Analysis lean and green manufacturing in the ship production process at PT XYZ

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ABSTRACT

The manufacturing industry, especially in sectors like shipbuilding, is experiencing rapid growth and heightened competition, necessitating ongoing enhancements in productivity and operational efficiency. PT XYZ, a prominent shipyard in Indonesia, is dedicated to advancing its business operations, which include new ship construction, maintenance, repair, and engineering consultancy. Despite these efforts, the company faces significant challenges in optimizing production processes, resulting in inefficiencies and potential delays in project delivery. This study examines waste in ship production processes at PT XYZ using lean manufacturing principles and proposes strategies for waste reduction through green manufacturing approaches. By identifying and addressing issues such as waiting times and inventory waste in fabrication workshops, the research seeks to boost operational efficiency and secure a competitive edge in the shipbuilding industry. The results reveal that implementing targeted improvements using VALSAT and other lean methodologies has markedly enhanced system efficiency. The identification and rectification of waste sources have led to increased production efficiency and improved product quality, demonstrating the effectiveness of these lean strategies in refining manufacturing operations.

1. Introduction

The rapid evolution of the manufacturing industry, particularly in shipbuilding, reflects the escalating demands for enhanced productivity and competitiveness (Jebbor et al., 2023). Shipbuilding which is critical for mass transportation and logistics amidst rapid economic growth, underscores the critical importance of competitive positioning in the market (Khadim et al., 2021). The global shipbuilding industry is projected to grow significantly due to rising demands for maritime transport (Caesar, 2024). PT XYZ is one of the shipyard in Indonesia, engages in a broad spectrum of activities including new vessel construction, maintenance, non-ship repairs, consultancy, and general engineering (Jian et al., 2024). In response to industry dynamics, PT XYZ focuses on developing marketable products while managing operations efficiently to sustain competitiveness in ship production (Jebbor et al., 2023). Effective management of production processes and continuous innovation are key to maintaining a competitive edge in this sector (Rosário et al., 2024).

The nature of job-order-based demands in shipbuilding necessitates tailored production planning and control to ensure project effectiveness and efficiency (Hadžić et al., 2023). Custom orders in shipbuilding require precise coordination and resource allocation to meet specific client requirements (Park & Huh, 2022). However, PT XYZ faces challenges stemming from suboptimal production processes, which disrupt the timely delivery of vessels and compromise contractual obligations,

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constituting wasteful practices that need mitigation (Klakegg et al., 2021)]. Studies have highlighted that inefficiencies in production processes can lead to significant delays and increased costs, impacting overall project profitability (Skėrė et al., 2023; Krajčovič et al., 2024).

One significant example is the waiting waste observed in fabrication workshops due to incomplete material arrivals, leading to inventory buildup and subsequent production delays (Huang et al., 2022). This type of waste not only hampers productivity but also escalates operational costs (Ding et al., 2024). Addressing such inefficiencies is crucial for optimizing lead times and improving overall production efficiency within PT XYZ's operations (Berk et al., 2023). Research indicates that implementing lean manufacturing techniques can effectively reduce waiting times and streamline production workflows (Orynycz et al., 2020).

Furthermore, the environmental impact of ship production cannot be overlooked, with significant waste generated from ongoing operations and repairs (Olaniyi et al., 2022). The shipbuilding industry must adhere to stringent environmental regulations to minimize its ecological footprint (Serra & Fancello, 2020). Effective waste management strategies, aligned with lean and green manufacturing principles, are imperative for reducing environmental footprints while enhancing operational efficiency. Green manufacturing practices not only help in compliance with environmental standards but also promote sustainable development by reducing waste and conserving resources (Yang et al., 2024).

Several lean-related studies have had a major impact on the manufacturing industry, including reducing labor, reducing lead time, saving costs, increasing productivity, and increasing customer satisfaction (Castro & Riedel, 2017). In the production process at a company, there are several activities that have no added value or waste, resulting in the use of resources ranging from labor, human resources, and time, causing the process to be inefficient (Ikatrinasari et al., 2018). One method to minimize waste is lean manufacturing which functions as an effort to improve the efficiency of the production process and eliminate waste by identifying waste (Setiawan et al., 2022). The application of green manufacturing continues to develop with 5 perspectives that are points of attention for the manufacturing industry, including work safety, production waste, revenue, production costs and solid material residues.

