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Original Article

Integration of VSM and SMED for Optimization of the CCB Milling Process

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Abstract:

Productivity improvement in manufacturing systems requires systematic identification and elimination of waste, particularly in bottleneck processes. This study was conducted at PT XYZ, an automotive component manufacturer experiencing low productivity in the CCB part production line. The milling process was identified as the primary bottleneck, with an initial cycle time of 472 seconds for 6 pieces and an average output of 550 pcs/day, achieving only 75.6% of the production target. This research aims to identify the causes of waste, reduce cycle time in the milling process, and increase production output in line with management targets. The study applies Value Stream Mapping (VSM) to analyze material and information flow, Process Activity Mapping (PAM) to classify internal and external activities, and the Single Minute Exchange of Dies (SMED) method to minimize setup time. Improvements were implemented using the PDCA (Plan–Do–Check–Act) cycle. Root cause analysis using fishbone and 5W+1H identified manual clamping operations as the main contributor to excessive internal time and variability. A semi-automatic pneumatic clamping system was introduced to replace manual bolt tightening and clamp handling. The results show a reduction in internal setup activities from 12 to 9 activities and a decrease in cycle time from 472 seconds to 425 seconds (9.9%). Consequently, daily production output increased from 550 pcs/day to 652 pcs/day, representing an 18.5% productivity improvement and exceeding the initial 10% target. The findings confirm that integrating VSM and SMED with semi-automation effectively enhances operational performance without full-scale automation investment.

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Introduction

The rapid development of science and technology has intensified global competition in the manufacturing sector, compelling companies to continuously improve operational performance. Manufacturing organizations are increasingly required to enhance productivity while maintaining product quality and cost efficiency. In this context, human resources and process optimization become critical determinants of competitiveness. Lean manufacturing has emerged as a systematic approach to eliminating waste and maximizing value-added activities within production systems (Kartika, 2020; Litvaj, 2023). Originating from the Toyota Production System, lean principles emphasize waste reduction, flow efficiency, and continuous improvement to enhance organizational performance (Litvaj, 2023; Solís-Quinteros et al., 2021).

In 2024, PT XYZ, an automotive component manufacturer located in Bekasi, Indonesia, experienced stable sales volume compared to the previous year. However, profitability declined due to increasing operational inefficiencies and external market pressures. Industry projections indicated a potential contraction in the automotive market for 2025, placing additional pressure on manufacturing firms to maintain margins without sacrificing competitiveness. Rather than increasing selling prices or reducing workforce costs—both of which involve significant strategic risks—management decided to focus on internal process optimization, targeting a 10% productivity improvement under the FY 2025 Management Policy.

One of the most critical production lines at PT XYZ is the Cap Crank Bearing (CCB) component, a precision automotive part requiring high dimensional accuracy. Preliminary operational data revealed a significant imbalance in production flow, where the milling process exhibited the longest cycle time of 472 seconds per six pieces. This condition created a bottleneck that constrained overall daily output, despite downstream processes having higher theoretical capacities. Such imbalance is consistent with lean theory, which states that system throughput is limited by the slowest process within the value stream (Fatinnisa & Saifuddin, 2024; Khairai & Khalil, 2024). Consequently, non-value-added (NVA) activities and idle time increased across other workstations.

Lean manufacturing literature emphasizes that waste reduction is fundamental to performance improvement. The seven categories of waste—including overproduction, waiting, motion, transportation, inventory, defects, and overprocessing—directly affect operational efficiency (Litvaj, 2023; Rahman, 2021; Solís-Quinteros et al., 2021). Several studies have demonstrated the effectiveness of Value Stream Mapping (VSM) in identifying waste and visualizing material and information flows. Koh and Singgih (2021) reported significant lead time reduction through VSM implementation in a plywood manufacturing company. Fatinnisa and Saifuddin (2024) showed that VSM effectively minimized waste in medical manufacturing, while Simamora and Insanita (2024) confirmed its impact in precious metal production. These findings reinforce the relevance of VSM as a diagnostic and strategic improvement tool.

