Engineering Innovations
ISSN: 2813-1002, Vol. 17, pp 109-122
doi:10.4028/p-R2QkXI

Submitted: 2025-02-20
Revised: 2025-09-11
Accepted: 2025-09-29
Online: 2026-02-12

The Impact of Lean Tools and Waste Analysis on the Improvement of Process Cycle Efficiency and Manufacturing Lead Time of Pipe Sleeve Fabrication: A Case Study

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Keywords: Lean manufacturing, pareto chart, process cycle efficiency, manufacturing lead time, value stream mapping.

Abstract. This study investigates the implementation of lean tools to enhance process cycle efficiency and reduce production lead time by at least 10% in a case study of pipe sleeve fabrication at one of manufacturing company in Indonesia. Improving production efficiency is a critical investment for manufacture sustainability and competitive advantages. The application of lean tools, such as value stream mapping and pareto analysis, can help reduce process inefficiencies by eliminating non-value-added activities, such as machine breakdowns, waiting, and material handling. The results demonstrate that the implementation of lean tools can increase Process Cycle Efficiency (PCE) from 39.76% to 51.40% and reduce *manufacturing lead time* (MLT) by 22.63%. This case study provides insights into how lean tools can be applied to improve productivity in manufacturing processes. Lean tools can be implemented across various manufacturing industries to enhance their productivity. Broader implications of implementing lean method suggest that companies can enhance productivity, reduce cost of production, improve quality, and ultimately increase their competitive advantage in the market.

Introduction

Economic globalization has had a profound impact on the global economy, both in terms of domestic and international markets. One of the most notable effects of globalization is the increased competition in the manufacturing sector [1]. In today's globalized economy, manufacturing industries face increasing competition. In order to succeed, companies must focus on providing high quality products and services that meet the needs of their customers. Lean manufacturing is a production strategy that emphasizes waste reduction and efficiency, and it is becoming increasingly popular in global manufacturing [2]. Waste is any activity that does not add value to the product or service being produced it can be reduced through lean manufacturing methods, which involve everyone in the organization working together to identify and eliminate waste [3]. This strategy is led by automotive manufactures and their equipment suppliers, who have seen significant benefits from adopting lean manufacturing. According to a recent survey, approximately 36% of manufacturing companies in the United State have adopted lean or are in the process of doing so. [4]. The implementation of lean manufacturing concepts is full of flexible tools and techniques such as *just in-time inventory* (JIT), *kanban*, *kaizen*, 5S, *single minute exchange of dies* (SMED), *one point lesson* (OPL), and *value stream mapping* (VSM). Lean manufacturing is a soft technology that accommodates qualitative and quantitative techniques as well as computing to demonstrate a commitment to continuous improvement. Therefore, lean manufacturing systems are flexible for implementation in manufacturing and service industries [5].

The *process cycle efficiency* (PCE) is a measure of the efficiency of a production process. It is calculated by dividing the value-added time by the total cycle time. A higher PCE indicates a more efficient production process. In a study conducted by Md Abu Sayid, he was able to improve the PCE of shoes production in Bangladesh from 8.32% to 19.46% [6]. This improvement was achieved through the implementation of lean manufacturing principles and practices. Besides, in other cases a researcher in Bangladesh, has successfully improved the efficiency of mango juice production in the food industry. He did this by implementing lean tools, which are a set of principles and practices that focus on eliminating waste and improving efficiency. As a result of his research, the process cycle efficiency of mango juice production increased from 15.28% to 34.05% [7]. This represents a significant improvement in efficiency, and it has the potential to lead to a number of benefits for the food, including reduced costs, improved quality, and increased customer satisfaction. In this study investigated the use of lean tools to improve the efficiency and lead time of pipe sleeve fabrication at a leading manufacturing company in Indonesia. The study found that lean tools led to significant improvements in both metrics.

Methodology

The research methodology was designed to systematically examine the pipe sleeve fabrication process and identify sources of inefficiency. A case study approach was employed, focusing on direct observations, process documentation, and semi-structured interviews with operators and supervisors. Lean manufacturing tools – specifically *value stream mapping* (VSM), pareto analysis, and fishbone diagrams were applied to map current processes, quantify waste, analyze root cause. Activities were classified into *value-added* (VA), *necessary but non-value-added* (NNVA), and *non-value-added* (NVA), enabling a structured assessment of process performance.

This methodological framework provides a comprehensive basis for analyzing the current state of fabrication, diagnosing inefficiencies, and formulating targeted improvements. The subsequent section presents the results of this analysis and discusses their implications for manufacturing performance.

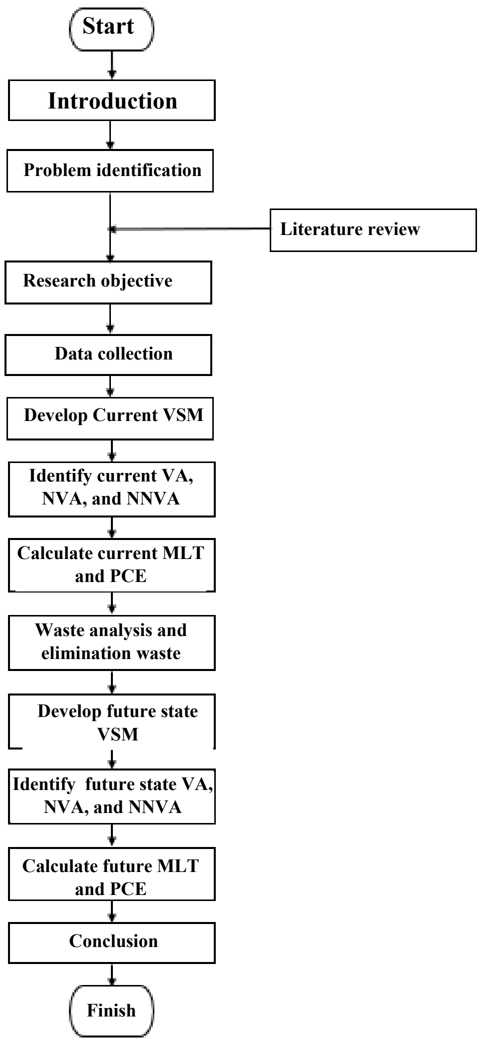

Fig 1. Methodology

Result and Discussion

The application of lean tools yielded valuable insights into the inefficiencies present within the pipe sleeve fabrication process. The current state Value Stream Mapping (VSM) revealed that considerable proportion of production time was consumed by non-value-added and necessary but non-value-added activities, including prolonged waiting times, redundant inspections, and inefficient material handling. Pareto analysis further emphasized that human related factors were the dominant contributors to waste, while machine related factors played a comparatively smaller role. Fishbone diagrams were then employed to explore the underlying causes of these inefficiencies across the dimensions of man, method, machine, and materials.

