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Minimization of waiting time in coal loading and unloading processes to reduce demurrage using value stream mapping

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ABSTRACT

Demurrage issues pose a significant challenge that affects operational efficiency in the coal transportation industry, particularly in the coal transhipment process using mother vessel and barges. This study aims to identify and reduce waiting times that cause demurrage. Waste identification leading to demurrage was conducted through a structured Value Stream Mapping (VSM) approach consisting of current-state mapping, waste identification and analysis, process activity mapping, and future-state mapping to develop improvement recommendations for coal loading and unloading operations. The results from the Port of Loading (POL) showed a significant improvement in operational efficiency after the proposed improvements were incorporated into the future-state process. Before the improvements, value-added activities contributed 28.20% of the total time and increased to 84.97%. The total loading time was reduced from 10.04 days to 3.17 days. At the Port of Discharge (POD), value-added activities increased from 47.27% to 77.24%, and the unloading time decreased from 14.58 days to 4.89 days. This improvement was achieved through better coordination, equipment maintenance, and optimization of the loading and unloading process, which significantly enhanced overall efficiency and reduced demurrage costs. This study highlights the importance of process optimization in the coal shipping industry, offering valuable insights to reduce delays and improve profitability.

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1. INTRODUCTION

Coal is an efficient energy source used in various countries and serves as a dominant force in electricity generation. Accounting for at least 27% of the world's total energy output and more than 39% of all electricity generated by coal-fired power plants, its relatively cheap and simple extraction process compared to other resources makes coal highly sought after in many countries. Additionally, Indonesia's coal industry has experienced rapid export growth [1]. According to the International Energy Agency (IEA), global coal demand is projected to reach a record level of approximately 8.8 billion tonnes in 2025. Although coal demand is expected to remain relatively stable in the near term, long-term projections indicate a gradual decline in several regions due to energy transition policies, while demand remains strong in developing economies, particularly in Asia [2]. Due to the increasing demand for energy, the amount of coal consumed is likely to double by 2030 [3]. Due to the continuously growing demand for coal as a primary energy source in many countries, this has led to an increase in the volume and frequency of coal shipments through transhipment ports.

Transhipment is the process of transferring cargo in open waters from one vessel to another, commonly referred to as a mother vessel [4]. A mother vessel is a large ship that serves to transport cargo from a transit port to various destination ports around the world [5]. Coal transhipment refers to the process of delivering or transporting coal from producers or sources to recipients or end consumers. This transhipment process is one of the activities within the energy supply chain and coal industry. The economic aspects of coal transportation are crucial in the coal industry, as they affect production costs, company profits, and the selling price of coal. Economic, transportation, and territorial aspects must align for this mode of transportation to function effectively [6]. In Indonesia, coal shipments use barges accompanied by tugboats, and due to shallow waterways, transhipment activities are required to transfer cargo from barges to mother vessels [7]. The use of barges for coal shipments to mother vessels can be considered a more efficient solution in some cases because they are smaller and more flexible, capable of reaching ports or locations inaccessible to large ships. This helps minimize the overall cost of coal shipping. Each transhipment project typically lasts about seven days, involving an average cargo volume ranging between 50,000 and 80,000 metric tons (MT) [8].

The scheduling and dispatch of tugboats significantly affect transhipment efficiency [9]. However, poor planning and imperfections in shipping schedules or transport operations can lead to the inability to transfer cargo efficiently. This may result in shipment delays known as demurrage. Demurrage is a crucial factor in profit and loss management because it directly relates to lost revenue [10]. Demurrage refers to losses incurred due to breaches of the laytime limits specified in the contract [11]. According to estimates provided by the Indonesian Coal Mining Association, shipment delays result in significant financial losses for shippers, ranging from 250 million to 1 billion Rupiah per day. Therefore, the transhipment process must be expedited according to the set targets and agreed schedule with the shipper. Demurrage often occurs due to several factors, such as weather [12], vessel waiting time [13], [14], [15] suboptimal loading rates, damage to loading and unloading equipment [16][17], delays in the issuance of the Sailing Permit (SPB) [18] and expired vessel certificates[19].

The Coal Mining holds a Special Mining Business License for Coal Transportation and Sales Operations and is authorized to transport and sell coal from holders of Production Operation IUPs, as well as build and utilize transportation infrastructure such as stockpiles and ports in accordance with regulations. The total coal to be delivered by the Seller during the Contract Period is 50,000 MT, with a shipping tolerance by the Vessel of +/- 10%. The nominated vessel must be a gear-and-grab vessel with a minimum crane capacity of 4 x 25 to 30 tons and grab capacity of 4 x 10 to 12 cbm, with fully operable cargo holds, supported by an ISM code certificate, and a maximum age of 20 years unless otherwise agreed. If The Coal Mining fails to load the vessel provided by the Buyer within the permitted laytime based on the guaranteed loading rate, The Coal Mining shall pay demurrage to the Buyer for the lost time after the laytime has expired, in accordance with the rate per 24 hours or prorated.

The demurrage shall be paid at the rate determined at the time of the vessel's nomination by the charter party, and the settlement of demurrage/despatch must be completed within 15 days after loading is finished. The time lost will not be counted as Laytime or demurrage if caused by: the vessel's unpreparedness when berthing, issues caused by the vessel, the shipowner, or the buyer, time taken to open and close the hatch covers, vessel damage or non-compliance with port regulations, cleaning and inspecting the holds, time for the initial survey and final draft, as well as 8 hours for export documentation after loading is complete. If the vessel's equipment is damaged, the loading rate will be adjusted on a prorated basis. Demurrage applies under the principle of "Once on demurrage, always on demurrage", except in the circumstances mentioned, including disruptions due to bad weather and major public holidays. Time lost due to force majeure will not be counted as Laytime unless the vessel is already on demurrage.

The Coal Mining experiences demurrage issues with an average of 3 mother vessels each month out of a total of 5 mother vessels exported monthly. Each mother vessel, with a capacity ranging from 45,000 to 60,000 MT, requires approximately 6 to 8 barges, sized between 270ft to 330ft, to transport coal. The barges sail to the anchorage point, with an estimated travel time of 1 to 2 days, while the loading process at the Port of Loading (POL) takes 1 to 2 days. The average demurrage cost incurred per mother vessel is USD 20,000 per day. Therefore, it is crucial to design strategic measures to manage and anticipate demurrage issues. To address this, efforts are required to improve the efficiency of the coal transhipment process to prevent demurrage [11].

In several case studies related to demurrage across various locations and industries, it can be observed that demurrage represents a significant burden for the companies involved. At Ulsan Port, South Korea, demurrage costs reached $2,045,000 USD over a five-year period (2015-2019), with an average demurrage cost per vessel of approximately $1,576.72 USD [11]. This indicates that delays in loading and unloading activities can result in substantial additional costs for shipowners and port stakeholders. In the mining sector, PT Indominco suffered losses of $11 million USD due to unprepared coal supplies, which resulted in demurrage [20]. This situation highlights the importance of readiness in logistics management to avoid unexpected additional costs. Meanwhile, at the bulk port owned by PT Krakatau Steel, demurrage in 2019 reached $511,025.18 USD, demonstrating that ports are also vulnerable to additional costs caused by delays in the unloading process [21].

In South Sulawesi, the dedicated terminal owned by PT Semen Indonesia Group (SIG) (Persero) Tbk., PT Semen Tonasa, incurred demurrage costs of $3,476,573.92 USD between 2017 and 2021 [22]. This shows that even large companies with dedicated infrastructure are not exempt from the negative impact of demurrage. Demurrage has been widely discussed in the logistics and transportation literature. Kim and Cho [23] synthesized previous studies addressing the impact of demurrage and detention (D&D) on inland container transport performance, approaches for mitigating D&D-related challenges, and the factors influencing container dwell time (CDT), with particular emphasis on terminal infrastructure and operational efficiency based on data-driven analytical methods . However, limited research has addressed demurrage reduction from a lean supply chain perspective, particularly in coal transhipment operations involving barges and mother vessels. Moreover, few studies have applied Value Stream Mapping (VSM) to systematically identify operational waste across both loading and unloading processes. Therefore, this study employs a comprehensive VSM approach to identify non-value-added activities, analyze waste sources, and propose improvements to reduce demurrage in coal transhipment operations.

