[Journal of Environmental Science and Sustainable Development](https://scholarhub.ui.ac.id/jessd)

Volume 5
Issue 2 *December 2022*

Article 4

12-31-2022

SIMULATION OF BLOOD INVENTORY MANAGEMENT: CASE OF THE INDONESIAN RED CROSS JAKARTA BRANCH

Azaria Ekaputri
Department of Management, Faculty of Economics and Business, Universitas Indonesia, ekaputriazaria21@gmail.com

Ratih Dyah Kusumastuti
Department of Management, Faculty of Economics and Business, Universitas Indonesia, ratih.dyah@ui.ac.id

Recommended Citation

Ekaputri, Azaria and Kusumastuti, Ratih Dyah (2022). SIMULATION OF BLOOD INVENTORY MANAGEMENT: CASE OF THE INDONESIAN RED CROSS JAKARTA BRANCH. *Journal of Environmental Science and Sustainable Development*, 5(2), 280-298.
Available at: https://doi.org/10.7454/jessd.v5i2.1144

Journal of Environmental Science and Sustainable Development
Volume 5, Issue 2, Page 280-298
ISSN: 2655-6847
Homepage: http://scholarhub.ui.ac.id/jessd

SIMULATION OF BLOOD INVENTORY MANAGEMENT: CASE OF THE INDONESIAN RED CROSS JAKARTA BRANCH

Azaria Ekaputri[1], Ratih Dyah Kusumastuti[1*]
[1]Department of Management, Faculty of Economics and Business, Universitas Indonesia

[*]Corresponding author: ratih.dyah@ui.ac.id

(Received: 19 January 2022; Accepted: 22 December 2022; Publish: 31 December 2022)

Abstract

Blood supply is an essential part of the healthcare services. Adequate blood supply is critical in ensuring that life-saving measures can be done at the required time. However, excess supply of blood can cause wastage and increase operational costs. The focus of this study is simulating the blood inventory management at The Indonesian Red Cross Jakarta Branch (PMI Jakarta) to fulfil the demand of blood while minimizing blood wastage. This study is conducted with the objective of simulating the blood supply chain process to analyse its problem and propose solutions to improve the blood management. The model is developed by using discrete-event simulation approach with ARENA software. The results show that the number of blood products produced by PMI Jakarta exceeds the number of blood products needed. Therefore, a lot of blood products are disposed because it has reached its expiration time. Three alternatives are proposed to tackle the problem, namely reducing blood production, reducing blood donation events using mobile unit, and increasing the amount of blood demand from other donor recipient institutions and PMI branches. Results of the simulation show that all the alternatives can decrease the number of disposed blood while keeping all the demand for blood fulfilled. It is recommended that PMI Jakarta increases the flow of information within the organization to support the proposed solution using an integrated information system.

Keywords: Blood management; Demand fulfilment; Elimination of wastage; Inventory management.

1. Introduction

Blood is a basic human necessity that is often forgotten. The availability of blood has a vital role in human life (Zanin et al., 2016). Ranging from childbirth activities, accidents, diseases, and natural disasters are just a few examples of situations that require blood transfusions or blood donations (Aneke & Okocha, 2017). Therefore, the availability of blood is essential and needs more attention to ensure that the supply is sufficient when needed (Mohammadi et al., 2022). Furthermore, as blood is mostly given by donors voluntarily, it is necessary that the supply must be reliable (Clay et al., 2018).

DOI: https://doi.org/10.7454/jessd.v5i2.1144

According to the data from WHO (2022), based on samples of 1000 people, the rate of blood donation in high-income countries, upper-middle income countries, lower-middle income countries, and low-income countries are 31.5, 16.4, 6.6, and 5.0 donations respectively. This indicates different levels of access to blood supply in different countries, which are lower in the developing countries.

Ideally, the number of blood donors in a country is 2.5% of the total population (Infodatin Kemenkes RI, 2014). Thus, we can say that in 2013 Indonesia needed a blood supply of 2,5% of its 247,837,073 inhabitants, or equivalent to 4,956,741 bags of blood. However, in 2013, the number of available blood bags was only 2,480,352. These data indicate that in 2013, Indonesia was only able to fulfill around half of the needed number of blood bags.

In Indonesia, blood supply services are carried out by the Blood Donor Unit (UDD) under the auspices of the Indonesian Red Cross (PMI) and the Regional Government. In 2018, there were 417 UDD operating across Indonesia (Infodatin Data and Information Center of the Indonesian Ministry of Health, 2018). In addition to the unfulfilled need for national blood supply, there is also imbalance in the amount of blood available in each region in Indonesia as one of the main current problems. Based on the data published by The Indonesia Ministry of Health, Jakarta, Yogyakarta, East Java, Bali, and East Kalimantan are 5 (five) provinces in Indonesia that have succeeded in meeting the blood demands of their population in 2016 (Infodatin Kemenkes RI, 2018). Meanwhile, other provinces are struggling to meet the blood demands in their areas.