The manufacturing industry, particularly in shipbuilding, is undergoing rapid growth and intense competition, necessitating ongoing improvements in productivity and operational efficiency. PT XYZ, a leading Indonesian shipyard, seeks to enhance its operations in new ship construction, maintenance, repair, and engineering consultancy. This research aims to increase productivity, minimize waste, and promote sustainable practices in PT XYZ's shipbuilding operations. By applying lean manufacturing principles and green manufacturing strategies, the study identifies and addresses inefficiencies in production processes. The findings reveal that implementing targeted improvements using VALSAT and other lean methodologies has led to more efficient production processes, reduced operational costs, and lower environmental impacts. These enhancements contribute to PT XYZ's overall sustainability and strengthen its competitiveness in the global market (Salah et al., 2023). Thus, the research successfully meets its objectives by improving operational efficiency and supporting sustainable manufacturing practices.

2. Methods

This research employs both qualitative and quantitative approaches to enhance PT XYZ's shipbuilding operations. The qualitative approach involves conducting in-depth interviews and focus groups with stakeholders to identify inefficiencies and explore green manufacturing practices. These insights help understand the nature of waste and the potential for sustainable practices. In contrast, the quantitative approach focuses on measuring productivity, waste levels, and environmental impacts through the analysis of numerical data and performance metrics. By combining these methods, the research not only gains a comprehensive understanding of the challenges and strategies but also empirically evaluates the effectiveness of implemented changes in improving operational efficiency, reducing costs, and minimizing environmental impact. Primary data was obtained through direct observation and interviews to find out the production system and material flow of the ship production process. Meanwhile, secondary data was obtained through historical production data and other supporting data to complement the research.

The Waste Assessment Model (WAM) employs the Waste Relationship Matrix to identify and analyze waste within production processes by defining and measuring the seven types of waste—

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overproduction, waiting, transportation, extra processing, inventory, motion, and defects. This method classifies the strength of relationships between different types of waste on a scale from strongest to weakest, allowing for a comprehensive understanding of how various wastes interact and impact efficiency. Typically, 10-20 key personnel provide insights through surveys or interviews, which are then aggregated to populate the matrix. The resulting data is analyzed to identify significant waste interactions and develop targeted strategies for improvement. This structured approach helps in pinpointing critical areas for waste reduction and enhancing overall operational efficiency. After completing the Waste Relationship Matrix method, the process continues with the Waste Assessment Questionnaire, which combines the results of the Waste Relationship Matrix with the results of the questionnaire (Afrianto et al., 2022). The seven types of waste are defects, overproduction, waiting, unnecessary inventory, improper processing, excessive transportation, and unnecessary movement (Kosasih et al., 2019). After waste is identified, waste weighting will be carried out with one of the VALSAT tools, namely Process Activity Mapping. PAM will be analyzed based on the ship's production process and produce activity values and value added, non-value added, and necessary non-value added. Furthermore, the root causes of waste are analyzed and recommendations for improvement are proposed based on existing production waste.

Using these methods, this study provides a comprehensive analysis of waste in PT XYZ's ship production process and offers actionable recommendations to improve production efficiency and sustainability.

3. Results and Discussion

Current State Mapping

The production process follows a material flow approach, typically involving several stages such as raw material acquisition, manufacturing, assembly, and quality control. For instance, in shipbuilding, the process includes designing, cutting steel plates, assembling hulls, outfitting, and final inspections.

The current state map provides a visual representation of the existing production flow, identifying key stages and bottlenecks in the process. This helps in understanding the inefficiencies and areas needing improvement.

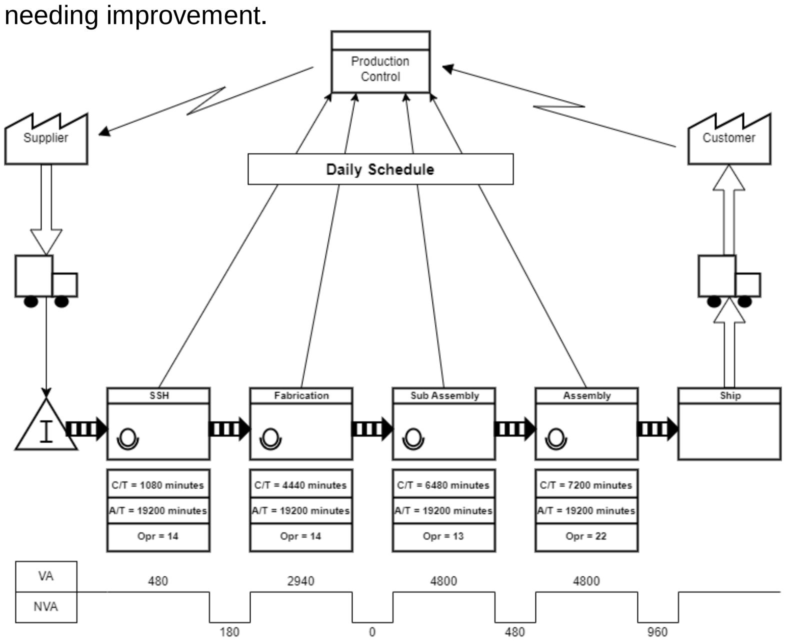

Fig 1 Current state mapping.