VSM is a crucial tool in applying lean approaches and can be implemented across various industrial sectors [24]. The core focus of this research is to investigate various methods for implementing Lean in the mining industry and how practitioners in this sector can effectively apply Lean[25]. Through VSM, the goal is to identify non-value-added activities in the delivery process and propose improvements to reduce waste and enhance added value. A structured approach to waste reduction and fostering a culture of continuous improvement is a key feature and primary driver in implementing Lean principles in the mining industry. VSM is used to evaluate the efficiency of the coal transhipment process. This can help ports and shipping companies make better decisions, optimize operations, and reduce additional costs associated with demurrage or excessive waiting times.

2. MATERIALS AND METHODS

2.1. Material

The operational data used in this study were collected during the period of January 2022 to December 2024. The data consisted of vessel loading and unloading records, demurrage reports, barge and mother vessel operational data, loading rates, waiting times, and supporting logistics documentation. Data collection was conducted using a combination of three approaches: (1) historical records obtained from company operational databases and voyage reports, (2) direct observations of coal transhipment activities at the POL and anchorage area to understand actual process flows and operational constraints, and (3) semi-structured interviews with operational personnel, including logistics coordinators, vessel operators, and port representatives, to validate process information and identify factors contributing to delays and inefficiencies. The integration of these data sources enabled a comprehensive analysis of the existing coal transhipment process and supported the development of improvement scenarios using VSM.

In the coal transhipment process, activities can be divided into three main parts: input, process, and output. Figure 1 illustrates the integrated process, starting from the provision of coal, the transfer of coal from the barge to the mother vessel, to the delivery to the customer, which involves several operational stages at the and Port of Discharge (POD). The transhipment process plays a key role in facilitating large-scale coal shipments, which cannot be made directly from the stockpile to the customer, requiring the use of a mother vessel as an intermediary to ensure efficient and timely delivery.

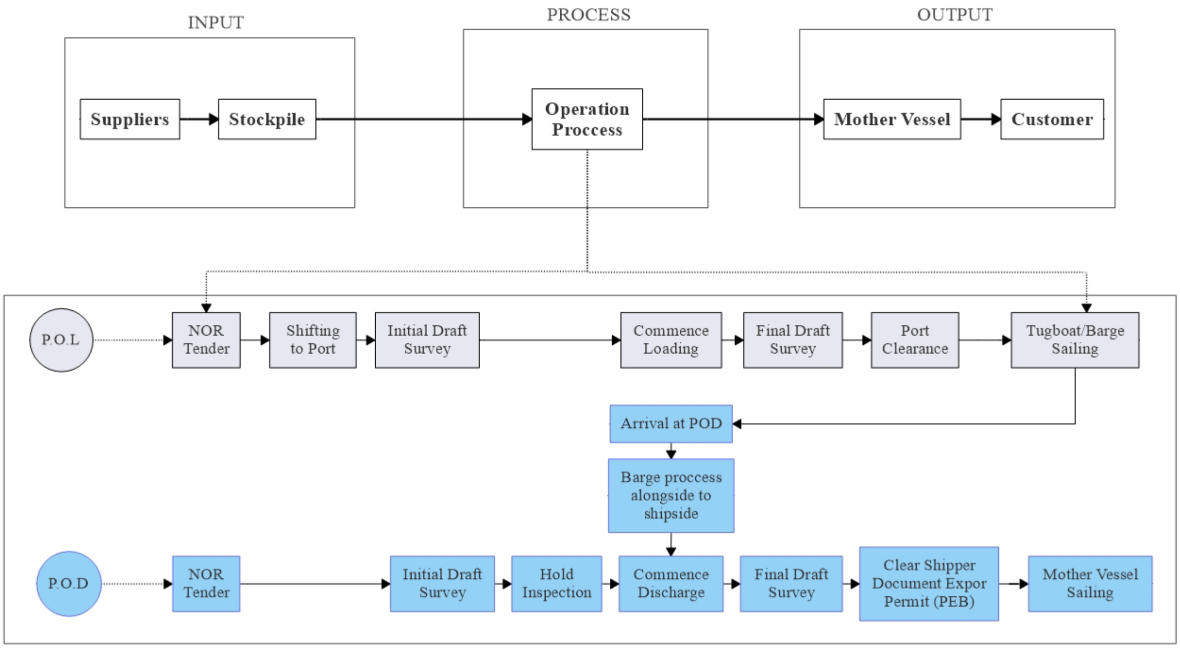

Figure 1. Supply chain process of coal transhipment

2.2. Research Method

The waste analysis process was conducted through an integrated application of VSM, Process Activity Mapping (PAM), and Fishbone Diagram analysis. First, the Current State VSM was developed to visualize the entire coal transhipment process and identify activities contributing to excessive lead time and demurrage. Subsequently, PAM was employed to classify each activity into Value Added (VA), Non-Value Added (NVA), and Necessary Non Value Added (NNVA) categories, allowing detailed identification of waste within the process. The dominant wastes identified included waiting time, transportation delays, and inventory-related inefficiencies. After the waste activities were identified, Fishbone Diagrams were used to investigate the root causes of these wastes by analyzing factors related to manpower, methods, machines, materials, and operational environment. The findings from VSM, PAM, and Fishbone analyses were then used as the basis for developing improvement scenarios and designing the Future State VSM.

2.2.1. Literature Review and Research Trends Analysis

Lean supply chain management has emerged as a pivotal approach in modern supply chain practices, focusing on waste reduction, efficiency enhancement, and sustainability. In Figure 2, the integration of lean principles with emerging technologies, such as Industry 4.0 and digital twins, enables data-driven decision-making that enhances supply chain quality and resilience [26]. Recent studies emphasize the synergy between lean and green practices to support sustainability goals, with frameworks developed to optimize performance in diverse sectors, from food supply chains to healthcare and construction [27], [28] Furthermore, lean strategies have been instrumental in improving supply chain resilience during crises, such as pandemics, by ensuring agile and adaptive responses [29]. The incorporation of lean methodologies in sustainable supply chain frameworks underscores their role in addressing global challenges, including food waste, energy efficiency, and carbon reduction [30], [31]. Additionally, lean practices synergize with Big Data Analytics, fostering innovations in LARG (Lean, Agile, Resilient, and Green) performance systems and advancing sustainability metrics [32] Collectively, the research highlights that lean supply chains not only optimize operational efficiency but also contribute significantly to sustainable development across industries.

Studies such as Rojas-García et al. [33] emphasize the role of lean logistics in improving post-pandemic distribution processes, leveraging big data to optimize decision-making. Similarly, Liu et al. [34] explores lean strategies in SMEs, linking inventory and operational leanness to financial performance, providing insights that can be applied to coal transhipment for better resource allocation and cost management. Furthermore, integration with advanced technologies, as discussed by Ferreira et al. [35], can align lean VSM with Industry 4.0 tools, enhancing real-time tracking and operational adaptability in coal supply chains.