Unfulfilled demand of blood can certainly cause problem as it involves human life. However, an excessive supply of blood bags can also be detrimental. This is because blood, just like vegetables, fruits, baked goods, bread, milk, meat, seafood, radioactive and chemical materials, pharmaceuticals, christmas trees, and winter clothings, are perishable in nature (Chaudhary et al., 2018). Hence, inventory items can sometimes expire or experience depreciation. Inventories can depreciate when they decrease in value over time which can be caused by rapid developments in technology or the introduction of new products in the market (Ferreira et al., 2018). Depreciation can be interpreted as a loss caused by damage that can occur due to damage, spoilage, and evaporation of a product (Goyal & Giri, 2001).

There are at least 4 (four) areas in inventory management policies for perishable items, namely ordering policies, issuing policies, disposal policies, and pricing policies. Ordering policy answers questions about when and how many products to order, while issuing policy determines how to eliminate or use the product (Ferreira et al., 2018). Products that have a predetermined lifetime are products that can be categorized into fixed-lifetime products (Chaudhary et al., 2018). Items such as food and human blood are examples of products that have a fixed lifespan. These products usually use a FIFO (First In First Out) and LIFO (Last In First Out) issuing policy. The level of product damage can also depend on the age of the product (meaning that the product is age dependent). I n this case, the lifetime of the product is assumed to be a random variable. Analysis of random lifetime items is difficult as compared to fixed ones. The product lifetime follows arbitrary probability distribution, and the remaining inventory at the end of the period is assumed to be worthless. Meanwhile, products that do not have a predetermined life span and decay over time can be categorized into products with a time-dependent period. Some examples of this are vegetables and fruits as vegetables and fruits will rot in a random and unknown period of time. In addition to time, the lifetime of the product can be affected by other conditions such as the environment (Chaudhary et al., 2018).

Good inventory management for perishables entails carrying enough stock to guarantee on-shelf availability whilst at the same time minimizing time expiry (Nahmias, 1982). For many organizations, the results of managing this trade-off incorrectly will lead to increased costs and increased wastage (Stanger et al., 2012).

Frank (2013) conducted a study which stated that there was a reduction in elasticity of red blood cells over time. Thus, it is believed that the flexibility of blood cells will decrease with the length of its storage time. Therefore, the longer the blood is stored, the quality of the blood will decrease and will slowly become un-usable. This implies that excessive production of blood for prolonged storage is not an alternative that can be done either (Meneses et al., 2023).

Generally, there are two main criteria for a good blood management system. The first one is to ensure that all the demands for blood are fulfilled (minimize shortage), while at the same time also being able to minimize the number of bloods that are unused and must eventually be disposed (or to minimize wastage) (Rytilä & Spens, 2006). With respect to blood bank, Lowalekar and Ravichandran (2014) stated the similar notion, that a blood bank must be able to improve the availability of different types of blood products for the patients and reduce the amount of blood wastage.

Hence, the management of blood supply must be able to overcome the shortage and wastage of blood products (Najafi et al., 2017). The main goal of inventory management for the blood supply is to identify the optimal inventory levels and order quantities. Jennings

(1973) described the fundamentals of how the blood supply chain operates and identified the three key measures of performance: namely, shortage, outdating/wastage, and the cost of information and transportation (Stanger et al., 2012). Over time, several experts emerged describing methods for blood supply management (Civelek et al., 2015). Brodheim et al. (1975) developed an inventory model based on the average age and average wastage of blood units using a Markov chain approach. Further, in 1976, Cumming et al. subsequently developed a planning model for the collection of donations and a basic model for issuing units to hospitals (Cumming et al., 1976).

Civelek et al. (2015), on the other hand, focused on analyzing the blood inventory management for blood platelets which demand exists for different products ages. The problem was modeled as a Markov Decision Process (MDP) and solved heuristically. Furthermore, Lowalekar and Ravi (2017) analyzed the problems of blood bank in India, identified the constraints related to the problems, and actions to handle the constraints. They used Theory of Constraints (TOC) thinking process to generate the solutions, and a simulation model developed using R language was used to assess the performance of the solutions.

In Indonesia, particularly at PMI Jakarta, it seems that the organization has successfully fulfilled their blood demand every month, which can be used as the main example for UDDs in other areas. However, PMI Jakarta still has problems in managing their excess of blood supply. According to the data from PMI Jakarta, in 2018, PMI Jakarta produced 953,842 bags of blood and discharged 496,524 bags, indicating that there was a wastage rate of 47.9%. Therefore, the improvement on the blood management system in PMI Jakarta is needed to reduce the wastage.

This study aims to analyze the blood management process carried out by PMI Jakarta, using discrete-event simulation approach, and propose solutions to improve the operations. In discrete-event simulation, evaluation of a system is carried out using computer software to evaluate the model numerically, and the data collection is carried out to estimate the actual characteristics of a model (Law, 2015). The blood management process is analyzed using the discrete-event simulation as blood management is considered as a complex problem (Bellen & Force, 2012; Clay et al., 2018), and simulation provides fewer limitations compared to analytical approach (Rytilla & Spens, 2006; Law, 2015). Furthermore, it allows scenarios of different circumstances to be developed and analyzed (Mohammadi et al., 2022). Inventory analysis using simulation approach, for example, have been carried by Marcikic and

Radovanov (2009), and Schwartz et al. (2006). Specifically for blood inventory management, analysis using simulation have been done by some studies (Belien & Force, 2012), for instance, by Rytilla and Spens (2006) and Mohammadi et al. (2022).