The Fig 1 above illustrates a manufacturing process flow, highlighting key metrics such as Cycle Time (C/T), Available Time (A/T), and the number of Operators (Opr) required at each production stage. Cycle Time (C/T) refers to the duration needed to complete one cycle of a specific process,

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while Available Time (A/T) represents the total time available for the task. The number of Operators (Opr) indicates how many workers are involved in each stage.

Value-Added (VA) activities are those that directly contribute to the creation of the product and are beneficial from the customer's perspective, while Non-Value-Added (NVA) activities do not add value and often represent waste, such as waiting times or unnecessary movements. For example, in the Sub Assembly stage, if the Cycle Time is 6480 minutes and only 4800 minutes are spent on VA activities, the remaining 1680 minutes would be considered NVA.

Identification Waste

In identifying waste, researchers distributed questionnaires according to the criteria. The questionnaires were filled out by employees who were directly involved with the ship production process.

Table 1 Waste Relationship Matrix

F/T	O	I	D	M	T	P	W
O	**A**	A	E	E	E	X	E
I	O	**A**	O	E	I	X	X
D	O	O	**A**	E	O	X	I
M	X	I	U	**A**	X	U	I
T	O	I	U	U	**A**	X	O
P	I	I	O	E	X	**A**	E
W	O	I	O	X	X	X	**A**

Table 1 shows the relationship between each waste where O (Overproduction), I (Inventory), D (Defect), M (Motion), T (Transportation), P (Overprocess) and W (Waiting). Next is to make Waste Matrix Value by converting symbols above with a score of A=10, E=8, O=4, U=2 and X=0 (Syafira, 2019). Following are the results values Waste Value Matrix.

Table 2 Waste Value Matrix

F/T	O	I	D	M	T	P	W	Skor	(%)
O	10	10	8	8	8	0	8	52	21.67%
I	4	10	4	8	6	0	0	32	13.33%
D	4	4	10	8	4	0	6	36	15.00%
M	0	6	2	10	0	2	6	26	10.83%
T	4	6	2	2	10	0	4	28	11.67%
P	6	6	4	8	0	10	8	42	17.50%
W	4	6	4	0	0	0	10	24	10.00%
Skor	32	48	34	44	28	12	42	240	
(%)	13.33%	20.00%	14.17%	18.33%	11.67%	5.00%	17.50%		100%

Based on Table 2, it can be seen that after calculating the results by weighting the questionnaire, the percentage of waste is obtained from the "from" column, namely Overproduction which is worth 21.67% and waste which comes from the "to" column, namely Inventory worth 20.00%. To analyze the waste in the process, we can calculate specific metrics like Yj (the sum of all scores in a particular column) and Pj (the percentage contribution of that column to the total waste). Using the “from” Overproduction (O) column as an example:

1. **Yj (Sum for From Overproduction)**: Add the scores from the Overproduction column (O):
   Yj = 10 + 10 + 8 + 8 + 8 + 0 + 8 = 52
2. **Pj (Percentage for From Overproduction)**: To find the percentage, divide the sum for Overproduction (Yj) by the total score (ΣYj) and multiply by 100:
   $$\text{Pj} = \left(\frac{52}{240}\right) x100 = 21.67\%$$

This means that Overproduction contributes 21.67% to the total waste, which is a significant portion compared to other types of waste listed in the matrix.

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Table 3 Result Waste Assessment Questionnare

F/T	O	I	D	M	T	P	W
Yj (Score)	0.265	0.274	0.248	0.228	0.290	0.166	0.207
Pj Factor	0.029	0.027	0.021	0.020	0.014	0.009	0.018
Yj Final	0.00765	0.00729	0.00527	0.00454	0.00395	0.00146	0.00361
Final Result (%)	22.65%	21.59%	15.61%	13.43%	11.70%	4.31%	10.70%

Based on Table 3 that to calculate the value for each waste (Yj Final) must be know the initial indicators for each wasta (Yj) and the probability value for each waste (Pj). Percentage yield obtained from the Waste Assessment Questionnaire will then be used as initial weights in Value Stream Analysis Tools (VALSAT) by multiplying the initial weights waste that occurs with factors which has been specified. Following are the value results which has been obtained using VALSAT.

VALSAT

Based on Table 4 it can be seen that of the seven mapping tools (Pratiwi et al., 2020) that received marks the biggest is Process Activity Mapping where got a score of 464.29, hence this tool selected to identify and analyse waste that occurs in the ship production process.

