endemic disease outbreak such as dengue fever [6] or disaster [7].

Blood supply quantity is based on the number of donors that come to blood bank. The blood bank usually held blood donor events or sponsored many events to get supplies from donors [8]. Besides that, blood bank also reminds the permanent donors and non-permanent donors to do blood donors by broadcast messages or through social media. However, with all of the efforts, blood bank cannot predict the number of blood products that obtained will be on target. Therefore, with the lack of blood supply that can damage the patients’ life when they need the blood product.

There are a lot of researches that develops many kinds of inventory model that taking into account various factors like product age, discount, increasing-price even up to inflation rate. One of the researches that develops inventory optimization model is developed stochastics model to determine the optimum quantity from blood inventory and [9] considered an inventory system with discrete event and safety stock in platelet ordering case. In this research, six policies will be built and simulate with Monte Carlo in 30 days. The result of the simulation will decide the appropriate policy to minimize the total cost of inventory in the blood bank Kabupaten Sleman case study. Monte Carlo simulation will be done by Microsoft Excel.

2. Literature Study

The previous research studied blood inventory optimization or minimizing the operational cost of blood inventory with a heuristic approach solution has been done by previous researchers until now. Researches about blood inventory that easily broken have developed many methodologies to solve that case. There was a research developed in the challenge of dealing with demand uncertainty in problems from inventory management. Previous research in blood inventory usually assumed that the uncertainty demand can be modelled with Poisson distribution or Normal distribution. Because of the proposed approach to overcome the model limitation is not rely on the assumption about how the demand uncertainty can be modelled.
The characteristic of the blood product that is easy to be broken is difficult to be modelled in blood supply management. Blood inventory that is easy to be broken will cause the heap of stocks because of uncertainty demand will make the long-time blood releasement and related costs incurred. Moreover, blood that received from the donor also limited. Hence, efficient blood inventory in blood bank is very important. Whereas [9] deliberated an inventory system with discrete event and safety stock for platelet ordering case.

In the last 10 years, the blood supply chain has gained significant attention, there are several methods that can be implemented to do observation, like the queuing theory and Markov chain, statistics analysis, simulation, and optimization [6]. Previous research has made inventory mathematical model that considering the product age and discount factors. After that a research was made a model with considering all unit discount factor and repair the algorithm functions from model that previously made. Moreover, there is an inventory model that made for multiple items that considering product age factor and all unit discount where the demand for the product is deterministic.

3. Research Methods

This research is based on the case study in one of regional blood bank in Yogyakarta. The purpose of this research is to minimize the inventory cost that can optimize the blood inventory platelet component using Monte Carlo Simulation.

This research uses Microsoft Excel as the research instrument to run the Monte Carlo simulation. Therefore, a mathematical function is needed to determine the total inventory cost to solve the blood inventory problem so the optimum inventory rate can be known. The total inventory cost function that is developed can be explained as:

3.1. Simulation Parameter and Index

Parameters that used in the total inventory cost are as follow:

Index
\( t \) = simulation period index
\( p \) = incoming blood index
\( h \) = inventory index
\( s \) = shortage index
\( E \) = expired index

Parameters
\( C_p \) = ordering cost
\( C_h \) = holding cost
\( C_s \) = shortage cost
\( C_E \) = expired cost

\( Q_t^s \) = rate of blood shortage in t period
\( Q_t^E \) = rate of expired blood in t period
\( I_t \) = rate of blood inventory in t period
\( P_t \) = rate of blood supply in t period

3.2. Total Inventory Cost Function

The function of total inventory cost is as follows:

\[
\sum_{t=1}^{30} Q_t^s \cdot C_s + \sum_{t=1}^{30} Q_t^E \cdot C_E + \sum_{t=1}^{30} I_t \cdot C_h + \sum_{t=1}^{30} P_t \cdot C_p
\] (1)

Equation (1) is a function to minimize the total inventory cost. This total cost is influenced by the rate of blood supply variable, the blood inventory rate, shortage rate and also expired rate. In the above
function, the inventory total cost consists of the ordering cost, holding cost, expired cost, and shortage cost components.

4. Result and Discussion

4.1. Validation Test
The validation test that used in this research is the mean comparison test and variance comparison test.

4.1.1. Mean Comparison Test. The mean comparison test is used to compare the performance between the real system with the simulation model from the value of output mean on both population data. Because the data is from two populations, so the test used is double-sided test. The t-value from the mean comparison test in the demand of O blood is 0, and the t-value in the supply of O blood is -0.7376. Since the range of acceptance is between -2.048 and 2.048, so the result is $H_0$ is accepted, which means that the simulation data is in line with the real system data.

4.1.2. Variance Comparison Test. To make sure that the assumption of both populations has the same variance, the variance comparison test is done. According to the calculation, the result of the F-value is 1. Since the range of acceptance is between 0.476 and 2.101, then the $H_0$ is accepted or the simulation result is in line with the real system.

4.2. Scenarios Development
From Monte Carlo simulation that has been done, then several scenarios were made to search the optimum total inventory cost. According to the observation result and interviews, there are several scenarios as follow:

4.2.1. Scenario 1. The first scenario is presenting the current condition in a blood bank in Kabupaten Sleman. It can be known that the current condition in blood bank in Kabupaten Sleman has not determined the safety stock policy.