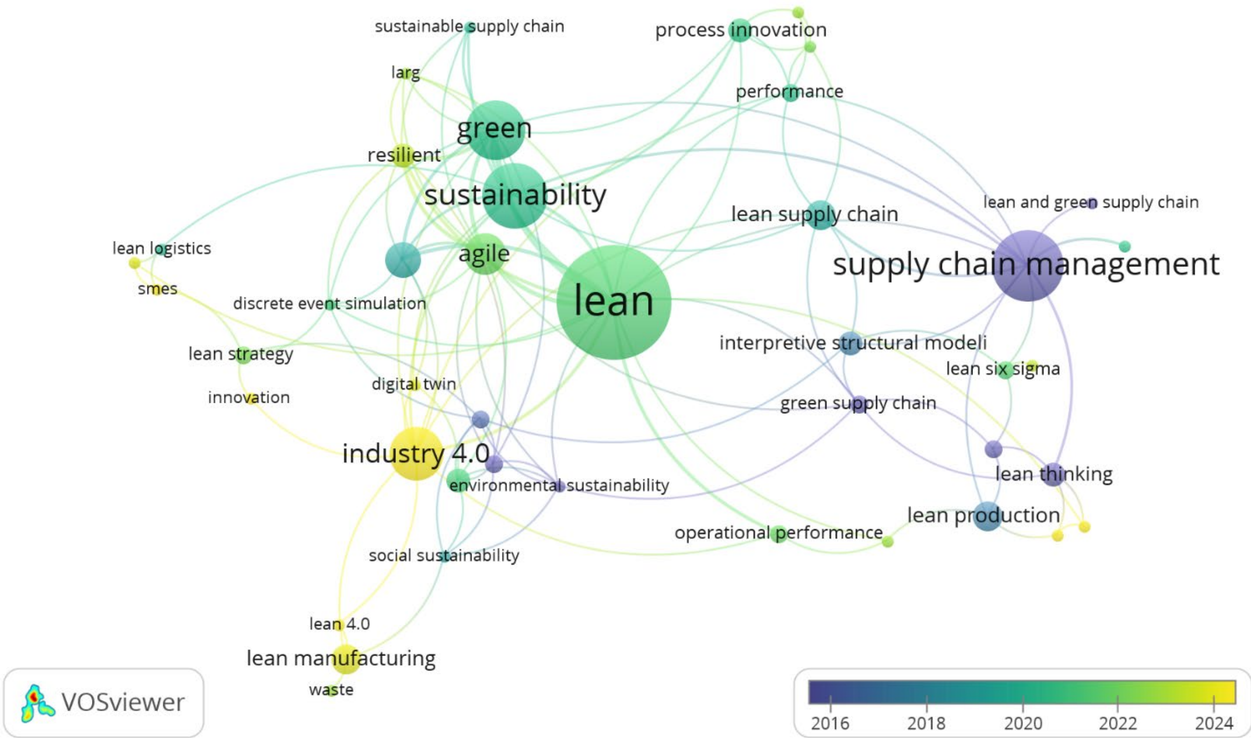

Figure 2. VOSviewer of lean supply chain

2.2.2. Application Areas and Implementation Concept of VSM

VSM has been widely applied in several sectors:

- Healthcare Sector [36], [37], [38]
- Sustainability Improvement [39], [40], [41]
- Industry 4.0 and Digitalization VSM [39], [40], [42], [43], [44]
- Educational Services [45]
- Manufacturing Processes [46], [47], [48].

This broad application demonstrates that VSM is a versatile tool for identifying waste and improving process efficiency across different operational environments. VSM focuses on identifying inefficiencies and optimizing the flow of materials and information throughout the transhipment process to reduce costs, minimize delays, and improve overall operational efficiency. Implementing VSM in coal transhipment involves mapping the current state of operations, identifying waste, and redesigning the process flow to achieve an optimized future state. It identifies and reduces waste in the flow of materials and information in the Mediterranean ports (Naples and Algeciras Bay), thus improving logistics efficiency and technology integration [49]. The purpose of this tool is to determine value-added activities [50], [51] and to identify the potentials for improvement [52],[52]. Successful results from the implementation of lean and VSM across industries have also been demonstrated [53].

2.2.3. Waste Identification

Waste in coal transhipment activities generally occurs due to various factors, such as delays in the shipping process, inefficiency of working equipment, and the lack of knowledge and understanding among workers. Delays are often caused by suboptimal coordination between the port, ship, and supporting facilities, leading to additional costs for fuel, labor, and equipment rental. Furthermore, the underutilization of resources, such as damaged or non-standard operational equipment, also triggers inefficiency. The Toyota Production System (TPS) is a production framework aimed at eliminating waste in the manufacturing process [54]. The concept of "seven wastes" (Seven Wastes or Muda) is at the core of TPS, which describes various forms of waste that can occur in production processes. Overproduction: coal accumulation in stockpiles, which not only increases storage costs but also has the potential to damage coal quality. Waiting: time waste occurring when barges or mother vessels have to wait for the coal transhipment process. Transportation: delays in sending barges to the anchorage point, which can also cause loading delays and increase the risk of demurrage. Excess processing: unnecessary procedures in coal transhipment process or transportation. Inventory Waste: coal that has been produced and is ready for shipment but is delayed at the mine site due to coordination issues or unprepared transportation equipment. Unnecessary motion: unnecessary movements or activities in the coal shipping process. Defect: refers to damage to the loading and unloading equipment, ship, or coal itself, causing discrepancies or delays in the loading process. Non-utilized talent: labor or resources that are not maximally utilized or empowered to improve efficiency.

2.2.4. Mapping the Current State

Current State VSM is used to map the flow of processes and information within the supply chain and the company's production processes with the aim of identifying waste [55]. This mapping covers activities starting from the arrival of the barge used to transport coal, the process of loading coal into the barge, to the unloading of coal onto the Mother Vessel. With Current State VSM, the company can more easily identify the problems of waste that occur in the actual operational conditions.

Based on the key elements of the Current State Map, here are the adjustments for the loading and unloading process of coal to the mother vessel:

1. Process Flow: Describes the process flow starting from the loading of coal at the POL to the delivery to the mother vessel. This process involves several steps, including preparing the ship, loading the coal into the barge, sending the barge to the anchorage point, and transferring the load to the mother vessel. Each step in this process flow must be performed in sequence and efficiently to avoid delays. The unloading process from barge to mother vessel requires a minimum transfer rate of 8,000 MT per day.
2. Value-Added and Non-Value-Added Activities: Value-added activities in the coal delivery process include efficient coal loading, proper ship operation, and on-time delivery to the mother vessel. These activities directly contribute to achieving the delivery goals and customer satisfaction. On the other hand, non-value-added activities include long waiting times, equipment damage, and delays due to bad weather. These activities do not contribute positively to the process and instead add operational costs.
3. Waiting Time and Delays: Waiting time occurs when the barge or mother vessel cannot immediately load coal, which can be caused by various factors such as waiting cargo, unprepared ships, equipment malfunctions, or bad weather. These delays may lead to demurrage, which is an additional cost that The coal mining must pay.
4. Inventory Points: The inventory points in the coal delivery process at the coal mining include locations where the coal is stored before and after loading. At the POL, the coal is stored in stockpiles before being loaded onto the barge. After loading, the barge sails to the anchorage point, where the coal will be transferred to the mother vessel.
5. Decision Points and Information Flow: The Decision Points are located in the Operational Control section, which serves as the coordination center between various parties, such as the forwarding company, surveyor, and stevedore. From this point, the information flow directs to various processes involving actions and approvals. This information flow ensures that each stage in the coal transhipment process is carried out according to established procedures and schedules.

2.2.5. Process Activity Mapping (PAM)

This mapping helps to understand the flow of activities in the coal delivery process from the supplier to the production of components, within the context of coal transhipment. In this mapping, there are five main types of activities: operations (O), transportation (T), inspection (I), storage (S), and delay (D). In the Process PAM, the activity classification symbols are defined as follows:

- O= Operation, representing activities that directly transform or process the material;
- T = Transportation, indicating the movement of materials or equipment from one location to another;
- I = Inspection, referring to checking or verifying the quality, quantity, or condition of materials and processes;
- S = Storage, representing activities where materials are held or stored before the next process; and
- D = Delay, indicating waiting time or interruptions that do not add value to the process.
- Each activity is then analyzed to identify the types of waste, which include eight types: waiting, transportation, excess processing, inventories, inefficient motion, defects, and non-utilized talent.