Table 4 Value Stream Analysis Tools

Waste	Weight	Mapping Tools						
		PAM	SCRM	PVF	QFM	DAM	DPA	PS
O	22.65	22.65	67.95		22.65	67.95	67.95	
I	21.59	64.77	194.31	64.77		194.31	64.77	21.59
D	15.61	15.61			140.49			
M	13.43	120.87	13.43					
T	11.70	105.30						11.70
P	4.31	38.79		12.93	4.31		4.31	
W	10.70	96.30	96.30	10.70		32.10	32.10	
Total		464.29	371.99	88.4	167.45	294.36	169.13	33.29

Explanation of Abbreviations:

- **PAM (Process Activity Mapping):** A tool used to identify all the activities in a process and categorize them as value-added, non-value-added, or necessary non-value-added.
- **SCRM (Supply Chain Response Matrix):** Used to analyze the responsiveness of the supply chain and identify areas where lead times can be reduced.
- **PVF (Production Variety Funnel):** A tool to evaluate how variety in products impacts the production process, potentially leading to inefficiencies or waste.
- **QFM (Quality Filter Mapping):** Identifies where quality issues occur within a process, focusing on detecting and eliminating defects.
- **DAM (Demand Amplification Mapping):** Analyzes the amplification of demand variability along the supply chain, often leading to increased waste.
- **DPA (Decision Point Analysis):** Focuses on decision points in the process that could contribute to inefficiencies, helping to streamline decision-making processes.
- **PS (Physical Structure):** Examines the physical setup of the production process, assessing how the layout contributes to waste or inefficiencies.

Based on (Kosasih, 2019), it is explained that there are relationships from value stream mapping tools where “H” (high correlation and usefulness) is 9, “M” (medium correlation and usefulness) is 3, and “L” (low correlation and usefulness) is 1. Let’s calculate the total value for a specific series in the "Overproduction (O)" row for the PAM column:

1. Weight:
   The weight of Overproduction is obtained from the final result (%) in Table 3 Result Waste Assessment Questionnare, which is 22.65.

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2. Value Assigned:
   - The table suggests that for Overproduction, the weight using PAM is 22.65, which is obtained from the weight multiplied by the value stream mapping tools relationship multiplier factor of 1.
   - If we sum this across all tools where PAM is applied, we only have one value for Overproduction with PAM, which is already 22.65.
3. Total Value Calculation:
   - The table shows that for Overproduction, the weight using PAM is 22.65.
   - If we add this across all tools that use PAM, we get a total of 464.29.

This calculation shows how a specific waste type (Overproduction) is measured using a process activity mapping (PAM), which helps in determining its impact within the overall process.

PAM

Next step in Process Activity Mapping (PAM) is doing grouping jobs based on activities are: operations, transportation, inspection, storage, and delay. Apart from that, there are also 3 types of activities that occur in the production process, namely Value Added (VA), Necessary Non Value Added (NNVA) and the last one is Non Value Added (NVA).

Table 5 Clasification VA, NVA, NNVA

Category	Percentage
Value Added	85.76%
Non Value Added	3.73%
Necessary Non Value Added	10.51%

The values in Table 5 for the classification of Value Added (VA), Non-Value Added (NVA), and Necessary Non-Value Added (NNVA) were likely derived from a detailed analysis of the entire process workflow. This analysis involved categorizing each activity within the process as either VA, NVA, or NNVA based on whether they directly contribute to the product's value, do not add value at all, or are necessary but do not add direct value (e.g., inspections, transportation). For example, if 85.76% of the time was spent on activities that directly added value, it was classified under VA, such as blasting, marking, cutting, grinding, sub assembly, and assembly activities. Then there are 3.73% of time spent on activities that do not add value, then these activities are classified as NVA, such as control, sorting, buffer, and transportation transfer activities

The recommendations provided are based on a thorough analysis of the wastes identified in the VALSAT (Value Stream Analysis Tools) study. For each type of waste, the root causes were traced back to inefficiencies such as unsynchronized production schedules, inadequate maintenance, inefficient factory layouts, lack of standardized procedures, and insufficient quality control. By addressing these root causes, the recommendations aim to implement targeted solutions like Kanban for overproduction, TPM for reducing downtime, and Six Sigma for quality improvement. These strategies are designed to streamline processes, eliminate non-value-added activities, and enhance overall operational efficiency, leading to a more effective and waste-free production system. Based on the VALSAT analysis, the following PAM is developed to address the identified wastes:

1. Overproduction: Implementing a Kanban system to regulate production schedules and align them with actual demand.
2. Waiting: Introducing Total Productive Maintenance (TPM) to ensure regular maintenance and minimize downtime.
3. Transportation: Redesigning the factory layout to streamline the movement of materials and reduce transportation waste.
4. Overprocessing: Standardizing operating procedures to eliminate redundant steps in the production process.
5. Inventory: Adopting Just-In-Time (JIT) principles to maintain inventory levels that match production requirements.
6. Motion: Applying the 5S methodology to organize and maintain an orderly workplace.

