OPERATIONS AND SUPPLY CHAIN MANAGEMENT
Vol. 16, No. 1, 2023, pp. 77 - 96
ISSN 1979-3561 | EISSN 2759-9363

Improving Blood Bank Performance in A Decentralised Blood Supply Chain Using Discrete Event Simulation

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ABSTRACT

Indonesian Red Cross (IRC) is assigned to operate the blood bank in Indonesia's blood supply chain system. Due to the system decentralization, the regional blood banks are responsible for providing blood supply in their municipal area. Blood banks need to meet certain performance indicators to minimize shortages and outdated blood bags and generate sufficient income to cover operational costs and organizational development. This research aims to build a blood-bank management model by focusing on a multi-product arrangement and considering the unpredictability of supply and demand. Discrete event simulation was used to model the actual system and evaluate policy options to enhance blood bank performance. The simulation experimentation examines four control variables: supply arrangements based on Fixed Location Service (FLS), Mobile Unit Service (MUS), inventory target, and the setting of output product percentages. This study successfully provided solutions that can enhance the quality and efficiency of blood bank services. In this study, each scenario reveals the trade-off between the extent of the shortage and the level of obsolescence. The regulatory environment where donors are recruited greatly impacts shortages, obsolescence, and net income. Blood bank management must create an optimum targeted service level and revenue expectation to make strategic decisions.

Keywords: *blood supply chain, decentralized, discrete event simulation, Performance.*

1. INTRODUCTION

Blood transfusion is an essential health service in the healthcare system. To date, no alternative method has been developed to substitute blood transfusion. Rytilä & Spens (2006) suggest that extensive procedures in the blood supply chain are necessary to meet the demand for blood. Collection, manufacture, inventory, and distribution are the four tiers that make up the supply chain stages (Osorio et al. (2015). Supply chain management aims to optimize blood-bag supplies at a safe or required service level. Careful planning and collaboration among stakeholders are necessary to maximize available resources and create synergies (Ghandforoush & Sen, 2010; Stanger, 2012; 2013).

Increasing the forecasting and computation precisions is a problem that needs to be solved in the blood supply chain (Belin & Force, 2012). Controlling the fluctuation of supply and demand is critical because variability downstream will create a ripple effect of variability upstream. Controls over variability enable controls over inventory, which is needed to minimize the development of multiplier effects in the supply chain network (Balakrishnan *et al*., 2004).

The findings of exploratory studies involving blood banks in Indonesia show that the problem is reducing the shortage rate and outdated products and improving cost-efficiency (Mansur *et al*., 2018). Therefore, a model for improving blood supply chain management is needed. Past research has accounted for demand uncertainty in model development, but they have not considered supply uncertainty. For example, Duan & Liao (2013, 2014) and Duan & Lu (2018) have attempted to reduce the number of outdated blood products, but they should have noticed the impact of uncertain supply on product obsolescence. Another study related to distribution in healthcare supply chain management is the optimization of the COVID-19 vaccine distribution (Lusiantoro *et al*, 2022). The research was conducted by developing a mathematical model with the aim of minimizing the coverage area distance between healthcare facilities in Yogyakarta. Syahrir *et al*. (2022) developed an inventory model for managing drug demand for endemic dengue. The results show that hospital managers can determine the right inventory with accurate predictions by minimizing total costs.

This research aims to develop a simulation model to improve blood bank performance with a better improvement action (scenarios) in a decentralised supply chain such as Indonesia. The novelty of this paper is to propose a discrete-event simulation model to improve the blood bank performance by considering supply and demand uncertainty. The performance of Indonesia's blood bank which is decentralized is still low, especially in service levels and total costs performance. Improving the performance of blood blanks will improve blood bag service needs for patients and improve the welfare of Indonesia's blood bank employees.

The inability to address supply and demand uncertainties impacts blood supply availability and increases the risk of expired blood. Rytila & Spens (2006) considered supply uncertainty but not demand uncertainty, so the level of demand for blood bags is constant. On the other hand, the research conducted by Katsaliaki & Brailsford (2007); Osorio *et al*. (2017) involved the demand uncertainty and the number of donors that could me*et al*l requirements. One aspect that has not been discussed in previous studies is that the flexibility of hospital consumer preferences regarding blood age has not been considered. In real conditions, blood storage facilities at each hospital are different, so that blood banks need adaptability and flexibility in their services. Hospitals in processing and storing blood can be grouped into two types, namely: 1) hospitals with blood storage technology facilities and 2) hospitals without blood storage technology. The difference between these hospitals is that the age of the blood bags sent from the blood bank to type 1 hospital is younger than type 2 hospitals. This study proposes a model that offers opportunities for hospitals' blood age flexibility. This flexibility may influence the blood age adjustment requirements of each hospital type. This condition will affect the performance of the blood bank supplying blood demand, so this research simulates to increase the total profit of the system. More detail related to the research contribution of this paper is shown in subsection 2.3.

The section of this paper is organized as follows: literature review in Section 2, the proposed model development in Section 3, a case study and result in analysis in Section 4, the managerial implications in Section 5, and conclusions in Section 6.

2. LITERATURE REVIEW

2.1 Performance Indicators in Blood Supply Chain

Evaluating the performance of blood supply chains often involves indicators such as outdated stocks and shortages. **Table 1** summarises the performance indicators in the literature. Past research has also proposed strategies to reduce shortages and outdated products in the blood supply chain, including Civelek *et al*. (2015), Haijema (2014), Katsaliaki (2007), Kopach *et al*. (2008), Lowalekar *et al*. (2015), Luo & Chen (2021), Puranam *et al*. (2016), Razavi *et al*. (2020), Rytilä and Spens (2006). Recent improvements in cost and health performance have piqued experts' interest.

Table 1 Performance Indicators in Blood Supply Chain

Indicator	Author
Shortages and outdated stock	(Chapman *et al*., 2004), (Rytilä & Spens, 2006), (Kopach *et al*., 2008), (Delen *et al*., 2011), (Stanger *et al*., 2012), (Smid *et al*., 2013), (Duan & Liao, 2013), (Yuzgec *et al*., 2013), (Abbasi & Hosseinifard, 2014), (Hosseinifard & Abbasi, 2016) , (Dillon *et al*., 2017).
Shortage	(Reynolds *et al*., 2001), (Dijk *et al*., 2009), (Filho *et al*., 2012), (Fahimnia *et al*., 2015), (Zahraee, *et al*., 2015), (Bedi *et al*., 2016).
Transportation Cost	(Hemmelmayr *et al*., 2009), (Ghandforoush & Sen, 2010), (Delen *et al*., 2011).
Service Level	(Cohen, 1979), (Prastacos, 1979), (Rytilä & Spens, 2006), (Galloway *et al*., 2008), (Hemmelmayr *et al*., 2009).
Safety in Transfusion	(Alfonso *et al*., 2013), (Katsaliaki, 2015).

Table 1 shows that the most used measurement standard in the blood supply chain is the amount of shortage and outdated inventory. Financial performance metrics have not been used as much. The current study considers financial components to inform policymaking for blood bank improvement.

2.2 Simulation Approach in Blood Supply Chain Research

Compared to an analytical model, a simulation model is more adaptable to complicated situations (Lowalekar &

Ravichandran, 2015; Kamalapur & Lyth, 2020). Researchers often employ a simulation model to research blood management to convert the system's complexity into realistic scenarios. The complexity includes groups and variations, cross-matching, and inter-blood bank transfers. These are complicated to model mathematically concurrently, and the simulation model approach can resolve this problem (Rytilä & Spens, 2006).

Because discrete event simulation (DES) can overcome complex stochastic systems, it has been widely used to model blood supply chain systems. The advantage of DES is that it can analyze system bottlenecks and determine their causes (Banks *et al*., 2010). Another advantage of DES is that it is flexible enough to examine the current situation and forecast future occurrences by the modeller's scenario (Jacobson *et al*., 2013). Considering the complexity of the blood supply chain system and the advantages of DES shown in previous research, the current research uses DES to address the problems.

2.3 Research contributions

The blood supply chain study has attracted many researchers' attention. Each country has its differences in the complexity of the problem. J. Blake & Hardy (2013) and J. T. Blake & Hardy (2014) studied the blood supply chain network system in Canada. Improving the performance of the blood supply chain in India has been proposed by Lowalekar & Ravichandran, (2013), Lowalekar & Ravi, (2017), and Dharmaraja *et al*. (2020). Meanwhile, the proposed model for improving the blood supply chain in Iran has been proposed by Razavi *et al*. (2020) and Zahraee *et al*. (2015). This study continues the research of Zhou *et al* (2021) considered two uncertainty factors but did not consider the blood bag age. In contrast to the study conducted by Abbasi et al. in 2017, their investigation focused on the effects of modifying the blood age limit, particularly on PRC products. Their investigation focused on the blood supply chain's supplier.