It is expected that the study can help the PMI Jakarta to better manage its blood inventory management. The remainder of the paper is structured as follows. Relevant literature is discussed in Section 2, while the research method is explained in Section 3, followed by results and discussions in Section 4, and conclusions and recommendations in Section 5.

2. Methods

2.1.Data Collection

The data was collected from the Indonesian Red Cross Jakarta Branch (PMI Jakarta) through an interview and obtaining historical records of the operations. The interviews were conducted in April and May 2019 at the Indonesian Red Cross Society headquarters in South Jakarta, with three representatives from PMI Jakarta, namely, the medical doctor in charge at PMI South Jakarta Branch, the Head of Data Processing Division at PMI Jakarta, and the staff at Data Processing Division at PMI Jakarta. They were chosen as they understand the production process of different types of blood products, and the activities conducted by PMI Jakarta as well as the resources needed for such activities. The interview mainly focused on the aforementioned aspects, and the historical records provided insights on the supply and demand of blood for the year of 2018.

2.2.Discrete-event Simulation

Discrete-event simulation (DES) is a method of simulating the behavior and performance of a real-life process, facility or system (Allen et al., 2015). DES models the system as a series of 'events' that occur over time. A discrete simulation model would study specific measurable variables at different points in time with the assumption that there is no change in the system between events. Arena is a discrete-event simulation software developed by Systems Modelling Corporation and acquired by Rockwell Automation. Arena is commonly used for applications such as manufacturing, supply chains, defense, health care, and contact centers (Law, 2015). Arena provides the user with different modules with their own inherent logic that can be connected and programmed to replicate different systems in the world.

The simulation model developed in this study is modified from Rytilä dan Spens (2006). A few adjustments were made to properly incorporate the blood supply chain system at PMI

Jakarta. First, the cross matching (activity to match the available blood with the prospect receiver) was not included in the model as this activity is carried out by the recipient institutions, not by PMI Jakarta. Second, the cost and benefit analysis of the process were not incorporated in this study as this research is more focused on the level of fulfillment and wastage.

2.3.Determining Input Probability

When performing simulations using random inputs (such as arrival time or number of requests), the data used must have a specific probability distribution (Law, 2015). It is necessary to choose the correct probability distribution so that the developed model can be the best representation of the system in the real world.

Arena has provided a tool called an input analyzer to process and determine the best-fitting distribution from the sample data provided. The input analyzer can observe the data, provide estimates of data parameters, and measure the degree of fit between the distribution and the sample data and will provide you with the most suitable data distribution with the lowest level of error. This distribution expression will then be used for the required fields, inputs, or processes in the Arena simulation model.

2.4.Model Verification and Validation

Verification is the process of ensuring that the simulation model programming is the correct and accurate translation of the existing system on which it is based. This process is relatively easy because Arena provides a function to verify the simulation model programming. The program can detect programming errors related to disconnected modules, inconsistent logic, incorrect input, or replication settings. If there is a problem, Arena will not perform the simulation, but will display a message explaining the error and guiding the programmer to the module or setting that needs to be fixed.

On the other hand, validation is the process of determining if the simulation model is accurate enough to represent the real-world system (Law, 2015), which can be measured using a simple t-confidence interval method. The formula is as follows:

$$\bar{X}(n) \pm t_{n-1,1-\frac{\alpha}{2}}\sqrt{\frac{S_X^2(n)}{n}} \quad (1)$$

Where:

$\bar{X}(n)$ = The average of model data sets

$S_x^2(n)$ = The variance of model data sets

n = Number of model system sets

α = Significant level

t = Critical value of *T*-distribution

2.5.Scenario Analysis

In scenario analysis, a test must be conducted to analyze the statistical differences between the base-case and alternative scenarios. This test attempts to determine whether changes made to the model have caused significant changes. It is important as a less significant change may be an indicator of an irrelevant relationship between the change and the result, and therefore will weaken the effect of the change on the simulation model. In order to determine whether the scenario has significantly changed the system results through a valid model, a paired-t test is performed by determining the confidence interval of the difference between the base-case and alternative scenarios. The formula is as follows:

$$\bar{Z}(n) \pm t_{n-1,1-\frac{\alpha}{2}}\sqrt{\widehat{Var}[\bar{Z}(n)]} \quad (2)$$

Where:

Z¯(n) = The difference in the average number of data sets model 1 and Var [¯Z(n)] = Estimate of population variance from data set 1 and 2

n = Number of system data sets

α = Significance Level

In this study, three alternative scenarios were developed based on the results of the base case scenario, aiming at fulfilling the demand and minimizing the wastage, as these are the main problems of blood inventory management mentioned in most previous studies. The best scenario would be chosen based on the amount of blood wastage.

