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Development of a Warehouse Management System for Reusable Materials in Power Plant Maintenance, Repair, and Overhaul Activities

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Abstract. Ineffective management of reusable material warehousing at the Indralaya power generation unit has caused inefficiencies in material service time, primarily due to ineffective systems for receiving, storing, and issuing materials. These deficiencies have resulted in delays in the power plant's Maintenance, Repair, and Overhaul (MRO) processes. This study aims to develop an efficient and systematic Warehouse Management System (WMS) for managing reusable materials used in MRO activities, with the objective of improving warehouse operational efficiency and reducing material service lead time. The research methodology involved field observations, literature review, data collection, material classification, and service time analysis using Bizagi Modeler. The findings indicate that the development of a WMS—supported by redesigned business processes, improved warehouse layout, structured recording systems, and process digitalization—significantly enhances the efficiency of receiving, storage, and dispatch activities. These improvements contribute to faster material distribution and reduce search time, ultimately shortening the overall warehouse service time.

Keywords: *Warehouse Management System (WMS); reusable materials; maintenance, repair, and overhaul (MRO); process efficiency; Bizagi Modeler; lead time reduction*

1 Introduction

PT PLN Indonesia Power – Keramasan Generation Business Unit, Indralaya Power Generation Unit, plays a critical role in the provision of electrical energy in the South Sumatra region. Therefore, it is essential to develop and maintain a systematic, transparent, and effective corporate management system that is designed for continuous performance improvement. The Indralaya unit operates as a gas and steam power plant (combined-cycle power plant), and it manages a reusable materials warehouse that stores various types of used materials resulting from maintenance, repair, and overhaul (MRO) activities. Reusable material warehouses are not limited to the Indralaya Generation Unit but are also implemented across power generation units worldwide, as they play a vital role in enhancing operational efficiency and ensuring the long-term reliability of power plants.

The reusable materials warehouse at UP Indralaya has not yet implemented a proper Warehouse Management System (WMS) for either inbound or outbound operations. When reusable materials are returned from users, they are stored arbitrarily in a single location without prior categorization. This leads to material accumulation, making it difficult to monitor inventory effectively. Only when a request is made for a specific reusable material are the items categorized and processed according to their respective classifications. Such a reactive approach results in prolonged service times in the reusable materials warehouse.

A study by Proudlove *et al*. in [1] demonstrated that BPMN is a process modeling standard that is easily understood by non-specialists and can facilitate collaboration among various stakeholder groups, particularly frontline staff, quality improvement personnel, and operations research analysts. Recent studies have also highlighted the effectiveness of BPMN-based digital process modeling in warehouse optimization and coordination across departments (Kirikkayis *et al*. in [2]; Teixeira *et al*. in [3]).

Inventory control and recording systems are integral components of warehouse management. This management process involves regulating incoming and outgoing goods through specific administrative recording procedures conducted within the warehouse (Kusuma *et al*. in [4]). Warehouse management is designed to support warehousing activities, which in turn influence the overall production process. Properly managed warehouse operations can enhance the efficiency of material handling within the facility (Azizi *et al*. in [5]). Furthermore, with advancements in technology, the handling and management of warehouse materials and inventory have become increasingly faster and more practical (Ogbo *et al*. in [6]). Technological solutions, such as IoT-enabled and cloud-based warehouse systems, have also emerged as effective tools for improving traceability, responsiveness, and real-time inventory management (Taj *et al*. in [7]; Soori *et al*. in [8]; Mashayekhy *et al*. in [9]).

Manual execution of complex warehouse management activities can be inefficient and prone to error. Relying on manual documentation may result in delayed or inaccurate information, leading to misjudgments in inventory evaluation (Chow *et al*. in [10]). The evolution of technology provides an effective alternative by enabling the implementation of computerized warehouse systems, which enhance operational control, improve workflow efficiency, and ensure greater data accuracy (Alyahya *et al*. in [11]). Studies in logistics system integration have shown that digitized warehouse workflows can significantly reduce lead times and improve service accuracy in material handling environments (Krishnan *et al*. in [12]).

Given the aforementioned phenomenon, it is essential to investigate the Warehouse Management System (WMS) for reusable materials by modeling the business processes using the Business Process Model and Notation (BPMN) standard within the Bizagi Modeler application. The aim is to improve and align business processes with existing Standard Operating Procedures (SOPs). The development of the WMS is intended to optimize material logistics processes efficiently, reduce time and process-related waste, and ultimately enhance service efficiency in the reusable materials warehouse that supports maintenance, repair, and overhaul (MRO) activities.

