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Productivity Improvement Strategy in Oil Seal Manufacturing Using Lean and Cost Time Profile Approach

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Abstract

This study aims to improve the productivity of the oil seal manufacturing process at PT XYZ by applying Lean Manufacturing principles through the integrated use of Value Stream Mapping (VSM), line balancing, and the Cost Time Profile (CTP) method. Initial observations showed that the production line experienced significant non-value-added (NVA) activities, particularly waiting time between curing, post-cure, and trimming processes, which resulted in long lead times and high work-in-process (WIP) accumulation. The current state VSM identified curing as the major bottleneck across multiple product families. Improvement strategies were implemented by reducing curing time, adjusting lot size, eliminating deflashing through sensor replacement in trimming machines, reorganizing work sequences, and redistributing operator workloads. The application of line balancing allowed operators to handle multiple machines simultaneously, reducing idle time and improving flow efficiency. As a result, several product families experienced substantial reductions in total lead time, with decreases ranging from 60% to 70%, and increases in value-added ratio. The productivity index also improved, with total output rising from 3,782,400 pcs to 3,808,380 pcs per month, while manpower was reduced from 116 to 100 operators without additional overtime. Analysis using the Cost Time Profile further demonstrated a 3–11% reduction in cumulative cost added per piece. Overall, the integrated Lean Manufacturing and CTP approach successfully enhanced efficiency, reduced waste, lowered production cost, and improved productivity performance in a sustainable manner.

Keywords: *Lean Manufacturing; Value Stream Mapping; Line Balancing; Cost Time Profile; Productivity Improvement; Oil Seal Manufacturing.*

1. Introduction

Global competition in the manufacturing sector continues to demand higher productivity, lower costs, and more flexible production systems. The oil seal industry, as part of the automotive component supply chain, faces increasing pressure to deliver consistent quality while maintaining cost efficiency. PT XYZ, one of the national oil seal manufacturers in Indonesia, has experienced fluctuating productivity performance due to long production lead times, unbalanced workloads among operators, and a high proportion of non-value-added activities. These issues have resulted in inefficiencies, particularly within the curing, post-cure, and trimming processes, where waiting time and work-in-process (WIP) accumulation often occur. Without a structured and data-driven improvement approach, such inefficiencies will continue to erode production capacity and competitiveness, especially amid rising customer demand and global cost pressures.

Several studies have highlighted the effectiveness of Lean Manufacturing in identifying and reducing waste through process mapping and workflow optimization. Tools such as Value Stream Mapping (VSM) are widely used to visualize material and information flow, enabling companies to detect bottlenecks and reduce non-value-added time. Meanwhile, Line Balancing techniques help to equalize workloads across operators, improving resource utilization and reducing idle time. However, while Lean tools effectively improve process flow, they often overlook the financial impact of these improvements. In practice, many manufacturing firms fail to sustain improvement gains because operational analyses (e.g., through VSM or Line Balancing) are not directly linked to measurable financial outcomes. This gap underscores the urgent need to integrate time-based cost analysis such as the Cost Time Profile (CTP), ensuring that process efficiency translates into tangible economic performance.

This research integrates VSM, Line Balancing, and CTP into a single framework to comprehensively measure both operational and financial impacts of process improvement. The combination of these methods allows not only the identification of waste but also the quantification of cost reductions and productivity gains. Such integration is crucial because single-method analyses provide only a partial view—VSM visualizes flow efficiency, Line Balancing optimizes manpower allocation, while CTP monetizes time improvements. When applied simultaneously, these tools form a complete diagnostic and decision-making framework urgently needed in today's cost- and speed-driven manufacturing environment. The novelty of this study lies in its dual evaluation approach—analyzing efficiency through both process time and cost behavior simultaneously. The purpose of this research is to design and propose an integrated productivity improvement strategy for the oil seal manufacturing process at PT XYZ, providing a structured model that can be replicated by similar manufacturing industries aiming for sustainable efficiency and competitiveness.

2. Research Methodology

The first step involved observing the existing production flow and conducting time studies to record cycle time, waiting time, operator movements, and machine operation patterns. These observations were used to construct the current state Value Stream Mapping (VSM), which enabled visualization of the material and information flow as well as identification of bottlenecks and non-value-added (NVA) activities.

After the current state was mapped, the next step was to analyze operator workload and task distribution using the Standardized Work Sheet (SWS) and Standard Work Combination Sheet (SWCS). These tools helped identify imbalances between manual work and automated machine time, revealing opportunities to reduce idle time and rearrange task assignments. Based on the findings, improvement strategies were formulated, which included adjusting curing time, reducing lot size, eliminating unnecessary steps, and redistributing operator responsibilities to create a smoother workflow.

Once the future state production arrangement was implemented, time studies were repeated to obtain the updated cycle time and lead time. These new data sets were then compared with the original measurements to assess the magnitude of improvement. To evaluate how time reduction affected production cost, the Cost Time Profile (CTP) method was applied by converting cumulative process time into cumulative cost for each production stage. This approach provided a clear comparison of the cost structure before and after improvement, allowing the study to determine the effectiveness of the lean implementation not only in terms of time but also in financial impact.

