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Research Article

Enhancing Production Process Performance in Traditional Shipyards: An Integrated Approach for Waste Identification and Performance Optimization

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Abstract

This research introduces an innovative approach to enhance efficiency and effectiveness in traditional shipyard production. It aims to identify and categorize various production waste types and propose performance optimization strategies. The approach integrates the PDCA-CR method with the Waste Assessment Model (WAM), Value Stream Mapping (VSM), and Value Stream Analysis Tool (VALSAT) to effectively categorize waste in ship production processes. Subsequently, waste analysis and performance optimization techniques, such as lean principles and process reengineering, are applied to improve identified processes, enhancing overall performance, productivity, and profitability. The study provides valuable insights into traditional shipbuilding production processes by identifying various waste types, including transportation, excess inventory, unnecessary movement, waiting times, overprocessing, overproduction, and product defects. This analysis enables shipyards to pinpoint areas for improvement and implement optimization methods to boost performance and profitability. While primarily focused on the shipyard industry, the approach's applicability to other sectors should be explored, along with potential implementation challenges. Practically, it offers shipyards a tool to reduce inefficiencies and improve performance, ensuring competitiveness in the maritime industry. Socially, enhanced production processes can lead to job creation, economic growth, and industry development while promoting environmentally sustainable practices. In summary, this research presents a tailored integrated approach combining waste identification and performance optimization strategies for traditional shipyards, offering a comprehensive framework to enhance production process performance.

Keywords: Waste identification; PDCA-CR; Performance optimization; Traditional shipyard industry (TSI).

1. Introduction

Shipyards play a crucial role in driving the development of the shipping industry and can serve as key catalysts for growth in the shipping and trade sector (Badrus et al., 2019; Soh et al., 2019). The shipyard industry in Indonesia, particularly traditional shipyards, exhibits limited production capacity due to its capital-intensive and labor-intensive nature, requiring substantial investments (Bodul & Jakovac, 2020; Sukisno & Singgih, 2019). Furthermore, the traditional shipyard industry (TSI) operates on a made-to-order basis, producing ship units according to specific customer requirements (Tan et al., 2020). As a result, the fisheries and marine sector's contribution to Indonesia's Gross Domestic Product (GDP) remains relatively low, amounting to only 3.7% (BPS RI, 2021).

TSI exhibits distinct characteristics, where ship owners dictate ship designs, wood is the predominant material used, traditional shipbuilding methods are commonly employed, work practices rely heavily on the expertise of the workers, simple tools are utilized, specialized companies to handle specific tasks are scarce, the produced ships tend to be small in size ranging from 0-30 Gross Ton (GT), and the application of technology remains minimal, with human power playing a dominant role in most work activities (Rizwan et al., 2021). Consequently, waste frequently arises in the ship production process within TSI, diminishing productivity and resulting in a decline in company revenue (Sulaiman et al., 2017; Xue et al., 2020). To enhance production performance, it is crucial to avoid wasteful activities in the production process, as highlighted by previous studies (Habidin et al., 2018; Maalouf & Zaduminska, 2019; Muñoz-Villamizar et al., 2019). Unfortunately, these wasteful activities often receive insufficient attention, reducing company efficiency (Abreu et al., 2017; Dhiravidamani et al., 2018; Gupta et al., 2018; Shah & Patel, 2018). In TSI, the production process exhibits high levels of waste, including excess inventory, extended processing times, unnecessary transportation and movement activities, improper processing practices, and increased product defects (Fitriadi & Ayob, 2022). Excessive production waste produces surplus raw materials or products, resulting in unnecessary stockpiling. Inefficient processing times (PT) stem from the absence of standard operating practices (SOPs) and unclear quality acceptance standards/specifications. Defective products require additional resources and materials for rework or

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*Corresponding author Email address: ahmad.faisal@umt.edu.my replacement. Transportation waste pertains to the flow of materials and semi-finished products between processes, while movement waste refers to non-value-added (NVA) labor activities within workstations. Furthermore, waiting for waste arises when subsequent workstations must wait for the completion of production activities at previous workstations (Praharsi et al., 2019).

Hence, waste is anticipated to significantly impact the decline in production performance at TSI, necessitating a deeper understanding of its root causes. Conversely, reducing waste can enhance the effectiveness and efficiency of shipbuilding production, both of which are key facets of lean principles that contribute to sustainable production performance improvements (Bhattacharya et al., 2019; Martínez León & Calvo-Amodio, 2017). Therefore, concerted efforts and continuous improvement are imperative. A production process's value added (VA) heavily relies on the efficiency with which an organization implements its corporate strategy and manages production (Horváth & Szabó, 2019; Veres et al., 2018). Enhancing effectiveness and efficiency necessitates addressing the sources of waste within shipyard production. To achieve this, a suitable method is required to accurately identify waste sources, as current research on waste identification remains limited and relies on separate, non-integrated methods. Employing separate waste identification methods often yields incomplete results due to their distinct characteristics and applications. This study focuses on integrating multiple methods to identify waste from seven sources within the production process of traditional ships at TSI. The integration of these methods is expected to produce more comprehensive results, enabling waste reduction and continuous improvement endeavors.

This research aims to investigate opportunities to increase production efficiency in TSI. The methods used include Plan-Do-Check-Act-Check Recursive (PDCA-CR), Waste Assessment Model (WAM), Value Stream Mapping (VSM), and Value Stream Analysis Tool (VALSAT) to categorize production waste. Additionally, optimization techniques such as lean principles and process engineering will be researched to improve performance, productivity, and overall profitability. This study aims to build a comprehensive framework to guide TSI in identifying and implementing critical process improvements. Finally, this research will explore the potential adaptation of these methods in various industrial sectors, considering the potential challenges of their implementation.

The paper is structured as follows: Section 2 offers a comprehensive literature review of our work. In Section 3, the research methodology is detailed. Section 4 presents the results and discussion, along with proposed interventions. Finally, Section 5 concludes the paper and highlights potential avenues for future research.

2. Literature Review

2.1. Waste identification practices

Numerous prior studies have focused on waste identification. For instance, Chiarini (2011) emphasizes the importance of streamlining production flow and simplification to minimize all forms of waste in the production process when implementing lean principles. Rauch et al. (2017) highlight the significance of waste reduction in boosting production value through the implementation of lean manufacturing (LM) techniques pioneered by Taiichi Ohno. The distinctiveness of the Lean approach has led to its structured implementation in production processes over the past few decades, notably in the automotive industry and other sectors, including small-scale industries (Bajjou et al., 2017; Garre et al., 2017; Kadarova & Demecko, 2016; Kurilova-Palisaitiene et al., 2018; Narayanamurthy et al., 2018). Furthermore, companies across diverse fields worldwide have embraced integrated lean applications as a new management system strategy to enhance process efficiency (S. Gupta & Jain, 2013).

The initial step in implementing LM to enhance company performance is identifying waste. This aligns with the findings of Anvari et al. (2011) who state that the application of LM commences with identifying and understanding the types and causes of waste in the production process. The subsequent step involves devising solutions based on the identified waste. Finally, the solutions are implemented to assess their suitability for improving production performance. Chaudhari & Raut (2017) highlight that lean implementation can enhance both the quantity and quality of production by eliminating NVA activities that contribute to increased costs, waiting time (WT), and inventory. This implementation approach focuses on quality improvement, preventive maintenance, facility repairs, pull production systems, and the utilization of a flexible workforce. Additionally, according to Widodo et al. (2020) waste elimination in the production process aligns with process improvements and enhancements, enabling more effective and efficient resource utilization.

The identification and reduction of waste in production processes have gained widespread adoption in the manufacturing industry. This concept originated from the successful implementation of the Toyota Production System (TPS) in the automotive industry. The TPS has demonstrated the ability to decrease production costs, thereby increasing company profits and ultimately enhancing production process performance (E Cress & Fiala, 2022; Jylhä, 2021; Kumar et al., 2020; Mccracken, 2022). In this paper, various waste identification methods will be employed to identify and categorize waste in ship production at TSI. Subsequently, solutions will be provided aimed at improving performance.

2.2. Waste identification methods

The process of reducing or eliminating waste in a production system begins by identifying the specific waste present. Previous researchers have made substantial progress in identifying waste using various methods. In this study, the specific focus is on three methods: the WAM, VSM, and VALSAT. These methods are chosen due to their compatibility and ability to be integrated seamlessly, while also being highly relevant to the research objectives.