2 Methodology

The research activities began with interviews and direct on-site observations aimed at analyzing and modeling the current business processes. Subsequently, a business process development phase was carried out to identify which processes demonstrated greater service time efficiency. The data collected included business process activity records and time measurements for each activity, obtained using a stopwatch.

The methods used in this study, as illustrated in the schematic shown in Figure 1, are as follows:

1. **BPMN** (Business Process Model Notation)
2. **Efficiency Testing**
3. **Bizagi Modeler**
4. **Lean Principles**

The combination of Business Process Model and Notation (BPMN) and Lean principles holds significant potential for addressing issues in reusable material warehouses, particularly in the context of operational efficiency, waste reduction, and improved process flow visibility. Each method is explained in detail in the following sections, highlighting its role and contribution to the development of an efficient Warehouse Management System (WMS) in the context of MRO activities.

2.1 BPMN (Business Process Model Notation)

BPMN was employed as the primary approach for mapping the business processes of the reusable materials warehouse. Through BPMN, the entire process flow from material receipt and storage to redistribution can be visualized in a systematic and standardized manner. This facilitates the identification of non-value-added activities, process bottlenecks, and opportunities for improvement.

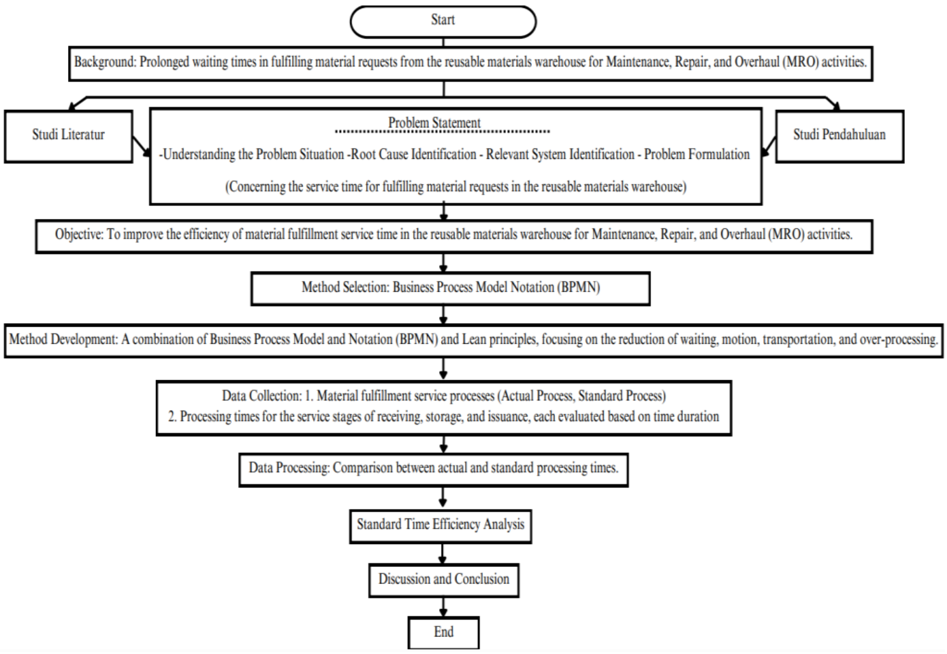


Figure 1 Research Methodology

2.2 Efficiency Testing

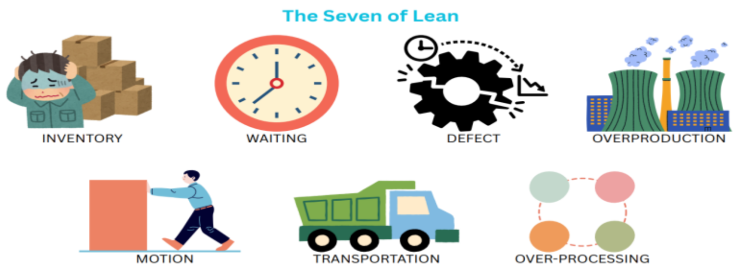
Efficiency testing was conducted to measure the extent to which process improvements impacted the smoothness and speed of material flow within the warehouse. By measuring cycle time, waiting time, and material processing rate, the actual efficiency of the system before and after the implementation of lean-based improvements could be determined (Heizer *et al*. in [13]).