The following discussion elaborates on these findings, highlighting how each category of waste emerged, how it aligns with prior studies on lean implementation, and what strategic measures can be applied to reduce lead time and enhance process cycle efficiency.

Observed Process Fabrication. The pipe sleeve fabrication process is shown in Fig. 1, The raw materials used in this process were not a major concern in this study. Instead, the focus was on identifying and eliminating waste and downtime. Production delays were caused by a variety of factors, and downtime was measured in terms of non-value-added time.

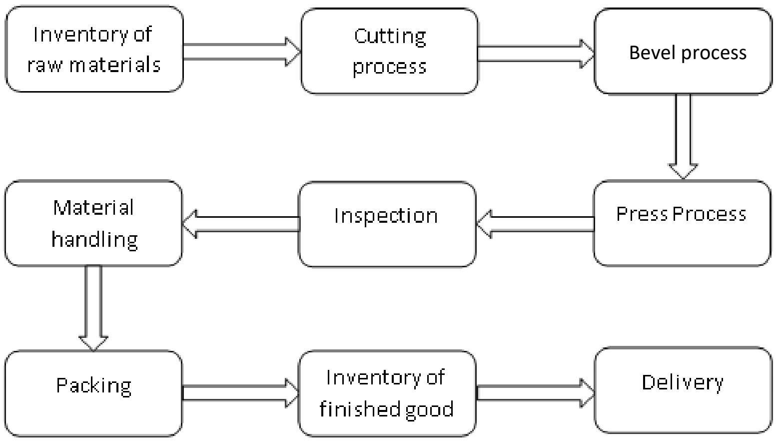

Fig 2. Stage processing of fabrication pipe sleeve

Value Stream Mapping (VSM). Value Stream Mapping (VSM) is a lean manufacturing tool that can be used to identify and eliminate waste in a production process [8]. Studies have shown that *value stream mapping* (VSM) is effective in improving production speed, reducing costs, saving time, and minimizing environmental impact. *value stream mapping* (VSM) is also considered flexible and adaptable for redesigning production systems with different flow paths [9]. In *value stream mapping* (VSM), activities are classified into three types: *value-added* (VA), *non-value-added* (NVA), and *necessary but non-value-added* (NNVA). VA activities are those that increase the value of a product from the customer's perspective. NVA activities do not create value and are considered waste, such as waiting, rework, or unnecessary movement. NNVA activities do not directly add value but are still required under current process or regulatory conditions, such as inspections or equipment setup. This classification helps identify which parts of the process should be improved or eliminated to increase efficiency.

Current state VSM of Fabrication Pipe Sleeve. The current state *value stream mapping* (VSM) of a pipe sleeve fabrication system is shown in Fig. 2, *value stream mapping* (VSM) shows that production begins upon receiving customer request for specified quantity. The required raw materials are procured from suppliers, stored in the warehouse, and subsequently transferred to the production floor for cutting, inspection, bevel and press/roll processing, and final inspection. The finished pipe sleeve is then packaged and shipped.

Value stream mapping (VSM) also reveals the presence of 31 bottlenecks in the process, which hinder the smooth flow of materials and information. The analysis indicates that 2,919 seconds, equivalent to approximately 17.76% of the total production time, were classified as *non-value-added* (NVA) activities. This represents a substantial portion of time that could potentially be eliminated. In addition, 6,977 seconds, or about 42.47% of the total production time, were categorized as *necessary but non-value-added* (NNVA) activities, which could be reduced through process streamlining and the elimination of inefficiencies.

Overall, the study concludes that the implementation of lean tools has the potential to significantly enhance the efficiency of pipe sleeve fabrication by eliminating NVA activities and reducing VA time. These improvements are expected to increase productivity, minimize downtime and mitigate the risk of production delays.

Table 1 Current stage NVA, NNVA, NVA

Processing stage	VA (sec)	NNVA (sec)	NVA (sec)
Inspection of material arrival from logistics		604	
Material transfer from logistics		1,456	
Marking of the material to be cut		129	
Material cutting process using in housen machines	168		
Inspection of measurements of cutting results by the operator			256
Arrange the product after the cutting process			117
Waiting for the QC team			373
Material inspection by QC team		303	
Waiting for the forklift			357
Loading material after the cutting process		860	
Transfer of materials to the next workshop area		1,538	
Setting the degree of the ABM 14 bevel machine	196		
Loading material that will be bevel process		68	
Rough bevel process using ABM 14 machine	288		
Inspection of measurements by operator			187
The smoothing process uses a manual bevel process	392		
Unloading		73	
Waiting for the arrival of the QC team			257
Inspection of bevel angle measurements by the QC team		77	
Material arrangement after the bevel process		84	
Move the material to the bipel press machine		93	
Press/roll machine setup (set up the required dies according to size)	1,919		
Press/roll process	361		
Inspection of measurements by the operator after press/roll process			307
Arranging the material after the press/roll process		112	
Waiting QC team			409
Final inspection by QC team after press/roll process		424	
Transfer of pipe sleeve to logistic area		1,156	
Checking quantity by the delivery control team			656
Packaging process		2,367	
Transport in truck		843	
Total	6,534	6,977	2,919

Note: VA time is an activity that provides added value;
NVA time is an activity that does not provide added value;
NNVA time is an activity that does not provide added value, but is still necessary