2.2.1. WAM method

The WAM method has garnered significant attention in waste identification, as highlighted in the study by Rawabdeh (2005) which emphasizes its capacity to address and eliminate waste. Several subsequent papers by Henny & Budiman (2018), Paramawardhani & Amar (2020), Pomalia et al. (2020), and Satria (2018) corroborate the effectiveness and simplicity of the WAM method in connecting the seven types of waste, enabling accurate waste identification and subsequent elimination. In line with these findings, Hidayati & Nurhidayat (2021) emphasize that the WAM method serves as a simplified model aimed at identifying the root causes of waste and identifying the most critical waste components.

The application of the WAM method to identify waste involves a combination of mentoring methods that utilize relevant matrices and questionnaires to conduct systematic assessments and evaluations. This approach aligns with subsequent studies conducted by Fitriadi & Ayob (2022), Naziihah et al. (2022), and Prambudi & Giyanti (2021) which emphasize that WAM combines the Waste Relationship Matrix (WRM) and the Waste Assessment Questionnaire (WAQ). The WRM analyzes the interrelationships among the seven types of waste present in the production line, while the WAQ serves to identify and allocate the waste occurring in the production line.

According to Tannady et al. (2019), the WRM measures the impact of waste on other waste, employing a matrix format that yields Waste Matrix Values (WMV) expressed as percentage scores. Simultaneously, the WAQ functions as a tool for identifying waste and quantifying its occurrence in the production line. The WAQ consists of 68 distinct questions. Rahayu Putri et al. (2017) outline the three-step process for identifying waste using the WAM method: initial identification through the Seven Waste Relationship (SWR), followed by the application of the WRM, and culminating in the use of the WAQ. Dekrita Jauza et al. (2021), and Erlina Puspitaloka Mahadewi et al. (2021) affirm that WAM is a model developed to facilitate the identification of waste problems and the identification of waste reduction strategies. The WAM method employs metrics and questionnaires, including the SWR, WRM, and WAQ, to assess waste effectively.

Previous studies utilizing the WAM method have successfully provided solutions to enhance production and company performance. Notably Yadrifil et al. (2020) and other studies such as Febianti et al. (2020), Inderawibowo et al. (2020), Jufrijal & Fitriadi (2022), and Kasanah & Suryadhini (2021) have applied the WAM method to identify and eliminate the seven types of waste in production lines, resulting in recommendations for improving company performance, meeting demand, and enhancing customer satisfaction. Setiawan et al. (2021) integrated the WAM method with Lean Automation techniques, successfully reducing waste in the assembly production line and improving company performance. Furthermore, Kusrini & Parmasari (2020) combined the WAM method with VSM, Single Minute Exchange of Dies (SMED), and 5S (Seiri, Seiton, Seiso, Seiketsu, Shitsuke) to increase efficiency, ultimately boosting productivity and performance at the Container Terminal Unit.

These studies demonstrate the effectiveness of the WAM method in providing valuable insights and practical solutions to optimize production processes, enhance company performance, and achieve various performance goals.

2.2.2. VSM method

The VSM method has gained widespread popularity since its introduction by Rother & Shook (2003) in their book "Learning to See." This method has proven effective in addressing challenges in LM implementation in recent years. Its practicality and ease of application have led to numerous benefits across various fields, enabling companies to enhance productivity and performance. Notably, a study by Klotz et al. (2008) exemplifies how VSM can identify waste and improve the company's ability to forecast future performance by targeting areas such as WT and inventory waste reduction.

Further research by Andrade et al. (2016), and Singh & Singh (2012) confirms VSM as a valuable LM technique capable of waste identification and reduction, ultimately enhancing organizational performance and productivity. Additionally, De Steur et al. (2016), Lacerda et al. (2016), and Tyagi et al. (2015) highlight VSM as a powerful tool for systematically identifying waste and NVA activities throughout the production process, facilitating the visualization of material and information flows across the supply chain. According to Meudt et al. (2017), VSM applies to all production system activities and can be effectively employed across various industries, from upstream to downstream processes. The widespread adoption and successful implementation of the VSM method validate its significance in waste identification and performance improvement within organizations.

The application of the VSM method yields various benefits, including the reduction of WT, cycle time (CT), and PT in manufacturing production processes. Seth et al. (2017), Shou et al. (2017), and Fitriadi et al. (2020)

implemented VSM successfully to identify and minimize waste in the Palm Oil Sorting Process, resulting in increased VA activities and process efficiency. In the iron and steel industry, Schoeman et al. (2020) emphasized the practicality of VSM in waste management, including waste identification, analysis, and visualization. This method contributes to the implementation of lean production systems (LPS) within the industry. Similarly, Salwin et al. (2021) achieved positive outcomes by applying the VSM tool in the steel pipe manufacturing industry, reducing waste and improving availability, productivity, and production quality.

VSM's effectiveness extends beyond manufacturing. Ramani & KSD (2021) showcased successful VSM implementation in the construction sector, where waste identification and elimination led to reduced project duration and increased productivity. Furthermore, Reda & Dvivedi (2022) highlighted VSM's ability to identify and eliminate waste in low-level technology organizations, offering opportunities for improvement.

The widespread adoption of VSM across different industries underscores its effectiveness in waste reduction and process optimization, enabling organizations to enhance efficiency and achieve positive outcomes.

The integration of VSM with other methods or software applications, such as simulation, enhances the accuracy and effectiveness of waste identification. Stadnicka & Litwin (2019) combined VSM with system dynamics analysis (SDA) to identify and eliminate waste, providing insights into inventory, work in process (WIP), and production volume. Liu & Yang (2020b) integrated VSM with fuzzy set theory to address variability and uncertainty in LPS, enabling a comprehensive analysis of time intervals, inventories, and operating variables in value streams. Another study by Liu & Yang (2020a) enhanced the VSM procedure by combining it with simulation and multiple attribute decision-making (MADM), enabling the handling of additional factors and the provision of multiple priority improvement solutions. Jamil et al. (2020) effectively implemented VSM in conjunction with the defined measure analysis improvement and control (DMAIC) method, systematically aligning VSM with sustainable manufacturing practices. Mishra et al. (2020) successfully applied simulation-based VSM in the hood manufacturing industry, leading to reduced CTs, raw material inventory, and environmental emissions.

Salvador et al. (2021) combined VSM with the Life Cycle Assessment (LCA) method, facilitating continuous improvement efforts by reducing WTs, CTs, and environmental impacts and promoting environment-based production practices. Sultan et al. (2021) implemented VSM to optimize supply chain operations through supply chain integration designs, resulting in reduced lead time (LT), energy consumption, and emissions, ultimately achieving cleaner production and continuous improvement.

Furthermore, Ferreira et al. (2022) utilized hybrid simulation in conjunction with VSM to develop roadmaps and aid companies in understanding production system changes. Rathore et al. (2022) integrated VSM with ergonomic aspects, addressing social, economic, and environmental factors, leading to waste reduction in WT, CT, scrap, and defects, as well as mitigating work-related risks and enhancing operational efficiency.

The integration of VSM with various methodologies and tools demonstrates its versatility in different contexts, enabling organizations to identify waste, optimize processes, and drive continuous improvement.

Several studies focusing on shipyard or ship production have explored the application of the VSM method. Storch & Williamson (2003) emphasized the potential of VSM to enhance the ship design process by providing a detailed analysis of process steps aligned with company goals and strategies. Kolic et al. (2012) applied VSM to the steel pre-assembly process in shipyards and discovered that it led to the formulation of an improved value flow map, resulting in significant reductions in work hours and time duration. In another study, Kolich et al. (2014) combined VSM with grouping techniques for panel assembly, leading to time savings and the elimination of redundant work processes, ultimately increasing the value and availability of resources. Sharma & Gandhi (2017) recommended the adoption of lean principles and practices in the shipbuilding industry, highlighting VSM as a valuable tool that can drive fundamental changes in the work culture. By implementing VSM, it is expected that manufacturing time will decrease gradually, leading to increased shipyard productivity.

These studies demonstrate the applicability and effectiveness of VSM in shipyard and ship production contexts, offering insights and recommendations for improving processes, reducing waste, and enhancing overall productivity.

In their research, Estiasih et al. (2017) employed VSM to comprehensively map individual products, product groups, and production lines throughout the ship production process at the Madura UKM Shipyard. Their study showcased the effectiveness of VSM in identifying waste and providing a visual representation of production process activities, facilitating a detailed understanding of VA and NVA activities. This significant outcome greatly enhanced the overall effectiveness of the production process at the Surabaya Shipyard. Similarly, Tebiary et al. (2017) emphasized the capabilities of VSM in waste identification and visualizing the flow of production processes. Their study demonstrated how this method enabled a meticulous assessment of VA and NVA activities, leading to improved efficiency in the production process at the Surabaya Shipyard. In another study, Fatouh et al. (2020) employed the VSM waste identification tool, which revealed time deviations in planned tasks within a shipbuilding project. By developing a future state map (FSM), VSM assisted in eliminating time wastage from the value flow process in engineer-to-order (ETO) production networks in the Norwegian shipbuilding industry.