$$Time\ Efficiency = \frac{Standard\ process\ time}{Total\ actual\ processing\ time} \times 100\% \quad (1)$$

$$Activity\ Efficiency = \frac{Standard\ process\ activities}{Total\ actual\ process\ activities} \times 100\% \quad (2)$$

2.3 Bizagi Modeler

Bizagi Modeler served as a digital tool to support the development of BPMN-based business process diagrams. It enables users to design, modify, and validate processes within an interactive platform, fostering collaborative efforts in documenting and evaluating warehouse workflows. Additionally, Bizagi Modeler was employed to analyze the differences between the current business process simulation and the simulation results of the recommended improved process (Rahmatillah and Farhatinnisa in [14]).



Source: https://businessmap.io/lean-management/value-waste/7-wastes-of-lean

Figure 2 The Seven Wastes in Lean Principles

2.4 Lean Principles

Lean principles eliminate non-productive activities, improve workflow continuity, and promote a culture of continuous improvement. (Jain *et al*. in [15]). Lean application eliminates waste, such as excess inventory and inefficiencies, enhancing connectivity across operational functions. (Baby *et al*. in [16]). These principles serve as a foundational framework for formulating improvements in layout design, standard operating procedures, and workflow structures.

As shown in Figure 2, this study focuses on waiting, motion, transportation, and overprocessing due to the types of waste observed in the reusable materials warehouse. These inefficiencies arise from MRO processes waiting for material availability, unnecessary movements by warehouse personnel during material service, disorganized warehouse layout, and excessive business process steps.

3 Data Processing

Based on the results of interviews and observations, the business process under investigation primarily focuses on the receipt, storage, and issuance of reusable materials, which constitute the core issues identified in the warehouse operations.

3.1 Actual BPMN Modelling

In the current BPMN modeling, simulation results were obtained to determine the time differences in completing the business process before and after improvements. The simulation was conducted using BPMN notation through the Bizagi Modeler software.

3.1.1 Actual Receiving Process

The actual receiving process refers to the current material receiving procedure carried out by the warehouse division to accept materials from the user, either during or after MRO activities. The BPMN model of the receiving process is presented in Figure 3 below. In the actual receiving business process, there are nine warehouse-related activities, which are completed within a total service time of 33 minutes and 41 seconds.

The process starts with the user submitting reusable materials after performing MRO activities. The warehouse officer then receives the materials, searches and records the data, and prepares a goods request form (TUG10), which requires managerial approval.

After approval, the materials are brought to the reusable warehouse, and a material label card is created and signed. The process involves several manual steps and approvals, which contribute to delays and highlight areas for improvement.

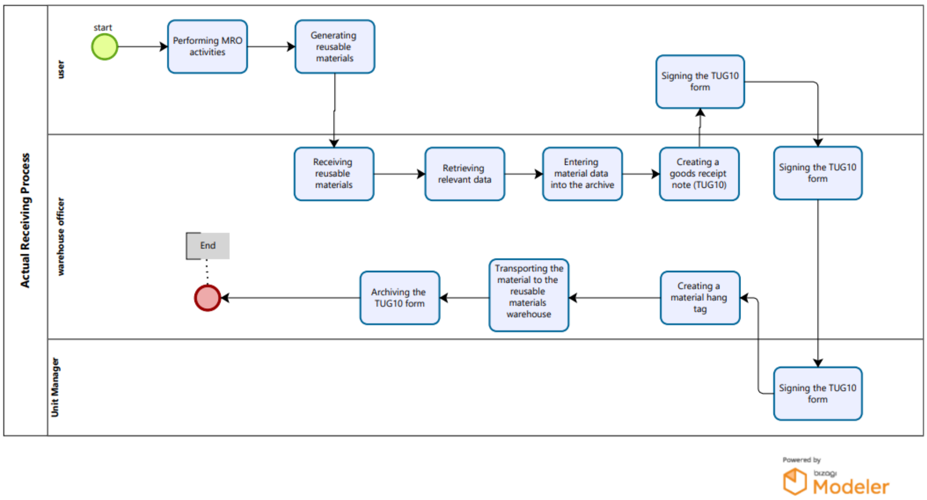


Figure 3 BPMN Simulation Model of the Actual Receiving Process

3.1.2 Actual Storage Process

The actual storage process refers to the current material storage procedure carried out by the warehouse division after the material receiving process has been completed. The BPMN model of the storage process is shown in Figure 4. In the current storage business process, there are five warehouse-related activities, which are completed within a total service time of 6 minutes and 7 seconds. The process involves material entry, basic maintenance, location assignment, placement, and data input into the system.