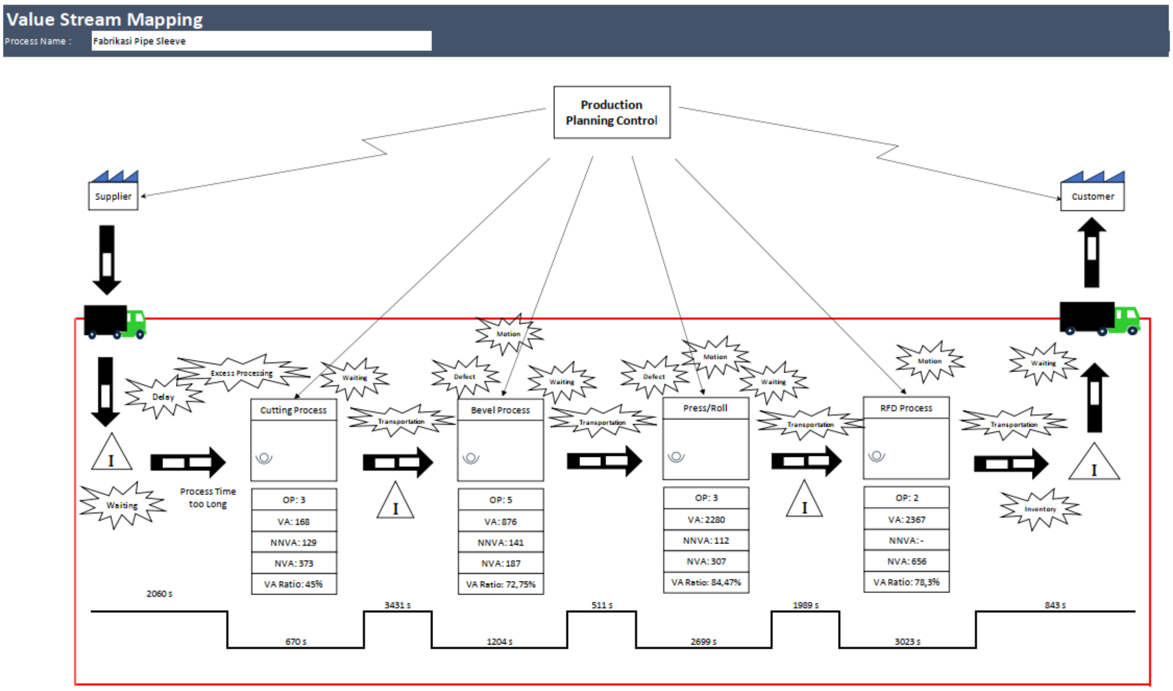

Fig 3. Current state value stream mapping

Current state Manufacturing Lead time of Fabrication Pipe Sleeve. Manufacturing lead time is the time it takes to produce a product from start to finish, including all the steps in between, whether they are necessary or not [10]. The data required to calculate *manufacturing lead time* (MLT) includes the time of *value added* (VA), *non-value-added but necessary* (NNVA), and *non-value added* (NVA) activities that have been carried out in the production process. The formula for calculating MLT is as follows:

$$MLT = VA + NNVA + NVA \tag{1}$$

The fabrication process is carried out for shifts per day, each shift lasting 28,800 seconds, excluding lunch time and planned downtime.

Current state Process Cycle Efficiency of Fabrication Pipe Sleeve. PCE is how efficiently a manufacturing process produces value-added products. It is calculated by dividing the time required to produce *value-added* (VA) by the *manufacturing lead time* (MLT) and expressing the result as a percentage. The formula PCE can be shown in formula (2) below:

$$PCE = \frac{VA}{MLT} \times 100\% \tag{2}$$

The study found that the *value-added* (VA) time for pipe sleeve fabrication was 6,534 second and the MLT was 16,430 seconds. The resulted in a PCE value of 39.76%, which is above the international competitiveness level of 25% [11]. The study sought to improve *process cycle efficiency* (PCE) to mitigate delays in meeting customer demand by applying lean tools such as *value stream mapping* (VSM), pareto analysis, fishbone diagram, pareto charts.

Fishbone Diagram. Delays can be caused by a large amount of waste during the production process. Waste analysis can be done when the material is already on the production floor. Waste is any activity or action that does not add value to the product or service being produced. Lean manufacturing identifies seven types of waste that must be eliminated in production systems [12]:

- o Waiting: time spent waiting for materials, equipment, or people.
- o Transportation: moving materials or products unnecessarily.
- o Inventory: excess stock of materials, work in progress, or finished goods.
- o Overprocessing: performing unnecessary steps in the production process.

- Motion: unnecessary movement of people or equipment.
- Defect: products or services that do not meet customer requirements.

A fishbone diagram is used to identify the root cause of a waste problem. The analysis considers four factors: man, machine, methods, materials. Figure 4 shows one of the wastes, namely defects in production.