However, although VSM is effective in identifying bottlenecks and waste sources, it often does not directly address setup-related inefficiencies in batch production environments. In machining industries, setup time and changeover processes frequently contribute significantly to cycle time variability. Single-Minute Exchange of Die (SMED) has been widely recognized as a structured methodology to reduce setup time by converting internal activities into external activities and streamlining remaining internal operations (Marcella & Widjajati, 2024; Nurrizky et al., 2021). Marcella and Widjajati (2024) demonstrated a substantial reduction in setup time in injection molding processes through SMED implementation, while Nurrizky et al. (2021) confirmed its effectiveness in CNC machining operations.

Despite the extensive application of VSM and SMED independently, the integration of both methods in precision machining environments—particularly in semi-automated clamp systems within automotive component production—remains limited in current literature. Previous studies predominantly focus on assembly lines, general manufacturing processes, or injection molding systems (Fatinnisa & Saifuddin, 2024; Koh & Singgih, 2021; Marcella & Widjajati, 2024; Simamora & Insanita, 2024). Furthermore, few empirical studies quantitatively evaluate the impact of semi-automation on reducing internal setup variability and operator-dependent cycle time fluctuations. This represents a research gap in understanding how integrated lean tools can systematically reduce bottleneck-driven cycle time in high-precision machining processes.

From a theoretical perspective, lean manufacturing emphasizes continuous improvement (Kaizen) supported by the PDCA cycle (Arfan et al., 2023; Hethsia.S, 2025). Integrating VSM for macro-level value stream diagnosis with SMED for micro-level setup optimization provides a comprehensive framework for addressing both systemic imbalance and localized inefficiencies. Moreover, lean practices have been empirically linked to improved sustainable firm performance (Hassan & Pasha, 2023). Therefore, implementing a semi-automatic pneumatic clamping system aligned with lean principles presents both operational and theoretical relevance.

Accordingly, this study aims to:

1) identify the primary waste factors contributing to cycle time inefficiency in the CCB milling process at PT XYZ;
2) propose and implement improvement strategies based on integrated VSM and SMED methodologies; and
3) evaluate the extent of productivity improvement achieved through cycle time reduction, targeting a minimum 10% increase in output.

The findings of this study are expected to contribute theoretically to the development of lean manufacturing applications in machining-based industries and practically to provide a replicable improvement framework for automotive component manufacturers facing similar bottleneck challenges.

Methods

This study employed a quantitative case study approach to examine the implementation of Lean Manufacturing principles in a real industrial setting. The case study design was selected to enable in-depth investigation of operational inefficiencies within a specific production system and to evaluate the measurable impact of improvement interventions. Lean manufacturing emphasizes systematic waste elimination and continuous improvement to enhance operational efficiency (Litvaj, 2023; Solís-Quinteros et al., 2021). In line with prior empirical studies demonstrating the effectiveness of lean tools in manufacturing optimization (Fatinnisa & Saifuddin, 2024; Koh & Singgih, 2021), this research integrated Value Stream Mapping (VSM) and Single-Minute Exchange of Die (SMED) methodologies to reduce cycle time and increase productivity in a machining environment.

The research was conducted at PT Ganzu Gisma Seiko, located in the Jababeka Industrial Area, Cikarang Selatan, Bekasi, Indonesia. The study period extended from January to June 2025. Baseline data collection was carried out during February–March 2025, while improvement implementation and post-intervention measurement were conducted between April and June 2025. The research focused specifically on the milling process of the Cap Crank Bearing (CCB) component in Plant 1 Machining, which had been identified as the primary bottleneck within the production line.