Furthermore, Kunkera et al. (2022) elaborated on the positive impacts of VSM. Their study highlighted the effectiveness of VSM in reducing losses by minimizing WTs in internal and external communications within the ship sales process. This optimization led to cost savings, increased employee productivity, and overall efficiency improvements in production activities at shipyards. Notably, the application of VSM contributed to significant growth in sales and operating revenues at the shipyard. Lastly, Fitriadi et al. (2023) integrated VSM with sustainability indicators encompassing environmental, economic, and social aspects. This innovative approach of incorporating sustainability into VSM has generated valuable recommendations for implementing sustainable strategic improvements within the ship production process at TSI.

These studies collectively underscore the effectiveness of VSM in waste identification, process visualization, and productivity improvement within shipbuilding contexts, offering valuable insights and practical applications for optimizing ship production processes.

2.2.3. VALSAT method

The VALSAT method, developed by Hines & Rich (1997) has gained wide application across various fields of study for waste identification. According to the creators, this method facilitates a comprehensive understanding of the value stream and provides recommendations for improving waste within it. VALSAT encompasses seven mapping tools within a matrix framework, including process activity mapping (PAM), supply chain response matrix (SCRM), production variety funnel (PVF), quality filter mapping (QFM), demand amplification mapping (DAM), decision point analysis (DPA), and physical structure (PS). Waste identification is achieved through waste weighting, followed by the application of the seven mapping tools for selection. It should be noted that VALSAT is not typically used in isolation for waste identification in LM applications. Therefore, in numerous research studies, VALSAT has been combined with other tools such as VSM, WAM, root cause analysis (RCA), DMAIC, simulation, response surface methodology (RSM), and Analytical Hierarchy Analysis (AHP), as detailed in the subsequent paper.

Paramawardhani & Amar (2020) employed the VALSAT method in their research by integrating VSM and WAM. This combined approach facilitated the identification of waste as a continuation of the previous methods, with VALSAT used to map the flow of value in detail, focusing on VA processes. According to Yadrifil et al. (2020), the use of VALSAT for waste reduction on production lines differs from the identification process of VSM and WAM. Their paper provides recommendations for improvements that can reduce LT, increase CT, and enhance production capacity. In a similar vein, Suparno et al. (2021) utilized VALSAT as a continuation of VSM identification to identify waste. Their findings led to improvements in reducing wasted WT and LT.

Haekal (2022) applied VALSAT in conjunction with VSM, WAM, and RCA methods. The research identified waste in the production process and proposed improvements such as merging production processes and rearranging the production floor, resulting in reduced processing time. Kholil et al. (2022) incorporated VALSAT, VSM, and DMAIC to identify waste, specifically motion, inventory, waiting, and process waste. The identified areas for improvement led to a reduction in CT and increased production capacity efficiency. Rosarina et al. (2022) conducted a study on malt powder production, utilizing VALSAT in combination with VSM and PAM to identify VA and NVA activities. QFM and SCRM were employed for waste analysis. In another study, Suwasono et al. (2022) implemented the VALSAT method for LM. Their findings demonstrated a reduction in CT, LT, and changeover time (CoT). VALSAT was combined with VSM, PAM, and SCRM to enhance efficiency and production capacity in the coffee processing industry.

Meanwhile, in the field of shipyard and shipbuilding, several studies have utilized the VALSAT method. Hines et al. (1998) explained that VALSAT is a modified approach derived from the quality function methodology initially developed for product development in the Japanese shipping industry. In their paper, Estiasih et al. (2017) combined VALSAT with simulation methods, RSM, and AHP, enabling the design of optimal lean and green manufacturing systems for ship production processes. Muflihah (2017) employed VALSAT to determine the highest correlation among critical waste identified through VSM, thereby proposing alternative improvements. Riyadi (2017) used the VALSAT method to analyze waste in the ship production process. Furthermore, Kurniawan & Rochmoeljati (2022) conducted research that applied VALSAT to identify waste, followed by PAM to gain a more detailed understanding of VA and NVA activities. Additionally, they integrated the DMAIC method as a lean Six Sigma framework, highlighting the identification of defective product waste in their study.

2.3. Performance improvement

Numerous approaches and methods have emerged to enhance performance and accelerate product innovation and production processes in shipyards. Inozu et al. (2006) developed production process improvement methods by integrating Six Sigma, Lean, Theory of Constraints (TOC), and Design for Six Sigma (DFSS) models. Halawi et al. (2017) emphasized the significance of Change Management and Knowledge Management for the successful implementation and sustainability of production process improvements. Combining these two initiatives with software development and integration, as suggested by Yan & Zhang (2019), can further enhance their effectiveness.

Praharsi et al. (2022) presented a guideline for improving the performance of traditional shipyard supply chains in Indonesia. They measured internal and external performance using the Supply Chain Operations Reference (SCOR), which incorporates five attributes: reliability, flexibility, responsiveness, costs, and assets. This paper provides recommendations for continuously improving the performance of all system processes. In another study, Praharsi et al. (2021) evaluated project management performance in traditional shipyards using indicators such as the cost performance index (CPI), schedule performance index (SPI), and S-curve. da Silva et al. (2021) proposed the adoption of manufacturing cycle efficiency (MCE) indicators through the Multiple Criteria Data Envelopment Analysis (MCDEA) approaches to improve production process performance and meet LM requirements.

To enhance shipyard performance, companies can set higher production targets and improve production effectiveness. This can be achieved through the implementation of various quality control methods and ship production system improvements, such as LM Edwin Joseph et al. (2020), and Primo et al. (2021) the concept of Lean Six Sigma, and supply chain resilience (Praharsi et al., 2021). Furthermore, Kunkera et al. (2022) suggested that continuous performance improvement in the sales process in shipyards can be achieved by implementing lean management. This approach leads to cost reduction, increased employee productivity, and substantial growth in sales and revenue at the shipyard.

2.4. *Evaluating the paper's conclusive insights and contributions*

This work underscores several pivotal aspects. Firstly, the research is dedicated to enhancing production efficiency in traditional shipyards, a matter of significant importance within the maritime industry. The expected outcome of this heightened production efficiency includes cost reduction, increased productivity, and greater profitability. Secondly, the study combines methodologies such as PDCA-CR, WAM, VSM, and VALSAT to pinpoint production waste. Such combinations foster a comprehensive approach to waste management and reduction in shipbuilding production, providing a more discerning insight into areas requiring improvement. Thirdly, the research delves into optimization techniques, encompassing lean principles and process engineering, which hold the potential to enhance overall performance, productivity, and profitability. Fourthly, the study devises an all-encompassing framework to aid shipyards in recognizing and executing essential process enhancements, serving as a guiding compass for industries seeking to elevate their performance.

This research aims to expand further within the existing works of literature discussed in the earlier sections regarding waste identification and reduction in production processes. Numerous prior studies have underscored the significance of waste reduction in production processes and the application of LM principles. This research is centered on applying three principal methodologies: WAM, VSM, and VALSAT. Specifically, this research applies these methodologies to discern and categorize waste in ship production at TSI and presents solutions directed at improving production performance. The efficacy of each method in waste identification within manufacturing and shipbuilding contexts is emphasized. For instance, the WAM method utilizes matrices and questionnaires to assess waste systematically.

The widespread application of the VSM methodology across diverse industries has markedly reduced WTs, cycle durations, and processing intervals within the production process. VALSAT, which amalgamates mapping tools, is instrumental in identifying waste in value streams and potential waste sources. This research also corroborates the efficacy of these methodologies in the shipyard and ship production situation, yielding invaluable recommendations for enhancing the ship production process.

As elaborated in the later sections, this research aims to offer practical guidance to companies in the shipbuilding industry for identifying and reducing waste in the production process, ultimately striving to enhance efficiency and overall performance. This study is valuable to the literature on WI and improving production process performance.

3. Research Methodology

In this method section, the outline is of the robust framework established to conduct this research systematically. Employing meticulous approaches, tested methods, and reliable instruments, the aim was to accomplish well-defined research objectives and generate compelling findings. As each step is described, emphasis will be placed on the relevance, accuracy, and reliability of the chosen methods, demonstrating their selection based on sound judgment.

The integration of waste identification methods in traditional ship production was developed to improve ship production performance at TSI. This method will have an impact on increasing production efficiency and effectiveness, increasing production quality and quantity, reducing production costs, more effective resource utilization, and increasing income at TSI. In addition, developing methods through the integration of methods requires a new scientific theoretical and methodological framework based on their single approach, which coherently applies the two principles and simultaneously ensures improvements in traditional shipbuilding productivity and working conditions in TSI.