2.2.6. Mapping the Future State

Mapping the future state aims to design a more efficient and waste-free coal delivery process. In this phase, the company will develop a plan to implement the improvements identified during the current state mapping and PAM analysis. This plan includes rearranging processes, reducing waiting times, and improving loading speed. By mapping the future state, the company can set clear goals and concrete steps to achieve higher efficiency, reduce demurrage costs, and improve customer satisfaction.

3. RESULTS

3.1. Current State Map Analysis

The cycle time values presented in the current-state map were obtained from historical operational records, direct observations during transhipment activities, and verification through interviews with operational personnel involved in loading and unloading operations. In Figure 3, this VSM illustrates the process of coal loading onto a barge. In the VSM of coal loading onto the barge, there are two main flows working simultaneously: the material flow and the information flow. The process begins with the coal mining placing an order for coal with the supplier. The supplier then delivers the coal and provides information regarding the specifications and the quantity of coal available. The coal from the mine is transported from the mine and stored at the POL stockpile before being loaded onto the barge. The Forwarder company plays a role in organizing the barge, including securing the necessary permits for the barge to dock at the POL and coordinating the docking process with the port authorities. The port operator is responsible for loading the coal from the stockpile onto the barge using a conveyor system.

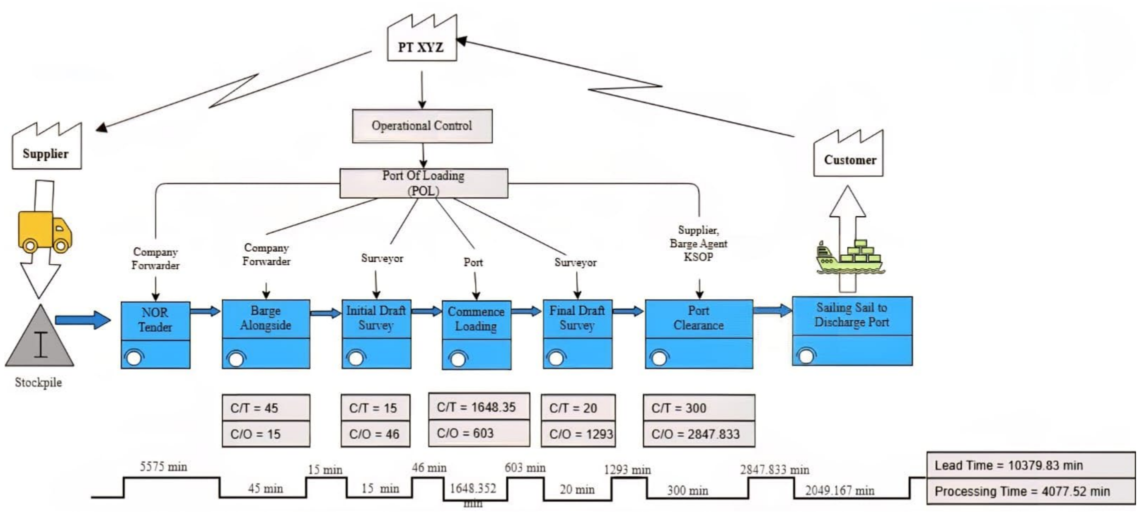

Figure 3. Current state VSM at POL

During this process, a surveyor measures the coal quantity at both the beginning and end of the loading to ensure the quantity being transported aligns with the ship's capacity and complies with shipping regulations. The coal mining supervises the entire process to ensure that all stages proceed as planned. Once the loading is complete, the supplier is responsible for the documentation and hands it over to coal mining.The coal mining then forwards the documentation to the barge agent for clearance with the KSOP so that the vessel can continue its journey without legal issues. The customer receives the coal at the POD as per the information received. A Process Cycle Efficiency (PCE) of 28.20%, as presented in Table 1, indicates that more than 70% of the total lead time is consumed by NVA and NNVA. The 1,293-minute delay in the "Barge Prepared for Cast-Off" activity was mainly caused by waiting for port clearance, completion of shipping documents, engine readiness checks, and unfavorable weather conditions before departure. These activities must be completed before the barge can safely leave the loading port, resulting in a substantial waiting period. The low PCE is primarily driven by excessive waiting and inventory-related delays, which represent the largest sources of waste in the loading process. Significant time losses occur during coal storage at the stockpile, barge preparation and departure, engine preparation, and port clearance activities. Furthermore, transportation disruptions caused by adverse weather conditions, equipment breakdowns, road congestion, and fluctuations in coal availability further extend lead times. These operational inefficiencies reduce the proportion of productive loading activities and increase the likelihood of demurrage. Therefore, improving stakeholder coordination, optimizing vessel scheduling, minimizing stockpile waiting time, and enhancing equipment reliability are essential to improving process efficiency.

Table 1. Current state VSM analysis at POL

No	Activity	Cycle Time (Minute)	Changeover time (Minutes)	Activity Type					Category		
				O	T	I	S	D	VA	NNVA	NVA
1	Suppliers transport coal from the mine area to the POL stockpile		5575		√					√	
2	Coal stored in stockpile						√			√	
3	Notice of Readiness (NOR) Tendered							√			
4	Alongside at POL	45						√	√		
5	In position and well moored		15					√		√	
6	Initial draft surveyor	15				√			√		
7	Preparation for Loading Commencement		46					√			√
8	Coal loading via conveyor to barge	1648.35		√					√		
9	Surveyor Prepares Final Draft		603			√					√
10	Final draft survey surveyor	20				√			√		
11	Barge Prepared for Cast-Off		1293					√			√
12	Supplier Document Clearance	300						√	√		
13	Port Clearance		1173					√		√	
14	Documents on board		309					√		√	
15	Engine preparation		1365.83					√		√	
16	Sailing to POD	2049.167			√				√		

No	Activity	Cycle Time (Minute)	Changeover time (Minutes)	Activity Type					Category		
				O	T	I	S	D	VA	NNVA	NVA
	Total (Minute)	4077.52	10379.83								
	Total (Hour)	67.96	173.00								
	Total (Day)	2.83	7.21								
	PCE	28.20	%								

The coal mining is responsible for managing the entire process of coal shipment and unloading. As shown in Figure 4, several key entities are involved in the operation. The customer serves as the final recipient of the shipped goods, while the surveyor, stevedore, and forwarding company support the loading and unloading activities. The detailed classification of activities, cycle times, changeover times, and value-added categories at the POD is summarized in Table 2, providing a quantitative basis for evaluating process efficiency and identifying sources of delay. The surveyor is responsible for measuring the quantity and quality of the unloaded coal to ensure it meets the agreed specifications. The stevedore performs all the loading and unloading activities on the mother vessel. Meanwhile, the company forwarder facilitates the shipping process using barges to transport the cargo from POL to POD, and then to be docked on the mother vessel.

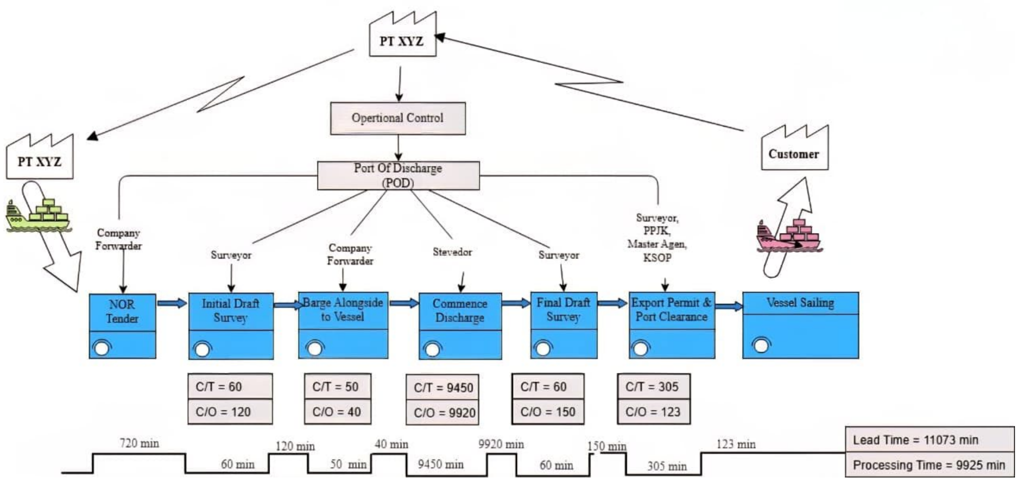

Figure 4. Current state VSM at POD

Table 2. Current state VSM analysis at POD

No	Activity	Cycle Time (Minute)	Changeover time (Minutes)	Activity Type					Category		
				O	T	I	S	D	VA	NNVA	NVA
1	Vessel arrived at outerbar Muara Sabak				Ö					Ö	
2	Drop Anchorage							Ö		Ö	
3	Turn Time 12 Hours							Ö			Ö
4	Agent, Port Authorities & Quarantine on board					Ö				Ö	
5	Check all document certificate & passport		720			Ö				Ö	
6	Free Pratique Granted					Ö				Ö	
7	Stevedore On Board			Ö							
8	Surveyor On Board					Ö				Ö	
9	Notice of Readiness (NOR) Tendered							Ö		Ö	