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7. Defects: Implementing Six Sigma to enhance quality control and reduce the incidence of defective products.

Root Causes of Waste and Recommendations

Overproduction and its impact on efficiency

The study identified overproduction as the most significant waste in PT XYZ's ship production process, a critical issue that has been observed in various real-world scenarios within the company. For instance, over the past year, PT XYZ consistently produced 15-20% more ships than were actually ordered by customers. This surplus led to a significant accumulation of unsold inventory, requiring the company to lease additional warehouse space to store the excess ships. The cost of maintaining this excess inventory—through storage, insurance, and periodic maintenance—has been substantial, directly impacting the company’s bottom line. Additionally, these unsold ships have tied up valuable capital, reducing the company’s liquidity and limiting its ability to invest in other growth opportunities. By closely examining these real conditions, it is evident that aligning production schedules more accurately with actual demand could alleviate these issues, leading to a more efficient and financially sustainable operation for PT XYZ.

Overproduction, a significant type of waste in manufacturing, occurs when goods are produced in excess of demand or before they are needed in the production process. This phenomenon not only ties up valuable resources such as labor, materials, and equipment but also disrupts the flow of operations. According to Lean manufacturing principles, overproduction is considered one of the most serious forms of waste as it can lead to increased lead times, higher storage costs, and unnecessary strain on production capacities (Jodlbauer et al., 2023). It creates inefficiencies by pushing products into the inventory before they can be sold, potentially resulting in excess inventory and tying up capital that could be used more effectively elsewhere (Abdel-Aty et al., 2024).

Overproduction also affects the quality of production planning and scheduling. When goods are produced in excess, it becomes challenging to accurately forecast demand and adjust production schedules accordingly (Bilal et al., 2024). This can lead to increased lead times for customers and a decrease in overall responsiveness to market changes, diminishing the competitiveness of the manufacturing operation. Moreover, excessive production can mask underlying problems in the production process, such as inefficiencies in workflow or quality issues that need to be addressed.

From an environmental perspective, overproduction contributes to increased energy consumption and carbon emissions. The unnecessary production of goods consumes resources that could otherwise be allocated to more sustainable practices or products (Vargas-Merino et al., 2023). This environmental impact underscores the importance of lean and green manufacturing practices, which advocate for reducing waste and optimizing resource use throughout the production process.

Inventory waste and Just-in-Time (JIT) implementation

Implementing a Just-in-Time (JIT) inventory system can help PT XYZ minimize inventory levels, reduce storage costs, and improve cash flow. JIT systems ensure that materials and components arrive only as they are needed in the production process, which aligns well with lean manufacturing principles and reduces waste.

Inventory waste, often associated with excessive stockpiling of materials or finished goods beyond immediate demand, is a significant concern in manufacturing industries. Just-in-Time (JIT) is a methodology that addresses this issue by emphasizing the delivery of goods or materials just as they are needed in the production process, thereby minimizing inventory waste.

JIT implementation aims to streamline operations by synchronizing production with customer demand, reducing the need for large inventories that tie up capital and storage space. This approach not only lowers inventory carrying costs but also enhances responsiveness to market fluctuations and customer requirements (Tao et al., 2024). By maintaining lean inventories, manufacturers can improve cash flow and allocate resources more effectively toward value-adding activities rather than stockpiling.

Furthermore, JIT facilitates better quality control and defect detection. With reduced inventory levels, defects and quality issues are identified more promptly as production processes become more visible and manageable. This leads to continuous improvement initiatives aimed at enhancing product quality and reducing waste throughout the manufacturing cycle (Ortiz et al., 2024).

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From a logistical standpoint, JIT implementation requires robust supplier relationships and efficient transportation networks to ensure timely delivery of materials and components. This approach fosters collaboration and trust between manufacturers and suppliers, enabling them to work together to meet fluctuating customer demands while maintaining lean inventories.

Enhancing quality control to reduce defects

Defect waste, which contributes to 15.61% of total waste, highlights inefficiencies in PT XYZ's quality control processes. This defect waste often includes issues such as substandard materials, errors in workmanship, and inconsistencies in production, leading to increased rework and scrap. Identifying these defects is crucial for understanding the root causes and implementing effective solutions.