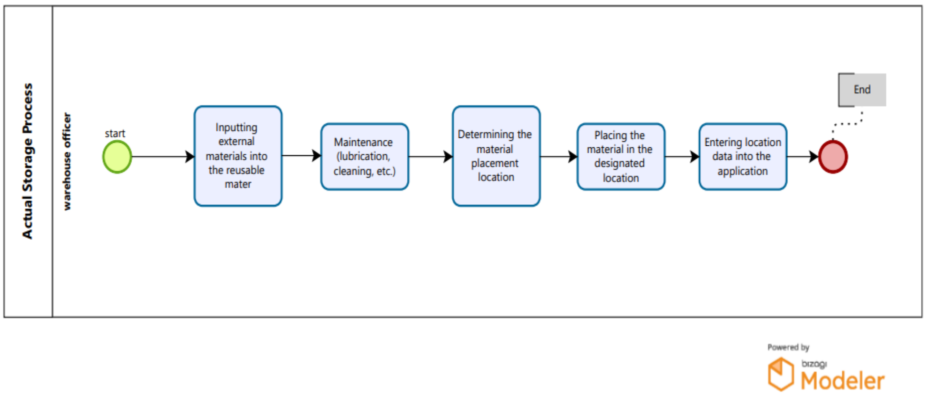


Figure 4 BPMN Simulation Model of the Actual Storage Process

3.1.3 Actual Issuance Process

The actual issuance process refers to the current material issuance procedure when materials are required by the user for MRO processes. The BPMN model of the storage process can be seen in Figure 5. In the current issuance business process, there are 40 warehouse-related activities, which are completed within a total service time of 2 hours, 50 minutes, and 11 seconds. It includes multiple verification steps, approvals, coordination across divisions, and physical handling, making it the most complex and time-consuming process in the warehouse workflow.

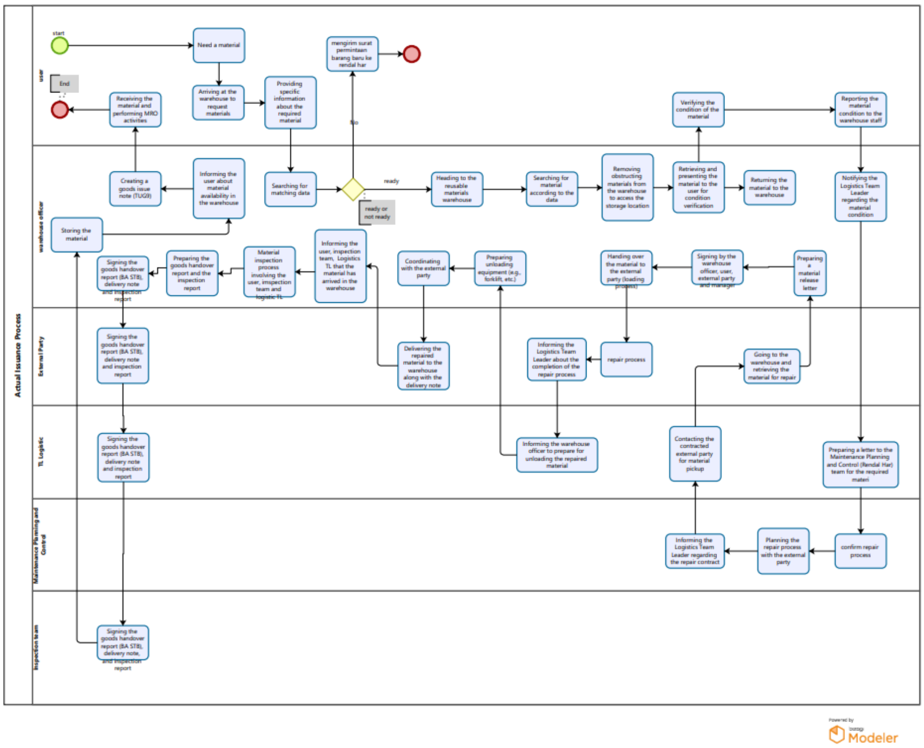


Figure 5 BPMN Simulation Model of the Actual Issuance Process

3.2 Implementation of Lean Principles

The implementation of Lean principles in the reusable materials warehouse aims to enhance warehouse operations by eliminating waste related to waiting, motion, transportation, and overprocessing.