The assumption used was that the blood supply from the blood bank is always sufficient. Based on the actual condition, this research proposes a simulation model to improve the performance of blood supply based on the actual condition in Indonesia. This study considers the complexity of the blood supply chain system in managing supply and demand uncertainty. In addition, various blood products with different shelf-life have been considered in this study. The slight novelty of this research is how to manage the blood supply chain in a multi-product blood bank by considering supply and demand uncertainties and providing space for flexibility in requests related to different blood expiration date periods. **Table 2** shows the contribution of this research to related studies on blood supply chain research.

Table 2 Main Contribution of Related Studies on Blood Supply Chain Research

No	Author(s) (years)	Supply Uncertainty	Demand Uncertainty	Flexibility (Different Demand Requirement)	Organization Structure	Performance	Methods	Variety of items
1	Haijema *et al*. (2007)	NA	A	NC	Centralized	1, 3	Dynamic Programming	S
2	K. M. Spens & Rytila (2006)	NA	A	NC	Centralized	1, 2, 3	Modelling - DES	M
3	Katsaliaki & Brailsford (2007)	1,2	A	NC	Centralized	1, 2, 3, 4	Modelling - DES	S
4	Kopach, Balcıog˘lu & Carter (2008)	NA	A	C	Centralized	1, 2, 4	A Queuing Model	S
5	Haijema (2014)	NA	A	NC	Centralized	3	Dynamic Programming	S
6	Lowalekar & Ravichandran (2015)	NA	A	NC	Centralized	1, 2, 3	Modelling - DES	S
7	Civelek *et al*.(2015)	NA	A	NC	Centralized	1, 2, 3	Markov Decision Process	S
8	Puranam *et al*.(2016)	NA	A	NC	Decentralized	1, 2, 3, 4	Dynamic Programming	S
10	Dillon, Oliveira, & Abbasi (2017)	NA	A	NC	Centralized	1, 2, 3	two-stage stochastic programming	S
11	Abbasi *et al*. (2017)	NA	A	C	Centralized	1, 2, 3	Discrete Event Simulation	S

No	Author(s) (years)	Supply Uncertainty	Demand Uncertainty	Flexibility (Different Demand Requirement)	Organization Structure	Performance	Methods	Variety of items
12	Mahmood *et al*., (2017)	NA	A	NC	Centralized	3	Robust Probabilistic Programming	S
13	Osorio *et al*., (2016)	NA	A	NC	Decentralized	1, 2, 3	Simulation - Optimization (DES-ILP)	M
14	Razavi *et al*. (2020)	NA	A	NC	Centralized	1, 2	Genetic Alghoritm-Goal Programming	M
15	Abbasi *et al*. (2020)	NA	A	NC	Centralized	1, 2, 3	Machine Learning	S
16	Hamdan and Diabat (2020)	1,2	None	NC	Centralized	5	Lagrangian relaxation	S
17	Zhou *et al*. (2021)	A	A	NC	Decentralized	5	DES -MILP	S
18	Luo and Chen (2021)	NA	A	NC	Centralized	1, 2, 3	Numerical Anaysis	S
19	Karadağ *et al*. (2021)	NA	NA	NC	Centralized	1, 2, 3	MILP	S
20	This article	A	A	C	Decentralized	1, 2, 3, 4	DES	M

Remarks
A : Accommodate NA : Not Accommodate
NC : Not Consider with Customization
C : Consider Customization
Variety of items: S = single product; M = multi products
Performance: 1 = shortages, 2 = outdated, 3 = inventory costs, 4 = service level, 5 = time & delivery cost

3. METHODOLOGY

3.1 Description of Blood Bank System and Business Process

This study proposes improvements to Indonesia's blood management system. A non-profit organization manages the national blood supply system called, the Indonesian Red Cross (PMI), as shown in **Figure 1**.

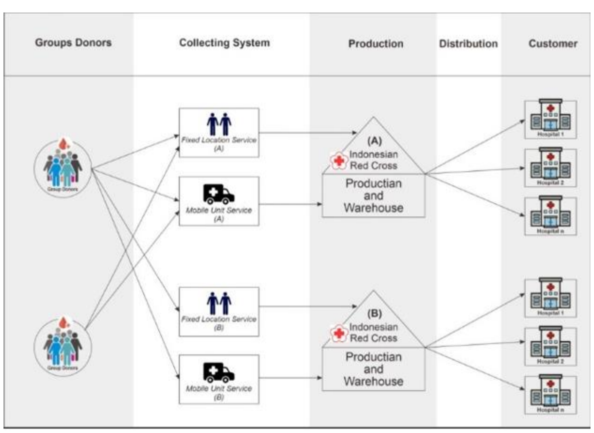

Figure 1 Blood Supply Chain Role in Indonesia

Figure 1 shows that a blood bank has two supply channels: fixed location service (FLS), provided at the blood bank's office, and mobile unit service (MUS), provided by visiting the donors. Blood banks will transform donated blood into various products that hospitals demand. In Indonesia, the blood supply system is decentralized, as shown in **Figure 2**. Generally, there are two models for managing the blood supply chain: centralized and decentralized blood bank systems. The government of Indonesia, whose landmass encompasses 8.3 million square kilometers and over 17,000 islands, decided to create a decentralized system due to the country's vast size (Mansur *et al*., 2022). The decentralization aligns with the Indonesian government management paradigm, which gives local governments autonomy. As a result, each city/district has its local blood bank organization. In a decentralized system, the local blood bank in each city/district controls the planning, collecting, production, and delivery to hospitals. The local blood bank interacts with the local government, which is solely responsible for meeting blood demand within its authority. The following factors contribute to the complexity of controlling the blood supply chain in Indonesia:

- Limited shelf life because blood is a perishable substance.
- Uncertain blood demand patterns as consumers' demands for the type and the number of blood bags are stochastic.
- Uncertain blood supply pattern because supplying blood involves voluntary donors under stochastic conditions.
- In-silo practices because each player in the blood-bag supply chain is a self-contained entity capable of making its own decisions, so synchronizing players needs a series of complex judgments.

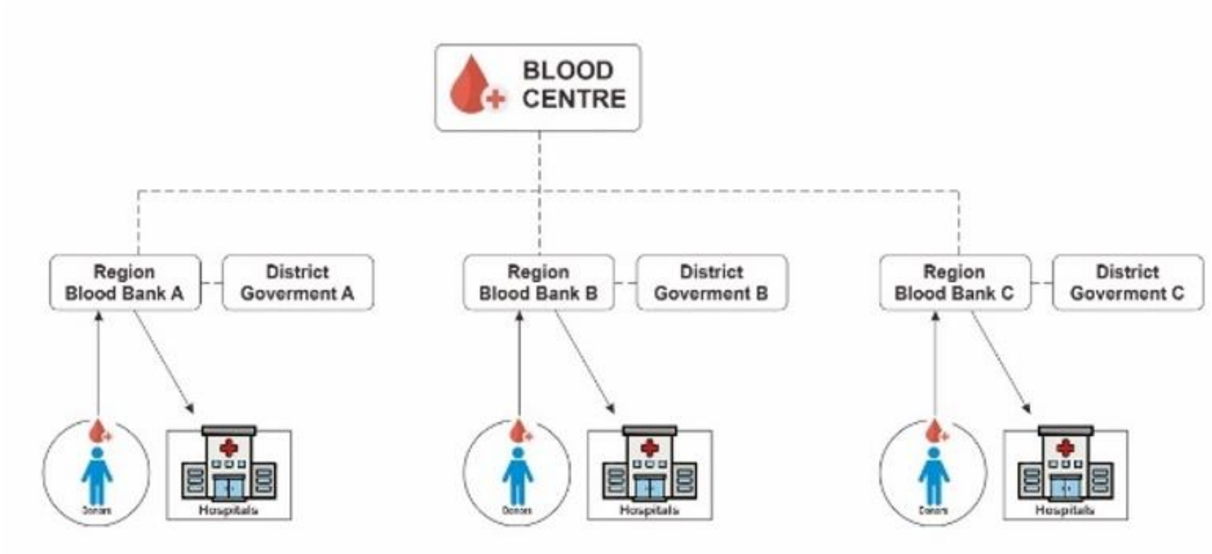

Figure 2 Decentralized Model in Blood Supply Chain

The blood banks' roles in the blood supply chain are to serve as a hub between the upstream (donors) and the downstream (hospitals and patients) (Afshar *et al*., 2014). **Figure 3** provides the detailed business process of managing a blood bank in Indonesia.