No	Activity	Cycle Time (Minute)	Changeover time (Minutes)	Activity Type					Category		
				O	T	I	S	D	VA	NNVA	NVA
10	Initial Draft Survey	60				Ö			Ö		
11	Hold Inspection		60			Ö				Ö	
12	Transfer Heavy Equipment		60	Ö						Ö	
13	Barge Processing alongside to vessel	50						Ö	Ö		
14	Prepare for Vessel Loading Commencement		40	Ö						Ö	
15	Start of Loading Operations	9450		Ö					Ö		
16	Break Loading		9920	Ö							Ö
17	Final draft by surveyor	60				Ö			Ö		
18	Intermediate		150			Ö				Ö	
19	The coal mining Export Permit Clearance	305						Ö	Ö		
20	Port Clearance		123					Ö		Ö	
21	Vessel Sailing				Ö					Ö	
	Total (Minute)	9925	11073								
	Total (Hour)	165.417	184.550								
	Total (Day)	6.892	7.690								
	PCE	47.27	%								

As shown in Table 3 the activities were classified into three categories: VA, NVA, and NNVA with a total process time of 14,457.35 minutes. Of this total, Value-added activities contribute 28.20% of the total process time, non-value-added activities account for 13.43%, and necessary non-value-added activities represent 58.36%. Additionally, the table classifies activity types into operations, transportation, inspection, storage, and delay, with delays being the largest contributor to time (56%). In the waste analysis, the time spent on waiting and inventory wastes each account for approximately 28–29% of total process time, indicating potential for efficiency improvements in the process. Overall, 70.76% of the total time is spent on activities deemed as waste, highlighting the need for greater attention to reduce unproductive time.

Table 3. Summary of activity mapping process at POL

Description	**Number of Activities**	**Total Time (Minutes)**	**Activity Percentage**	**Time Percentage**
Activity Category				
Value Added	6	4077.52	37.50%	28.20%
Non Value Added	3	1942.00	18.75%	13.43%
Necessary Non Value Added	7	8437.83	43.75%	58.36%
Total	**16**	**14457.35**	**100%**	**100%**
PCE		28.20%		
Type of Activity				
Operation	1	1648.35	6.25%	11.40%
Transportation	2	3489.17	12.50%	24.13%
Inspection	3	638.00	18.75%	4.41%
Storage	1	4120.00	6.25%	28.50%
Delay	9	4561.83	56.25%	31.55%
Total	**16**	**14457.35**	**100%**	**100%**

Description	Number of Activities	Total Time (Minutes)	Activity Percentage	Time Percentage
		Waste Type		
Waiting		4107.92		28.41%
Transportation		874.50		6.05%
Excess Processing		120.00		0.83%
Inventories		4120.00		28.50%
Unnecessary Motion		1007.42		6.97%
Total		**10229.83**		**70.76%**

An analysis of activities within the process is presented in Table 4, which classifies activities into three categories: VA, NVA and NNVA. Out of the total 21 activities that took 20,998 minutes, 47.27% of the total process time was spent on value-added activities, 49.77% on non-value-added activities, and 2.96% on NNVA activities. In terms of activity types, operations dominated, accounting for 46% of the total time, followed by delays, which contributed 52% of the total time, while transportation and storage did not contribute any time at all. Additionally, the analysis also shows that 66% of the total time was spent waiting, reflecting the presence of waste within the process.

Table 4. Activity mapping process summary at POD

Description	Number of Activities	Total Time (Minutes)	Activity Percentage	Time Percentage
		Activity Category		
Value Added	5	9925.00	23.81%	47.27%
Non Value Added	2	10450.00	9.52%	49.77%
Necessary Non Value Added	14	623.00	66.67%	2.96%
Total	**21**	**20998.00**	**100%**	**100%**
PCE	47.27%			
		Type of Activity		
Operation	4	9610.00	19.05%	45.77%
Transportation	2	0.00	9.52%	0.00%
Inspection	8	450.00	38.10%	2.14%
Storage	0	0.00	0.00%	0.00%
Delay	7	10938.00	33.33%	52.09%
Total	**21**	**20998.00**	**100%**	**100%**
		Waste Type		
Waiting		13869.00		66.05%
Transportation		0.00		0.00%
Total		**13869.00**		**66.05%**

3.2. Determination of Dominant Waste Categories

The dominant waste categories were determined by integrating the results of Process Activity Mapping (PAM) and Fishbone Diagram analysis. First, PAM was used to quantify the time associated with each waste category identified in the current-state process. The analysis showed that waiting waste and inventory waste at the POL, as well as waiting waste at the POD, contributed the largest proportion of non-value-added activities. Subsequently, Fishbone Diagrams were developed for these high-impact wastes to investigate their root causes. The frequency and recurrence of causal factors identified in the fishbone analysis, such as equipment breakdowns, scheduling inefficiencies, administrative delays, limited port capacity, and adverse weather conditions, confirmed that waiting, inventory, and transportation-related wastes were the dominant contributors to demurrage. Therefore, these waste categories were prioritized for improvement in the future-state value stream mapping.

Delays in barge arrivals at the POL during coal loading operations, as shown in Figure 5, are mainly caused by Machine factors (barge damage and technical failures), Method factors (administrative and scheduling delays), and Environment factors (adverse weather and low river water levels). These factors disrupt logistics flow and increase operational costs.

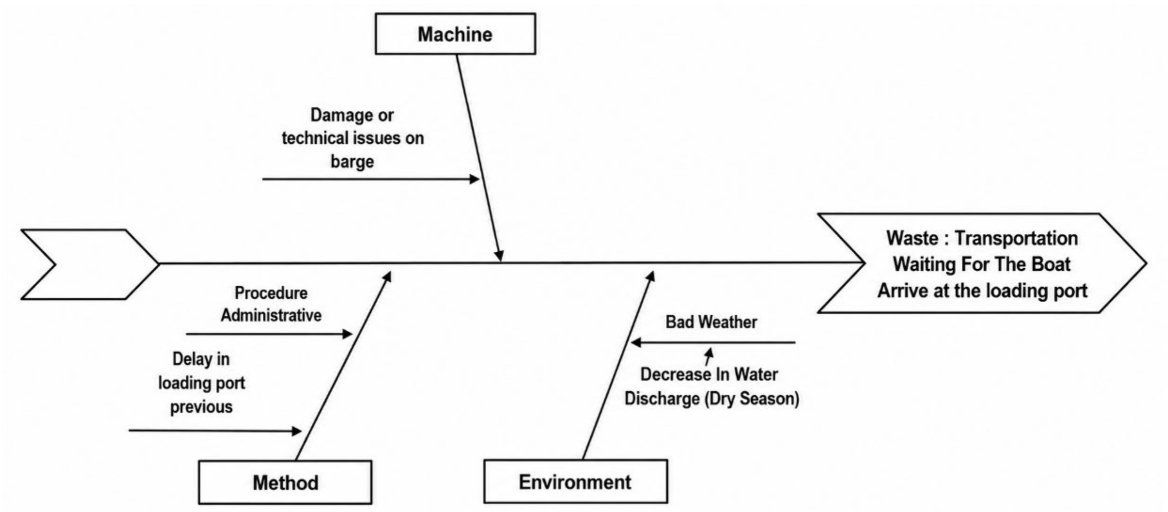

Figure 5. Fishbone diagram of transportation waste

The main causes of barge queues at the port during the coal loading process to the mother vessel, as shown in Figure 6, include Machine factors such as limited port capacity and conveyor damage, Man factors such as inefficient slot-booking schedules, Method factors related to additional crushing requirements, and Environment factors such as queues from other shippers. These factors contribute to waiting waste and operational delays.

