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(Research/Review) Article

Analysis of Lean Manufacturing Implementation to Improve Production Efficiency and Reduce Supply Chain Costs Using the Value Stream Mapping Approach

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Abstract: In response to increasing competition in the manufacturing sector, PT X—a copper busbar manufacturing company—implemented Lean Manufacturing supported by Value Stream Mapping (VSM) to improve production efficiency and reduce supply chain costs. This study utilizes VSM, Value Stream Analysis Tools (VALSAT), and Root Cause Analysis (5 Whys) to identify sources of waste and formulate improvement strategies. The analysis identified three dominant wastes: waiting time, product defects, and excess inventory. These were mainly caused by the lack of standardized material preparation procedures, inadequate supporting equipment, and poor integration between the incoming inspection process and the Enterprise Resource Planning (ERP) system. To address these issues, the study proposes installing silica rolls, providing air wipers and flatness tools, developing standardized work instructions, and integrating Internet of Things (IoT) technology with the ERP system for real-time monitoring. As a result of implementing these solutions, PT X successfully reduced its defect rate from 6.23% to 1.32%, decreased lead time, and achieved notable savings in supply chain costs. The findings demonstrate that integrating Lean Manufacturing principles with VSM can effectively eliminate non-value-added activities, streamline production processes, and enhance overall competitiveness. This study reinforces the strategic value of Lean tools in continuous improvement initiatives within the manufacturing industry.

Keywords: Lean Manufacturing, Production Efficiency, Supply Chain Optimization, Value Stream Mapping, Waste Reduction

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1. Introduction

The manufacturing sector in Indonesia is currently facing significant challenges, as reflected in the continued decline of the Manufacturing Purchasing Managers' Index (PMI) over the past few months. The PMI has shown a downward trend since April 2024. Data released by Standard & Poor's (S&P) Global indicates that Indonesia's manufacturing PMI in July and August 2024 fell below the 50 threshold, recorded at 49.3 and 48.9 respectively (Wuryandani, 2024).

Various methodological approaches must be implemented to continuously improve productivity and quality. The concept of lean production was first introduced by Krafcik (1988), and later popularized by Womack et al. (1990), with the aim of minimizing waste. (Womack & Jones, 1997) stated that the implementation of lean principles is not only necessary on the production floor but also throughout the entire supply chain. This requires time and effort to streamline inventory for greater efficiency, minimize defective outputs, and enhance the potential for more optimal production quantity variance.

Waste can occur throughout the entire production process, either consciously or unconsciously, and often happens repeatedly in the same activities (Gupta et al, 2013). Based on these findings, the concept of lean thinking evolved, incorporating five core principles: first, defining value from the customer's perspective; second, identifying the value stream; third, ensuring that value flows smoothly and without interruption to the customer; fourth, implementing a pull system (value is only delivered when requested by the customer); and fifth, producing products that offer competitive advantages and differentiation, while also ensuring high quality through efficient production processes to minimize costs and enable on-time delivery to customers.

PT. X is a manufacturing company specializing in the production of automotive cables and copper busbars. The types of cables produced include those for vehicle electrical systems (automotive cables) and battery cables. In addition, the company manufactures other copper components such as copper busbars, which are large electrical conductors commonly used in power distribution systems. However, during the copper busbar production process, significant waste is still generated, resulting in considerable profit loss. Waste is defined as any activity that does not add value along the process flow of transforming inputs into outputs (Indriati et al., 2023).

Initial observations in the raw material casting line further reveal the presence of non-value-added activities that contribute to increased lead time. For example, the preparation of raw materials and tools for copper rods takes longer than expected due to repeated and excessive tooling processes. Meanwhile, the rotary extrusion line frequently experiences machine breakdowns and long start-up times caused by material cracks, delaying operations. In addition, high work-in-process (WIP) levels lead to production downtime, preventing the achievement of optimal output.