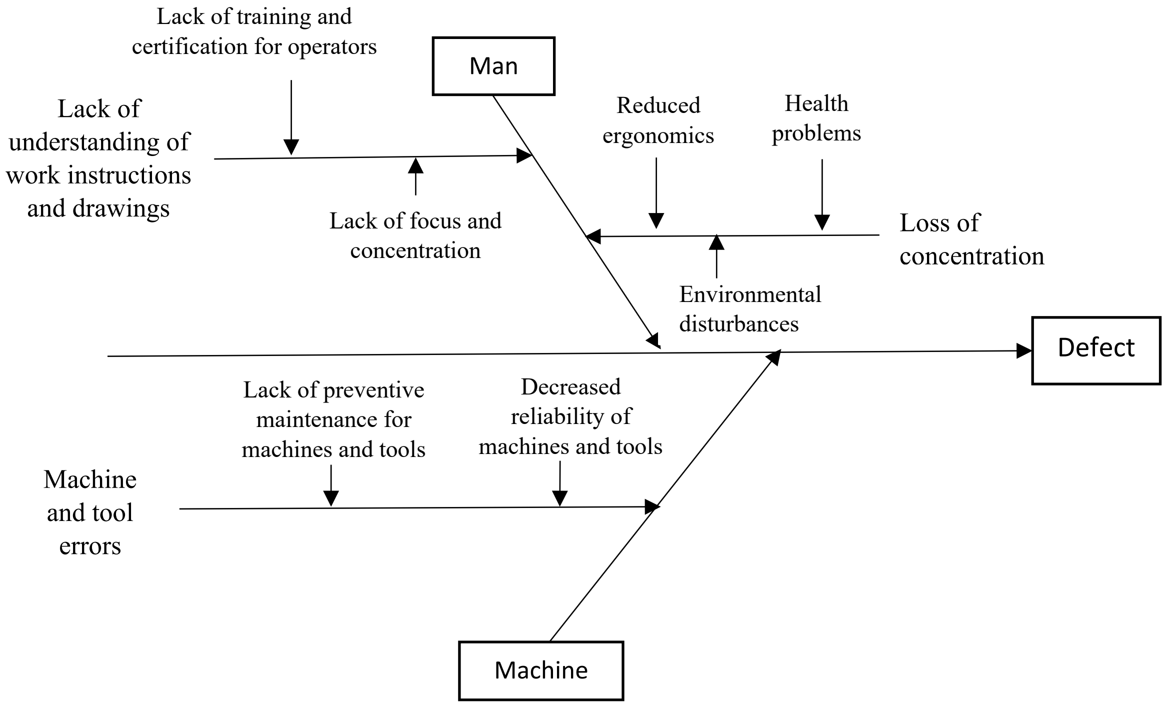

Fig 4. Fishbone diagram waste defect

Man factors such as fatigue, environmental disturbances, and poor physical health can lead to a loss of concentration, which in turn increases the likelihood of production defects and subsequent rejections. Similarly, rushing and a lack of focus may contribute to errors as workers are more prone to overlooking details and misinterpret instruction. Machine factors including wear and tear on tools and components due to inadequate preventive maintenance, as well as calibration errors arising from irregular maintenance schedules, are also common causes of product defects. Method factors such as insufficient spacing and inadequate packaging, can further result in product damage. For example, the absence of pallets and the use of simple block separators may exacerbate these issues. Materials factor on defects are frequently associated with prolonged storage, exposure to fluctuating environmental conditions, and improper storage or handling practices. Refer with: Fig. 5, illustrates one of the identified wastes – transportation, which is caused by man, method, machine and materials factors.

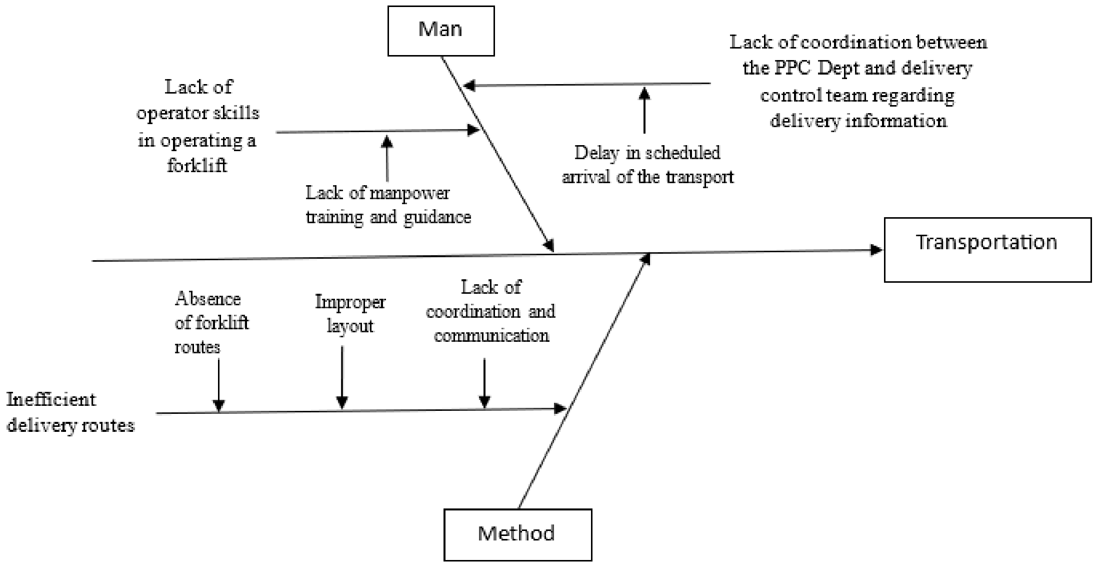

Fig 5. Fishbone diagram waste transportation

The Overproduction factors are primarily associated with a lack of coordination caused by inefficient processes, frequent changes in delivery allocation, incorrect material placement due to misidentification, and delays in material handling resulting from overloaded trucks. Machine factors contributing to transportation waste include production downtime caused delayed material handling and interruptions in processes from other plants or vendors due to inadequate machine capacity within the workshop area. Method factors include congested factory traffic caused by excessive material transport trucks and inefficient facility layouts arising from the simultaneous presence of various products in the *ready for delivery* (RFD) area. Material factors include the generator of excessive scrap material due to high product tonnage, and frequent changes in fabrication location caused by long distances between workshops. Refer with: Fig. 6, illustrates one of the identified wastes, excess processing, which is caused by man, method, machine and materials factors.