Figure 3 shows that a blood bank's first action is communicating with potential donors, inviting them to donate via FLS or MUS. Following the blood donation process, blood banks run serological and hematological tests to determine whether the blood bags received are suitable for blood component processing. Certain blood products, such as packed red cells, whole blood, platelets, and others, are stored in specific cabinets before being transported to hospitals. Two types of hospitals are served. Type 1 hospitals have a blood storage unit that stores blood bags before being transfused to patients. Type 2 hospitals do not own this unit, so the ordered blood bags need to be transfused directly to patients. Due to the inter-chain connectivity in the blood supply chain, one echelon's effectiveness will affect the next stage of the process/echelon, which means that close coordination between stakeholders in each echelon is mandatory (Stanger, 2013; Dillon *et al*., 2017; Hosseinifard & Abbasi, 2016).

3.2 Simulation Model

The model developed in this study is based on the decentralized Indonesian blood bag supply chain. The blood bank observed in this study as a model is located in the Special Region of Yogyakarta. The model is constructed using a DES technique and developed by the Arena software.

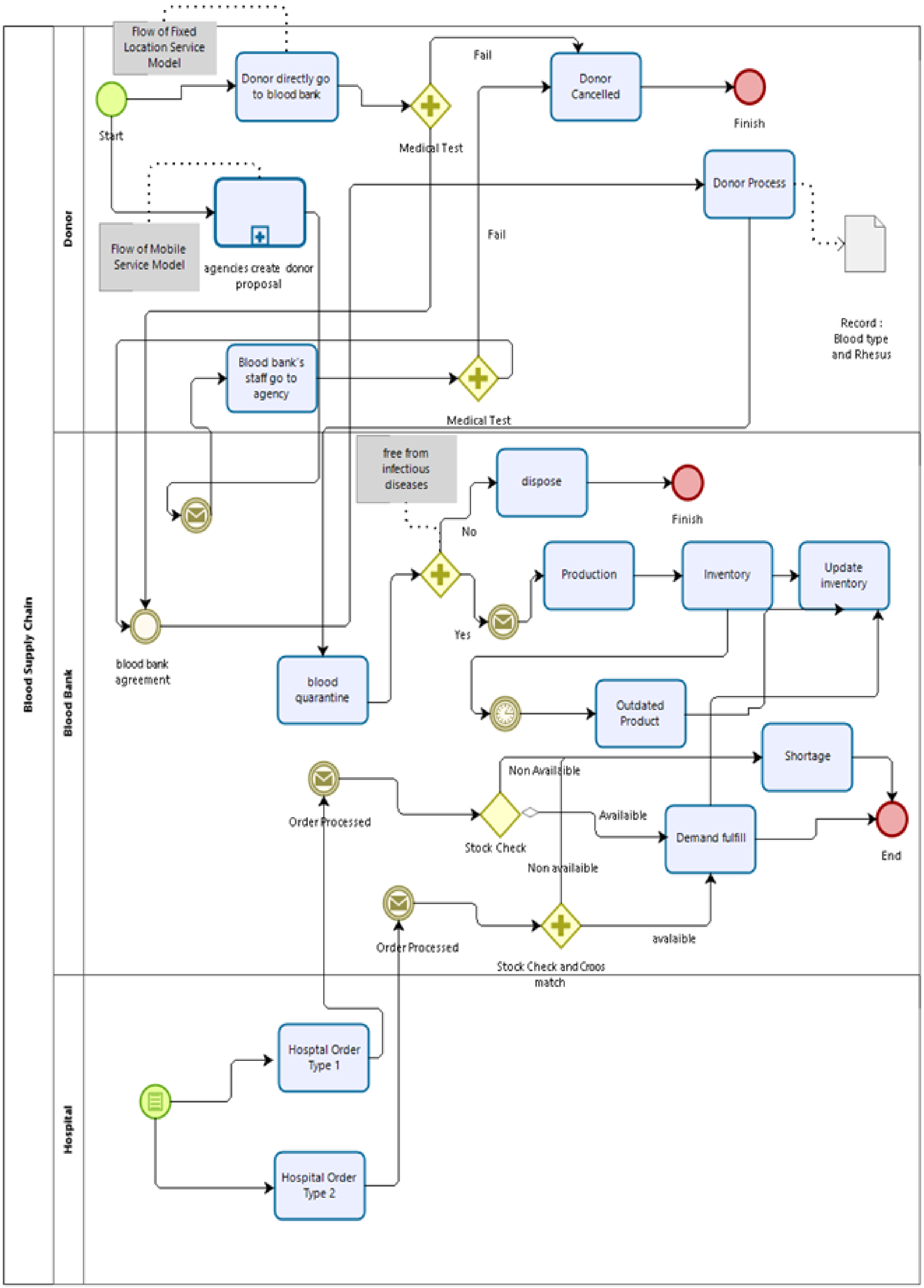

Figure 3 Blood Bank Business Process in Indonesia

3.2.1 Model Development

In this research, the players in the simulation model are donors in a fixed location service (FLS), mobile units service (MUS), blood banks, and hospitals. **Figure 4** depicts the relationship between players in the simulation model. The entities studied in this study are blood bag products with four types (A, AB, B, and O) in three varieties, namely:

a. Whole blood (WB) contains all components used to treat patients with sustained severe bleeding—e.g, those involved in a traffic accident—and require erythrocytes and plasma.
b. Packed Red Cells (PRC), red blood cells that transport oxygen from the heart to the rest of the body and remove carbon dioxide, are used to treat patients who suffer from anemia or diminished hemoglobin as a result of cancer or other diseases.
c. Thrombocyte (TC) is a blood component transfused to treat patients who cannot produce enough thrombocytes dues to pregnancy, infectious agents, leukemia, or chemotherapy.

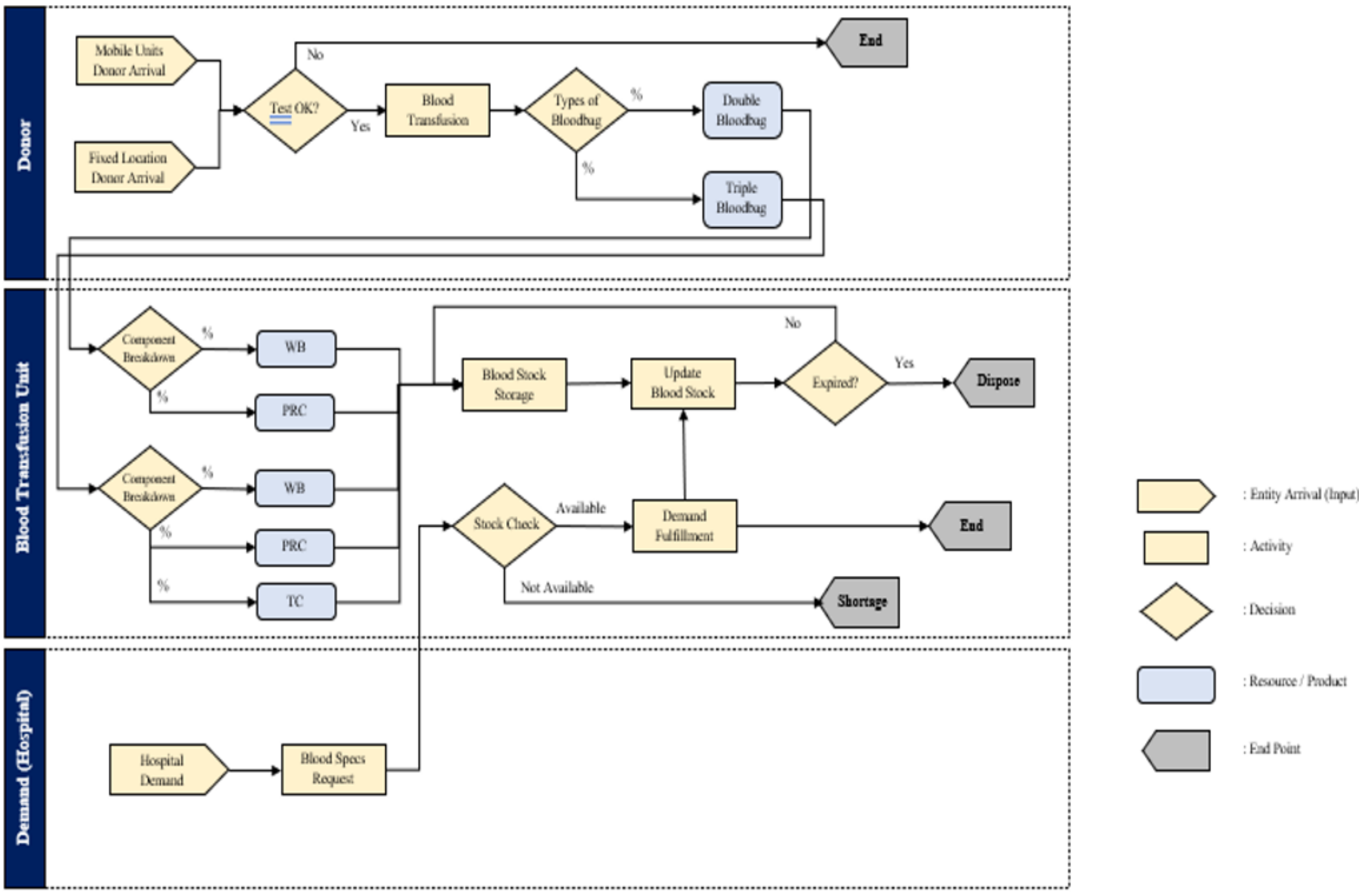

Figure 4 Simulation Model Flow

3.2.2 Model Input

The simulation requires three types of data: donor, demand, and operational data from blood banks. **Figure 5** shows the input parameters in the simulation model and their descriptions. For example, the first parameter is the demand, divided into type 1 hospitals and type 2 hospitals. The demand parameters are demand arrival rate, demand per arrival, product demand proportion, blood types of demand proportion, and rhesus demand proportion. The second parameter is the location, divided into a fixed location (FLS) and a mobile location (MUS). The donor location parameters consist of donor arrival rate and the number of donors per arrival. Finally, the blood specification parameters consist of blood bag proportion and donor type proportion.