The integration of the waste identification method consists of several methods that work simultaneously and in parallel to identify waste in the traditional ship production process at TSI, where each method has a different way of working that influences decision-making in this study. Therefore, various theories can be used to develop a conceptual framework for the integration of waste identification methods.

This research utilizes primary data collected from five shipyards among the eleven TSI in the West Aceh District (Open Data Aceh Barat, 2020). Step one involves conducting direct observations and interviews with owners of traditional shipyards. Additionally, a thorough literature review was conducted with a focus on obtaining novel frameworks, structures, and processes for waste identification within the context of LM, combining various waste identification methods. The research workflow is visually depicted in Figure 1, showcasing the step-by-step approach followed in this study.

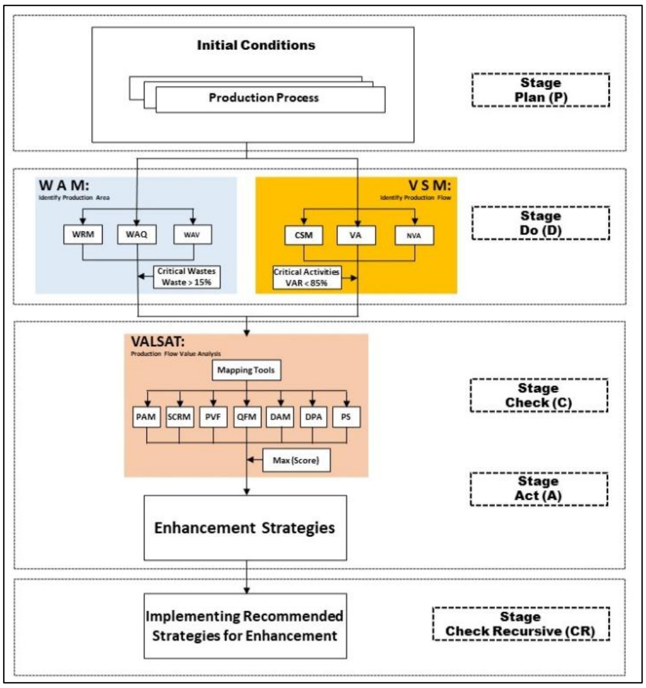

Fig. 1. Visualizing the research's conceptual framework

The research conceptual framework illustrated in Figure 1 can be implemented using a five-stage process that incorporates the Plan-Do-Check-Act (PDCA) concept and Checks Recursive. In this study, the PDCA-CR approach is adopted in the research steps to tackle the challenges faced in the traditional ship production process at TSI. The following sections will offer a detailed account of each step involved in this research undertaking.

3.1. Stage plan (P)

In order to enhance the efficiency and optimize the traditional ship production process at TSI, a comprehensive Stage P has been formulated, encompassing the following essential components: thorough identification and understanding of prevailing conditions, the establishment of research objectives and target outcomes, strategic planning for data collection methodologies (including the concurrent utilization of WAM and VSM), and precise definition of pertinent Key Performance Indicator (KPI) parameters to effectively gauge the overall effectiveness of the production process.

3.2. Stage do (D)

To actively address waste generation and optimize the production process, Stage D encompasses a series of key actions, including the simultaneous utilization of the WAM and VSM methods to comprehensively gather data on waste, analyzing the data obtained through the WAM method to identify significant waste instances with a Waste value exceeding 15%, and employing the VSM method to analyze data and identify critical activities with a Value-Added Ratio (VAR) below 85%.

3.3. Stage check (C)

Stage C plays a crucial role in evaluating the effectiveness of waste reduction efforts and identifying areas for further improvement within the production process. This stage involves a comprehensive analysis of the outcomes obtained from waste identification through the WAM and VSM methods, the utilization of these results to perform targeted production flow value analysis focusing on critical waste, the employment of waste identification outcomes to conduct production flow value analysis centered around critical activities, and the identification of root causes for waste and inefficiency through the application of the VALSAT method.

3.4. Stage act (A)

Stage A marks a pivotal phase in the continuous improvement process, where a comprehensive set of actions is undertaken to address waste and inefficiency within the traditional ship production processes at TSI. This phase encompasses the utilization of the VALSAT method to select the most relevant and effective analysis techniques based on their highest scores, resulting in the choice of seven tools. These seven selected analytical techniques are then employed to thoroughly analyze waste within the value stream, with the aim of identifying the root causes of waste and inefficiency. Furthermore, various options for repair and improvement are assessed, and their effectiveness is meticulously evaluated based on the analysis results. Based on these findings, recommendations for improvement strategies are provided, with a focus on prioritizing the selected solution. Finally, the implementation of the recommended improvement strategies commences, with a specific emphasis on enhancing the traditional ship production processes at TSI.

3.5. Stage check recursive (CR)

The Stage CR phase plays a crucial role in the continuous evaluation and refinement of the traditional ship production process at TSI, focusing on the modifications made to the predefined KPI parameters. This phase involves a thorough assessment of whether substantial improvements have been achieved by examining the changes in the values of the KPI parameters. If the evaluation reveals notable changes, it indicates the successful implementation of corrective actions. However, if the evaluation shows insignificant changes, it signifies the need to revisit or further enhance the corrective measures, ensuring an iterative and adaptive approach toward optimizing the production process.

By adopting the comprehensive PDCA-CR approach throughout this study, the ultimate objective is to significantly elevate the efficiency and effectiveness of the traditional ship production process at TSI. Through the rigorous identification and targeted resolution of prevailing waste and inefficiencies, this approach aims to drive continuous improvement, fostering a culture of optimization and excellence in ship production operations

4. Results and Discussions

Our comprehensive research uncovers a nuanced understanding of the intricate interplay between waste identification methods aimed at enhancing the performance of the production process at TSI. The outcomes of this study are anticipated to make a significant contribution toward expanding comprehension of waste identification mechanisms and fostering the development of strategies to optimize production performance. This research encompasses four key dimensions, namely: Operational conditions of the production process in the TSI, integrated waste identification, enhancement strategies, and implementing recommended strategies for enhancement. The research case study was conducted at five TSI which produce 20 GT traditional ships located in West Aceh District, Indonesia.

4.1. Operational conditions of the production process in the TSI

This study unveils noteworthy insights into the operational conditions of the production process at TSI. Employing a meticulous scientific approach and structured research methodology, the study delves into the multifaceted aspects that influence operations within the traditional shipbuilding process at TSI. The research findings serve to identify potential areas of waste occurrence in the traditional ship production process at TSI, fostering a comprehensive understanding and offering effective solutions to enhance production efficiency and sustainability.

A case study was conducted on the production process of traditional 20 GT ships at TSI. Through careful observations and interviews, valuable data was gathered, revealing that TSI's traditional ship production process operates with a six-day workweek and eight hours of daily available time (AT). Notably, the production process exhibits zero changeover time for each activity. Detailed information regarding the number of operators, CT, inventory time (IT), and downtime for each activity can be found in Table 1.

Table 1

Operational parameters of 20 GT traditional ships production process at TSI

Activity description	Number of operators	CT (hours)	IT (hours)	Downtime (hours)
Ship keel making	7	28.8	6.5	0.33
Construction of the bow	3	24.3	6.2	0.25
Installation of the bow	3	15.8	6.5	0.50
Manufacture of stern high	3	75	10.0	0.42
Installation of stern height	3	11	5.5	0.17
Installation of basic frames	3	279	19.0	0.50
Installation of canopy frames	3	101.3	13.5	0.67
Installation of the lower hull skin	5	81	11.0	0.50
Installation of the hull skin/upper wall	5	108	16.5	0.42
Deck making	3	114	14.5	0.25
Hatch making	4	69	11.0	0.50
Manufacture of ship decks	5	110	13.0	0.42
Sanding and patching	4	70	9.0	0.17
Installation of plastic sheeting	3	23.1	6.1	0.50
Aluminum zinc installation	3	107	13.5	0.42
Painting	4	82	11.0	0.25
Installation of engines, propellers, and rudders	5	139.5	17.5	0.50
Sum	-	1438.5	190.25	6.75

Table 1 presents a comprehensive breakdown of time allocation and the number of operators involved in each production activity within TSI's traditional shipbuilding process. Among the activities, the highest time consumption was observed in the installation of the basic frames, totaling 279 hours, while the lowest was recorded for the installation of the stern height activity, with a mere 11 hours. Similarly, the activity with the highest operator involvement, as indicated by the IT metric, was the installation of the basic frames at 19 hours, whereas the lowest was found in the installation of the stern height activity, requiring 5.5 hours. Notably, the activity with the longest downtime was the installation of canopy frames at 0.67 hours, while the shortest downtime was observed in the combined activities of installation of the stern height and sanding and patching, totaling only 0.17 hours. For a comprehensive visual representation of each activity's fluctuating trends in time allocation, please refer to Figure 2.