Based on the existing conditions, it is necessary to implement a lean manufacturing approach to minimize waste by identifying value-added, necessary but non-value-added, and non-value-added activities. Lean manufacturing focuses on time efficiency and cost reduction by eliminating waste in all activities required to fulfill customer orders. This approach improves system and production process performance by identifying, measuring, analyzing, and finding comprehensive improvement solutions (Rother & Shook, 2003). To identify the most dominant waste in this case, the study applies Value Stream Mapping (VSM) to create current and future state maps of the production flow, supported by the comprehensive use of Value Stream Analysis Tools (VALSAT) through seven mapping tools to address issues in the copper busbar production process at PT. X.

2. LITERATURE REVIEW

Supply Chain

Supply chain refers to a series of integrated activities that range from raw material procurement, production processes, distribution, and ultimately delivering the product to the end customer (Punjawan, 2017). This concept encompasses not only the internal activities of a company but also involves various external parties such as suppliers, distributors, and logistics service providers. The main goal of the supply chain is to create an efficient and value-added flow of goods, information, and finances throughout the process.

In a competitive business environment, effective supply chain management can enhance responsiveness to market demand, reduce operational costs, and strengthen a company's competitiveness. Therefore, the supply chain is not merely seen as a logistics system, but as a strategic element that influences the overall performance of a company. Proper management of the supply chain is key to building sustainable competitive advantage. The main aspects of supply chain management in a manufacturing company include:

1. Product Development – Activities related to designing new products
2. Procurement or Purchasing – Activities related to acquiring raw materials
3. Planning & Control – Activities for production and inventory planning
4. Production – Activities involved in the manufacturing process
5. Distribution – Activities related to delivering products to customers
6. Return – Activities related to handling and managing returned products

Supply Chain Cost

Revenue and cost are the main factors in the supply chain, where cost data provides deeper insights compared to other sources (Koberg & Longoni, 2018). Reducing costs becomes an essential strategy for increasing net profit and the market value of a company (Kumar & Chang, 2007). Further emphasize that reducing supply chain costs (Supply Chain Cost/SCC) has become a strategic tool in achieving competitive advantage (Su & Lei, 2008).

Supply chain costs can be classified into five main categories: Manufacturing Costs (MANF), Administration Costs (ADMN), Distribution Costs (DIST), Warehouse Costs (WRHS), and Capital Costs (CPTL), along with one supporting category, namely Installation Costs (INSTL) (Pettersson & Segerstedt, 2013). The total supply chain cost is calculated by summing these six elements. By understanding and managing these costs effectively, companies can enhance operational efficiency and improve their competitiveness in the market.

Lean Manufacturing

Lean is an approach aimed at creating an efficient production flow along the value stream by eliminating all forms of waste and enhancing value-added activities within the production process. The main objective of this concept is to improve the value-to-waste ratio, thereby maximizing the benefits delivered to customers. In the context of Lean Manufacturing, identifying which activities add value and which do not is a crucial step in improving process efficiency. Manufacturing activities can be classified into value-adding activities, non-value-adding activities, and necessary non-value-adding activities, each playing a different role in determining how efficiently resources are utilized in production (Tay & Loh, 2022).

In lean thinking, waste is defined as any activity that does not contribute value in transforming inputs into outputs (Indriati *et al.*, 2023). The core of lean manufacturing lies in the systematic elimination of these wastes, which often obstruct a company's ability to deliver optimal customer value. Waste in lean manufacturing is categorized into seven types, commonly referred to as the seven wastes: transportation, inventory, motion, waiting, over-processing, over-production, and defects. These categories highlight inefficiencies that, if left unaddressed, can significantly impact operational performance and reduce competitiveness in the marketplace.

3. RESEARCH METHODOLOGY

Approach Study

The research approach used in this study is a qualitative approach. A qualitative research approach is a method that focuses on an in-depth understanding of a phenomenon, emphasizing not just statistical data but also the processes and experiences of research subjects (Subhaktiyasa, 2024). This approach assumes that reality is subjective and shaped through social interactions and individual perceptions. It was chosen because the study aims to deeply understand the phenomena occurring within a manufacturing company that produces copper busbars, particularly regarding the implementation of Lean Manufacturing using the Value Stream Mapping method to improve production efficiency and reduce supply chain costs within the company.