4.2.2. Scenario 2. The next scenario is the policy to have safety stock for TC blood products. Since the product TC age is only for 5 days, so the inventory management will be more complex. In this scenario, the safety stock is 1 blood bag each day. This applied when the total inventory of blood is less than 1 blood bag, so on the next day, the supply will increase 1 blood bag. The policy of safety stock is based on the average of the shortage replication data that happened each day. This is caused because the blood bank has no shortage data for the TC component.

4.2.3. Scenario 3. Unlike the second scenario that regulates the safety stock, the third scenario makes policy to decrease the supply of the TC component. This is based on the demand data for the TC component that is rare, but there is daily supply each day. The number of blood demand cannot be predicted, and the blood bank is striving to get donors every day. Therefore, the expired product rate will be high. In the third scenario, a policy to decrease the supply rate will be built to make the supply rate near to the demand rate. This scenario is based on the average comparison of supply and demand on each day for a number of replications to determine the percentage of supply declination rate.

4.2.4. Scenario 4. In line with the second scenario, this scenario 4 applies the safety stock to decrease the shortage faced by blood bank. The number of safety stock in scenario 4 policy is 2 blood bags in every day. This policy is implemented if the number of bloods in inventory is less than 2 blood bags, so 2 blood bags will be added in the next day.

4.2.5. Scenario 5. Scenario 5 contains a policy that has a purpose to decrease the supply rate of the TC component. This is based on the low level of demand for TC component, while the TC supply is increasing every day. The reduction of the TC supply is to make the rate of supply is close to the rate of
demand, so the number of expired blood products can be decreased. The decrease of supply in this scenario is 90% of the previous supply.

4.2.6. Scenario 6. Correlated with the previous scenario, the researcher in scenario 6 simulate if the policy of supply rate decrease is implemented with a 95% rate of reduction. It is intended to know where is the equilibrium point to make no shortage and a low number of expired products, so the inventory cost can be minimized.

### Table 1. Total Cost Comparison

| Scenario | Stock  | Holding Cost | Donors  | Ordering Cost | Shortage | Shortage Cost | Expired  | Expired Cost | Total Inventory Cost |
|----------|--------|--------------|---------|---------------|----------|--------------|----------|--------------|----------------------|
| Sc1      | 33692  | 1853060000   | 251     | 3765000       | 2        | 720000       | 207      | 414000000   | 231191000             |
| Sc2      | 32874  | 1808070000   | 255     | 3827000       | 1        | 360000       | 212      | 424000000   | 227392000             |
| Sc3      | 5307   | 291885000    | 60      | 900000        | 9        | 324000       | 42       | 8400000     | 41728500              |
| Sc4      | 33569  | 1846295000   | 254     | 3810000       | 0        | 0            | 212      | 424000000   | 230839500             |
| Sc5      | 4886   | 26873000     | 60      | 900000        | 11       | 396000       | 37       | 7400000     | 39133000              |
| Sc6      | 3975   | 21862500     | 60      | 900000        | 13       | 468000       | 30       | 6000000     | 33442500              |

4.3. Total Inventory Cost Comparison

This research is expected to know the most optimum scenario to decrease the total inventory cost. Total inventory cost consists of ordering cost, holding cost, expired cost, and shortage cost. Based on the 30 replications that have been done, the result of the total inventory cost is as in Figure 4.1.

From the simulation result with 30 times replications, different inventory costs are shown depends on the scenarios. From the first scenario which represents the current system, the total inventory cost spent on a month is Rp231.191.000,00. The mean of the inventory cost is Rp7.706.366,67 with Rp1.315.407 variance. The result of scenario 2 which adding 1 product as a safety stock has the total inventory cost as Rp227.392.000,00 with the mean of inventory cost is Rp7.579.733,33 and Rp1.581.354 of variance. The scenario 3 policy is to decrease the supply rate as 88% to make the supply number close with the demand, and the result of the simulation is Rp41.728.500,00 as the total inventory cost. The mean and variance of the total inventory cost are Rp1.390.950,00 and Rp192.160.

In scenario 4, 2 blood bags are used as safety stock. The total inventory cost in scenario 4 is Rp230.839.500,00 with the mean of Rp7.694.650,00 and Rp1.116.856 as the variance. The result of inventory cost in scenario 5 is Rp39.133.000,00, applying declination of supply rate by 95%. The mean of inventory cost in scenario 5 is Rp1.304.433,33 and Rp227.069 as the variance. Scenario 6 was built to know the impact if the declination rate changed to 90%. The result of the simulation showed that the total inventory cost is Rp33.442.500,00 with Rp1.114.750,00 and Rp205.661 as mean and variance respectively.

5. Conclusion

To get the appropriate policy in order to optimize the platelet component inventory and minimize the total inventory cost, Anova and Bonferroni test has been done to test the simulation result. In the Anova test, the result of the F-value is 385.59 with F-critical value is 2.266. Since the F-value is higher than F-critical, the scenarios result from scenario 2,3,4,5, and 6 has different mean with the current system or scenario 1. From the Bonferroni test, the output from the first scenario with the second scenario and fourth scenario has no difference. The outputs of scenario 3 with scenario 5 and scenario 2 with scenario 4 are also have no difference. However, the others are having different outputs. From the total inventory cost result, the minimum cost is from the scenario 6 with a declining supply rate on 95% and resulting in the total inventory cost Rp33.442.500. The rate of cost decreased is 14.45%. Thus, it can be concluded that the best scenario to minimize the total inventory cost and optimize the blood inventory system is
the scenario 6. For the next research, it is better if considering the blood production not only platelet, considering the seasonal demand and considering if the demand from customers are different age request.

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