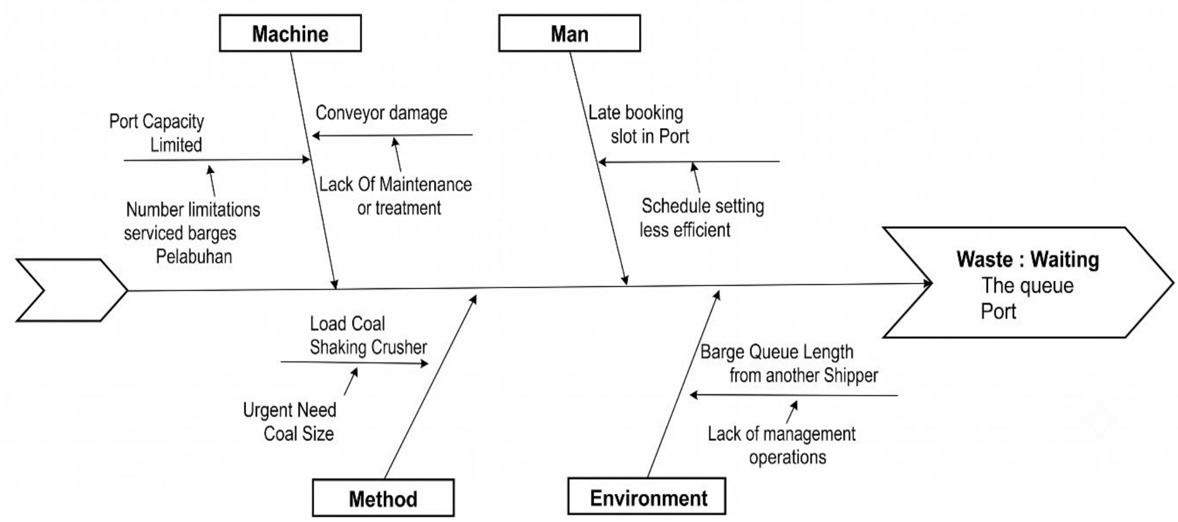

Figure 6. Fishbone diagram for waiting waste

The primary causes of inventory waste in the form of coal accumulation at the stockpile during loading and unloading operations are illustrated in Figure 7. These causes include Machine factors, such as limited barge capacity; Method factors, including regulations and transportation requirements that slow the process; and Environment factors, such as limited port infrastructure, shallow water draft, congestion, and the absence of dedicated coal transportation routes.

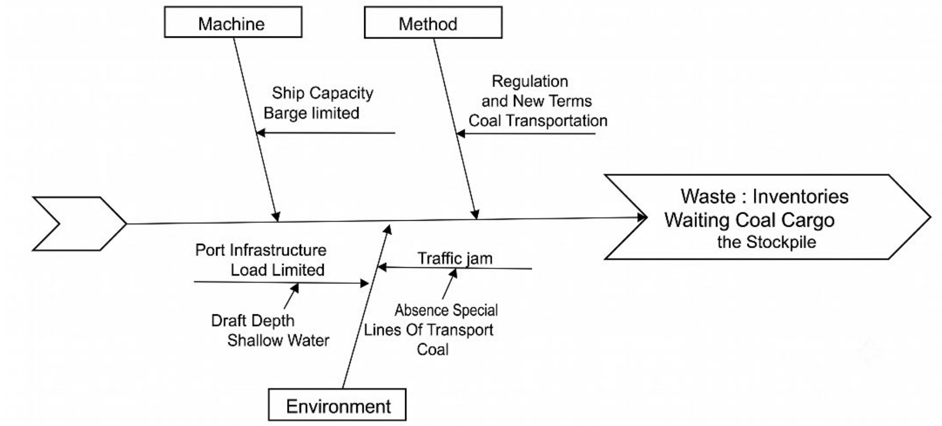

Figure 7. Fishbone diagram of inventory waste

The root causes of delays in the coal transfer process from barges to the mother vessel, as illustrated in Figure 8, include Environment factors such as adverse weather conditions and high waves, Machine factors such as crane and grab hydraulic failures, Materials factors including vessel queues and slow loading rates, Method factors related to poor coordination and scheduling, and Man factors such as delays in document verification. These factors collectively contribute to operational delays and increase the risk of demurrage.

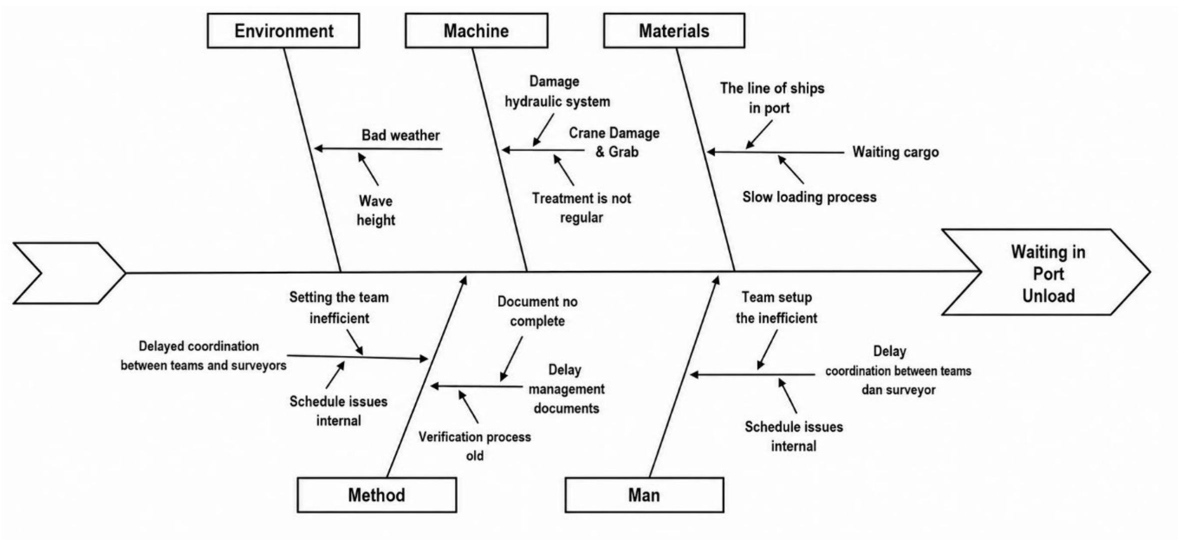

Figure 8. Fishbone Diagram of Waiting Waste at POD

3.3. Waste Reduction Strategies

The improvement proposals were developed based on the dominant wastes identified through Process Activity Mapping (PAM) and Fishbone Diagram analyses. At the POL, inventory waste (4,120 minutes; 28.50%) and waiting waste (4,107.92 minutes; 28.41%) were the major contributors to lead time. At the POD, waiting waste accounted for 13,869 minutes (66.05%) of the total process time. Therefore, the proposed improvements specifically target the root causes of these wastes.