To address defect waste, PT XYZ must enhance its quality control measures. This can be achieved through comprehensive employee training, more rigorous inspections, and the adoption of advanced quality management systems. By improving these processes, the company can significantly reduce defect occurrence, minimize waste, and enhance product quality. Effective quality control not only improves product reliability but also meets customer expectations, thereby maintaining a competitive edge in the shipbuilding industry.

Implementing robust quality control measures involves several key strategies. First, companies can invest in advanced inspection technologies and tools to detect defects early in the manufacturing process. Automated inspection systems, such as computer vision and machine learning algorithms, enable real-time monitoring and analysis of product quality, identifying deviations from specifications promptly (Psarommatis & May, 2023).

Second, fostering a culture of quality throughout the organization is essential. This entails training employees on quality standards, encouraging adherence to standardized procedures, and promoting a proactive approach to problem-solving. Engaged and skilled workforce contributes significantly to detecting and preventing defects before they escalate, thus reducing rework and material waste.

Third, implementing statistical process control (SPC) methodologies can significantly improve quality assurance efforts. SPC involves monitoring production processes using statistical techniques to ensure consistency and detect variations that could lead to defects. By analyzing process data in real-time, manufacturers can proactively address potential quality issues and make timely adjustments to maintain product integrity.

Moreover, fostering strong supplier relationships is crucial in enhancing quality control. Collaborating closely with suppliers to establish stringent quality standards and conduct regular audits ensures that raw materials and components meet required specifications. Effective supplier management helps mitigate risks associated with defective inputs, thereby preventing downstream quality issues in the manufacturing process.

In conclusion, enhancing quality control through advanced technologies, employee empowerment, statistical process control, and supplier collaboration is essential for reducing defects in manufacturing. By continuously improving quality assurance processes and fostering a culture of quality across the organization, manufacturers can minimize waste, enhance product reliability, and ultimately, deliver superior products that meet or exceed customer expectations.

Streamlining motion and transportation

Motion and transportation wastes, contributing 13.43% and 11.70% respectively, indicate inefficiencies in the movement of materials and workers within the production facility. Implementing lean tools such as Value Stream Mapping (VSM) and 5S can help identify and eliminate unnecessary Movements (Costa et al., 2024). Optimizing the layout of the production floor to reduce travel distances and improve workflow can lead to substantial efficiency gains and cost savings.

Streamlining motion and transportation in manufacturing processes is crucial for optimizing efficiency, reducing waste, and improving overall operational performance. Motion waste refers to unnecessary movements of personnel or equipment within the production environment, while transportation waste pertains to inefficient handling and movement of materials throughout the supply chain. Addressing these aspects effectively can lead to significant cost savings and enhanced productivity.

To streamline motion, companies can adopt various strategies. One approach is to redesign workstations and layouts to minimize unnecessary movements and optimize workflow (Liker, 2004). Implementing ergonomic principles ensures that workstations are organized to reduce operator fatigue

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and improve efficiency. Additionally, providing adequate training to workers on efficient work methods and standard operating procedures (SOPs) can further reduce unnecessary motion and enhance productivity.

Similarly, optimizing transportation processes involves implementing just-in-time (JIT) principles and lean logistics strategies (Ohno, 1988). JIT aims to reduce inventory levels and transportation waste by synchronizing production with demand, thereby minimizing the need for excessive material handling and storage. Utilizing efficient material handling equipment and establishing clear transportation routes further streamline operations and reduce lead times.

Moreover, integrating digital technologies such as RFID (Radio Frequency Identification) and GPS tracking systems can provide real-time visibility into material movements and streamline transportation logistics. These technologies enable accurate tracking of inventory, optimize delivery schedules, and mitigate risks associated with delays and disruptions in the supply chain.

Addressing waiting times to improve flow

Waiting waste, which accounted for 10.70% of the total waste, is often a result of production bottlenecks and unbalanced workflows. By identifying and addressing these bottlenecks, PT XYZ can reduce waiting times, improve production flow, and increase overall throughput. Techniques such as takt time analysis and production levelling can be employed to ensure a smoother and more consistent production rate, thereby reducing idle time.

Addressing waiting times in manufacturing processes is crucial for improving flow efficiency and reducing waste. Waiting waste occurs when production activities are delayed due to idle time caused by factors such as waiting for materials, equipment, information, or personnel availability. Effectively managing and minimizing waiting times can lead to enhanced productivity, smoother operations, and overall cost savings.

One effective strategy to tackle waiting times is implementing lean manufacturing principles, specifically focusing on eliminating non-value-added activities. This involves conducting value stream mapping (VSM) to identify bottlenecks and inefficiencies in the production flow where waiting times occur. By mapping out the current state of operations, companies can pinpoint areas where waiting waste is prevalent and develop targeted solutions to mitigate these delays.