3. Results and discussion

3.1.Case Study Description

PMI Jakarta gets its blood supply through direct donation activities at the UTD (Blood Transfusion Unit) and carries out donation activities through unit cars. With a total of 15 units of cars that are actively operating every year, about 63% of the blood supplies of PMI Jakarta is acquired through unit cars. Based on the data given in 2018, PMI Jakarta carried out 2,510 blood donation activities with unit cars.

After the blood collection process, the blood obtained from the donor is directly processed to later be converted into several different products. One donor can produce up to 4 (four) different types of blood products at once. Decision on the type of product to be processed from each donor is determined by the examining doctor based on the data of blood demands from the hospital. Table 1 shows four types of blood products that can be produced in the blood supply chain and their lifespans (Cardigan & Williamson, 2003; Murphy & McSweeney, 2009; Katsaliaki, 2008).

Table 1. Types of Blood Product

Types of Blood Product	Lifespan
Whole Blood	42 days
RBC (Red Blood Cell)	35 days
TC (Thrombocyte Concentrate)	5 days
FFP (Plasma)	24 months

In Indonesia, every region can produce various sorts of products, depending on their abilities and types of available equipment. In PMI Jakarta, other than the four main products, there are ten types of blood product that can be produced. Therefore, in total, PMI Jakarta is able to produce 14 types of blood product each month.

DOI: https://doi.org/10.7454/jessd.v5i2.1144

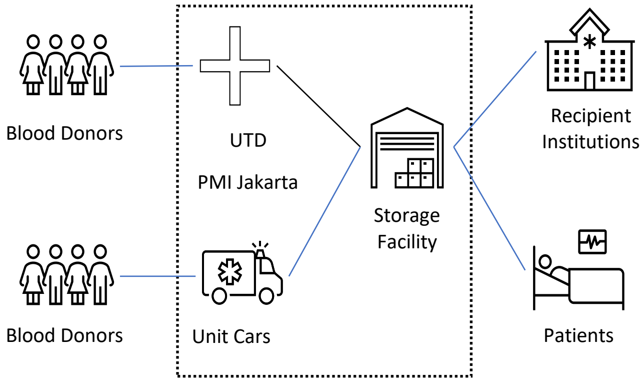

Figure 1. Blood Supply Chain PMI Jakarta

Source: Interview results

The blood is processed into blood products, namely the blood sample, and is then taken for screening to match the blood type as well as testing to ensure that the blood obtained is not infected with any of the 4 viruses that can be transmitted through blood donation activities, such as HIV, Hepatitis B, Hepatitis C, and Syphilis.

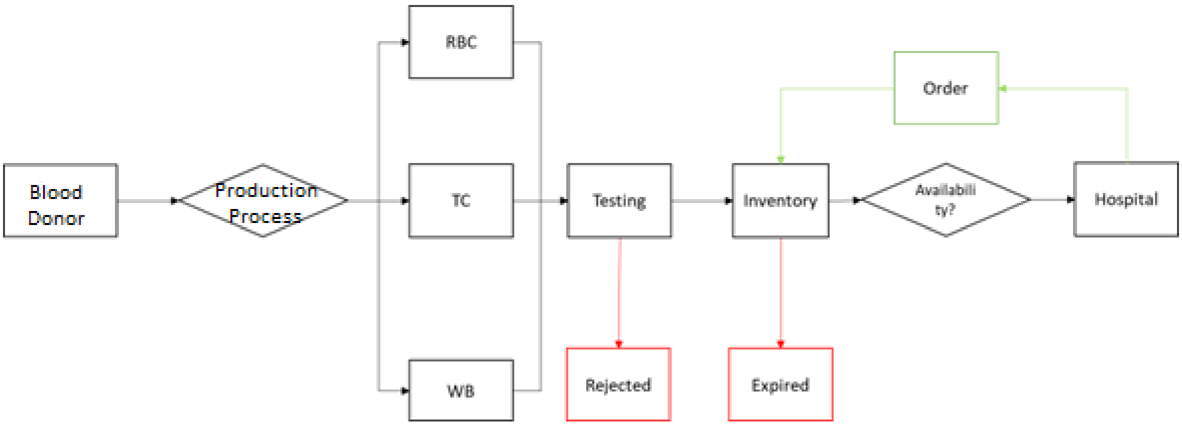

Figure 2. Blood Management Process PMI Jakarta

Source: Interview results

After the test results are received, the blood that does not pass the screening process will be immediately destroyed. Meanwhile, for the blood that fulfill the requirements, they can be sent directly to the BDRS (Hospital Blood Bank), or to patients who need blood donation (See Figure 1). Because of its characteristic as a perishable item, blood products usually have a limited life span. Thus, blood that is not used and has passed the time limit of its shelf life will be immediately destroyed and become wastes (See Figure 2). In PMI Jakarta alone, all the 14 blood products still produce waste every year.

In this study, the blood supply chain that will be analysed is the blood supply chain for the product of TC (Thrombocyte Concentrate). TC is chosen to be the subject of this study because it is a highly demanded blood product, especially at PMI Jakarta. In addition to its high demand, TC product also has a relatively short life span. In the ideal condition, TC can only survive within five days. Therefore, with a high level of demand and a short lifetime, managing TC product requires special treatment and appropriate strategy.