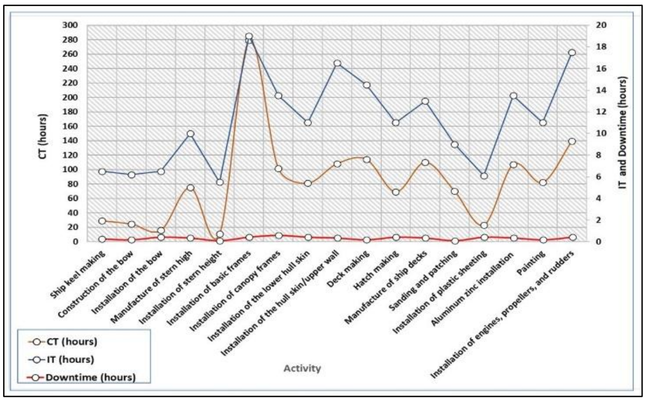

Fig. 2. Dynamic time allocation patterns across activities

The fluctuations in Figure 2 result from various factors, including variations in task complexity across different activities, variances in workforce expertise and experience impacting task efficiency and speed, changes in conditions or constraints such as technical issues, material shortages, or other limitations leading to activity downtime, and the adoption of diverse work methods or processes in specific activities influencing completion time.

4.2. Integrated waste identification

The waste identification process within the traditional ship production process at TSI is meticulously conducted through an integrated approach, comprising several comprehensive stages. During the initial stage, a meticulous waste identification process is undertaken, leveraging the simultaneous application of two powerful methods: WAM and VSM. The waste identification outcomes derived from both methods are meticulously compiled and presented in a well-structured tabular format, ensuring convenient reference. For a comprehensive breakdown of the waste identification results, please consult Table 2 and Table 3, which specifically present the findings obtained through the WAM method, and Table 3, which provides a holistic overview of the results achieved through the VSM method. These tables serve as invaluable references, enabling stakeholders to understand the specific areas of waste within the ship production process at TSI. Moreover, they facilitate the implementation of targeted improvement strategies, ultimately leading to a significant enhancement in operational efficiency.

4.2.1. WAM method implementation

The application of the WAM method for waste identification in the production process of traditional 20 GT ships is conducted at 5 TSI. In this sub-chapter, a comprehensive presentation of the research findings on the implementation of the WAM method will be provided. An in-depth investigation of the findings will be conducted, analyzed data will be presented, and a comprehensive interpretation of the practical application of the WAM method will be offered. By extracting valuable insights from this research, a deeper understanding of the potential of WAM methods across various domains, especially in the context of traditional shipbuilding processes at TSI, can be achieved. This knowledge will empower decision-makers to make informed choices by leveraging the benefits of weighted averages. Please consult Table 2 below for the WMV analysis results obtained from the production process of traditional 20 GT ships at TSI. These results have been obtained through the WRM data processing stages, as explained in the methodology section. In this table, O refers to overproduction, I to inventory, D to defects, M to motion, T to transportation, P to the process, and W to waiting.

Table 2
Exploration of WMV of 20 GT traditional ships production process at TSI

Origin of Waste		O (%)	I (%)	D (%)	M (%)	T (%)	P (%)	W (%)
TSI 1	From	14.38	14.38	16.44	14.38	13.70	15.75	10.96
	To	17.81	22.60	15.75	12.33	10.96	6.85	13.70
TSI 2	From	15.04	15.79	14.29	13.53	15.04	15.79	10.53
	To	15.04	17.29	17.29	18.05	11.28	6.02	15.04
TSI 3	From	17.93	14.48	14.48	15.17	13.79	14.48	9.66
	To	15.86	18.62	18.62	16.55	9.66	5.52	15.17
TSI 4	From	17.04	14.81	15.56	15.56	12.59	14.07	10.37
	To	14.81	16.30	18.52	14.81	11.85	7.41	16.30
TSI 5	From	17.56	17.56	15.27	12.98	11.45	13.74	11.45
	To	15.27	15.27	19.85	16.03	11.45	6.11	16.03

Referring to Table 2, the most dominant waste causing other waste is from overproduction in TSI 3 with a percentage of 17.93%. In addition, the most common type of waste caused by other wastes is the inventory in TSI 1 with a percentage of 22.97% of the total percentage.

The WMV results can be utilized for WAQ analysis, enabling the determination of the initial waste score (Sj) and frequency value (Fj) for each TSI. Subsequently, final Sj and Fj values can be derived based on these results. This analysis allows for the determination of the proportion of final waste for each waste source and TSI. Detailed information about this analysis stage can be found in the methodology section. The results of this analysis are documented in Table 3.

Table 3
The proportion of final waste by waste source and analysis results at TSI

Origin of Waste		O	I	D	M	T	P	W
TSI 1	Sj initial	72.49	86.41	74.41	59.23	52.29	37.19	59.78
	Fj initial	58	63	68	57	43	36	49
	Sj final	33.62	40.75	34.60	28.49	24.49	17.68	23.12
	Fj final	44	48	52	42	33	27	33
	Pj	0.0256	0.0325	0.0259	0.0177	0.0150	0.0108	0.0150
	Final percentage (%)	18.27	23.67	18.66	12.74	10.94	7.80	7.92
TSI 2	Sj initial	61.32	69.23	72.41	70.28	56.84	37.58	58.93
	Fj initial	58	63	68	57	43	36	49
	Sj final	28.83	30.46	32.93	30.84	26.79	16.17	23.85
	Fj final	41	44	48	38	30	23	34
	Pj	0.0226	0.0273	0.0247	0.0244	0.0170	0.0095	0.0158
	Final percentage (%)	17.23	19.24	18.18	16.38	12.79	5.99	10.19
TSI 3	Sj initial	77.04	74.41	80.90	76.93	48.29	39.43	62.28
	Fj initial	58	63	68	57	43	36	49
	Sj final	39.59	37.67	41.35	37.51	26.92	21.23	32.27
	Fj final	47	50	54	44	35	28	36
	Pj	0.0284	0.0270	0.0270	0.0251	0.0133	0.0080	0.0146
	Final percentage (%)	20.40	18.67	18.86	16.29	10.41	5.76	9.61
TSI 4	Sj initial	67.49	65.05	78.41	64.76	54.47	39.04	62.17
	Fj initial	58	63	68	57	43	36	49
	Sj final	35.25	32.31	39.86	33.52	28.15	20.27	28.90
	Fj final	46	49	54	44	35	28	37
	Pj	0.0252	0.0241	0.0288	0.0230	0.0149	0.0104	0.0169
	Final percentage (%)	18.33	16.35	20.39	16.14	11.00	7.38	10.40
TSI 5	Sj initial	69.81	65.91	78.41	65.23	52.14	33.55	60.04
	Fj initial	58	63	68	57	43	36	49
	Sj final	32.72	32.50	36.19	30.03	26.59	14.32	23.56
	Fj final	44	48	52	42	33	27	34
	Pj	0.0268	0.0268	0.0303	0.0208	0.0131	0.0084	0.0184
	Final percentage (%)	19.00	20.08	21.32	14.06	10.23	5.35	9.96
Average final percentage (%)		18.65	19.60	19.48	15.12	11.07	6.46	9.62
Rank		3	1	2	4	5	7	6

Based on Table 3, it is evident that the 4 sources of waste are highly significant and critical as they exceed a percentage value of 15%. The waste sources consist of inventory (19.60%), defects (19.48%), overproduction (18.65%), and motion (15.12%). To facilitate a comprehensive analysis, these four critical wastes are combined with the findings obtained through the VSM method. This integration enables further examination in conjunction with the VALSAT and OMAX methods.

4.2.2. VSM method implementation

The process of identifying waste in the production of traditional 20 GT ships at TSI, through the application of VSM, commences with the creation of a current state map (CSM) diagram. This meticulously constructed map encompasses the entirety of value streams within the 20 GT traditional ship production process at TSI. It encompasses the critical information flows, material flows, and data processing.

The data utilized for CSM generation in the production of traditional 20 GT ships at TSI includes CT, CoT, Uptime (UT), AT, and Process Cycle Efficiency (PCE). Upon mapping, the CT for traditional 20 GT ships at TSI is revealed to be 1409.7 hours for TSI 1, 1395.4 hours for TSI 2, 1481.5 hours for TSI 3, 1452.8 hours for TSI 4, and 1453.1 hours for TSI 5. The average of these values, obtained from the five TSI, yields a CSM diagram displaying a requisite CT of 1438.5 hours to complete a single traditional 20 GT ship at TSI. For a more comprehensive depiction of the results from the VSM of the 20 GT traditional ship production process at TSI, please refer to Figure 3.