Types of research

This study uses a case study method, which is commonly applied to explore specific problems or phenomena in various fields of science (Bado, 2021). As a qualitative research design, the case study approach allows for an in-depth analysis and evaluation of real-world events. It was chosen to explore the implementation of Lean Manufacturing using the Value Stream Mapping method within an automotive manufacturing company that produces copper busbars.

Through this method, the researcher can directly observe production processes, conduct interviews, and analyze data from multiple sources such as production documents, output inspection reports, and supply chain cost data. This approach also enables the identification of waste within the value stream and the design of improvement strategies aligned with Lean Manufacturing principles. The collected data is then analyzed using statistical methods to examine the relationship between Lean Manufacturing, Value Stream Mapping (VSM), and Supply Chain Cost Reduction.

Subject Research

Research subjects are individuals or groups that serve as the primary sources of data in a study, selected based on specific criteria aligned with the research objectives. In scientific research, these subjects are also referred to as data sources, which may include people or objects investigated through methods such as observation, literature review, or interviews. The information gathered from these sources forms the basis for analysis and becomes the research (Nashrullah et al., 2023). In qualitative research, subject selection follows several criteria (Rahmadi, 2011): individuals who have long been actively involved in the area being studied, those directly engaged in the activities, and individuals with sufficient time to provide the necessary information.

In this study, the research subjects are all individuals directly involved in the implementation of Lean Manufacturing at the company being studied. This includes personnel from the Production department, Quality Control, PPIC & Logistics, Engineering, and Business Development, which encompasses Business Development, Marketing, and Purchasing. These subjects were chosen based on their experience and active involvement in production and supply chain management processes to ensure the data collected is relevant, comprehensive, and reflective of the actual conditions.

4. RESULTS AND DISCUSSION

Company Overview

PT. X is a manufacturing company specializing in the production and supply of automotive cables and copper busbars, particularly for the automotive manufacturing sector. Established in 1994 and located in Surabaya, East Java, PT. X offers several flagship products, with copper busbar being one of its main and newest offerings, launched in 2023. These busbars are flat, high-conductivity copper conductors with widths ranging from 15 to 100 mm and thicknesses between 2 and 10 mm. Widely used in power distribution systems, industrial control panels, electric vehicles, and solar power systems, copper busbars are crucial for modern electrical infrastructure due to their excellent electrical and thermal conductivity, durability, and ease of installation.

The copper busbar production process consists of five key stages: incoming raw material inspection, raw material casting, rotary extrusion, drawbench machining, and packing. The process begins with the inspection of high-purity (≥99.99%) copper cathodes to ensure material quality through chemical and physical tests. The cathodes are then melted and cast into rods using the upcast method. These rods undergo further transformation through rotary extrusion to form copper strips, followed by drawbench machining where the strips are pulled and cut to precise final dimensions. Quality checks are performed throughout to maintain technical standards and dimensional accuracy.

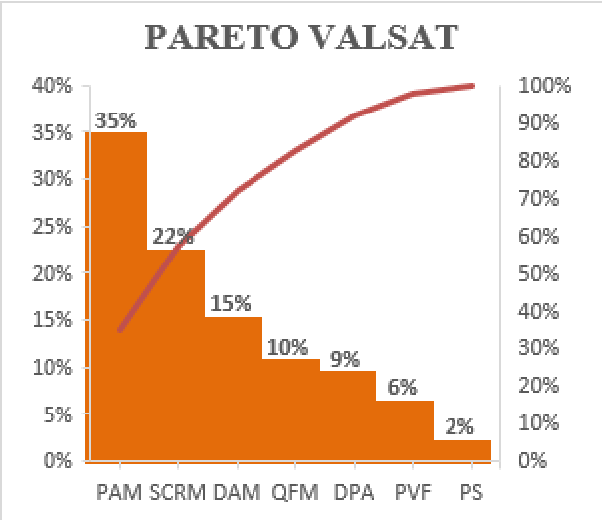
In the final stage, finished copper busbars are carefully packed in moisture-proof plastic and wooden crates, complete with batch labels and specifications. This ensures protection during storage and shipping and facilitates traceability in the logistics system. With the growing market demand both domestic and international PT. X views copper busbar production as a strategic opportunity to build competitive advantage and position itself as a market leader. Achieving production efficiency and maintaining high quality are essential for supporting the company's growth in the global energy and automotive sectors.