The object of analysis was the internal setup and machining activities associated with the CCB milling process. Particular attention was given to manual internal operations, including bolt tightening of clamps, clamp installation and removal, and workpiece positioning on the jig fixture. Preliminary observations revealed that these activities consumed an average of 404 seconds per cycle and exhibited operator-dependent variability with deviations reaching 21 seconds. Such variability contributed to unstable production flow and reduced throughput, consistent with lean theory that identifies waiting and motion as critical waste categories (Litvaj, 2023; Rahman, 2021). Therefore, this study aimed to systematically identify waste sources and redesign the setup process through structured lean interventions.

Data collection involved both primary and secondary sources. Primary data were obtained through direct shop-floor observation (genba), real-time time studies using a stopwatch, and structured interviews with machine operators, production supervisors, and engineering personnel. Time measurements were conducted over multiple production cycles to ensure reliability and consistency of cycle time data. Secondary data included production output records, standard operating procedures (SOPs), process flow charts, inspection reports, and historical performance documentation. The triangulation of these data sources enhanced the validity of findings and ensured accurate representation of operational conditions.

The analytical procedure began with the development of a Current State Value Stream Map (VSM) to visualize material and information flows across the CCB production line. VSM has been widely recognized as an effective diagnostic tool for identifying non-value-added activities and bottlenecks in manufacturing systems (Fatinnisa & Saifuddin, 2024; Simamora & Insanita, 2024). The mapping process quantified value-added time, non-value-added time, work-in-process inventory, and information flow delays. Based on the VSM analysis, the milling workstation was confirmed as the primary constraint in the value stream.

Following bottleneck identification, a detailed setup activity analysis was conducted using the SMED framework. SMED methodology focuses on separating internal and external setup activities and converting as many internal activities as possible into external activities to minimize machine downtime (Marcella & Widjajati, 2024; Nurrizky et al., 2021). Each setup element was categorized, timed, and evaluated for potential simplification, elimination, or mechanization. Root cause analysis was performed using Fishbone (Ishikawa) diagrams and Pareto analysis to prioritize dominant waste factors. Additionally, the 5W+1H framework was employed to formulate structured improvement proposals.

The improvement intervention involved redesigning the manual clamping system into a semi-automatic pneumatic clamping mechanism to reduce internal setup time and minimize operator dependency. This approach aligns with lean continuous improvement (Kaizen) principles supported by the PDCA cycle (Arfan et al., 2023; Hethsia.S, 2025). After implementation, post-improvement cycle time measurements were conducted using identical procedures as the baseline assessment to ensure comparability.

Data analysis was performed using comparative statistical evaluation of pre- and post-improvement cycle time, output capacity, and productivity levels. The percentage reduction in cycle time and the corresponding increase in daily output were calculated to determine whether the targeted 10% productivity improvement was achieved. Results were presented using tables and graphical comparisons to illustrate operational performance changes. This structured methodology ensures replicability and provides a practical framework for lean-based bottleneck optimization in machining-intensive manufacturing environments.

Results

Operational Data Collection

Data were collected through direct observation of the Cap Crank Bearing (CCB) production line under normal operating conditions. The production system operates in two shifts per day, with each shift consisting of 8 working hours. The effective working time was determined at 85% of total working hours, considering break times and minor stoppages.

The CCB production flow consists of four sequential processes: milling, visual inspection 1, press machine, and visual inspection 2. Each process operates using a batch system of six pieces per cavity. Daily production capacity was calculated using the following formula:

$$Daily\ Capacity = \frac{Effective\ Working\ Time}{Cycle\ Time} \times 6\ pcs$$

Table 1. presents the operational data obtained from the shop floor.

No	Process Name	Working Time (min)	Operators	Effective Time 85% (min)	Cycle Time / 6 pcs (min)	Daily Capacity (pcs)
1	Milling	480 × 2 shifts	2	816	7.86	623
2	Visual Check 1	480	1	408	1.50	1632
3	Press Machine	480	1	408	3.00	816
4	Visual Check 2	480	1	408	3.16	775

Source: Processed operational data, 2025

The data indicate significant capacity differences between workstations. The milling process recorded the lowest daily capacity at 623 pieces, while Visual Check 1 achieved the highest capacity at 1,632 pieces per day. The disparity confirms that the milling process acts as the bottleneck in the production line.