Moreover, adopting just-in-time (JIT) manufacturing practices can significantly reduce waiting times by synchronizing production processes with customer demand. JIT principles aim to minimize inventory levels and ensure materials arrive precisely when needed, thereby reducing the likelihood of waiting for stock replenishments or Deliveries.

Furthermore, improving communication and coordination among departments and suppliers is essential to minimize waiting times. Establishing clear communication channels and real-time information sharing systems can help streamline workflows and reduce delays caused by miscommunication or unclear instructions.

Additionally, investing in technology solutions such as advanced scheduling software and automated production systems can optimize production planning and scheduling, thereby reducing idle times and waiting periods. These technologies enable better resource allocation, efficient task sequencing, and proactive management of production schedules to ensure continuous workflow.

Reducing over processing to enhance efficiency

Over processing, although the least significant waste at 4.31%, still represents an opportunity for improvement. This waste occurs when more work is done than necessary, often due to outdated or inefficient processes. By continuously reviewing and optimizing production processes, PT XYZ can eliminate unnecessary steps, reduce cycle times, and improve efficiency. This not only cuts costs but also enhances the value delivered to customers.

Reducing overprocessing is crucial for enhancing efficiency in manufacturing processes. Overprocessing waste occurs when more work is performed on a product than is necessary to meet customer requirements, leading to unnecessary costs and time expenditures (Womack and Jones, 2003). Addressing overprocessing involves identifying areas where additional processing steps or resources are applied beyond what is needed, thereby streamlining operations and improving overall productivity.

One effective strategy to reduce overprocessing is to implement value stream mapping (VSM) to analyze the current state of production processes. VSM helps identify non-value-added activities and opportunities to eliminate excessive processing steps that do not contribute to product quality or customer satisfaction. By visualizing the flow of materials and information, companies can pinpoint areas of overprocessing and devise targeted improvement plans.

Moreover, adopting lean manufacturing principles, such as Kaizen (continuous improvement), can foster a culture of eliminating waste and optimizing processes. Encouraging employees at all levels to participate in identifying and eliminating overprocessing can lead to innovative solutions and more efficient workflows (Tao et al., 2024).

Furthermore, conducting thorough quality control and quality assurance checks throughout the production process is essential to ensure that products meet specifications without unnecessary additional work. Implementing robust inspection processes and quality management systems helps detect defects early, preventing rework and overprocessing that can arise from correcting errors downstream.

Additionally, investing in employee training and skill development can enhance efficiency by ensuring that workers understand optimal process standards and avoid unnecessary tasks (Schonberger, 2008). Training programs focused on lean principles and quality improvement empower employees to identify overprocessing and implement solutions to streamline operations.

In conclusion, reducing overprocessing requires a holistic approach that integrates lean methodologies, quality management practices, and employee engagement. By eliminating unnecessary work and focusing on value-added activities, companies can achieve significant efficiency gains, reduce costs, and improve overall product quality and customer satisfaction.

Integrating Lean and Green Manufacturing for Sustainable Production

The integration of Lean and Green Manufacturing principles at PT XYZ has shown promising results in reducing waste and improving sustainability. Lean strategies focus on identifying and eliminating non-value-added activities to streamline operations and enhance efficiency. Green manufacturing, on the other hand, is centred on minimizing environmental impact by reducing resource consumption, waste generation, and emissions throughout the product lifecycle. Together, these approaches ensure that PT XYZ not only operates more efficiently but also adheres to environmental regulations and meets corporate sustainability goals. This dual focus on efficiency and sustainability significantly enhances the company's reputation and competitiveness in the market.

Integrating lean and green manufacturing principles is crucial for advancing sustainable production practices in industrial settings. Lean manufacturing is centred on the elimination of waste and optimization of processes. It aims to streamline operations to enhance efficiency, reduce costs, and improve overall productivity. By systematically identifying and removing non-value-adding activities, lean manufacturing leads to more efficient resource use and improved process flow.

Conversely, green manufacturing emphasizes minimizing environmental impact. It seeks to reduce resource consumption, waste generation, and emissions throughout the entire product lifecycle. Implementing practices such as using energy-efficient technologies, recycling materials, and reducing hazardous emissions helps lessen the environmental footprint and contributes to long-term sustainability. This focus on environmental stewardship aligns with contemporary regulatory standards and corporate responsibility goals.

Combining lean and green principles creates a powerful synergy. Lean manufacturing’s focus on waste reduction complements green manufacturing’s environmental objectives. For instance, optimizing processes to reduce defects not only lowers waste but also decreases resource use, aligning with both lean and green goals. Adopting integrated practices enables PT XYZ to enhance operational efficiency while supporting environmental sustainability, leading to a more competitive and responsible manufacturing operation.