3.3.1. Improvement for Transportation Waste (Delay in Barge Arrival at POL)

The fishbone analysis in Figure 5 showed that transportation waste was primarily caused by barge breakdowns, delays at previous POL, administrative bottlenecks, and adverse weather conditions. These factors contribute to extended transportation time from the mine and anchorage area to the POL, resulting in interruptions to the loading schedule. To reduce this waste, The coal mining should implement preventive maintenance scheduling for barges and tugboats before vessel deployment. Weather-related delays cannot be eliminated; therefore, the proposed future-state process focuses on mitigating their impact through forecasting and proactive scheduling. In addition, voyage planning should incorporate weather forecasting data and alternative sailing schedules to minimize disruptions caused by rough sea conditions and low water levels during the dry season. Administrative processes such as sailing permits, clearance documents, and vessel readiness documents should be completed before barge mobilization. These improvements are expected to reduce transportation delays and improve barge arrival reliability at the POL.

3.3.2. Improvement for Waiting Waste at POL

Waiting waste at the POL was mainly associated with barge queues, limited port service capacity, conveyor breakdowns, delayed slot booking, and additional crushing activities to meet customer specifications. This waste contributed significantly to the total non-value-added time. To address this issue, Shipping Instructions (SI) should be submitted earlier to secure loading slots before barge arrival. Coordination between the coal mining, the port operator, and forwarding agents should be strengthened through a shared scheduling system to avoid berth congestion. Preventive maintenance programs should also be implemented for conveyors and loading facilities to reduce equipment downtime. Furthermore, customer coal size specifications should be confirmed before stockpile preparation to eliminate additional crushing activities that delay loading commencement. These actions directly reduce waiting time and improve loading flow continuity.

3.3.3. Improvement for Inventory Waste at POL

Inventory waste was identified as coal accumulation at the stockpile, accounting for 4,120 minutes or 28.50% of the total process time. According to the Fishbone analysis, this waste was caused by limited barge capacity, transportation restrictions, shallow draft conditions, port congestion, and the absence of dedicated coal transportation routes. To minimize inventory accumulation, coal production schedules should be synchronized with barge arrival schedules using a pull-based logistics approach. The utilization of 270-ft barges through river transportation routes should be optimized to increase coal evacuation capacity from the mine to the stockpile. In addition, stockpile monitoring should be integrated with shipping schedules to ensure that coal inventory levels remain aligned with vessel loading requirements. By reducing stockpile dwell time, inventory waste and associated handling costs can be significantly decreased.

3.3.4. Improvement for Waiting Waste at POD

The largest waste identified in the unloading process was waiting waste, which reached 13,869 minutes or 66.05% of total process time. Figure 8 indicates that the main causes were crane and grab failures, vessel queues, slow unloading operations, documentation delays, poor coordination among operational teams, and adverse weather conditions. To reduce this waste, preventive maintenance should be scheduled regularly for cranes, grabs, and hydraulic systems to improve unloading equipment availability. Operational coordination between stevedores, surveyors, vessel agents, and the coal mining should be strengthened through daily operational planning meetings and real-time communication systems. Documentation verification and export clearance activities should be completed before vessel arrival whenever possible to avoid administrative delays during unloading. In addition, unloading performance should be monitored using loading rate targets to ensure that the guaranteed unloading rate is achieved. These improvements directly address the dominant waiting waste and contribute to reducing demurrage exposure at the POD. By reducing inventory accumulation, transportation delays, and waiting times at both the POL and POD, the future-state process is expected to significantly improve PCE, shorten lead times, and reduce demurrage costs.

After the proposed improvements were implemented, operational efficiency increased significantly, as presented in Table 5. PCE improved from 28.20% to 84.97%, reflecting a substantial increase in value-added activities. Non-value-added activities decreased from 13.43% to 2.54%, while NNVA activities were reduced from 58.36% to 12.49%. Major wastes were also minimized, with waiting waste decreasing from 28.41% to 4.76% and inventory waste from 28.50% to 0.19%. Figure 9 further shows that value-added time increased from 28.20% to 77.24%, accompanied by reductions in non-value-added and NNVA activities. In addition, operation activities increased from 11.40% to 71.92%, while transportation and storage activities were eliminated. These results indicate that the proposed improvements effectively reduced waste and enhanced the efficiency of the coal loading process.

Table 5. Results of the Improvement in Activity Mapping Process Summary at POL

Description	Number of Activities	Total Time (Minutes)	Activity Percentage	Time Percentage
Activity Category				
Value Added	6	3877.92	37.50%	84.97%
Non Value Added	3	116.00	18.75%	2.54%
Necessary Non Value Added	7	570.00	43.75%	12.49%
Total	16	**4563.92**	**100%**	**100%**
PCE	84.97%			
Type of Activity				
Operation	1	1388.75	6.25%	30.43%
Transportation	2	2109.17	12.50%	46.21%
Inspection	3	45.00	18.75%	0.99%
Storage	1	60.00	6.25%	1.31%
Delay	9	961.00	56.25%	21.06%
Total	**16**	**4563.92**	**100%**	**100%**
Waste Type				
Waiting		688.00		4.76%
Transportation		60.00		0.42%
Excess Processing		120.00		0.83%
Inventories		28.00		0.19%
Unnecessary Motion		1007.42		6.97%
Total		**1903.42**		**13.17%**

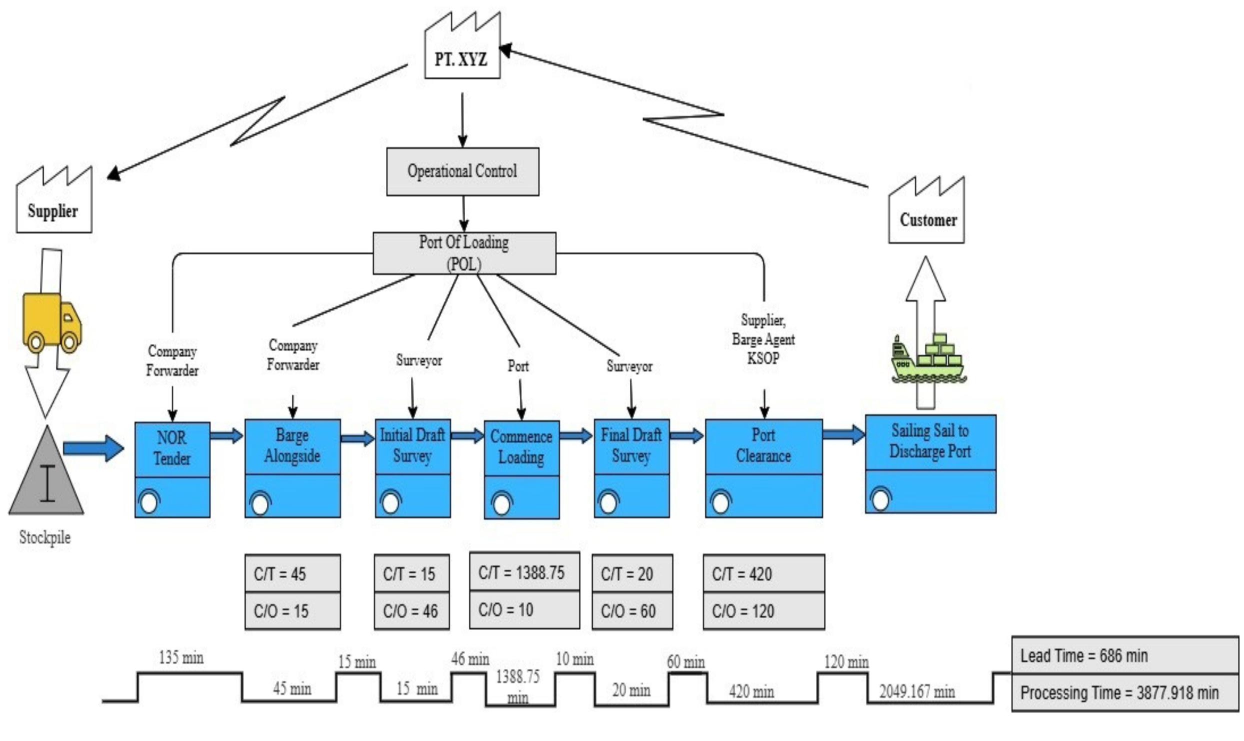

Figure 9. Future State VSM at POL

After the proposed improvements were implemented, operational efficiency at the Port of Discharge (POD) increased significantly, as presented in Table 6. PCE improved from 47.27% to 77.24%, indicating a substantial increase in value-added activities. Non-value-added activities decreased from 49.77% to 17.04%, while NNVA activities were reduced from 2.97% to 5.72%. Waiting waste, which was identified as the dominant source of inefficiency in the unloading process, decreased markedly from 66.05% to 20.20%, while transportation waste was completely eliminated. Figure 10 further illustrates that value-added activities increased from 47.27% to 77.24% of the total process time, accompanied by a significant reduction in non-value-added activities. In addition, operation activities increased from 45.77% to 71.92%, whereas delay activities decreased from 52.09% to 23.82%. These results demonstrate that the proposed improvements effectively reduced operational delays, minimized waste, and enhanced the overall efficiency of the coal unloading process.