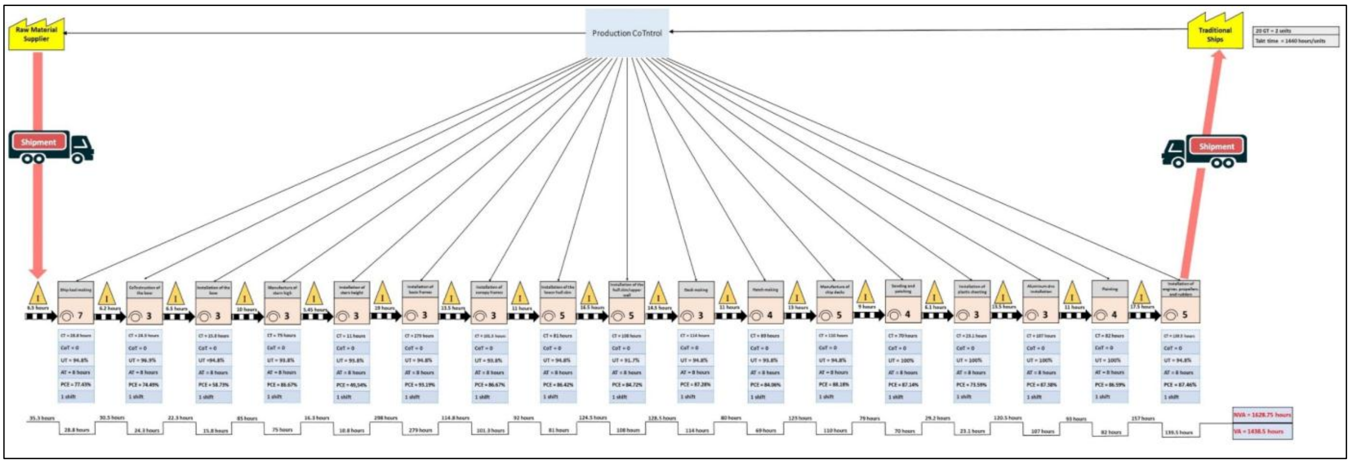

Fig. 3. CSM of 20 GT traditional ship production process at TSI

Referring to Figure 3, the VA time was calculated as 1438.5 hours, while the NVA time amounted to 1628.75 hours. The "Installation of basic frames" activity recorded the highest VA with 279 hours, while the "Installation of stern height" activity had the lowest VA value of 10.8 hours. In terms of NVA, the "Installation of basic frames" activity had the highest value of 298 hours, whereas the "Installation of stern height" activity had the lowest NVA value of 16.2 hours. The VAR for the production process of traditional 20 GT ships at TSI is 84.79%. For a more detailed analysis of the fluctuations in VA, NVA, and VAR values, please refer to Table 4 and Figure 4.

Table 4
Exploring the relationship between VA, NVA, and VAR of 20 GT traditional ships production process at TSI

Activity description	VA (hours)	NVA (hours)	VAR (%)
Ship keel making	28.8	35.3	81.59
Construction of the bow	24.3	30.5	79.67
Installation of the bow	15.8	22.2	70.80
Manufacture of stern high	75	85	88.24
Installation of stern height	10.8	16.2	66.47
Installation of basic frames	279	298	93.62
Installation of canopy frames	101.3	114.8	88.24
Installation of the lower hull skin	81	92	88.05
Installation of the hull skin/upper wall	108	124.5	86.75
Deck making	114	128.5	88.72
Hatch making	69	80	86.25
Manufacture of ship decks	110	123	89.43
Sanding and patching	70	79	88.61
Installation of plastic sheeting	23.1	29.2	79.12
Aluminum zinc installation	107.0	120.5	88.80
Painting	82	93	88.17
Installation of engines, propellers, and rudders	139.5	157	88.85
Sum	1438.5	1628.73	88.32

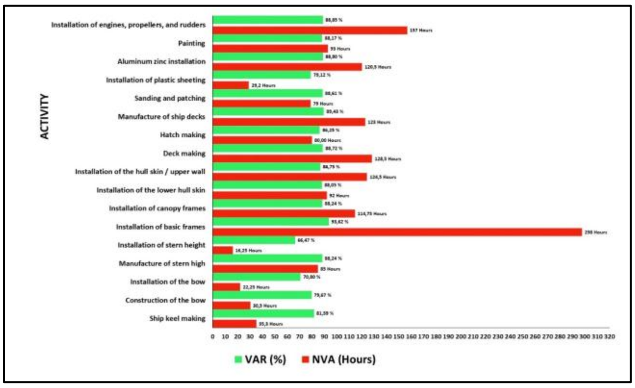

Fig. 4. Analyzing the impact of activity on NVA and VAR: A graphical representation

Based on the findings from Table 4 and Figure 4, it is evident that five critical activities exhibit a VAR value below 85%. These activities include stern height installation with a VAR value of 66.47%, bow installation with a VAR value of 70.80%, plastic sheeting installation with a VAR value of 79.12%, bow construction with a VAR value of 79.67%, and ship keel-making with a VAR value of 81.59%. Immediate improvements are required for these critical activities. To identify the specific waste sources that need to be addressed, they will be integrated with the WAM results.

4.2.3. Integrating WAM with VSM for process improvement

Following the analysis of WAM and VSM, four significant waste sources based on the final percentage value have been discovered, as well as five critical activities determined by the VAR percentage. The subsequent step involves integrating the findings from both methods, which will provide a foundation for improvement using the VALSAT approach of the 20 GT traditional ships production process at TSI. Figure 5 illustrates the findings regarding critical waste sources based on the final percentage value and highlights the critical activities based on the VAR percentage.

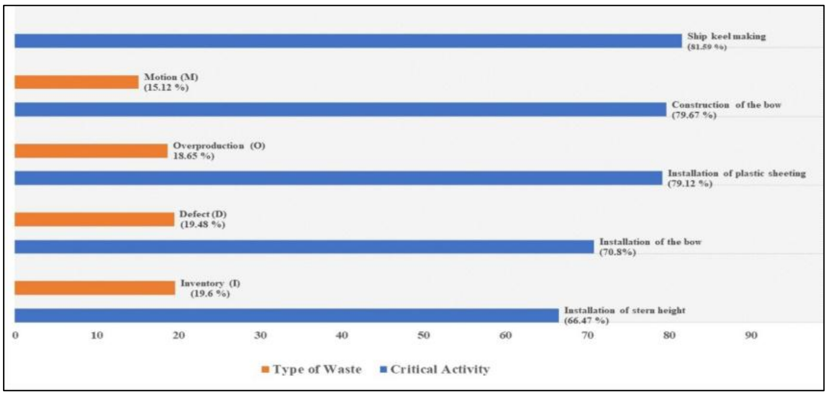

Fig. 5. Critical origin of waste and activities in the 20 GT traditional ships production process at TSI

4.2.4. VALSAT method implementation

Utilizing the insights presented in Figure 5, a VALSAT matrix can be constructed to conduct a thorough and comprehensive value stream analysis of the 20 GT traditional ships production process at TSI specifically focusing on critical origins of waste and activities. By employing the VALSAT matrix, the appropriate tool can be chosen to identify the root causes of waste within the 20 GT traditional ships production process at TSI. The outcomes of the analysis utilizing the VALSAT method are showcased in Table 5.

Table 5
VALSAT analysis of 20 GT traditional ships production at TSI

Critical Origins of Waste	Score	Mapping Tools						
		PAM	SCRM	PVF	QFM	DAM	DPA	PS
Overproduction (O)	18.65	18.65	55.94	-	18.65	55.94	55.94	-
Defect (D)	19.48	19.48	-	-	175.34	-	-	-
Inventory (I)	19.60	58.80	176.41	58.80	-	176.41	58.80	19.60
Motion (M)	15.12	136.10	15.12	-	-	-	-	-
Sum	72.85	233.03	247.48	58.80	193.99	232.36	114.75	19.60
Rank	-	2	1	6	4	3	5	7

According to the findings from the VALSAT analysis presented in Table 5, the SCRM mapping tool achieved the highest score of 247.48. Therefore, the subsequent step involves utilizing the SCRM tool to identify the root causes of waste within the traditional ship production process. This will involve examining activities encompassing AT, LT, and day physical stock (DPS) as key considerations for improvement. Table 6 presents the LT values associated with the DPS values in each area of the traditional ship production process at TSI, while Figure 6 illustrates the DPS relationship across different production areas. Analyzing these parameters will provide valuable insights into the behavior of the supply chain in the traditional 20 GT ships production process at TSI by constructing an SCRM that involves the relationship between LT and DPS as shown in Figure 7.