Input Parameter	Input Description
a. Demand	
a.1 Hospital Type 1	
Demand arrival rate (peak)	*Constant: 1 Day*
Demand arrival rate (mode)	*Constant: 1 Day*
Demand arrival rate (low)	*Constant: 1 day*
Amount of demand per arrival (peak)	*ANINT (11.5 + WEIB (31.1, 1.95))*
Amount of demand per arrival (mode)	*ANINT (11.5 + WEIB (28.6, 1.72))*
Amount of demand per arrival (low)	*ANINT (5 + WEIB (30.7, 1.73))*
Product demand proportion	*WB (2%), PRC (80%), TC (18%)*
Blood types of demand proportion	*A (25%), B (28%), AB (9%), O (39%)*
Rhesus demand proportion	*Rh+ (99.99%), Rh- (0.01%)*
a.2 Hospital Type 2	
Demand arrival rate (peak)	*Constant: 1 Day*
Demand arrival rate (mode)	*Constant: 1 Day*
Demand arrival rate (low)	*Constant: 1 Day*
Amount of demand per arrival (peak)	*ANINT (12 + WEIB (93.2, 1.55))*
Amount of demand per arrival (mode)	*ANINT (NORM (92.8, 45.7))*
Amount of demand per arrival (low)	*ANINT (NORM (73, 32.7))*
Product demand proportion	*WB (11%), PRC (84%), TC (5%)*
Blood types of demand proportion	*A (25%), B (31%), AB (10%), O (35%)*
Rhesus demand proportion	*Rh+ (99.99%), Rh- (0.01%)*
b. Donors	
b.1 Fixed Location	
Donor arrival rate (peak)	*Constant: 1 Day*
Donor arrival rate (mode)	*Constant: 1 Day*
Donor arrival rate (low)	*Constant: 1 Day*
Number of donors per arrival (peak)	*ANINT (37 + WEIB (109, 1.09))*
Number of donors per arrival (mode)	*ANINT (15 + 387 * BETA (1.87, 4.74))*
Number of donors per arrival (low)	*ANINT (-0.001 + ERLA (56.8, 2))*
b.2 Mobile Unit	
Donor arrival rate (peak)	*ANINT (0.5 + EXPO (0.732))*
Donor arrival rate (mode)	*ANINT (0.5 + EXPO (0.684))*
Donor arrival rate (low)	*ANINT (0.5 + EXPO (1.05))*
Number of donors per arrival (peak)	*ANINT (11 + WEIB (69.9, 1.37))*
Number of donors per arrival (mode)	*ANINT (NORM (63.7, 45.7))*
Number of donors per arrival (low)	*ANINT (10 + WEIB (38.6, 1.15))*
b.3 Blood Specifications	
Blood bag proportion	*Double (80%) dan Triple (20%)*
Blood type proportion	*A (24%), B (30%), AB (7%), O (39%)*
c. General	
IMLTD test passed the probability	*Passed (99.98%), Not Passed (0.02%)*
Bloodstock lifetime	*Constant: 25 Days from the Initial Date*

Figure 5 Input Parameters

3.2.3 Developing the Response and Control Variables

The critical point in simulation experimentation is determining the response and control variables. The response variable serves as a reference to determine the policy's success, presented in a numerical value to measure the metrics of performance (KPI). The control variable's changes determine the value of this dependent variable. In this study, the metrics used to measure blood bank performance are:

1. The number of outdated products or blood bag items that have passed their expiration date.

2. The rate of shortages shows how many requests for blood bags cannot be fulfilled.
3. The order fulfilment rate is a percentage of requests that can be met against the overall demand.
4. The net income is revenue generated from selling blood bags minus deducting costs.

This study proposes an improvement on the blood bank to obtain performance based on the key performance indicator. The control variables in this study are created as a corrective action taken to improve performance. The control variables can be manipulated to reach the desired level of performance. The following control variables are employed in this study based on the results of the literature analysis and the experts' opinions.

a. Donor Quantity
 The number of donors affects the supply of fresh whole blood to produce blood components. This research exercises control over two distinct supply sources: the fixed location model (FLS) and the mobile unit model (MUS).
b. Inventory to be Targeted (Imax)
 Imax is the maximum number of each blood product available each day. The Imax of each blood component affects the blood bank's reliability in meeting the demand. Imax also poses a risk of product obsolescence.
c. Product Combination in Actual Production
 Determine the percentage of product variants produced in the production activities. Once the blood received has passed a quality control test, this procedure is carried out. Product combination is critical since the blood product demand varies (blood type, component, and age).

The above factors were used as control variables in the simulation model's construction. The control variable is determined based on the blood bank's operational decisions. The effort required to determine the control variable is detailed in **Table 3.**

Table 3 Control Variable Setting Design

No	Control Variable	Control Design
1	Donor settings on FLS models	Limit the number of donors each day or allow unlimited donations to the blood bank
2	Donor settings on MUS models	Increase or decrease the intensity of MUS events
3	Inventory target	Control the Imax of each blood bag product
4	Setting the percentage of blood bag production	Calculate the percentage of each blood bag component to be produced

3.2.4 Simulation Experimentation

This section describes the simulation experiments, i.e., scenarios developed in this study. Based on the control factors defined in Table 3, simulation scenarios will be developed by considering their effect on blood shortage and outdated items. Each control variable is provided with three choices (levels). **Table 4** presents detailed information about the levels.

Table 4 Control Variables and Levels Used in the Simulation

No	Factor	Level 1	Level 2	Level 3
1	FLS target setting (Factor A)	Existing	Donors are limited to a maximum of 75 per day	Donors are limited to a maximum of 50 per day
2	MUS target setting (Factor B)	Existing	Aiming for a two-day inter-arrival time in the peak session and a one-day inter-arrival time in the regular session	Targeting a two-day inter-arrival time
3	Maximum inventory target setting (Factor C)	Existing	Based on the 75th percentile value of the existing condition	Based on the median value of the existing condition
4	Production per centage setting (Factor D)	Existing	WB:10% PRC:76% TC: 14	WB:6.6% PRC:81,6% TC:11.8%

This study has nine scenarios with the control variable design, as described in **Table 5.**

Table 5 Scenario Design of Changes in Control Variables

Scenario	FLS target setting (Factor A)	MUS target setting (Factor B)	Inventory target setting (Factor C)	Production per centage setting (Factor D)
Existing	1	1	1	1
2	2	1	1	1
3	3	1	1	1
4	1	2	1	1
5	1	3	1	1
6	1	1	2	1
7	1	1	3	1
8	1	1	1	2
9	1	1	1	3

The explanation of the scenarios in **Table 5** is as follows. Each parameter employed in Scenario 1 is set to the level 1 control variable, reflecting the present condition, as in **Table 4**. Scenarios 2 and 3 focus on changing the policy regarding the number of donors at an FLS facility. In these scenarios, it is proposed to set the maximum number of donors per day. The reason for using Scenarios 2 and 3 is that there is a limit to the number of donors who come to the FLS facility, which will reduce the amount of product outdated. However, it is necessary to look at the impact on the magnitude of the shortage that may arise due to these restrictions. Scenario 2 focuses on setting FLS parameters, with the control variable specified at level 2, as shown in **Table 4**. The maximum number of daily donors in the FLS model is 75. The remaining control variables stay at level 1 and remain unchanged from the initial conditions. As depicted in **Table 4**. Scenario 3 is a guideline to set FLS parameters, with the control variable set to level 3. The maximum number of donors per day is 50. The control variables remain at level 1 and unaltered from the initial conditions.