3.2.Simulation Model Development

The model was developed with the purpose of replicating the whole blood management process done by PMI Jakarta, particularly for the TC blood product. The desired outcome from the simulation are the data of number of bloods produced, demand, and the number of wastes created by PMI Jakarta. The simulation model was developed with the following assumptions:

a. There were no disruptions in the entire production process of PMI Jakarta
b. There were no disruptions in the whole process of blood delivery
c. There were no errors in recording data regarding demand, supply, and other statistical data
d. There were no catastrophic events which caused a significant spike in blood demand

All models were made to replicate the blood management system carried out by PMI Jakarta. There were at least 3 (three) types of processes being modeled, which consists of the blood supply and processing process into blood products, the blood testing process, and the last one was the blood storage and release process as shown in the Figure. 3 follows.

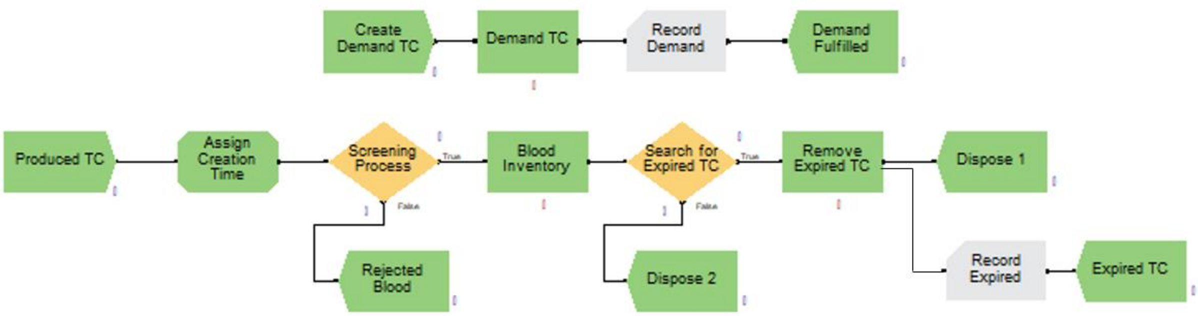

Figure 3. Base Case Scenario Model

The model begins with the process of supplying TC to PMI Jakarta (see Figure 3). The source of blood supply for PMI Jakarta is illustrated using the create module, which indicates blood that has been processed into TC Product. After the blood is processed, the blood will be given an attribute in the form of production date using the “Assign Creation Time” module.

After the processing stage, each blood bag will undergo a checking process to retest whether the blood bag that has been obtained is suitable for donor. Blood that has been processed and given the time attribute will later be separated in the “Blood Screening Process”, which will separate the blood that passes the test and the blood that does not pass the test. The blood that are unfit to use will then go directly to the “Rejected Blood” module.

Products that pass the screening process will be stored in the “Blood Inventory” module. The product release process starts with the “Demand TC” module which will signal the blood inventory to release the requested product. Requests that are successfully fulfilled will later be included in the “Demand Fulfilled” module.

As for the product that has expired and must be destroyed, it is illustrated using the decide module which is named “Search for Expired TC”. This module will separate TC Products that have passed their time limit. Once separated, then the remove module will remove these products from the blood inventory. Blood products that have expired and have been removed from inventory will be recorded using the “Record Expired” module.

3.3.Model Verification and Validation

Using the check model feature in Arena, the model was verified to not have any errors and can be executed. For validity test, the parameter that is used to validate the model is the amount of demand for TC that were created. Using the simple t-confidence interval with the output data of the model presented in Table 2, we can determine that the model’s intervals for demand for TC include the system’s total mean. This indicates that the model is valid.

Table 2. Model Validation

Data	Actual system’s mean of demand (units)	Base case scenario’s mean of demand (units)	Number of replications	95% Confidence interval
Demand	93,864	93,857	100	(93,757;93,957)

3.4.Base Case Scenario Analysis

The simulation resulted with a total of 100 replications that were done to the base case scenario. The results reveal that the average amount of TC produced in a year is 111,201 units, while the average number of TC demanded is only 93,857 units. Hence, it can be seen that that the number of TC produced by PMI Jakarta exceeds its demand. Further, it means that on average, 8,427 units of TC will become wastage, and increase the operational cost of PMI Jakarta due to the cost of obsolescence (Mohammadi et al., 2022; Rytilla & Spens, 2006). Previous studies offered different approaches in managing the wastage, but mainly centred on better order management (Meneses et al., 2023; Rytilla & Spens, 2006), reducing the supply (Mohammadi et al, 2022), and allowing trans-shipment or transferring the near-outdated blood to other recipient institutions (Najafi et al., 2017; Shokouhifar et al., 2021). Hence, in this study, the alternative scenarios to reduce the wastage are developed by limiting the production level of TC, limiting the supply of donated blood, and increasing the number demand by adding the number of recipient institutions.