Table 6
DPS of 20 GT traditional ships production at TSI

Area	AT (hours)	LT		DPS	
		Hours	Days	Hours	Days
Product storage area	8	139.50	17.44	32.80	4.10
Production process area	8	772.80	96.60	108.49	13.56
Materials storage area	8	526.20	65.78	48.95	6.12
Sum	-	1438.50	179.81	190.23	23.78

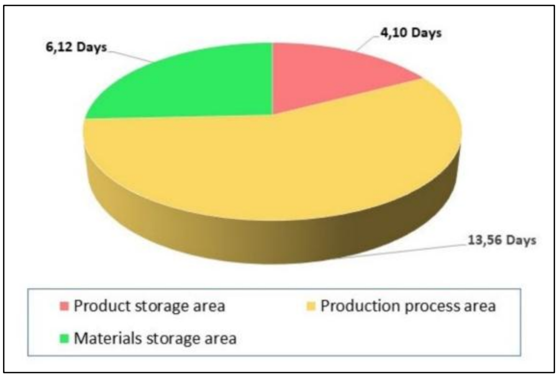

Fig. 6. Comparing DPS across different areas in the production of 20 GT

Figure 7 depicts the variations in inventory time and WT across different areas of the production process. Notably, the production process area exhibits the highest inventory time, reaching 13.56 days. This is attributed to the accumulation of WIP items in the production area, along with raw materials stacked around it. The overall inventory time for the 20 GT traditional ship production process at TSI amounts to 23.78 days, equivalent to 13.22% of the total LT. Based on the SCRM analysis, it is imperative to implement improvements aimed at reducing inventory time, thereby enhancing the efficiency of the production process for traditional 20 GT ships at TSI.

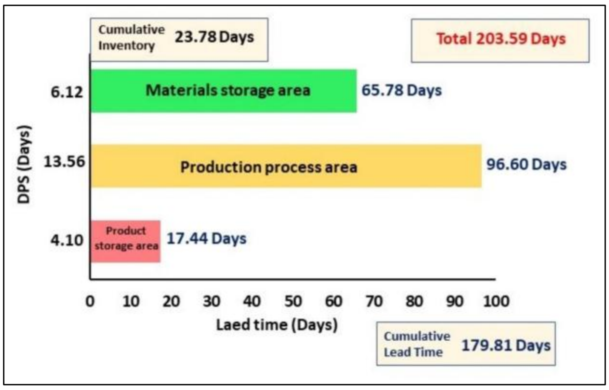

Fig.7. SCRM of 20 GT traditional ships production at TSI

4.3. Enhancement strategies

Drawing insights from the SCRM analysis in Figure 6, the proposed improvements in the 20 GT traditional ship production process at TSI are centered around five critical activities identified in Figure 5. These improvements target the reduction of DPS in each production area. By implementing corrective interventions for these activities, it is anticipated that the overall efficiency of the 20 GT traditional ship production process at TSI will be enhanced. Details of the improvement recommendations can be found in Table 7.

Table 7

Improvement recommendations of 20 GT traditional ships production at TSI

Critical activity/Area	Product storage area	Production process area	Materials storage area
1. Installation of stern height 2. Installation of the bow 3. Installation of plastic sheeting 4. Construction of the bow 5. Ship keel making	Optimization of product storage area: Evaluate and enhance the layout of the product storage area, with a focus on accommodating traditional ship products. Prioritize placing these products in the vicinity of the ship launching area, considering that customers will bring them along	Production analysis and planning: Enhance demand analysis and production planning for improved timeliness of product availability	Optimization of storage areas: Evaluate and enhance the layout of material storage areas, with particular emphasis on the five critical activities. Strategically position the raw materials needed for each process activity, especially those associated with the five critical activities, to ensure convenient accessibility. Consider grouping or organizing them based on categories or ingredient types to facilitate efficient search and retrieval
	Standardization of processes: Implement clear and standardized procedures for all process activities, with special emphasis on the five critical activities. This initiative will promote consistent work execution, reduce the need for additional information or instructions, and ultimately save valuable time	Streamlined production process: Evaluate and enhance the production process for each activity, with particular emphasis on the five critical activities, to optimize and simplify steps and reduce production time. Explore innovative methods or tools that can enhance efficiency and precision in the traditional shipbuilding process at TSI	Streamlined inventory planning: Conduct meticulous inventory planning, taking into account the manufacturing and assembly schedule for each process activity, particularly the five critical activities
	Enhanced training: Ensure that technicians or workers responsible for each process activity, particularly the five critical activities, possess the required skills and knowledge. Offer additional training as necessary to enhance efficiency and accuracy in task execution	Employee training and skill development: Ensure that employees involved in the production process, particularly in the five critical activities, possess the requisite skills and knowledge. Implement targeted training programs to enhance their proficiency, efficiency, and accuracy in task execution, fostering continuous improvement and optimal performance	Optimization of storage zones: When feasible, assess and reorganize storage zones within the material storage area to enhance the accessibility of raw materials, particularly those related to the five critical activities. Prioritize placing frequently used or high-demand items in proximity to the collection point, thereby reducing the time required for inventory management
	Maximizing tool and equipment utilization: Explore the adoption of specialized tools or equipment to expedite each activity process, with particular emphasis on the five critical activities. For instance, utilize appropriate lifting equipment or precision measuring tools to streamline tasks and ensure precise outcomes	Enhanced production scheduling: Enhance the planning of production schedules, considering the specific requirements of each process activity, particularly the five critical activities. Ensure seamless alignment between the completion of production in one activity and the commencement of production in the subsequent activity, facilitating the immediate utilization of	Implementation of efficient storage methods: Utilize effective storage techniques, such as the FIFO (First-In-First-Out) system or the ABC (Activity-Based Costing) method. These methods facilitate proper stock rotation, minimizing the likelihood of expired or spoiled inventory

		physically stored goods after production	
	Integrated inventory tracking and management system implementation: Introduce a unified system that facilitates real-time monitoring of stock levels and enables efficient tracking of WIP and product movements	Inventory monitoring and control: Utilize an integrated inventory management system to enable real-time monitoring of product inventory and WIP	Effective recording and tracking system: Implement a dependable system for recording and tracking to ensure accurate documentation of stock for all necessary raw materials, particularly those essential for the five critical activities
	Enhanced team coordination: Foster improved collaboration among teams engaged in every process activity, particularly the five critical activities. This initiative will reduce errors, minimize time wastage, and boost overall productivity	Enhanced inter-departmental coordination: Foster stronger communication and collaboration between departments engaged in the production process, with particular emphasis on the five critical activities. Promote effective coordination, especially between the production and installation departments, to minimize delays and errors in both product delivery and installation, ensuring a seamless workflow	Enhanced supplier coordination: Strengthen coordination with raw material suppliers, with particular emphasis on those providing materials for the five critical activities, to ensure timely and sufficient supply. Communicate the requirements for each required raw material, especially those about the five critical activities, and establish an efficient communication system to expedite delivery and minimize potential delays
	Continuous assessment and improvement: Regularly evaluate the processes and performance of each process activity, with a special focus on the five critical activities, to identify areas for enhancement and drive ongoing improvement	Continuous evaluation and improvement: Engage in ongoing assessments of the production process, with a particular focus on the five critical activities, to drive continuous improvement initiatives. Regular evaluations enable the identification of areas for enhancement, leading to optimized workflows, increased productivity, and enhanced outcomes	Continuous evaluation and monitoring: Regularly assess the performance of the materials storage area to identify areas for improvement and implement necessary enhancements

Overall, the improvement recommendations outlined in Table 7 encompass eleven categories: 1. Product storage area optimization, 2. Process standardization and simplification, 3. Simplified inventory planning, 4. Employee skills training and development, 5. Integrated inventory management, 6. Enhanced team coordination, 7. Strengthened supplier coordination, 8. Maximizing tool and equipment utilization, 9. Improved production planning and scheduling, 10. Implementation of efficient storage methods, and 11. Ongoing evaluation and improvement. These improvement recommendations will be implemented in the 20 GT traditional ship production process at TSI. The goal is to reduce waste in the production process and enhance the performance of the traditional ship production process at TSI.