Research Findings

The data for this study was obtained through questionnaires distributed to selected informants, including the Production Manager and Supervisor, Quality Control Manager and Supervisor, PPIC & Logistics Manager, Engineering Manager, and from the Business Development department: the Business Development Manager, Purchasing Manager, and Marketing Manager. In total, 9 employees were selected as samples to provide a comprehensive range of perspectives regarding production efficiency through the implementation of Lean Manufacturing using the Value Stream Mapping (VSM) method to improve efficiency and reduce supply chain costs.

Table 1. Questionnaire Data Recapitulation

Jenis Waste	R1	R2	R3	R4	R5	R6	R7	R8	R9	Total	%
Transportation	3	4	4	5	5	4	4	3	3	35	15%
Inventory	4	4	3	3	6	6	5	4	5	40	17%
Movement	2	3	2	3	3	3	2	3	3	24	10%
Waiting	4	5	4	4	5	6	5	4	4	41	18%
Over Production	4	3	3	3	2	3	3	3	4	28	12%
Excess Processing	3	3	2	3	2	3	3	2	3	24	10%
Defect	4	4	5	4	5	4	4	4	4	38	17%



Picture 1. Pareto VALSAT

The questionnaire focused on the frequency of occurrence of the seven types of waste throughout the process from order intake to product distribution. Based on the results, it was identified that the most frequent types of waste encountered during this process were waiting, inventory, and defect. Additionally, based on the weighting given by the respondents, the most recommended tools for identifying the seven types of waste during the production process are PAM (Process Activity Mapping), SCRM (Supply Chain Response Matrix), DAM (Demand Amplification Mapping), and QFM (Quality Filter Mapping).

Process Activity Mapping (PAM) is used to map detailed processes from production through to delivery to the customer, utilizing specific symbols to represent each activity: (O) for Operation, (T) for Transportation, (I) for Inspection, (S) for Storage, and (D) for Delay. The main objective of this mapping is to identify the proportion of value-adding and non-value-adding activities, including those that can be minimized or are unavoidable. The steps in developing PAM include direct observation of all activities from start to finish, systematically recording the type and sequence of each activity along with its duration, classifying them into the five categories, and calculating the percentage of activities that fall into value-adding (Operation and Inspection), necessary non-value-adding (Transportation and Storage), and non-value-adding (Delay). This process results in comprehensive data on the number, duration, and classification of each activity, helping to identify which activities contribute value and which do not. The following presents the PAM mapping results for the copper busbar production process.

Table 2. Process Activity Mapping (PAM) Current State

Activity	total	Time (s)	%	VA	NNVA	NVA
Operation	17	42.750	71%	42.750		
Transportation	8	3.845	6%		3.845	
Inspection	6	5.160	9%	5.160		
Storage	5	3.510	6%		3.510	
Delay	8	5.220	9%			5.220
Total	**44**	**60.485**	**100%**	**47.910**	**7.355**	**5.220**
	Ratio			**79%**	**12%**	**9%**

From the table above, it can be seen that a total of 44 activities are carried out during the production process up to the delivery of the copper busbar product to the customer. Non-Value-Adding activities still account for a relatively high ratio of 9% of the total activities, consuming 1.45 hours. This figure exceeds the company's predetermined threshold of 5% of total activities.

The Supply Chain Response Matrix (SCRM) is an analytical tool used in supply chain management to measure how the supply chain responds to market demand changes by considering both cost and response speed. It helps identify trade-offs between lead time and cost across supply chain processes. Reducing inventory and lead time contributes to value stream savings in the production line.