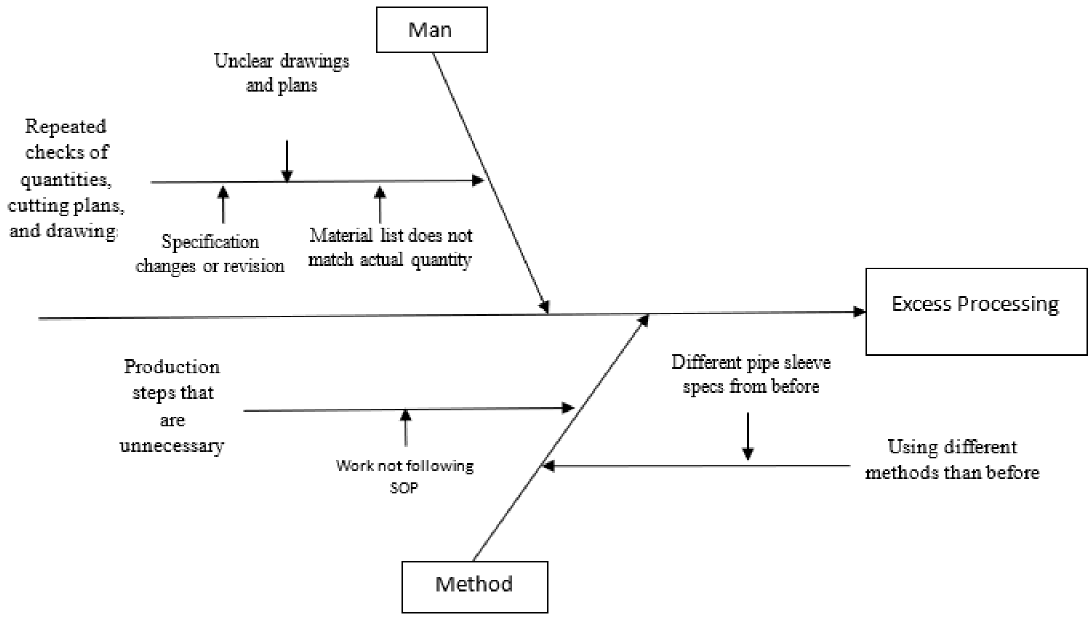

Fig 6. Fishbone diagram waste excess processing

Man factors contributing excess processing waste include repeated checks on quantities, cutting plans, and drawings due to sudden changes, as well as redundant inspections driven by fear of errors and lack of operator confidence. Errors during processing also lead unnecessary rework and additional activities. Method factor include the application of procedures that differ from previously established practices, particularly when tight tolerance is required. Material factors involve poor material quality caused by defects or corrosion, which necessitate special treatment to continue the fabrication process, along with additional steps for materials that do not meet raw material specifications. Machine factors include poor machine condition resulting from a lack of awareness regarding the importance of predictive maintenance, and limited machine capacity to meet production demands. Refer with Fig. 7, illustrates one of the identified wastes, namely motion, which is caused by the man, machine and method factor.

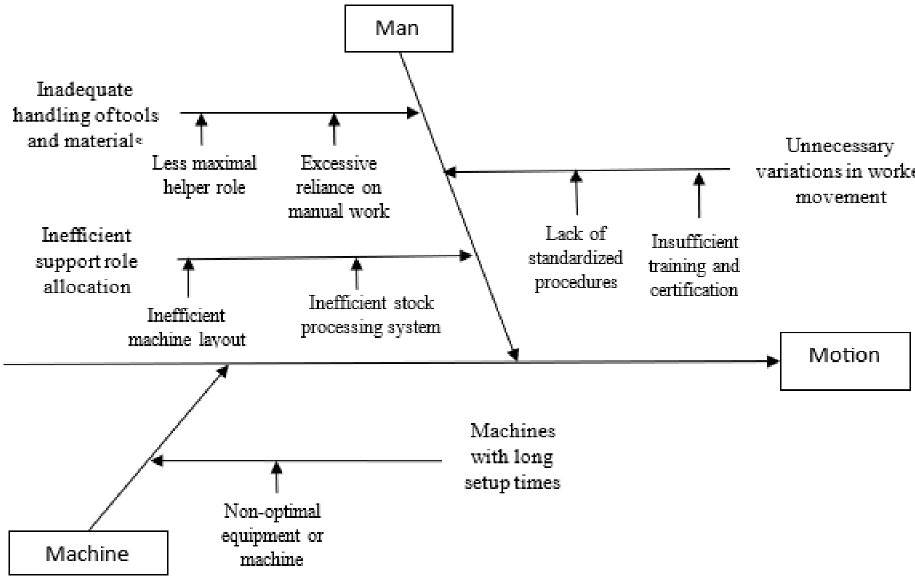

Fig 7. Fishbone diagram waste motion

Man factors contributing to motion waste include operators spending excessive time retrieving materials or tools due to inadequate tool preparation, as well as inefficient movements when handling materials caused by uncomfortable work areas and unnecessary variations in motion. Machine factors include poor machine condition, such as excessive friction and vibration, which lead to additional non-value-added movements by operators. Furthermore, inefficient facility layouts, particularly when machines are positioned far apart, exacerbate this type of waste. Method factors include inefficient work methods employed by operators and suboptimal fabrication sequences resulting from inadequate planning. Refer with: Fig. 8, illustrates one of the identified wastes - inventory, which arises from man, method, machine and materials factor.

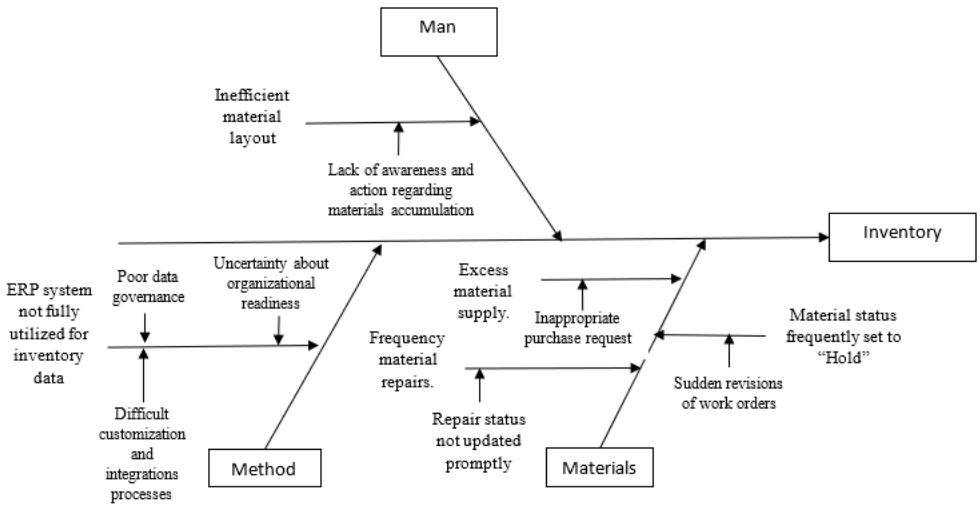

Fig 8. Fishbone diagram waste inventory

Man factors contributing to inventory waste include errors in ordering caused by poor communication and insufficient planning of material requests and supply, often resulting from late work orders. Method factors involve inefficient data recording due to the absence of an ERP/MRP system, improper storage and handling of materials caused by excess deadstock, and suboptimal inventory management stemming from high inventory levels in logistics. Material factors include a high frequency of product repairs due to substandard production outputs and poor material quality resulting from prolonged storage. Machine factors contributing to inventory waste consist of downtime and production delays due to machine conditions, delayed material handling that leaves materials waiting to be transferred to the *ready for delivery* (RFD) area, and material accumulation near machines caused by limited machine capacity relative to high demand. Refer with Fig. 9, illustrates one of the identified wastes, namely waiting, which arises from man, method, materials, and machines factors.