3.3 Standard BPMN Modeling

In the BPMN modeling process, the business process flow was defined by integrating Lean principles along with time estimations required to complete each activity. Subsequently, the standardized BPMN simulation model was designed using Bizagi Modeler software.

3.3.1 Standard Receiving Process

The standard receiving process refers to the material receiving procedure developed by the researcher, to be carried out by the warehouse division when receiving materials from the user following MRO activities. The standardized BPMN model of the receiving process (Figure 6) demonstrates a significant improvement compared to the actual process (Figure 3).

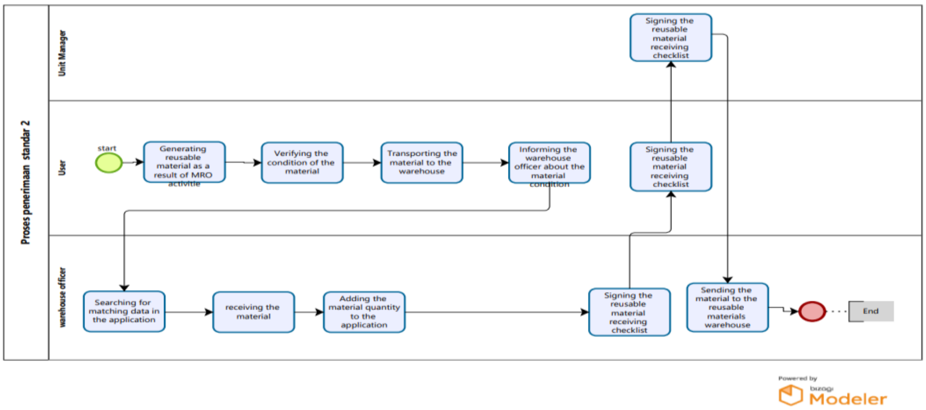


Figure 6 Standardized BPMN Simulation Model of the Reusable Material Receiving Process

Although the number of warehouse-related activities increased slightly from 9 to 10, the total service time was reduced, from 33 minutes and 41 seconds in the actual process to 12 minutes and 30 seconds in the standardized process. Among the 10 standardized activities, 5 are functionally similar to those in the actual process, including material reception, data verification, system entry, condition reporting, and document approval. These activities were retained but optimized in flow and sequencing.

The reduction in processing time was achieved by eliminating redundant steps, integrating approval processes, and streamlining communication between users, warehouse staff, and supervisors. In addition, digital input and checklist-based approval replaced the previously manual TUG10 documentation, contributing to faster and more reliable data handling. This redesign highlights how a minor increase in activity count can still lead to substantial performance gains when the process is leaner and better structured.

3.3.2 Standard Storage Process

The standard storage process refers to the material storage procedure developed by the researcher to be carried out by the warehouse division after the material receiving process has been completed. The standardized BPMN simulation model of the storage process is shown in Figure 7. Compared to the actual process (Figure 4), the number of warehouse-related activities increased from 5 to 24, while the total service time rose from 6 minutes and 7 seconds to 1 hour, 15 minutes, and 18 seconds.