To develop the SCRM and analyze cumulative raw material arrivals as well as WIP and finished goods output, the following data is required:

a. Days of physical stock

b. Lead time

Table 3. Supply Chain Response Matrix (SCRM) Current State

No	Item	*Days Physical Stock*	*Lead Time*	*Cummulative Days Physical Stock*	*Cummulative Lead Time*
1	*Raw Material Copper Cathode*	1,12	1,00	1,12	1,00
2	WIP Production	1,66	0,58	2,78	1,58
3	Stock *Finish Good Copper Busbar*	1,26	0,29	4,05	1,87
	Total				**5,92**

Based on the table above, the WIP area has the longest days of physical stock at 1.66 working days. This delay may lead to inventory and waiting waste, disrupting material flow and increasing lead time. The cumulative lead time is 6 working days, which exceeds the company's target of 5 days.

Demand Amplification Mapping (DAM) is a method used to identify, analyze, and understand demand fluctuations within the supply chain. It is specifically applied in lean supply chain management to address the bullwhip effect where small changes in end-customer demand cause larger fluctuations upstream. By mapping demand patterns, companies can evaluate inefficiencies and develop improvement strategies based on actual customer demand data.

Table 4. Demand Amplification Mapping (DAM) Future State

Month	*Beginning Stock* (Kg)	*Production* (Kg)	*Demand* (Kg)	*End Stock* (Kg)	*Days Physical Stock* (HK)
Nov-24	43.068,07	137.079,80	146.615,34	33.532,53	5,29
Dec-24	33.532,53	159.191,40	158.488,12	34.235,81	5,96
Jan-25	34.235,81	149.108,00	143.720,19	39.623,63	6,89
Total	**110.836,42**	**445.379,20**	**448.823,64**	**107.391,98**	

Based on the chart and table, the average finished goods stock of copper busbars is 35,797 kg or 6.05 working days—well above the company's maximum target of 2 working days. With an average customer demand of 149,607 kg, it is evident that monthly production plus initial stock consistently exceeds actual demand. This indicates a risk of unsold inventory potentially turning into dead stock.

Quality Filter Mapping (QFM) is one of the analytical tools within the Value Stream Analysis Tools (VALSAT) approach, used to map and evaluate the quality level of production processes.

This enables companies to implement more effective improvements at critical points that most impact the quality of production output. Below are the details of copper busbar production rejects from November 2024 to January 2025:

Table 5. Output Production Copper Busbar Feb 2025 – Apr 2025

Defect Variation (Kg)	Nov-24	Dec-24	Jan-25
Finish Good	137.080	139.191	117.108
Burry	220	588	73
Crack	1.617	4.923	1.837
Curved	73	441	441
Joint	3.527	1.837	1.690
Scratch	1.543	2.866	4.409
Total Defect	6.981	10.655	8.450
Total Output	**144.060**	**149.846**	**125.558**

The table shows that during the copper busbar production from November 2024 to January 2025, an average of 8,695 kg of defects occurred per month, with an average defect rate of 6.23%. This exceeds the company's maximum allowable defect rate of 4.5%.

Discussion

After conducting measurements using four key VALSAT tools Process Activity Mapping (PAM), Supply Chain Response Matrix (SCRM), Demand Amplification Mapping (DAM), and Quality Filter Mapping (QFM) the analysis revealed significant sources of waste in the copper busbar production process, including delays, excess inventory, and a high defect rate. To determine the root causes of these issues, a 5 Whys analysis was conducted, which uncovered specific contributing factors for each type of waste. Based on these findings, several improvement strategies were proposed to address the inefficiencies observed throughout the production and supply chain stages.

To overcome delays in the incoming material process and preparation of materials and tooling, it is recommended to implement a regulation table (RT) and integrate IoT technology with measurement tools to accelerate and improve the accuracy of setup activities. For the high inventory levels—indicated by extended cumulative lead times and excessive days of physical stock—the root cause was identified as the use of an ineffective forecasting method. Thus, replacing the current moving average forecasting method with a more responsive approach is suggested to better match actual demand. In addressing the high defect rate, which averaged 6.23% per month, the analysis pointed to inadequate quality control at critical process points. Recommended improvements include the installation of 3 roll silica, air wipers, flatness table tools, and the development of standardized work instructions to ensure consistent product quality and reduce defects.