Table 6. Results of the improvement in activity mapping process summary at POD

Description	Number of Activities	Total Time (Minutes)	Activity Percentage	Time Percentage
Activity Category				
Value Added	5	5440.42	23.81%	77.24%
Non Value Added	2	1200.00	9.52%	17.04%
Necessary Non Value Added	14	403.00	66.67%	5.72%
Total	21	**7043.42**	**100%**	**100%**
PCE	77.24%			
Type of Activity				
Operation	4	5065.42	19.05%	71.92%
Transportation	2	0.00	9.52%	0.00%
Inspection	8	300.00	38.10%	4.26%
Storage	0	0.00	0.00%	0.00%
Delay	7	1678.00	33.33%	23.82%
Total	**21**	**7043.42**	**100%**	**100%**
Waste Type				
Waiting		1423.00		20.20%
Transportation		0.00		0.00%
Total		**1423.00**		**20.20%**

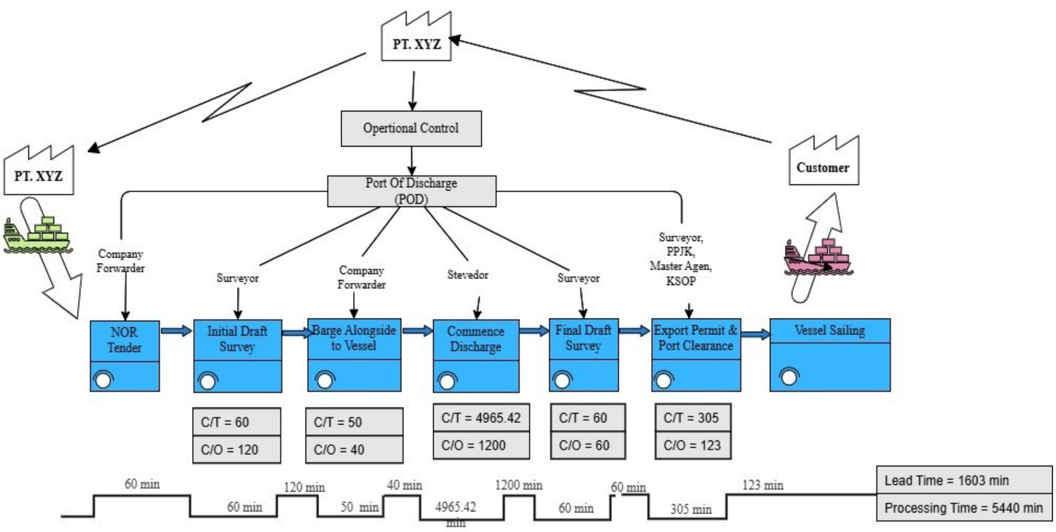

Figure 10. Future state VSM at POD

4. DISCUSSION

The findings of this study demonstrate that the application of Value Stream Mapping (VSM) effectively reduced waste and improved operational efficiency in coal transhipment activities. At the POL, PCE increased from 28.20% to 84.97%, while the total loading lead time decreased from 10.04 days to 3.17 days. Similarly, at the POD the PCE improved from 47.27% to 77.24%, and the unloading lead time was reduced from 14.58 days to 4.89 days. These results indicate that waiting time, transportation delays, and inventory accumulation were the dominant sources of waste contributing to demurrage. The results are consistent with previous studies on lean logistics, which emphasize that eliminating non-value-added activities can significantly improve supply chain performance and operational efficiency. Studies by Fazi and Roodbergen [56] highlighted that delays and detention activities reduce transportation efficiency and increase logistics costs. Likewise, Storms et al. [57] reported that improved coordination among stakeholders and better operational planning are critical factors in reducing demurrage and detention problems. The improvements proposed in this study, particularly enhanced scheduling, documentation management, and coordination between suppliers, ports, and vessel operators, support these findings.

From a port operations perspective, the results also align with previous research showing that vessel waiting time, equipment availability, and cargo handling performance are major determinants of operational efficiency. Moini et al. [58] found that operational bottlenecks and inadequate infrastructure significantly contribute to longer dwell times and logistics inefficiencies. In the present study, the identification of conveyor breakdowns, crane maintenance issues, vessel queues, and administrative delays as major causes of waste confirms the importance of operational reliability and resource readiness in minimizing delays. Compared with previous demurrage-related studies that primarily focused on cost analysis, vessel scheduling, or container transportation systems, this study contributes by applying a comprehensive lean approach through the integration of Current State VSM, Process Activity Mapping (PAM), Fishbone Diagram analysis, and Future State VSM. This integrated approach enables not only the identification of demurrage causes but also the systematic elimination of waste across both loading and unloading operations. Therefore, the study extends the application of lean logistics principles to coal transhipment operations involving barges and mother vessels, an area that has received limited attention in previous research. Overall, the findings confirm that lean-based process improvement can substantially reduce operational delays, increase value-added activities, and lower the risk of demurrage. The results provide practical evidence that the integration of waste identification, root cause analysis, and process redesign can improve the efficiency and profitability of coal transhipment operations.

The improvement results provide important managerial implications for coal transhipment operations. The increase in PCE at the POL from 28.20% to 84.97% and at the POD from 47.27% to 77.24%, along with the reduction of total process time from 10.04 to 3.17 days at the POL and from 14.58 to 4.89 days at the POD, indicate that operational waste can be significantly reduced through better scheduling, preventive maintenance, and improved coordination among suppliers, surveyors, stevedores, forwarders, and port authorities. These improvements enable management to reduce vessel waiting time, increase loading and unloading productivity, improve fleet utilization, and minimize demurrage costs. The findings also demonstrate that Value Stream Mapping can be used as an effective managerial tool to identify operational bottlenecks and support continuous improvement in coal transhipment operations.

5. CONCLUSION

Lean supply chain plays a crucial role in improving operational efficiency [59][60], [61], [62]at coal loading and POD, as revealed through the Current State Value Stream Mapping analysis. By using VSM, inefficiencies in the loading and unloading processes, such as waiting times and transportation delays, which previously contributed to low PCE, can be identified. Through the application of lean principles, such as reducing waiting times, optimizing conveyor loading, and streamlining documentation, PCE at the POL improved from 28.20% to 84.97%, while at the POD, the initial PCE of 47.266% was successfully increased with better coordination and the use of more efficient equipment.

This study has several limitations. The analysis was conducted based on operational data from a single coal transhipment company, which may limit the generalizability of the findings to other ports or shipping environments. Future research may extend this study by applying the proposed improvement framework to multiple coal transhipment operations, integrating simulation or optimization models to evaluate alternative operational scenarios, and incorporating real-time operational data to support predictive decision-making and further reduce demurrage risks.

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DECLARATION OF AI-TOOL USAGE

During the preparation of this work, the authors used Generative Artificial Intelligence (AI) tools to improve the quality of the language, grammar, and readability of the manuscript. The AI tools were used solely to assist with language editing and did not contribute to the study design, data collection, data analysis, interpretation of results, or scientific conclusions.