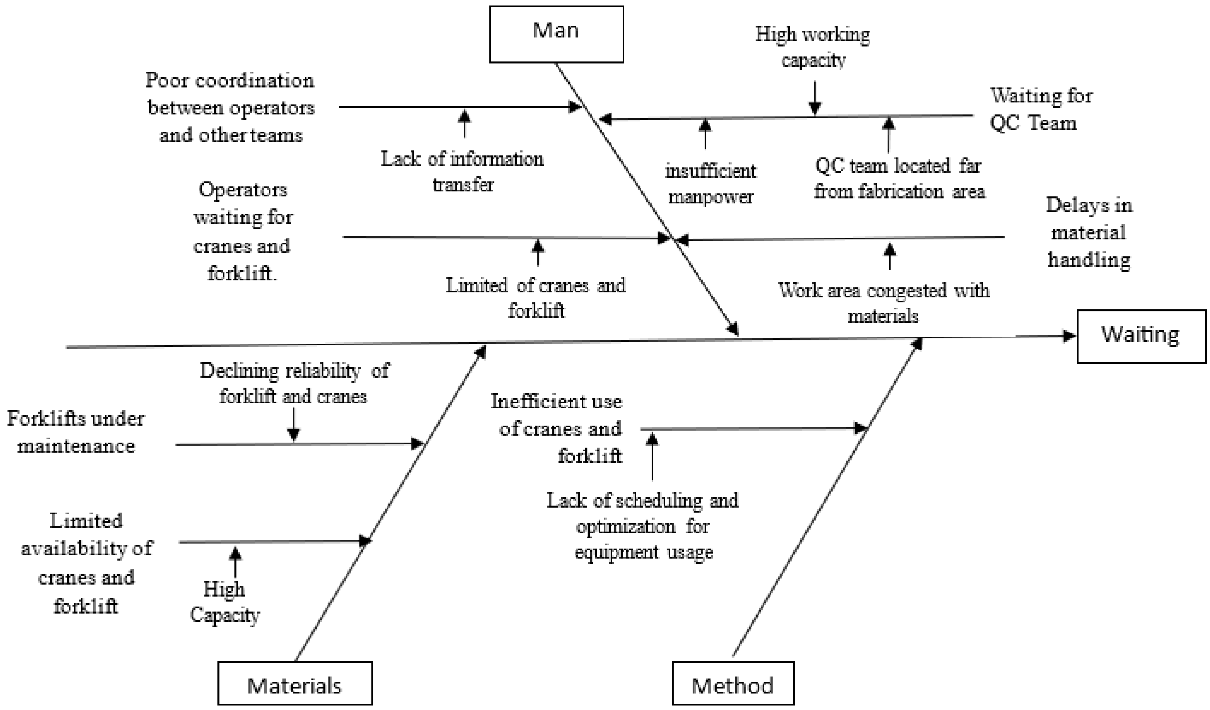

Fig 9. Fishbone diagram waste waiting

Man factors contributing to waiting waste include delays in QC inspection due to the remote location of the QC team from the work area, operators waiting for cranes and forklifts to move products and materials as a result of high utilization, and lack of coordination among teams that creates dependencies and prolongs waiting times between processes. Method factors involve delays in shipment preparation caused by unmet production schedules. Material factors include limited material availability due to pending material arrivals as well as delays associated with forklift and cranes that are either under maintenance or insufficient in number. Machine factors contributing to waiting waste consist of downtime resulting from capacity constraints, delays caused by dependence on preceding processes, and reduced machine speeds due to declining reliability.

Pareto Analysis. This statistical technique is a powerful tool for decision-making that significantly contributes to quality improvement. It is based on the Pareto principle, which states that approximately 20% of the causes are responsible for 80% of the problems [7]. In the words, the majority of issues arise from a relatively small number of root causes. The pareto chart follows the 80/20 rule, with the 80% threshold included to highlight the critical factors that require the greatest attention, as they lie below this line. In this study, the Pareto chart was applied to identify the 20% of factors responsible for 80% of *non-value-added* (NVA) activities.

Table 2 Cumulative percentage of frequency from waste factor

Factors	Frequency	Cumulative Frequency	Cumulative percentage
Man	7	7	44%
Method	4	11	69%
Materials	3	14	88%
Machine	2	16	100%

The Pareto chart was employed to analyze the negative impacts within the project. This tool facilitated the construction of a Pareto diagram that displays the factors contributing to waste, with the X-axis representing the types of waste and the Y-axis representing the cumulative percentage frequency. The most significant contributing factor was identified as the man factor, where human error frequently occurred throughout the process, while machine – related damage accounted for the lowest contribution. The factors associated with waste and NVA activities across different stages of the fabrication process are presented in Table 2, along with their corresponding cumulative frequency percentages. Refer with Fig. 10, the man factor was the most dominant contributor, accounting for 88% of waste in the fabrication of pipe sleeves, whereas the machine factor represented the lowest contribution at 20%. The waste factors are arranged in descending order according to their frequency. Through this diagram, waste – causing factors can be easily identified, allowing for the development of targeted and effective measures to mitigate and ultimately eliminate them.

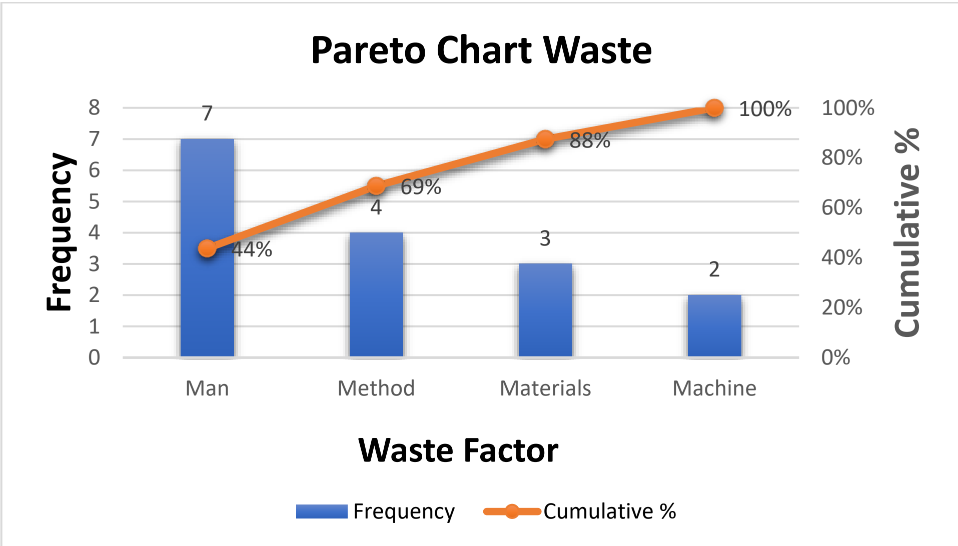

Fig 10. Pareto chart

Continuous Improvement. Continuous improvement, commonly referred to as *kaizen*, is one of the most fundamental and effective principles in lean manufacturing. *Kaizen* represent a philosophy of incremental and continuous improvement that can be applied across various context, including domestic, societal, and organizational settings. Within the workplace, *kaizen* emphasizes the active involvement of all personnel, from top management to top shop-floor workers in identifying and implementing small, gradual improvements [14]. This philosophy adopts a long-term perspective, focusing on systematic efforts to achieve incremental goals that enhance both quality and efficiency. The principle of *kaizen* supports simple yet meaningful improvements to end-to-end business processes as part of a broader continuous improvement strategy. Globally, many companies have adopted *kaizen* to increase productivity, improve quality, and enhance profitability, while minimizing cost, time, and effort [14]. Refer with Fig. 11 illustrates a *kaizen-based* strategy for sustaining long-term lean manufacturing implementation.