Scenario 4 focuses on MUS parameters, with the MUS control variable set at level 2, as shown in **Table 4**. The MUS schedule in this scenario is a two-day inter-arrival time during the peak session and a one-day interval during the regular session. The remaining control variables are at level 1, unaltered from the initial conditions. The focus of Scenario 5 sets the MUS control variable at level 3, as shown in **Table 4**. The expected inter-arrival time for MUS activities is two days. The remaining control variables are set at level 1. The consideration for choosing Scenarios 4 and 5 is that setting the frequency of mobile unit activities has an impact on the magnitude of shortage, outdated, and the purchasing cost of blood. Scenarios 6 and 7 focus on creating inventory target parameters. The consideration for selecting Scenarios 6 and 7 is that the Imax value set by the blood bank impacts the blood bank's capability to provide bloodstock. Scenario 6 focuses on the inventory target with the goal set to level 2 (**Table 4**). In this case, the inventory aim is set on the 75th percentile value. The remaining control variables remain at level 1. Scenario 7 focuses on establishing inventory target parameters, with the inventory objective set to level 3 per **Table 4**. In this case, the inventory goal is set to the 50th percentile value. The remaining control variables remain at level 1.

In Scenarios 8 and 9, the aim is to determine the percentage of blood bag production. The consideration for choosing these scenarios is because the scope of this research is multi-product, so each product's stock is analyzed in more detail. The availability of each product is one of which is influenced by the blood bank policy in providing the proportion of the amount of production for each product. As shown in **Table 4**, the production per centage control variable, in this case, is set to level 2. Meanwhile, the product composition is as follows: 10% Whole Blood, 81.6% Packed Red Cells, and 14% Thrombocytes. The control variables remain at level 1, unchanged from the initial conditions. Scenario 9 is concerned with blood bag production. The production percentage control variable is set to level 3, with the following production elements: 6,6% Whole Blood, 76% Packed Red Cells, and 11% Thrombocytes. The control variables remain at level 1, unaltered from their initial conditions.

3.3 Model Evaluation

The simulation model was run for 365 days (one calendar year), and 30 replications were carried out for each scenario. Replications were carried out to ensure that the results of the running simulation were in normal distribution conditions. The simulation results were used to assess the key performance metrics of the proposed scenarios. The model was also verified and validated experimentally to confirm that the simulation model accurately depicts the actual system.

3.3.1 Verification and Validation

Model verification was carried out to analyze the suitability of the logic flow in the computer simulation model compared to the logic in the actual system. In this study, the simulation model was created using the Arena software. Sargent (2005) formulated verification and validation techniques, including animation tests, computerized program verification, comparison with other models, face validity, degeneracy, and extreme condition tests. The tests carried out are summarised in **Table 6**.

Table 6 Verification and Validation Results

	No	Test Type	Result
Verification	1	Animation test	Verified
	2	Computerized program verification	Verified
Validation	1	Face validity	Valid
	2	Statistic validation using t-Test: Two-sample assuming equal variances with α = 0.01	Valid
	3	Comparison with other behavior models	Valid
	4	Degeneracy and extreme condition tests	Valid

Comprehensive statistical validation testing was conducted in this work. The test is conducted from the simulation's input side and the simulation's output outcomes. In the simulated input validation test, the number of supplies and the number of demands is examined as variables. **Table 7** shows the results of the input validation test based on *the t-test.*

Table 7 T-Test Results for Number of Donors and Demands

No	Variables	t_{stat}	$t_{critical\ two\text{-}tail}$
1	Number of donors in FLS (Low Session)	1.58	1.86
2	Number of donors in FLS (Medium Session)	0.98	1.86
3	Number of donors in FLS (Peak Session)	-1.10	1.86
4	Number of donors in MLS (Low Session)	-0.51	1.86
5	Number of donors in MLS (Medium Session)	-0.13	1.86
6	Number of donors in MLS (Peak Session)	-1.59	1.86
7	Number of demands at Hospital Type 1 (Low Session)	1.10	1.86
8	Number of demands at Hospital Type 1 (Medium Session)	-0.13	1.86
9	Number of demands at Hospital Type 1 (High Session)	0.09	1.86
10	Number of demands at Hospital Type 2 (Low Session)	-1.44	1.86
11	Number of demands at Hospital Type 2 (Medium Session)	1.00	1.86
12	Number of demands at Hospital Type 2 (High Session)	-0.37	1.86

In order to validate the simulation output, the number of outdated products for Whole Blood (WB), Packed Red Cells (PRC), and Thrombocyte (TC) in the existing system is compared to the size of outdated products based on simulation running. **Table 8** presents the outcomes of the *t-test* for output validation.

Table 8 T-Test Results for Product

Blood Type	*t-stat*			$t_{critical\ two\text{-}tail}$
	Whole Blood	Packed Red Cells	Thrombocyte	
A	0.31	1.38	1.12	2.30
B	-0.49	0.10	-1.78	2.30
AB	0.89	2.35	-0.01	2.30
O	-1.28	1.85	-1.29	2.30

According to **Tables 7** and **8**, the value of t_{stat} falls within the reception area H_0, where the reception area for H_0 is $-t_{critical\ two\ tails} \leq t_{stat} \leq t_{critical\ two\ tails}$. This suggests there is no compelling reason to reject hypothesis H_0 (there is no difference between the simulation model and the real system). So that the data can be utilized to establish that the model is valid (represents a simple system) and the model can be used to evaluate the recommended scenario for system improvement.

4. RESULT AND ANALYSIS

The influence of changes in operational policies on blood bank performance was examined using a verified and validated model. The case study is a blood bank located in the Special Region of Yogyakarta, Indonesia. The performance metrics studied are the number of shortages, obsolete inventory, order fulfilment rate, and net income.

4.1 Number of Product Shortages

Reducing the number of shortages is one of the major performance indicators in this research. **Table 9** details the number of products affected by shortages in each scenario. The value shown is the average of 30 replications.

Table 9 The Number of Product Shortages Based on the Simulation Results

#	WB				Total	PRC				Total	TC				Total	Grand Total
	A	B	AB	O		A	B	AB	O		A	B	AB	O		
1	32	15	33	47	**127**	73	22	101	99	**296**	112	106	17	12	**246**	**669**
2	244	305	162	211	**922**	834	878	934	424	**3,070**	62	50	89	37	**238**	**4,230**
3	61	76	89	28	**254**	107	115	271	120	**613**	23	15	49	12	**100**	**967**
4	369	475	192	419	**1,456**	2,516	2,852	1,456	2,563	**9,387**	181	169	129	11	**490**	**11,333**
5	32	36	65	14	**146**	52	62	66	53	**233**	11	6	36	5	**57**	**436**
6	9	9	12	8	**38**	130	133	213	124	**601**	5	6	19	6	**36**	**674**
7	52	70	86	30	**238**	101	99	112	4,456	**4,768**	12	9	33	10	**64**	**5,069**
8	48	58	72	25	**202**	99	97	141	95	**432**	19	13	48	13	**93**	**728**
9	41	51	72	24	**188**	99	97	121	96	**413**	18	12	46	13	**88**	**689**

Note: WB = Whole Blood, PRC = Packed Red Cells, TC = Thrombocyte

In order to analyze the impact of the proposed scenario on the number of shortages, this study conducted a statistical analysis by comparing the number of shortages between the proposed model and the existing condition (Scenario 1). Statistical test was carried out by statistical t-test (**Table 10**). These results show that in almost all of the proposed scenarios, there is a significant difference in the number of shortages between the proposed models in the existing conditions. Only Scenarios 6th and ninth have relatively the same number of shortages compared to Scenario 1. Meanwhile, Scenario 5 has the most significant difference in the number of shortages compared to the existing conditions.

Table 10 Statistical Test Results on the Number of Shortages for A, B, AB, and O Blood Types.

Product	Scenario	R_1	R_2	t_{stat}	$t_{critical\ two\text{-}tail}$	Result
WB, PRC, TC	1-2	30	30	-21.49	2.05	Difference
	1-3	30	30	-53.35	2.05	Difference
	1-4	30	30	-3.30	2.05	Difference
	1-5	30	30	3.42	2.05	Difference
	1-6	30	30	-0.46	2.05	No difference
	1-7	30	30	-107.38	2.05	Difference
	1-8	30	30	-4.40	2.05	Difference
	1-9	30	30	-1.92	2.05	No difference

Note: R_1 = Replication 1; R_2 = Replication 2

Figure 6 shows the comparison between shortages in the existing condition and Scenario 5. The figure shows only Scenario 5, those fewer shortages than the existing condition, based on statistics on the number of shortages in the nine tested scenarios. The shortage in the fifth scenario is 436 blood bags, or fewer than the current situation, which is 669 blood bags. Based on the number of shortages, Scenario 5 can be claimed to have resulted in a performance increase compared to the current state. It can reduce shortages for all blood groups except for the AB group.