Value-Added (VA) and Non-Value-Added (NVA) Time Analysis

To quantify system inefficiencies, value-added (VA) and non-value-added (NVA) times were calculated using the milling output (623 pcs/day) as the key throughput quantity. VA time was calculated as:

$$VA = \left(\frac{Quantity}{6}\right) \times Cycle\ Time$$

Non-value-added time was calculated as:

$$NVA = Effective\ Working\ Time - VA$$

The results are presented in Table 2.

Table 2. Value-Added (VA) and Non-Value-Added (NVA) Time

No	Process Name	Effective Time (min)	Processed Qty (pcs)	Cycle Time / 6 pcs (min)	VA Time (min)	NVA Time (min)
1	Milling	816	623	7.86	816	0
2	Visual Check 1	408	623	1.50	156	252
3	Press Machine	408	623	3.00	312	96
4	Visual Check 2	408	623	3.16	328	80

Source: Processed operational data, 2025

The milling workstation operated at full effective utilization, recording 816 minutes of value-added time and no idle time. In contrast, downstream processes recorded substantial non-value-added time:

- Visual Check 1: 252 minutes
- Press Machine: 96 minutes
- Visual Check 2: 80 minutes

These idle times resulted from limited material supply from the milling process.

Current State Value Stream Mapping (CS-VSM)

A Current State Value Stream Map (CS-VSM) was developed to visualize material and information flow across the CCB production line. The mapping confirms a sequential flow from supplier to customer with four primary processing stations.

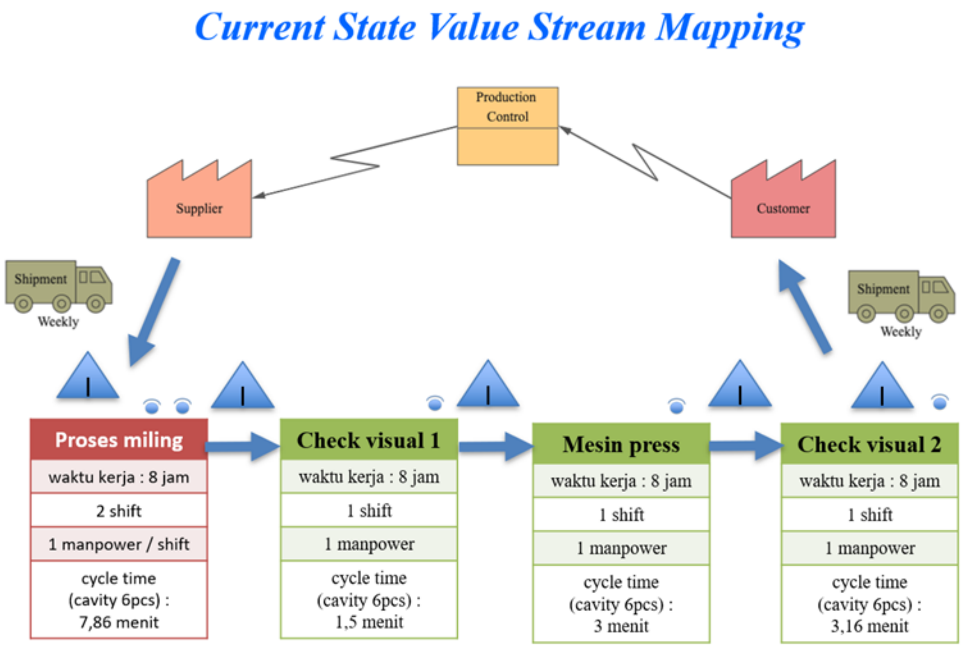

Figure 1. Current State Value Stream Mapping of CCB Production Line (Adapted from processed data, 2025)

The CS-VSM shows:

- Milling cycle time: 7.86 minutes per 6 pcs
- Visual Check 1 cycle time: 1.50 minutes per 6 pcs
- Press Machine cycle time: 3.00 minutes per 6 pcs

- Visual Check 2 cycle time: 3.16 minutes per 6 pcs

Total effective daily throughput is constrained to 623 pcs due to the milling bottleneck.