3.5.Scenario Analysis

Based on the base case scenario, three alternative scenarios are proposed to minimize the amount of blood wastage. The first scenario is to reduce the amount of TC production which can be done by reducing the amount of donated blood that is processed into TC products. The second alternative scenario is to reduce the number of blood donating events conducted through unit cars, due to the fact that PMI Jakarta cannot reduce or reject donors that come directly to PMI. On the contrary, PMI Jakarta can reduce blood supply obtained through PMI activities that come directly to potential donors. The third alternative scenario is by increasing the number of requests by expanding the number of recipient institutions or PMIs in other areas that require blood supplies.

In terms of the simulation model, there is no change for Scenarios 1 and 3. However, some modifications are needed for the model in Scenario 2. The modifications include the separation of blood supply from the car unit (Mobil unit TC module) and donors that come directly to PMI (UTD TC module). This modification is made in order to determine the number of bloods generated by each type of supply as depicted in Figure 4.

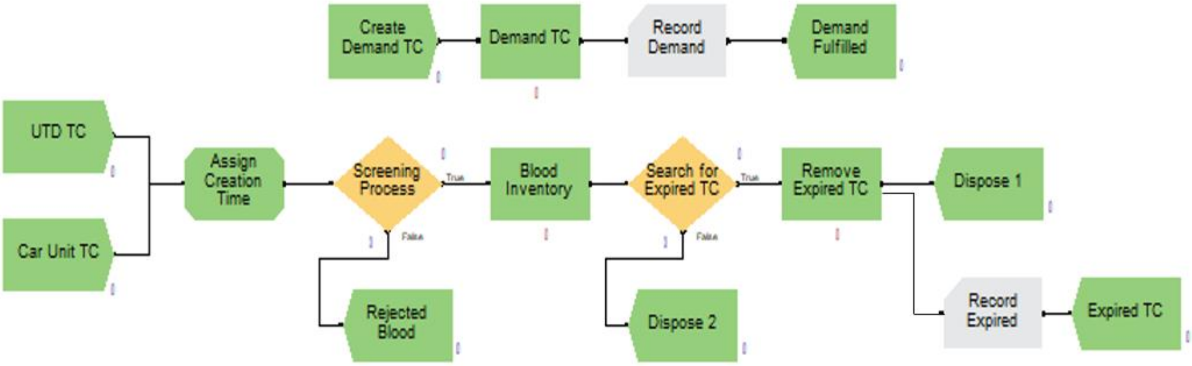

Figure 4. Scenario 2 Model Modification

Table 3. Alternative Scenarios Simulation Results

Scenario 1		Scenario 2		Scenario 3	
TC Produced	The Average Amount of Disposed Blood (Unit/year)	TC Produced from Unit Cars	The Average Amount of Disposed Blood (Unit/year)	Demand of TC	The Average Amount of Disposed Blood (Unit/year)
Decreased by 5%	2,705	Decreased by 5%	4,718	Increased by 5%	3,687
Decreased by 10%	0	Decreased by 10%	1,631	Increased by 10%	27
Decreased by 15%	0	Decreased by 15%	2	Increased by 15%	0

Table 3 shows the simulation results and the demand is fulfilled in all scenarios. It can be seen that all three scenarios have succeeded in reducing the amount of waste generated by PMI Jakarta. Comparing the results of the three scenarios, we can see that Scenario 1 has the least amount of average disposed blood when the production of TC is reduced by 5%. Simulation results of Scenario 1 show that when the production of TC is reduced by 5%, the amount of wastage is reduced significantly. In particular, the amount of disposed blood is reduced significantly from 8,427 to 2,705 units (67.9%). Furthermore, by cutting the production of TC by 10% and 15%, PMI Jakarta will be successful in eliminating the amount of disposed blood, while still fulfilling the demand. This means that with the same amount of blood supply, but reduced level of TC production, the demand will still be fulfilled, and wastage can be reduced.

Scenario 2, on the other hand, elucidates that the Unit Cars supply the majority of disposed blood in PMI Jakarta. With the aim of producing zero waste, the reduction of blood supplies by 5%, 10% and 15% can reduce up to 44%, 80%, and 99% of disposed blood respectively. Even though the average wastage is reduced significantly, the waste still exists even when the blood supplies are reduced to 15%. This indicates that blood donation events using Unit Cars should be planned carefully to avoid wastage.

Meanwhile in Scenario 3, adding more donor recipient institutions such as hospitals or other PMI branches is proven to reduce the amount of disposed blood. Increasing the number of blood recipients by 5% and 10% can reduce the amount of wastage as much as 56% and 99% respectively. Furthermore, increasing the number of blood recipients to 15% will eliminate the amount of wastage. The results show that increasing the number of recipients by transferring the blood to other institutions on other areas would significantly reduce or even eliminate the wastage. However, to able to do so, PMI Jakarta should have an integrated information system so that information of excess of supply can be disseminated promptly to the recipient institutions (Najafi et al., 2017).

After the simulating the three scenarios, a test is conducted to determine the significance of the statistical difference between each alternative scenarios and the base case scenario. In this study, only the best alternative scenario is tested. From these data, it can be said that Scenario 1 is the best alternative scenario because it reduces a significant amount of disposed blood compared to the other alternatives.