The Supply Chain Cost (SCC) was calculated by summing six main components: manufacturing cost, administration cost, distribution cost, warehouse cost, capital cost, and installation cost. Manufacturing costs include raw materials, direct labor, and factory overhead, while administration costs cover indirect operational expenses. Warehouse and capital costs account for storage and long-term investment in production assets, respectively. Distribution costs include transportation, temporary storage, and packaging. Installation costs, though typically included, were assumed to be zero in this study due to unavailable data. Following the implementation of VALSAT-based improvements, a cost comparison revealed substantial savings in multiple areas. Enhancements in material flow, demand forecasting, inventory management, and product quality collectively resulted in a total supply chain cost reduction of Rp 3,286,996,299, demonstrating the effectiveness of the proposed lean initiatives.

Table 6. Supply Chain Cost Copper Busbar

Description	Before Improvement		After Improvement		Deviation	
Manufacturing Cost	Rp	53.673.570.129	Rp	51.006.636.012	Rp	2.666.934.117
Administration Cost	Rp	1.341.839.253	Rp	1.275.165.900	Rp	66.673.353
Distribution Cost	Rp	4.696.437.386	Rp	4.463.080.651	Rp	233.356.735
Warehouse Cost	Rp	2.504.766.606	Rp	2.380.309.681	Rp	124.456.925
Capital Cost	Rp	3.936.061.809	Rp	3.740.486.641	Rp	195.575.169
Installation Cost		Rp -		Rp -		Rp -
Total	**Rp**	**66.152.675.184**	**Rp**	**62.865.678.885**	**Rp**	**3.286.996.299**

5. CLOSING

Conclusion

Based on the results and discussion presented in the previous chapter, this study concludes that three types of waste have the most significant impact on the copper busbar production process: *waiting* (18%), *inventory* (17%), and *defect* (17%). Among these, *waiting* contributes the most, occurring in 8 out of 44 total activities. The root causes of waiting include the absence of a regulation table (RT) for preparing materials and tools at each machine, as well as the lack of IoT integration between the weighing system and the company's ERP during the incoming material process.

Using the Value Stream Analysis Tools (VALSAT) approach, several mapping tools were applied. First, Process Activity Mapping (PAM) led to the recommendation of integrating the weighing system with the ERP and creating RTs for material and tool preparation. As a result, the waiting time was reduced from 5,220 seconds to 2,250 seconds. Second and third, Supply Chain Response Matrix (SCRM) and Demand Amplification Mapping (DAM) suggested switching to a double exponential smoothing forecasting method, which reduced cumulative lead time from 6 to 5 working days and lowered inventory turnover from 6 to 2 days. Fourth, Quality Filter Mapping (QFM) recommended the addition of 3 roll silica, air wipers, flatness table tools, and the creation of standardized work instructions for the drawbench process, which reduced the average defect rate from 6.23% to 1.32%.

The implementation of Lean Manufacturing from order intake to product delivery had a positive impact on supply chain costs. The improvements led to a reduction in manufacturing cost by Rp 2,666,934,117, administration cost by Rp 66,673,353, distribution cost by Rp 233,356,735, warehouse cost by Rp 124,456,925, and capital cost by Rp 195,575,169. Overall, the company achieved a total cost saving of Rp 3,286,996,299, or approximately 5%, helping to significantly reduce loss profit and improve operational efficiency.

Suggestion

The company is advised to begin implementing IoT integration with its ERP system to ensure a clear and accessible flow of production process information for all employees. Additionally, it is essential for the company to strengthen quality control throughout the production process by maintaining consistent product quality. Consistency in quality assurance has a positive impact on reducing the company's loss to profit ratio, thereby supporting operational efficiency and long term business performance.

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