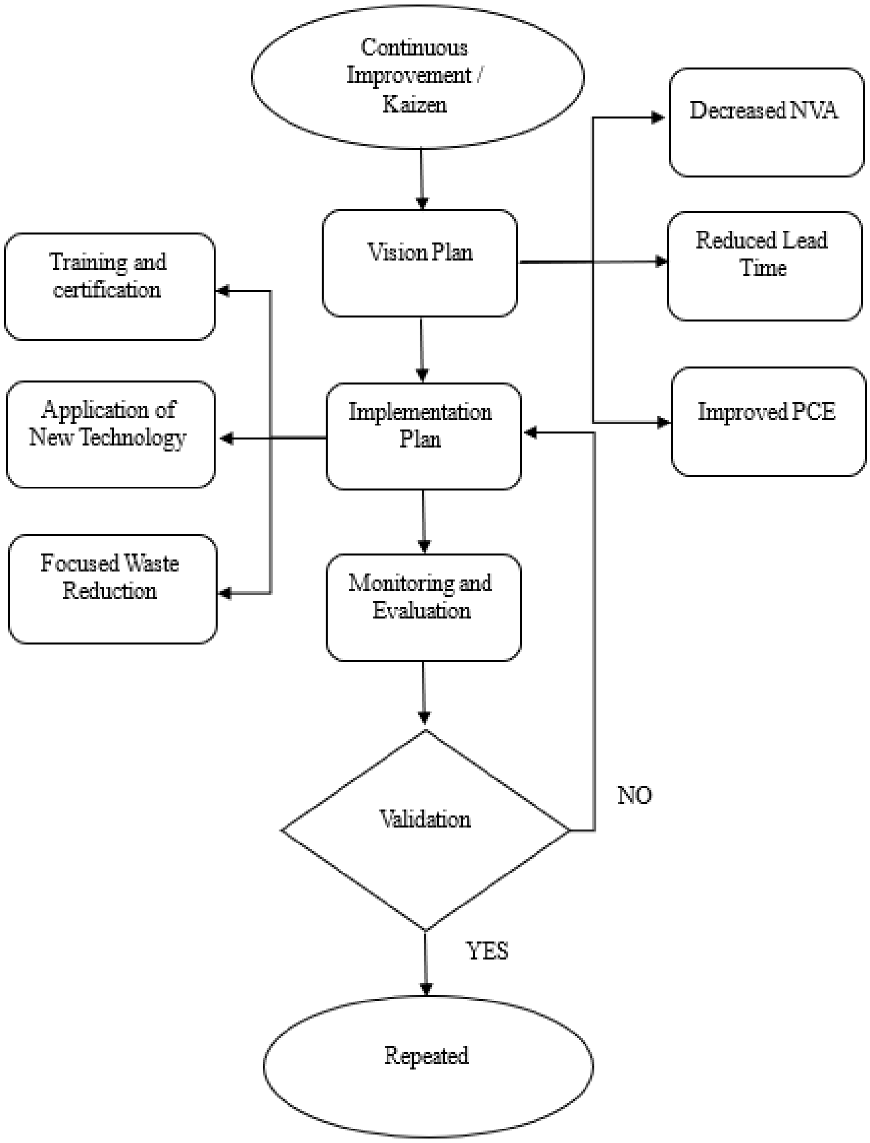

Fig 11. Kaizen implementation for strategic planning

Future Value Stream Mapping of Fabrication Pipe Sleeve. Refer with Table 3 shows that the future *process activity mapping* (PAM) consists of only 19 production activities out of 31. The first eliminated activities were material inspection processes, which were unnecessary upon material arrival but required when materials were transported from the supplier to the plant for fabrication. Operator inspections were also eliminated; inspections were conducted solely by *Quality control*, allowing operators to focus on their processes and accelerate production. Waiting for cranes, forklifts, and the *Quality control* team was also eliminated as these activities did not add value and could lead to delays if repeated. To avoid waiting, time schedules were implemented in the workshop for the *Quality control* team and crane usage, minimizing repetitive processes and waste, and preventing unnecessary movements. Additionally, post-process material arrangement was eliminated. To minimize this activity, clear planning was established regarding layout and inventory deadlines, preventing materials from being left in one place for extended periods.

Table 3 Future stage NVA, NNVA, NVA

Processing stage	VA (sec)	NNVA (sec)	NVA (sec)
Material transfer from logistics		1,456	
Marking of the material to be cut		129	
Material cutting process using in housen machines	168		
Material inspection by QC team		303	
Loading material after the cutting process		860	
Transfer of materials to the next workshop area		1,538	
Setting the degree of the ABM 14 machine	196		
Loading material that will be bevel process		68	
Rough bevel process using ABM 14 machine	288		
The smoothing process uses a manual bevel process	392		
Unloading		73	
Inspection of bevel angle measurements by the QC team		77	
Move the material to the bipel press machine		93	
Press/roll machine setup (set up the required dies according to size)	1,919		
Press/roll process	361		
Final inspection by QC team after press/roll process		424	
Transfer f pipe sleeve to logistic area		1,156	
Packaging process		2,367	
Transport in truck		843	
Total	6,534	6,177	0