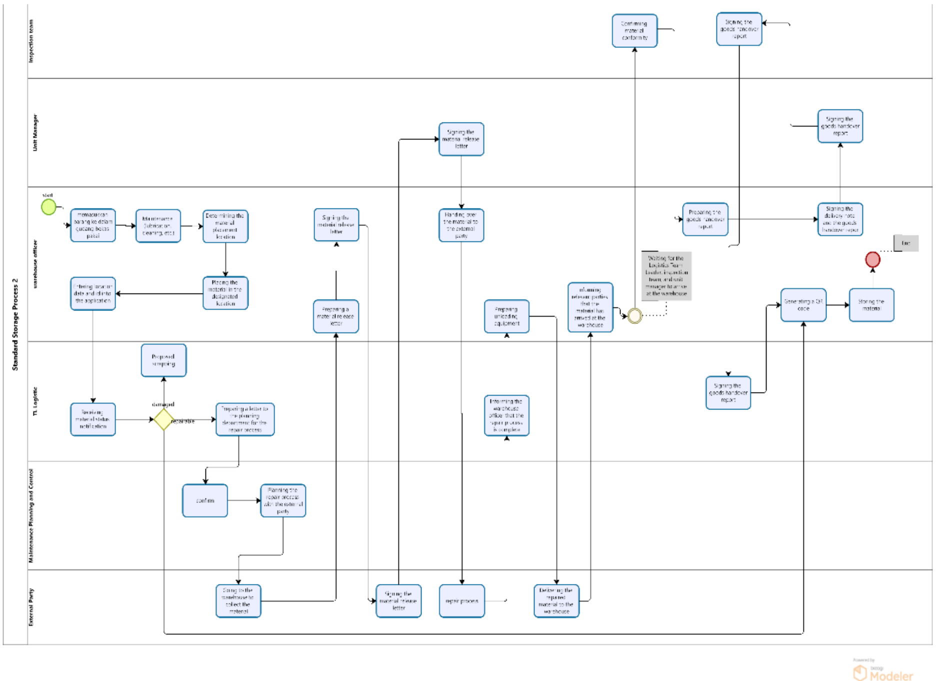


Figure 7 Standardized BPMN Simulation Model of the Reusable Material Storage Process

Although the standardized process takes longer, it introduces detailed verification steps, improved coordination across roles, and better data accuracy. The increase in activities reflects the addition of material inspection, classification, documentation, and control procedures that were previously absent or informal.

A shift in operational activities has occurred through digitalization. Initially, data recording within the storage system relied solely on manual methods such as notebooks and basic Excel sheets. Following system development, a dedicated application was introduced, allowing any authorized personnel to perform data entry efficiently and via mobile devices. This transformation has significantly improved the quality and consistency of the overall process. The redesign emphasizes traceability and accountability over speed, indicating a shift in priority from minimal handling time to ensuring data integrity and process standardization throughout the storage workflow.

The increase in time and activities within the storage system is considered acceptable, as the key service points in the reusable material warehouse are limited to the receiving and issuing processes. Therefore, storage operations are not included in the customer service performance calculations.

3.3.3 Standard Issuance Process

The standard issuance process refers to the material issuance procedure developed by the researcher to be carried out by the warehouse division when materials are required by the user for MRO (Maintenance, Repair, and Overhaul) processes. In the standard issuance process, work units can submit material requests digitally through the WMS. Once approved, the system generates a real-time picking list for warehouse personnel to execute the retrieval process efficiently. The standardized BPMN simulation model of the issuance process is shown in Figure 8. This improved process includes 9 warehouse-related activities, completed within a total service time of 13 minutes and 25 seconds. In comparison, the actual issuance process (Figure 5) included 40 activities and required 2 hours, 50 minutes, and 11 seconds to complete.

The standardized version streamlines workflows by integrating digital ordering, reducing manual approvals, and enabling quicker material retrieval, leading to a more efficient and coordinated issuance process, especially during power plant disruptions.

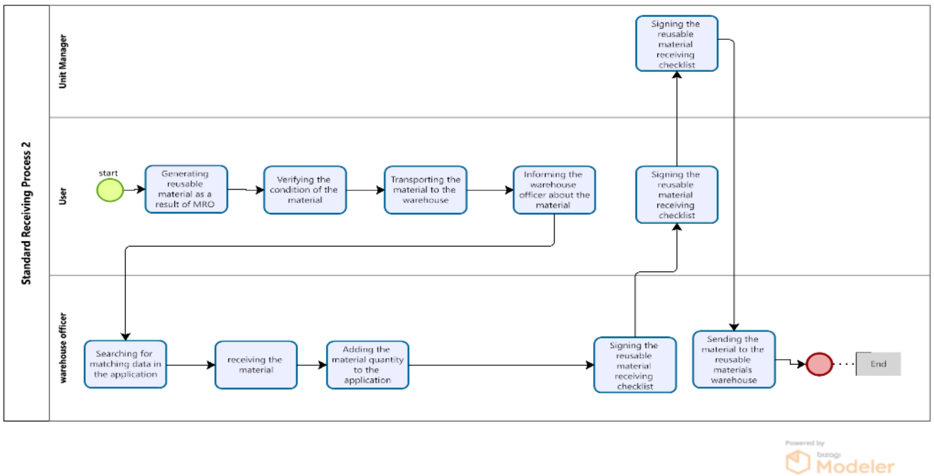


Figure 8 Standardized BPMN Simulation Model of the Reusable Material Storage Process