Line Imbalance Identification

Based on capacity comparison:

- Milling capacity: 623 pcs/day
- Visual Check 1 capacity: 1,632 pcs/day
- Press capacity: 816 pcs/day
- Visual Check 2 capacity: 775 pcs/day

The imbalance resulted in underutilization of downstream workstations. Idle time percentage per process is calculated as:

$$Idle\ Rate = \frac{NVA}{Effective\ Time} \times 100\%$$

Resulting idle rates:

- Visual Check 1: 61.8%
- Press Machine: 23.5%
- Visual Check 2: 19.6%

These results confirm systemic line imbalance, where throughput is locked by the milling process cycle time.

Summary of Baseline Performance

Before improvement implementation, the CCB production line exhibited:

- Milling as primary bottleneck (7.86 min/6 pcs)
- Maximum line throughput: 623 pcs/day
- Total downstream NVA time: 428 minutes/day
- High idle rates at inspection and press stations

These findings establish the baseline operational condition prior to improvement intervention.

Discussion

The findings indicate that the milling process was the primary bottleneck in the CCB production line, as identified through the current state Value Stream Mapping (VSM). During the July–December 2024 period, the average daily output of the milling machine was 549 pcs/day, achieving only 75.6% of the production plan. This performance gap reflects the presence of non-value-added (NVA) activities and inefficiencies in internal setup operations. According to lean manufacturing principles, bottlenecks and excessive internal setup times directly constrain throughput and overall system performance (Litvaj, 2023; Rahman, 2021). VSM serves as a strategic tool to visualize material and information flows, enabling organizations to identify waste and prioritize improvement initiatives

(Fatinnisa & Saifuddin, 2024; Simamora & Insanita, 2024).

The Process Activity Mapping (PAM) results revealed that total internal time before improvement reached 472 seconds, with several activities categorized as internal setup tasks. In the context of the Single Minute Exchange of Dies (SMED) methodology, internal activities—those performed while the machine is stopped—should be minimized or converted into external activities to reduce cycle time (Marcella & Widjajati, 2024; Nurrizky et al., 2021). The data in Table 4.5 further demonstrate variability in operator handling time, particularly in tightening clamp bolts (with a deviation of 5 seconds). This inconsistency supports the argument that manual processes increase variability and reduce process stability. Lean theory emphasizes standardization and waste elimination to achieve flow stability (Solís-Quinteros et al., 2021).

The Pareto analysis (Figure 4.5) confirmed that clamp tightening and loosening activities contributed the highest deviation and longest internal time. These activities were manually executed using a wrench without torque standardization, leading to operator fatigue and inconsistent clamping force. This condition aligns with the “method” and “man” factors identified in the fishbone diagram (Figure 4.8). Similar findings were reported by Koh and Singgih (2021), who observed that manual setup operations significantly affect productivity in manufacturing systems. Furthermore, lean implementation studies emphasize that reducing manual handling and integrating semi-automation can significantly improve operational efficiency (Hassan & Pasha, 2023; Hethsia.S, 2025).

To address the root causes, the improvement phase (Do stage of PDCA) introduced a pneumatic clamping system integrated into the milling jig. The implementation transformed multiple manual clamping activities into a single controlled motion using a hand valve that actuates four air cylinders simultaneously. This intervention aligns with the SMED principle of simplifying and mechanizing setup operations (Marcella & Widjajati, 2024). Moreover, the adoption of pneumatic systems supports lean manufacturing's objective of reducing internal setup time and operator dependency (Wijana et al., 2023).