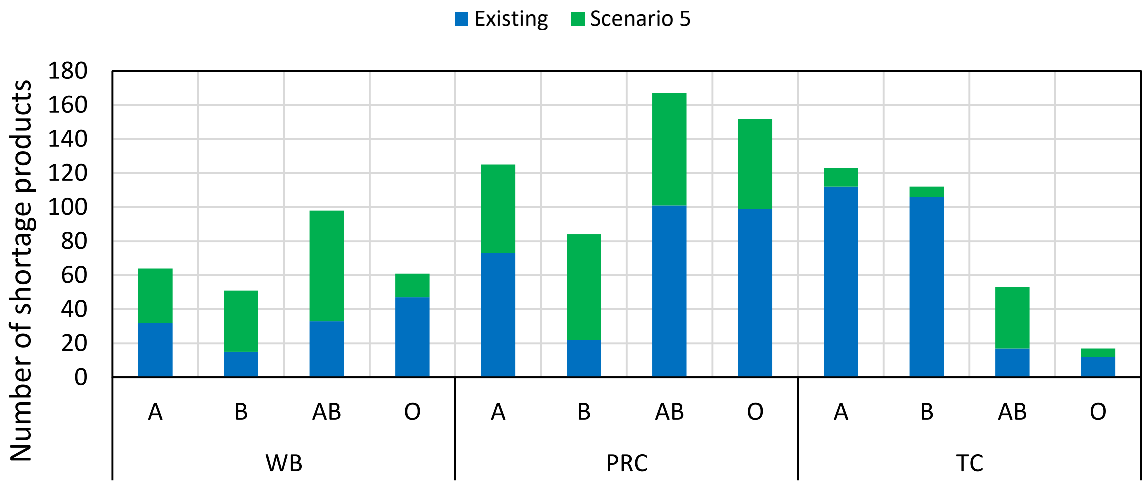

Figure 6 Comparison of the Number of Shortages in the Existing Condition and Scenario 5.

4.2 Number of Outdated Products

Reducing the number of obsolete items is critical for blood bank efficiency. In the same analysis for the number of shortages, **Table 11** summarizes the average of 30 replications related to the number of outdated products in each scenario based on the simulation results.

Table 11 The Number of Outdated Products Based on the Simulation Results

#	WB				Total	PRC				Total	TC				Total	Grand Total
	A	B	AB	O		A	B	AB	O		A	B	AB	O		
1	93	111	17	271	**491**	2,342	3,127	191	5,078	**10,738**	639	889	173	1,132	**2,833**	**14,062**
2	20	21	7	32	**80**	48	77	4	252	**381**	205	293	64	390	**952**	**1,413**
3	56	66	12	181	**314**	1,417	1,966	77	3,683	**7,143**	527	706	142	931	**2,307**	**9,763**
4	10	11	4	15	**39**	0	1	0	7	**8**	84	116	36	152	**388**	**435**
5	111	134	16	310	**572**	2,535	3,394	211	5,583	**11,722**	687	917	178	1,219	**3,001**	**15,295**
6	470	584	78	924	**2,056**	1,547	2,108	91	3,765	**7,511**	1,067	1,441	277	1,836	**4,621**	**14,188**
7	64	82	14	194	**354**	2,286	3,059	180	4,991	**10,516**	751	1,332	201	1,319	**3,603**	**14,473**
8	53	81	17	190	**340**	1,478	2,015	110	3,367	**6,970**	377	535	100	685	**1,697**	**9,007**
9	68	99	17	217	**400**	1,887	2,586	138	4,389	**8,999**	472	666	117	845	**2,099**	**11,498**

Note: WB = Whole Blood, PRC = Packed Red Cells, TC = Thrombocyte

This study conducted statistical tests on the number of products that were outdated for WB, PRC, and TC products with each blood type A, B, AB, and O. **Table 12** shows the results of statistical tests for the three types of products for the four types of blood types on the number of outdated products. The t-test statistical test results show a significant difference between Scenario 1 and Scenarios 2, 3, 4, 5, 6, 8, and 9. While the comparison of Scenario 1 (existing) to Scenario 7 shows that the number of outdated products is the same. **Figure 7** presents information on the obsolete levels by blood type. Scenario 4 is the best one for reducing the number of outdated products.

Table 12 Statistical Test Results on the Number of Outdated Products for A, B, AB, and O Blood Types.

Product	Scenario	R_1	R_2	t_{stat}	$t_{critical\ two\text{-}tail}$	Result
WB, PRC, TC	1-2	30	30	42.12	2.05	Difference
	1-3	30	30	48.12	2.05	Difference
	1-4	30	30	12.54	2.05	Difference
	1-5	30	30	-2.65	2.05	Difference
	1-6	30	30	-2.54	2.05	Difference
	1-7	30	30	-1.35	2.05	No difference
	1-8	30	30	27.31	2.05	Difference
	1-9	30	30	18.25	2.05	Difference

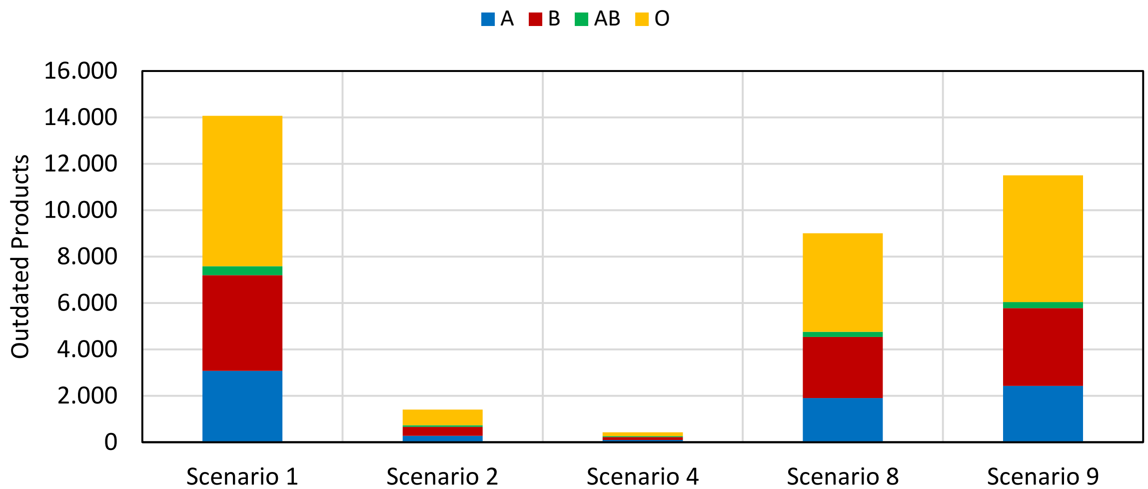

Figure 7 Comparison of the Outdated Product by Blood Type in Different Scenario

The simulation results show that each proposed scenario involves a trade-off between obsolete and scarce resources. In a situation where shortages are low, obsolescence is often high, and vice versa. We quantified the services provided in each scenario to corroborate the analysis results. **Table 13** illustrates how the service level is calculated based on the order fulfilment rate. The following formula can be used to get the order fulfilment rate (OFR):

$$OFR = \frac{Demand\ Fulfilled}{Demand} x\ 100\%$$

Table 13 Order Fulfilment Rate Value for Each Scenario

#	WB				PRC				TC				Average
	A	B	AB	O	A	B	AB	O	A	B	AB	O	
1	97%	96%	81%	98%	99%	99%	97%	99%	98%	99%	89%	99%	**96%**
2	74%	74%	58%	84%	91%	92%	74%	97%	94%	96%	76%	98%	**84%**
3	94%	94%	76%	98%	99%	99%	92%	99%	98%	99%	87%	99%	**94%**
4	61%	60%	48%	69%	73%	75%	59%	81%	82%	86%	66%	88%	**71%**
5	97%	97%	83%	99%	99%	99%	98%	100%	99%	100%	90%	100%	**97%**
6	99%	99%	97%	99%	99%	99%	94%	99%	99%	100%	95%	100%	**98%**
7	95%	94%	77%	98%	99%	99%	97%	67%	99%	99%	91%	99%	**93%**
8	95%	95%	81%	98%	99%	99%	96%	99%	98%	99%	87%	99%	**95%**
9	96%	96%	81%	98%	99%	99%	97%	99%	98%	99%	88%	99%	**96%**

Note: WB = Whole Blood, PRC = Packed Red Cells, TC = Thrombocyte

4.3 Cost and Revenue Analyses

We analyzed the blood bank's costs and revenues for a more comprehensive view of the efficiency value in each scenario. The cost analysis compares the proposed scenarios and the current situation in terms of cost and expected income calculation based on the set parameters. The total cost consists of the mobile unit cost, holding cost, outdated cost, cost of production, disposal cost, and cost of cross match. The following description for these costs is: a) mobile unit cost is the cost incurred for each blood donation using a mobile unit model; b) holding cost is the cost of storing blood bags in storage facilities; c) the outdated cost is calculated from the production costs and waste disposal costs; d) the cost incurred to produce a blood bag (production cost); e) the cost incurred to dispose of/destroy blood bag waste is called as the disposal cost; and f) Cross match cost as the cost incurred to test the suitability of a recipient's blood with the donated blood. The value of the parameter is given by:

- Mobile unit cost : IDR 500,000/activity
- Holding cost : IDR 150/bag/day
- Outdated cost : IDR 205,000/bag
- Production cost : IDR 200,000/bag
- Disposal cost : IDR 5,000/bag
- Cross match cost : IDR 60,000/bag

The comparison of total revenue, total cost, and net income for all scenarios can be explained as shown in **Figure 8**. From the figure, Scenario 2 is the best option in terms of net income. The income generated in the second scenario simulation is IDR 3,673,887,524.64, with a total revenue of IDR 14,922,588,000 and a total cost of IDR 11,248,700,475.36. The figure shows that the highest total revenue is Scenario 3 by IDR 17,160,144,000, with a total cost of IDR 14,556,414,805 and a net income of IDR 2,603,729,194.