Furthermore, integrating these approaches fosters innovation in sustainable product design and manufacturing processes. Lean principles such as value stream mapping (VSM) and Kaizen (continuous improvement) help identify and eliminate non-value-added activities and excessive resource use. This results in streamlined operations and reduced energy consumption, contributing to lower greenhouse gas emissions. Simultaneously, green strategies like implementing renewable energy sources and optimizing material usage enhance resource efficiency. This holistic approach not

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only improves operational efficiency and cost-effectiveness but also supports corporate social responsibility goals and enhances brand reputation in increasingly environmentally conscious markets.

Future State Mapping

The future state map illustrates the optimized production process after implementing the suggested improvements. The anticipated outcomes include reduced waste, improved efficiency, and enhanced product quality. The map shows a more streamlined flow of materials and information, shorter lead times, and better alignment between production and demand.

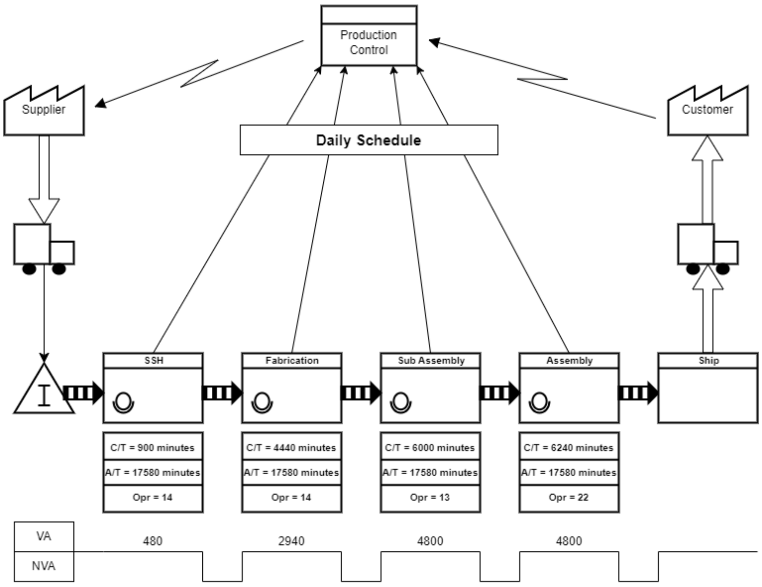

Fig. 2 Future state mapping.

To improve the current state map and move towards a future state mapping, each stage of the process must be analyzed for potential enhancements. Starting with **Fabrication**, the cycle time (C/T) is 900 minutes, while the available time (A/T) is 17,580 minutes with 14 operators. To improve the value-added (VA) time, we can reduce setup times, streamline workflows, or implement lean manufacturing techniques such as single-minute exchange of dies (SMED). By doing so, the fabrication process will have less downtime, increased productivity, and better utilization of resources, thus increasing the overall value added.

For other stages like **Sub Assembly** and **Assembly**, similar improvements can be made by focusing on reducing waste, such as unnecessary movements or waiting times. For example, optimizing the layout and sequence of operations can help reduce the cycle time (C/T) from 6480 minutes and 7200 minutes, respectively, and better align with the available time (A/T). By analyzing and addressing these inefficiencies, we can significantly improve the value-added activities in each process, leading to a more streamlined and cost-effective production flow that meets customer demands more efficiently.

4. Conclusion

The integration of Lean and Green Manufacturing principles at PT XYZ has proven to be highly effective in addressing the challenges associated with waste in ship production. By employing lean methodologies such as VALSAT, value stream mapping, and continuous improvement practices, the company has been able to identify and eliminate significant sources of waste, including defect waste, waiting times, and excessive inventory. These targeted improvements have streamlined production processes, reduced waste, and enhanced overall operational efficiency. Furthermore, the alignment of lean principles with green manufacturing practices has not only optimized resource use but also

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minimized environmental impact, demonstrating a commitment to both economic and ecological sustainability.

The application of these integrated approaches has achieved the research objective of enhancing production efficiency and product quality. By addressing the root causes of waste through systematic analysis and the implementation of advanced tools, PT XYZ has realized substantial gains in both operational performance and product reliability. This dual focus on lean and green principles has enabled the company to operate more efficiently while adhering to environmental regulations and corporate sustainability goals. Ultimately, this strategic integration has positioned PT XYZ as a more competitive and responsible player in the shipbuilding industry, offering a valuable example of how combining lean and green methodologies can lead to significant improvements in manufacturing practices.

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