After implementation, internal time decreased from 472 seconds to 425 seconds, representing a cycle time reduction of approximately 9.9%. Although numerically modest, the impact on throughput was significant. Production output increased from 550 pcs/day to 652 pcs/day, representing an 18.5% productivity improvement—exceeding the initial 10% target. This result is consistent with previous empirical studies demonstrating that lean-based setup reduction positively affects throughput and operational performance (Arfan et al., 2023; Pena et al., 2020).

Additionally, the reduction in bottleneck cycle time had a cascading effect on downstream processes. As shown in Table 4.10, non-value-added time in post-milling processes (visual inspection and press operations) decreased substantially. For example, NVA time in the press process decreased from 133 minutes to 82 minutes. This phenomenon confirms the Theory of Constraints perspective that improving the bottleneck enhances the entire system’s flow efficiency. The future state VSM (Figure 4.15) further illustrates improved material flow and manpower optimization, reducing operator requirements from three to two through process integration and cross-training.

From a contemporary industrial perspective, this study reflects a broader trend toward semi-automation and lean-driven digital transformation in manufacturing environments. Many industries currently face labor shortages, rising labor costs, and increasing demand variability. Semi-automated solutions such as pneumatic clamping systems provide a cost-effective alternative to full automation while maintaining flexibility. This hybrid improvement approach aligns with modern lean transformation strategies that combine mechanical innovation with continuous improvement culture (Hassan & Pasha, 2023).

Author's Commentary

From the author's perspective, the most significant insight from this research is that productivity improvement does not always require complex automation or high capital investment. The key lies in systematically identifying waste using VSM and PAM, followed by targeted setup reduction based on SMED principles. The study demonstrates that relatively simple mechanical innovation—such as pneumatic clamping—can generate substantial productivity gains when applied to the correct bottleneck process.

However, despite the achieved improvement, waiting time in downstream processes remains relatively high. This indicates that the production system still has opportunities for further lean integration, particularly in line balancing and workload distribution. Continuous monitoring through standardized control sheets and PDCA cycles is essential to sustain the achieved performance and prevent regression.

Overall, the findings reinforce lean manufacturing theory: eliminating internal setup waste, standardizing operations, and focusing improvement efforts on bottleneck processes significantly enhance production performance. The integration of VSM and SMED in this study not only improved cycle time but also contributed to system-wide efficiency and workforce optimization.

Conclusion

This study demonstrates that the primary cause of low production output in the CCB milling process was excessive internal setup activities and time variability due to manual clamping operations. The current state Value Stream Mapping (VSM) and Process Activity Mapping (PAM) identified that several internal activities—particularly loosening, installing, and tightening clamp bolts—were performed manually and exhibited inconsistent handling times. These conditions contributed to extended cycle time and limited daily production output. By applying lean manufacturing principles and integrating the Single Minute Exchange of Dies (SMED) concept, internal manual activities were redesigned into a semi-automated pneumatic clamping system. The implementation reduced internal setup time from 472 seconds to 425 seconds and shortened the milling cycle time to 7.08 minutes. As a result, average daily production output increased from 550 pcs/day to 652 pcs/day, representing an 18.5% productivity improvement, exceeding the initial improvement target of 10%. Furthermore, the bottleneck reduction generated a positive cascading effect on downstream processes, decreasing non-value-added (NVA) time and improving overall production flow efficiency. These findings confirm that systematic waste identification and targeted setup reduction significantly enhance operational performance without requiring full-scale automation.

For future research, several directions can be considered. First, an economic feasibility analysis incorporating Break-Even Point (BEP) and Return on Investment (ROI) calculations is recommended to evaluate the financial sustainability of pneumatic jig implementation. Second, further studies may expand the scope beyond the milling process to analyze the entire manufacturing system, including line balancing optimization and manpower allocation strategies. Third, integrating digital monitoring tools or smart manufacturing technologies could provide real-time performance tracking and further reduce variability. Continuous improvement through broader lean implementation and quantitative financial assessment will strengthen the long-term competitiveness and scalability of the proposed improvement model.

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