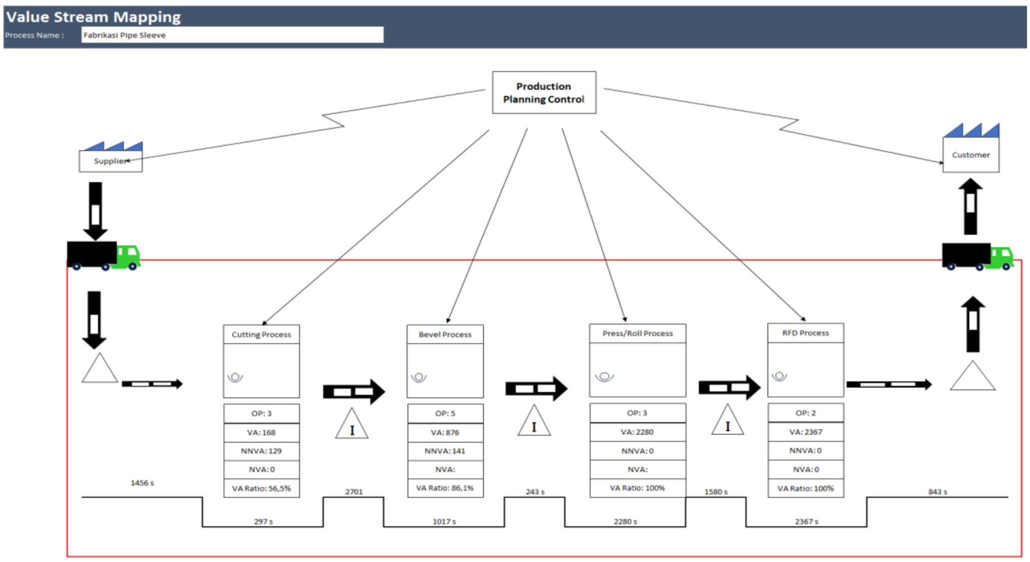

Fig 12. Future Value Stream Mapping (VSM) of Pipe Sleeve Fabrication

Expected Manufacturing Lead Time (MLT) of Fabrication Pipe Sleeve. *Manufacturing lead time* (MLT) refers to the total time required to produce a single unit of output. A shorter lead time indicates a more efficient production process. In this study, the implementation of lean tools demonstrated the potential to reduce the manufacturing lead time in pipe sleeve fabrication. In the current state, the *manufacturing lead time* (MLT) was recorded at 16.43 seconds, whereas the future state – after applying lean improvement initiatives – is expected a *manufacturing lead time* (MLT) of 12,711 seconds.

Future state PCE of Fabrication Pipe Sleeve. In the future state, the effective application of lean tools is projected to reduce NNVA time from 6,977 seconds to 6,177 seconds, while eliminating NVA activities entirely, as non-value-added fabrication processes are removed. As previously mentioned, the *process cycle efficiency* (PCE) is expressed as the ratio of VA time to *manufacturing lead time* (MLT). Based on this calculation, the future state *process cycle efficiency* (PCE) is expected to reach 51.4% which exceeds the international competitive benchmark of 25%.

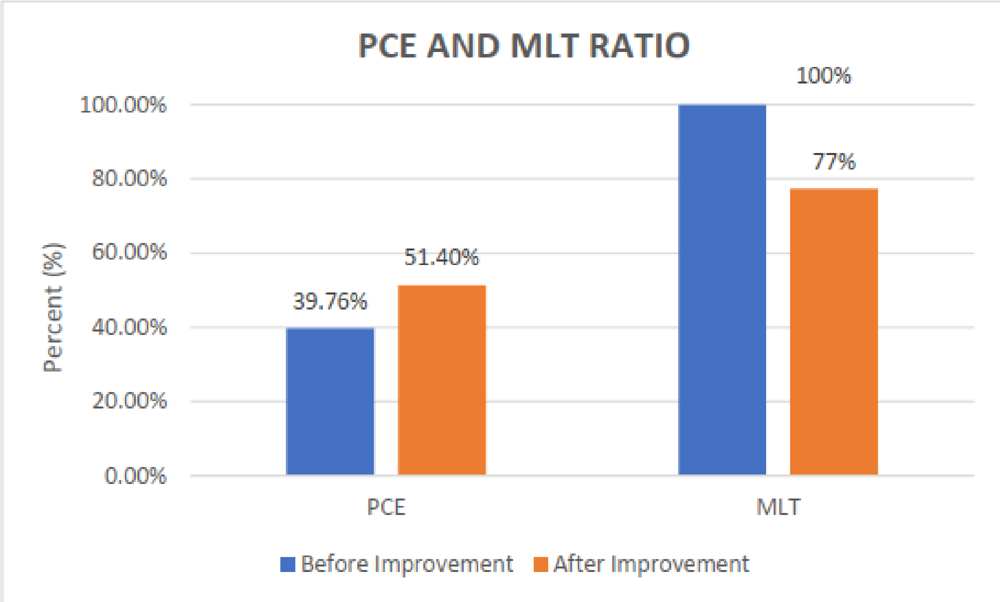

Fig 13. Comparison of PCE and MLT currently and after improvement

Process cycle efficiency (PCE) significantly improved from 39.76% to 51.4% following the evaluation and optimization of the pipe sleeve fabrication process. The primary driver of this improvement was the elimination of *non-value-added* (NVA) activities, which led to a substantial reduction in the *manufacturing lead time* (MLT). Refer with: Table 4, MLT decreased from 16,430 seconds to 12,711 seconds.

Table 4 Factors Contributing to the Improvement of PCE and MLT

	PCE (%)	MLT (s)	Factor
Current Condition	39.76	16,430	The MLT value was determined based on VA, NVA, and NNVA components. In the initial condition, the NVA category encompassed activities classified as waste, including redundant inspections, idle or waiting periods, and unnecessary movements.
Future Condition	51.40	12.711	Following the improvement initiatives, the PCE value increased as each activity was systematically evaluated, with non-value-added activities being eliminated and sources of waste reduced. Consequently, process effectiveness was enhanced, lead time was shortened, and a 23% reduction in overall lead time was achieved.

Conclusion

This study presents a case study of improvement in pipe sleeve fabrication by reducing *manufacturing lead time* (MLT) and improving process cycle efficiency (PCE) through lean tools. This study focused on operation renovation to eliminate *non-value added* (NVA) time, reduce *manufacturing lead time* (MLT), and improve *process cycle efficiency* (PCE) through *value stream mapping* (VSM), pareto chart, fishbone diagram, 5S, and kaizen. In conclusion, it can be concluded that lean tools are an effective way to identify waste and eliminate *non-value added* (NVA) and *manufacturing lead time* (MLT).

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