4.4. Implementing recommended strategies for enhancement

The implementation of these recommendations is carried out by redesigning the flow of the traditional ship production process at TSI in the form of an FSM diagram. Making the FSM is done by revising the CSM based on recommendations for improving five critical activities. Achieving improvements is done by optimizing the material flow from raw material suppliers to the final product, ensuring a seamless production process without any bottlenecks. The focus is on five critical activities, starting with ship keel manufacturing, and strategically eliminating material flow bottlenecks by implementing supermarkets. To enhance efficiency, a kanban system is established that aligns ship keel production with supermarket requests, allowing direct raw material input through production control via the kanban post command. This transition from a push production system to a pull production system is facilitated by the implementation of the Kanban system. Similar improvements have also been implemented for the Installation of plastic sheeting activities.

In addition to the aforementioned improvements, three other critical activities have undergone enhancements: Installation of stern height, installation of the bow, and construction of the bow. These improvements follow an Enhancement, Combination, Reduction, and Simplification (ECRS) approach (Burawat, 2019; Mohammed, 2020; Suhardi, Anisa & Laksono, 2019). The installation of the bow and construction of the bow activities have been consolidated into a single activity called construction and installation of the bow. Similarly, the Installation of stern height activity has been merged with the manufacture of stern height to form the manufacture and installation of stern height. The Kanban system is also implemented for both of these improvements, ensuring efficient material flow and production control. The FSM shown in Figure 7 is the result of improvement opportunities that have been carried out in five critical activities.

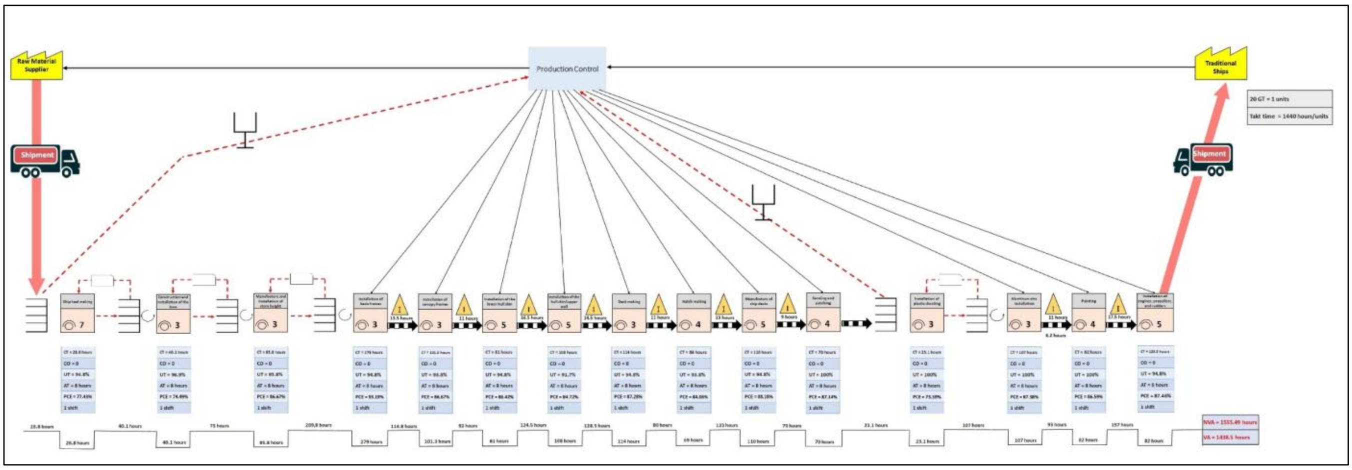

Fig. 8. FSM of 20 GT traditional ship production process at TSI

Referring to Figure 8, the production process for traditional 20 GT vessels at TSI has experienced a significant increase in performance. This increase is the result of a comprehensive and holistic approach that involves identifying waste and optimizing performance. The implementation of these improvements has brought significant changes to the KPI parameters that affect the value of waste in the traditional ship production process at TSI. Specific changes in KPIs are documented in Table 8.

Table 8

Comparison of KPI parameters before and after improvements: 20 GT traditional ships production process at TSI

KPIs Parameter	Before improvements	After improvements
NVA (hours)	1628.73	1555.49
VAR (%)	84.79	93.71
DPS (Days)	23.78	14.62
DPS to LT ratio (%)	13.22	8.13
PCE (%)	86.78	91.87

Table 8 presents noticeable variations in several KPI parameters, showcasing both decreases and significant increases. Among the parameters, the NVA parameter stands out with a decrease in NVA time from 1628.73 hours to 1555.49 hours. This reduction of 73.24 hours reflects a decrease in the waste within the 20 GT traditional ship production process at TSI. This decrease in time underscores the effectiveness of the implemented changes and improvements in TSI's traditional shipbuilding process. As a result, efficiency has increased, time wastage has been minimized, and the overall value added to the produced products has risen.

Furthermore, the DPS parameter and the DPS to LT ratio have also experienced declines. The DPS decreased from 23.78 days to 14.62 days, and the DPS to LT ratio decreased from 13.22% to 8.13%. These reductions signify improved performance and timeliness in the traditional ship production process, further emphasizing the positive outcomes of the implemented enhancements. A decrease in the DPS signifies the successful reduction of the average inventory holding period. This demonstrates improved efficiency in inventory management, which can be attributed to measures such as minimizing excess inventory, enhancing production planning, and ensuring accurate inventory information. The decline in the DPS to LT ratio indicates that the company or inventory management system has effectively reduced the percentage of physical inventory relative to the time required from order placement to inventory arrival. This points to enhancements in supply chain management, including reduced WTs, improved order and delivery management, and strengthened supplier relationships. These changes reflect increased efficiency and waste reduction in inventory management. By reducing the DPS and DPS to LT ratios, companies can optimize inventory levels, enhance cash flow, and decrease storage costs.

The VAR percentage parameter has experienced an increase, rising from 84.79% to 93.71%. This signifies an 8.92% increase in the ratio of VA activities to NVA activities within the production process of traditional 20

GT ships at TSI. This growth in the VAR percentage indicates a significant improvement in the production process. With a higher proportion of VA activities, there is enhanced efficiency, improved product quality, and increased customer benefits. Similarly, the PCE parameter has also witnessed an increase, climbing from 86.78% to 91.87%. These changes highlight the successful implementation of corrective and optimization actions, leading to improved efficiency and performance within the evaluated process or system. The increase in PCE represents tangible progress in enhancing operational efficiency and resource utilization within the traditional 20 GT ship production process at TSI.

5. Conclusion and Future Research

In conclusion, this research study sheds light on a comprehensive and innovative methodology aimed at driving significant improvements in the performance of production processes at TSI. Through a careful analysis of waste identification and a systematic approach to performance optimization, this research not only uncovers important insights but also presents a compelling case for the application of an integrated framework. By addressing key challenges and streamlining processes, the findings of this research pave the way for increased productivity, reduced costs, and increased competitiveness in the shipbuilding industry. The significance of this study lies in its potential to transform TSI into a modern, efficient, and sustainable production facility, positioning it for long-term success in an evolving market.

To enhance production process performance, increase competitiveness, and achieve sustainable growth, several recommendations for future research can be made. Firstly, exploring the application of the integrated approach in the context of other shipyards and different regions would provide valuable insights into its effectiveness in diverse operational environments. This evaluation would help determine the adaptability and scalability of the approach. Secondly, investigating the impact of waste reduction and performance optimization on quality assurance and customer satisfaction at TSI is essential. Understanding how these improvements influence overall quality and customer perception can guide further enhancements in these areas. Thirdly, it is crucial to conduct research that assesses the long-term sustainability of waste reduction initiatives and performance optimization strategies at TSI. This evaluation will ensure that the improvements implemented can be maintained over time and continue to yield positive outcomes.

Furthermore, studying the integration of digital technologies, such as automation, robotics, and data analytics, at TSI can significantly improve waste identification and performance optimization. Exploring the potential benefits and challenges associated with these technologies would pave the way for their effective implementation. Additionally, analyzing the role of human factors, including workforce skills, motivation, and organizational culture, in implementing waste reduction and performance improvement initiatives at TSI is essential. Understanding how these factors influence the success of such initiatives will provide valuable insights for effective implementation. Investigating potential challenges and obstacles faced by TSI in implementing lean and Six Sigma approaches and developing strategies to overcome them is also crucial. By identifying and addressing these barriers, TSI can optimize the implementation process and ensure the successful adoption of these methodologies.

Lastly, exploring the application of other continuous improvement methodologies, such as Total Quality Management (TQM) or Agile principles, in TSI operations for waste reduction and performance optimization would broaden the scope of improvement strategies. Assessing the suitability and effectiveness of these methodologies can provide alternative approaches for achieving waste reduction and performance enhancement goals. By focusing on these areas of future research, TSI can continue to enhance its production process performance, increase competitiveness, and achieve sustainable growth.

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