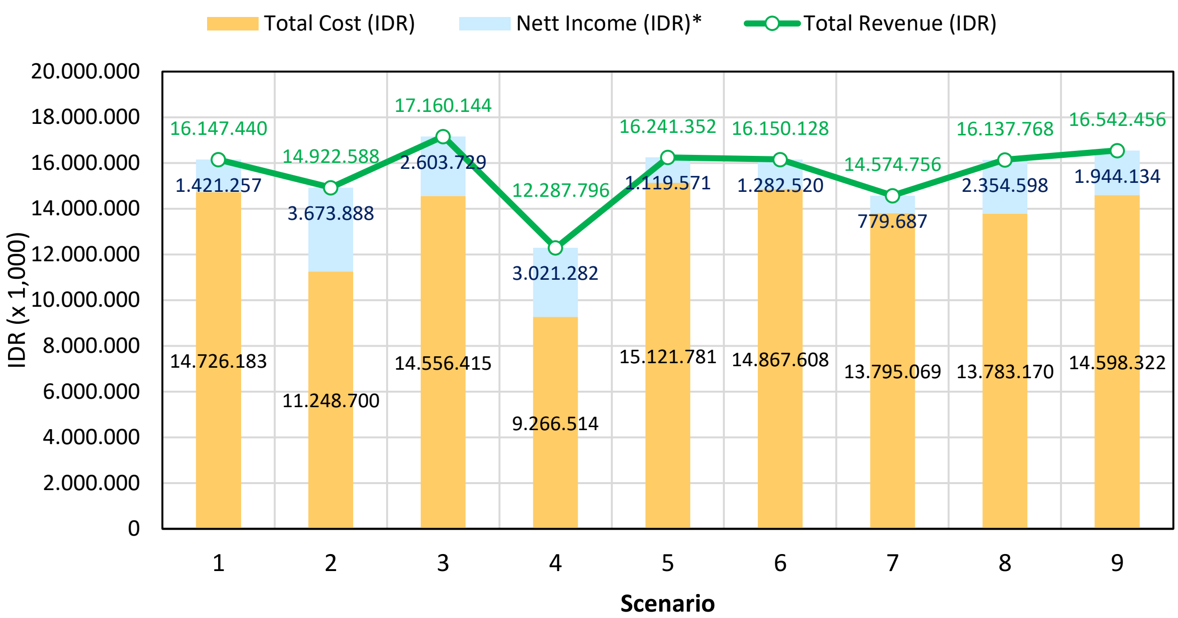

Figure 8 Comparison of Revenue Generated in Each Scenario (*net income = total revenue – total cost)

5. DISCUSSIONS

This study successfully develops a model that could provide recommendations to enhance blood bank management in a decentralized system. In the simulations, several scenarios offer a trade-off between a minor product shortage and a high rate of obsolescence. The scenario with the least obsolete products shows a high shortage rate and vice versa. Therefore, blood bank management must set the desired service level and the relevant cash flow changes that suit the implemented policy.

Figure 9 illustrates the percentage changes in the shortage and outdated inventory in each scenario relative to the existing condition (baseline value). As illustrated in the picture, Scenario 2 shows an increased shortage of 532% from the baseline value of 669 bags to 4,230 bags. In contrast, the outdated products decreased by 90% from the baseline value of 14,062 bags and 1,413 bags. Scenario 5 is optimal for minimizing shortages, cutting shortages by 35% or 233 bags. Meanwhile, Scenario 4 significantly reduces the outdated bags by 97%, from 14,062 to 435.

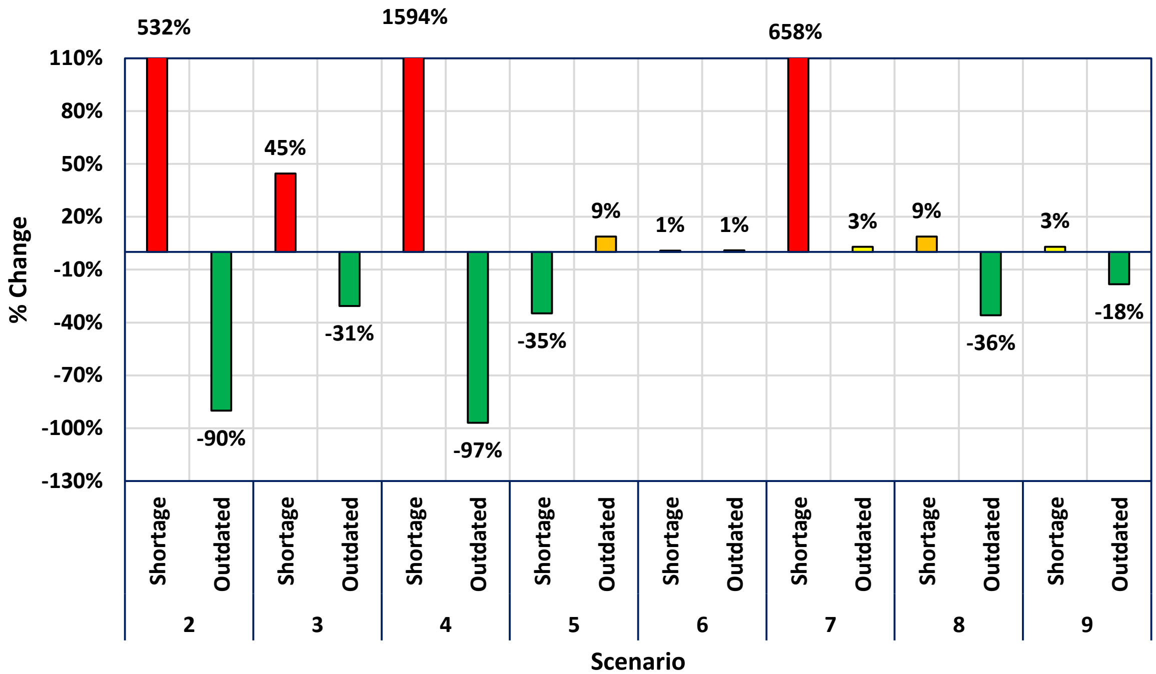

Figure 9 Changes in Shortages and Outdated Products in Each Scenario Compared to the Baseline Value

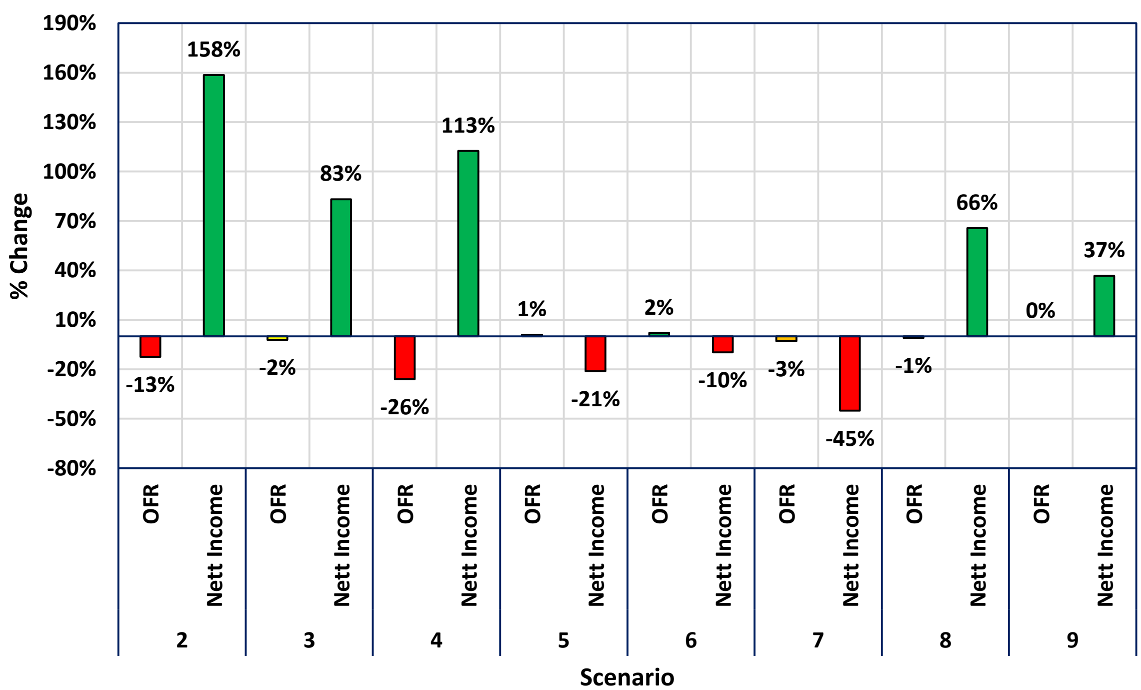

Figure 10 Changes in OFR and Net Income in Each Scenario Compared to the Baseline Value