3.4 Efficiency Testing of Standard Business Process Time

Standard business process time refers to the business process time developed by the researcher, calculated by measuring the time taken for each activity. Business process efficiency testing was conducted to evaluate whether the standardized process delivers significant improvements compared to the current process, which has a total service time of 3 hours, 23 minutes, and 34 seconds (equivalent to 12,214 seconds). Based on the collected data, the developed process resulted in a reduced total warehouse service time of 25 minutes, and 55 seconds (equivalent to 1,555 seconds). The time efficiency is calculated using Eq. (1), which compares the standard process time with the total actual processing time, as suggested by Heizer *et al.* in [13].

$$Service\ Time\ Efficiency = \frac{(Total\ actual\ process\ time - Standard\ process\ time)}{Total\ actual\ process\ time} \times 100\%$$

$$= \frac{(12{,}214 - 1{,}555)}{12{,}214} \times 100\%$$

$$= 87.27\%$$

3.5 Efficiency Evaluation of Standard Business Process Activities

Standard business process activities are activities developed by the researcher to enhance the efficiency of operations. Efficiency testing of business processes was conducted to evaluate whether the standardized process activities resulted in significant improvements compared to the current business process. The data showed a total of 19 service-related activities performed in the warehouse. As indicated in Eq. (2), the activity efficiency reached 61.22≈61%, which suggests that the number of process steps could still be streamlined to improve overall workflow performance.

$$Service\ Activity\ Efficiency = \frac{(Actual\ process\ activities - \ Standard\ process\ activities)}{Total\ actual\ process\ activities} \times 100\%$$

$$= \frac{(54-19)}{54} \times 100\%$$

$$= 61.22\%$$

4 Result and Conclusion

The implementation of the Warehouse Management System (WMS) effectively addresses common challenges in managing reusable materials, including inconsistent recordkeeping, delays, and inefficiencies. It enhances MRO processes and provides a strategic, structured, and measurable approach to managing reusable materials in both the power generation sector and other industries.

4.1 Result Business process

The results of the proposed business process simulation were then compared with the total processing time of the current business process. The simulated processing time was modeled using BPMN notation in the Bizagi Modeler software, as follows:

Table 1. Comparison of BPMN Business Process Simulation Time and Activities.

No	Process	Time (seconds)		Number of Activities	
		Actual	Standard	Actual	Standard
1	Receiving	2,003	750	9	10
2	Storage	367	4,518	5	24
3	Issuance	10,211	805	40	9
	Total Time	12,581	6,073	54	43
	$\%_{ef}$ Total Time		51.73%		20.37%
	Total Service Time	12,214	1,555	49	19
	$\%_{ef}$ Total Service Time		87.27%		61.22%

Based on the table of business process time calculations in BPMN, the proposed process shows a total duration of 6,073 seconds, with a time efficiency percentage of 51.73%≈52% and an activity efficiency percentage of 20.37%. These results show that even with a reduction in the number of activities from 54 to 43, the proposed process maintains critical functions while improving flow and eliminating unnecessary steps. The service time process efficiency was 87.27%, while the service activity process efficiency was 61.22%.

The WMS development and its process standardization demonstrate how digital modeling and lean principles can be integrated to optimize logistics operations and support organizational agility.

4.2 Conclusion

The system, built on a BPMN-based framework and lean principles, minimizes time inefficiencies and offers flexibility for varying activity volumes and organizational complexities. It enhances logistics efficiency, transparency in material traceability, and optimizes maintenance costs for power plants on a larger scale. The research identified problems through interviews and on-site observations to understand the organization's issues. Business process modeling and simulation were then conducted using BPMN and Lean principles, analyzed with Bizagi Modeler software. The results are presented in a time calculation table showing the efficiency levels and this study contributes to the digital transformation of warehouse operations in energy sector logistic, Future research is recommended to validate the proposed system across multiple power plant units to assess its scalability and adaptability to diverse operational environments.

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