Table 4. Paired-t test results of the difference between the alternatives dan base case Scenarios

	Mean	Z (n)	Confidence Interval 98,3%	Std Deviation	Range	Results
Base Case Scenario	8,426			533		
Scenario 1 (5%)	2,705	5,721	2,434	75	(5,538; 5,903)	Significant
Scenario 1 (10%)	0	8,426	2,434	533	(7,128; 9,723)	Significant

	Mean	Z (n)	Confidence Interval 98,3%	Std Deviation	Range	Results
Scenario 1 (15%)	0	8,426	2,434	533	(7,128; 9,723)	Significant

Table 4 displays the paired-t confidence interval range results from the significance test. As we can see, all three alternatives from Scenario 1 have a significant impact towards the model, because all three scenarios do not include the value 0 within their ranges (Law, 2015). Therefore, all alternatives in Scenario 1 are statistically different and better from the base case scenario, and hence, can be accepted. This indicates that reducing the TC production would not reduce the level of demand fulfilment but would reduce the amount of wastage leading to a more efficient blood inventory management system (Mohammadi et al., 2022).

4. Conclusion

The paper presents a simulation study of blood inventory management at PMI Jakarta. The analysis indicates that PMI Jakarta is responsible for the process of searching, processing, screening, storing, and distributing, as well as disposing blood in the Jakarta area and its suburban areas. The obstacles and difficulties experienced by PMI Jakarta is mainly related to the high number of TC Products that have been produced but must be destroyed because they have entered the expiration date. What PMI Jakarta can do to reduce the amount of waste it produces is to reduce the amount of TC production and increase the demand for TC by increasing the number of donor recipient institutions or distributing blood supplies to other PMIs that experience shortages as well as reducing the number of donors through blood donation events that are carried out using unit cars. Further, PMI Jakarta can also create an integrated information system with other PMIs throughout Indonesia which can later be used to control blood supply at each PMI branch to balance the amount of supply and demand in all PMI branches in Indonesia.

This study has limitations that can be recommended for future researches. First, the number of demand and production per day are assumed based on the monthly data. Second, this study only focused on one type of product, namely TC, whereas at PMI Jakarta there are at least 14 types of blood products produced. Third, this study does not take the elements of blood type into consideration, and solely focuses on blood products. Last, this study does not include the cost element in all the analyses and focusesmainly on the quantity of the product.

This study contributes to the blood inventory management by providing alternatives that can be implemented by institutions to better manage the blood inventory, which significantly reduce the amount of wastage. By doing so, blood management can be more efficient, no blood donation goes to waste, and more people's lives can be saved.

Acknowledgment

The authors would like to thank all the informants from PMI Jakarta for supporting this study.

Authors' contributions

Conceptualization, A. Ekaputri and R.D. Kusumastuti; Methodology, A. Ekaputri and R.D. Kusumastuti; Software, A. Ekaputri.; Validation, A. Ekaputri. Formal Analysis, A. Ekaputri and R.D. Kusumastuti; Data Curation, A. Ekaputri; Writing – Original Draft Preparation, A. Ekaputri; Writing – Review & Editing, R.D. Kusumastuti; Supervision, R.D. Kusumastuti.

References

Allen, M., Spencer, A., Gibson, A., Matthews, J., Allwood, A., Prosser, S., & Pitt, M. (2015). Right cot, right place, right time: improving the design and organisation of neonatal care networks–a computer simulation study. https://europepmc.org/article/nbk/nbk293953

Aneke, J. C., & Okocha, C. E. (2017). Blood transfusion safety; current status and challenges in Nigeria. *Asian Journal of Transfusion Science*, *11*(1), 1-5. https://doi.org/10.4103/0973-6247.200781

Belien J., & Force, H. (2012). Supply chain management of blood products: A literature review. *European Journal of Operational Research*, *217*, 1-16. https://doi.org/10.1016/j.ejor.2011.05.026

Brodheim, E., Derman, C., & Prastacos, G. (1975). On the evaluation of a class of inventory policies for perishable products such as blood. *Management Science*, *21*(11), 1320-1325. https://doi.org/10.1287/mnsc.21.11.1320

Cardigan, R., & Williamson, L. M. (2003). The quality of platelets after storage for 7 days. *Transfusion medicine*, *13*(4), 173-187. https://doi.org/10.1046/j.1365-3148.2003.00449.x

Chaudhary, V., Kulshrestha, R., & Routroy, S. (2018). State-of-the-art literature review on inventory models for perishable products. *Journal of Advances in Management Research,15*(3), 306-346. https://doi.org/10.1108/JAMR-09-2017-0091

Civelek, I., Karaesman, I., & Scheller-Wolf, A. (2015). Blood platelet inventory managementwith protection levels. *European Journal of Operational Research*, *243*(3), 826-838. https://doi.org/10.1016/j.ejor.2015.01.023

Clay, N. M., Abbasi, B., Eberhard, A., & Hearne, J. (2018). On the volatility of blood inventories. *International Transactions in Operational Research*, *25*(1), 215-242. https://doi.org/10.1111/itor.12326

Cumming, P. D., Kendall, K. E., Pegels, C. C., Seagle, J. P., & Shubsda, J. F. (1976). A collections planning model for regional blood suppliers: description and validation. *Management Science*, *22*(9), 962-971. https://doi.org/10.1287/mnsc.22.9.962

Ferreira, G. O., Arruda, E. F., & Marujo, L. G. (2018). Inventory management of perishable items in long-term humanitarian operations using Markov decision processes. *International journal of disaster risk reduction*, *31*, 460-469. https://doi.org/10.1016/j.ijdrr.2018.05.010

Frank, A. W. (2013). *The wounded storyteller: Body, illness, and ethics*. University of ChicagoPress.