Figure 10 depicts the percentage changes in order fulfilment rate (OFR) and net incomes received by the blood bank compared to the baseline value. Scenario 2 results in a decreased OFR from 96% to 84%, or a decrease of 13 percent from the baseline value. Meanwhile, the net income increased from IDR 1,421,256,858 to IDR 3,673,887,525, or a 158 percent increase from the baseline value. If OFR measures performance, Scenario 6 is the best scenario, with a 2 percent higher value than other scenarios. Meanwhile, Scenario 2 is the most profitable net income growth. Figures 9 and 10 show that the blood bank's management should select the optimal point of reference to determine the strategic policy to improve the blood supply in the community. A good policy satisfies both external and internal stakeholders. According to Lowalekar *et al*. (2017), the system's uncertainty increases the possibility of performance trade-offs between shortages and outdated products. Based on the simulation results, there is an inverse relationship between the level of shortage and outdated products. For example, the proposed supply limitation in the FLS model (Scenarios 2 and 3) significantly reduces the proportion of outdated products. However, the shortages increase sharply, which results in a decrease in the OFR performance. A similar pattern is observed in MUS-based supply arrangements (Scenarios 4 and 5). In Scenario 4, outdated products decrease, but the shortages increase. On the other hand, in Scenario 5, shortages decrease, but the outdated products increase. **Table 14** provides an overview of each scenario's performance based on the study's indicators.

Table 14 Performance Recapitulation in Each Scenario

Scenario #	Shortage value (bag)	Outdated value (bag)	Order fulfilment rate (%)	Net Income (IDR)
1	**669**	**14,062**	**96%**	**1,421,256,858**
2	4,230	1,413	84%	3,673,887,525
3	967	9,763	94%	2,603,729,194
4	11,333	435	71%	3,021,282,146
5	436	15,295	97%	1,119,570,817
6	674	14,188	98%	1,282,520,145
7	5,069	14,473	93%	779,686,877
8	728	9,007	95%	2,354,598,167
9	689	11,498	96%	1,944,134,088

Blood banks typically utilize Order Fulfilment Rates (OFR) and net income as their primary performance indicators for evaluating service performance. The management determines the minimum OFR goal value as representing the service level. When determining the desired service level, the blood bank's external and internal circumstances must be considered. In this study, the proposed optimal decision strategy for blood banks will be evaluated at the 90 percent and 95 percent OFR targets. Based on the data shown in **Table 14**, the following decisions are suggested:

1. If the minimum OFR required by the blood bank is 90 percent, Scenario 3 is recommended. This is because Scenario 3 yields the highest blood bank income within the minimal OFR threshold.
2. If a blood bank demands an OFR value of 95 percent, Scenario 8 is recommended. This is because Scenario 9 yields the highest blood bank income within the minimal OFR set.

Compared to the existing condition, Scenarios 3, 8, and 9 can reduce the number of outdated products and increase the blood bank's net income the most optimally. However, the size of the outdated products in these scenarios is still large because the average is still around 20 percent of the total production.

In the current state, even though the blood bank can achieve an OFR of up to 96 percent, the generated net income cannot be maximized due to the substantial amount of expired blood bags. This phenomenon shows that the planning has yet to be synchronized to overcome the uncertainty between supply and demand. For this reason, more effective coordination is needed between the blood banks and hospitals to design good strategies for collecting blood from donors. According to Arani et al. (2021), it is essential to integrate planning between blood banks and hospitals to prevent shortages and out-of-date items in blood inventory management. One of the factors that cause high outdated products is that the age limit for blood ordered by Type 1 hospitals is too young (such as the age requirement for PRC of less than seven days), which causes blood stocks to accumulate in the blood bank warehouse. Even though the bloodstock has not expired, the blood bags cannot be distributed to type 1 hospital, resulting in a high risk of expired blood. In line with Abbasi *et al*. (2017), the research shows that the age limit for PRCs below 21 days will trigger a spike in products classified as outdated. Therefore, blood banks need to coordinate and communicate with type 1 hospitals to discuss blood age limits.

The simulation results show that shortages and obsolescence occur in all blood types (A, B, AB, and O), but the most significant shortage is the AB type. Meanwhile, the blood type with the highest obsolescence is O. On this basis, the blood bank's collection system must be enhanced. To date, blood banks have set their supply targets solely based on donor numbers. A suggested improvement is to modify the system into a targeted blood collection. The aims are not only the number of blood bags collected but also the blood types.

The selection of blood bank performance indicators should focus on reducing shortages and on outdated products. Decreasing the rate of outdated products in addition to lowering costs is also a form of respect to donors (Lattimore, 2015; Najafi *et al*., 2017). While 100 percent order fulfilment is ideal for the organization's revenue, obsolete inventory may also be high (Alfonso *et al*., 2013). The question is which to prioritize between order fulfilment rate, decreasing outdated products, or net income. One possibility is that if there are multiple offered alternatives with differing performance degrees, the order fulfilment value should be preferred over other performance indicators. This is because the order fulfilment value directly affects the amount of service given. However, blood bank managers must make sound judgments in establishing the service level, as it will directly impact income (Rytilä & Spens, 2006). Therefore, the achievement aim for service must be adjusted to the capability of the blood bank's resources. Katsaliaki (2007) argued that the higher the baseline target, the more resources are needed. A blood bank is responsible for maintaining the organization's financial stability as an independent entity. On the one hand, blood banks have a social obligation to the community to provide blood supply. On the other hand, blood banks require funding to operate and provide services, so the business strategy must also prioritize cost efficiency.

6. CONCLUSION

This research has developed a simulation model that can be used to optimize the blood bag supply chain's performance. The implementation of the proposed scenarios could enhance service levels and cost-efficiency, as well as increase income. The ideal scenario is determined by the blood bank's management policy for calculating the expected service level or order fulfilment. The value assigned to the intended service level will affect the number of resources available to the blood bank and the risks it faces. This research successfully examines the proposed model that could be recommended to minimize shortages and outdated products and improve order fulfilment rates and net income. Based on the research results, one of the essential things we propose to the blood bank is the need for the blood bank to make improvements in comprehensive planning regarding the target inventory to be achieved. The inventory target will be used as a basis for conducting operational activities in recruiting donors. Furthermore, the recommended inventory target planning is based on targets per product because the target user is the number of blood bags, which often results in a discrepancy between the amount of stock and demand. Therefore, it is necessary to carry out intensive communication with the hospital in negotiating the age of the blood ordered to reduce the risk of expired blood.

Blood banks may implement policy modifications such as reorganizing the standard operating procedures for executing blood collecting events, evaluating inventory target rules, and increasing production percentage. The findings of this study can serve as a model for the Indonesian Red Cross (IRC) to strengthen the blood bag management system. Efficiency improvements are possible regarding donor recruitment, production, and waste disposal costs. This cost-cutting measure can be used as a benchmark for IRC performance improvement. Along with cost efficiency, maximizing donor blood use by eliminating outdated products could boost the community's active participation.

While this research successfully reduces the amount of obsolete inventory and increases order fulfilment, there are still issues that require more investigation. One limitation is that the research is predicated on assuming that environmental circumstances are typical. The report did not mention specific instances where demand for blood increased significantly due to natural catastrophes or other unforeseen situations. Numerous research opportunities remain open, including the development of a collaboration model between blood banks for managing supply and demand uncertainty to reduce shortages and outdated blood products, the development of a vendor-managed inventory model between the blood bank and the hospital, the development of a donor-blood bank cooperation model, and many others.

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