Goyal, S. K., & Giri, B. C. (2001). Recent trends in modeling of deteriorating inventory. *European Journal of operational research*, *134*(1), 1-16. https://doi.org/10.1016/S0377-2217(00)00248-4

Infodatin Kemenkes, R. I. (2014). Pusat Data dan Informasi Kementerian Kesehatan Republik Indonesia: Situasi Donor Darah di Indonesia (Center for Data and Information, Ministry of Health: Blood donation circumstances in Indonesia).

Infodatin Kemenkes, R. I. (2018). Pusat Data dan Informasi Kementerian Kesehatan Republik Indonesia: Pelayanan Darah di Indonesia (Center for Data and Information, Ministry of Health: Blood supply services in Indonesia).

Jennings, J. B. (1973). Blood bank inventory control. *Management Science*, *19*(6), 637-645. https://doi.org/10.1287/mnsc.19.6.637

Katsaliaki, K. (2008). Cost-effective practices in the blood service sector. *Health policy*, *86*(2-3), 276-287. https://doi.org/10.1016/j.healthpol.2007.11.004

Law, A. M. (2015). *"Simulation Modeling &Analysis"*. *5th Ed*. McGraw Hill, New York.

Lowalekar, H., & Ravi, R. R. (2017). Revolutionizing blood bank inventory management using the TOC thinking process: An Indian case study. *International Journal of Production Economics*, 186, 89-122. https://doi.org/10.1016/j.ijpe.2017.02.003

Lowalekar, H., & Ravichandran, N. (2014). Blood bank inventory management in India. *OPSEARCH*, *51*(3), 376-399. https://doi.org/10.1007/s12597-013-0148-z

Marcikic, A., & Radovanov, B. (2009). Simulation in inventory management. *Perspectives of Innovations, Economics, and Business*, *3*(1231-2016-100770), 98. http://dx.doi.org/10.22004/ag.econ.94592

Meneses, M., Marques, I., & Barbosa-Povoa, A. (2023). Blood inventory management: Ordering policies for hospital blood banks under uncertainty. *International Transaction in Operational Research*, *30*, 273-301. https://doi.org/10.1111/itor.12981

Mohammadi, N., Seyedi, S. H., Farhadi, P., Shahmohamadi, J., Ganjeh, Z. A., & Salehi, Z. (2022). Development of a scenario-based blood bank model to maximize reducing the blood wastage. *Transfusion Clinique et Biologique*, *29*(1), 16-19. https://doi.org/10.1016/j.tracli.2021.10.003

Murphy, W., & McSweeney, E. (2009). Donors and blood collection. *Practical Transfusion Medicine*, 190-199. http://dx.doi.org/10.1002%2F9781444311761.ch19

Nahmias, S. (1982). Perishable inventory theory: A review. *Operations research*, *30*(4), 680- 708. https://doi.org/10.1287/opre.30.4.680

Najafi, M., Ahmadi, A., & Zolfagharinia, H. (2017). Blood inventory management in hospitals: Considering supply and demand uncertainty and blood transshipment possibility. *Operations Research for Health Care*, *15*, 43-56. https://doi.org/10.1016/j.orhc.2017.08.006

Rytilä, J. S., & Spens, K. M. (2006). Using simulation to increase efficiency in blood supply chains. *Management Research News*, *29*(12), 801-819. https://doi.org/10.1108/01409170610717826

Schwartz, J. D., Wang, W., & Rivera, D. E. (2006). Simulation-based optimization of process control policies for inventory management in supply chains. *Automatica*, *42*(8), 1311- 1320. https://doi.org/10.1016/j.automatica.2006.03.019

Shokouhifar, M., Sabbaghi, M. M., & Pilevari, N. (2021). Inventory management in blood supply chain considering fuzzy supply/ demand uncertainties and lateral transshipment. *Transfusion and Apheresis Science*, *60*(3), 103103. https://doi.org/10.1016/j.transci.2021.103103

Stanger, S. H., Wilding, R., Yates, N., & Cotton, S. (2012). What drives perishable inventory management performance? Lessons learnt from the UK blood supply chain. *Supply Chain Management: An International Journal*, *17*(2), 107-123. https://doi.org/10.1108/13598541211212861

WHO (2022). *Blood Safety and Availability: Key facts*. https://www.who.int/en/news-room/fact-sheets/detail/blood-safety-and-availability.

Zanin, T. J., Hersey, D. P., Cone, D. C., & Agrawal, P. (2016). Tapping into a vital resource: understanding the motivators and barriers to blood donation in Sub-Saharan Africa. *African Journal of Emergency Medicine*, *6*(2), 70-79. https://doi.org/10.1016/j.afjem.2016.02.003