3. Result

3.1 Current State Mapping (VSM Analysis)

The production system consists of six product families that share a similar overall flow but differ in processing characteristics and batch size requirements. Despite variations in automation levels, all families exhibit the same systemic issue: the dominance of waiting time over actual processing time. Table 1 summarizes the current-state performance of each family.

Table 1. Current-State Lead Time and Value-Added Ratio Across Product Families

Family	Total Lead Time (s)	Cycle Time (s)	Waiting Time (s)	Value-Added Ratio (%)
A	35,700.62	33.62	35,667.00	0.09
B	14,433.35	33.35	14,400.00	0.23
C	17,447.62	14.62	17,433.00	0.08
D	78,388.30	50.32	78,337.98	0.06
E	71,886.88	59.88	71,827.00	0.08
F	35,713.62	36.92	35,676.70	0.11

Across all product families, the value-added portion of production time is consistently below 0.3%, indicating that the majority of time is spent waiting rather than transforming the product. This condition arises from the batch-based transfer between curing, post-cure, trimming, and screening stages, which requires products to accumulate before progressing to the next operation. As a result, work-in-process (WIP) accumulates, throughput slows, and lead time increases significantly compared to the actual processing time.
Although the level of automation varies—Families A, B, and C are predominantly automated while Families D and E include semi-manual elements—the underlying constraint remains the same: flow does not proceed continuously. This indicates that the root problem is not machine speed, but the synchronization of work across stations. A representative example of this condition can be seen in Family A, where the current-state Value Stream Mapping shows long idle periods between curing and post-cure despite short operational cycle times.

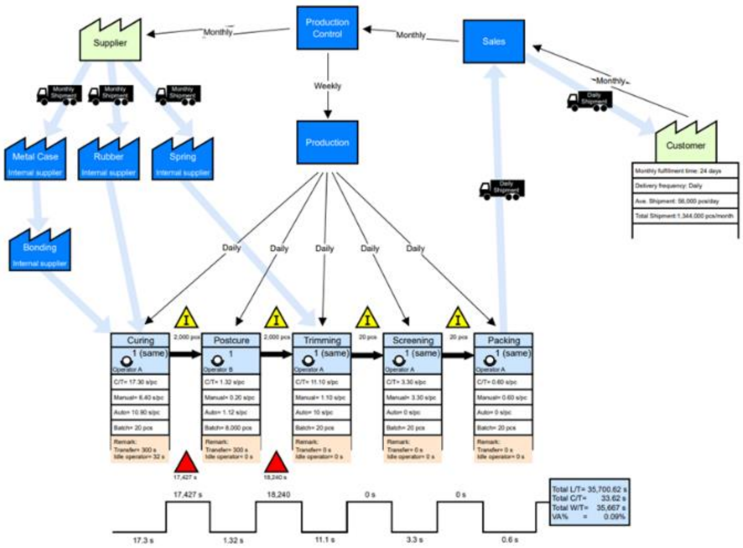

Figure 1. Current-State Value Stream Mapping (Example: Family A)

3.2 Waste and Bottleneck Identification

The analysis of the current production system revealed that the dominant forms of waste across the six product families were waiting, inventory, and motion. These waste patterns primarily resulted from the batch-transfer logic and mismatched process pacing among curing, post-cure, trimming, and screening stages.
The most significant bottleneck was identified at the curing process, which has a longer cycle time compared to downstream operations. Because post-cure and trimming can only begin once a full batch is completed, the output from curing accumulates in front of subsequent workstations. This leads to:

- Prolonged waiting time for both products and operators
- Increased work-in-process (WIP) between stations
- Reduced flow continuity and longer production lead time

Additionally, the layout arrangement contributes to motion waste. Material movement between curing and trimming areas requires manual handling and operator walking, which increases non-value-added time and reduces effective labor utilization.

3.3 Line Balancing Analysis

Line balancing was carried out to equalize workload distribution across curing, post-cure, trimming, screening, and packing activities. The Standardized Work Sheet (SWS) and Standard Work Combination Sheet (SWCS) analysis confirmed that imbalances in the current state were primarily caused by the mismatch between automated cycle time at the curing stage and the manual workload at subsequent stations. This condition resulted in idle time at upstream stations and high workload intensity downstream, which contributed to waiting, WIP accumulation, and inconsistent production rhythm.
To address this, operator assignments were reorganized so that manual and machine-paced tasks could be synchronized. In Families A and C, idle time during curing cycles was utilized by allowing one operator to

oversee multiple curing and trimming units, while downstream operations such as screening and packing were handled by a dedicated operator. In Family B, line balancing was combined with additional process capacity at the greasing/post-cure stage to reduce queue buildup. For Families D, E, and F, improvements focused on stabilizing manual task sequencing to reduce cycle time variation.

The impact of these adjustments is shown in Table 2. The total number of operators decreased from 116 to 100. This resulted in an improvement of system productivity from 1,359 pcs/man/day to 1,799 pcs/man/day, while the defect rate remained stable (≈0.39%), indicating that the improvement did not compromise quality.

Table 2. Line Performance Summary Before and After Line Balancing

Production Line	Operators Before (person)	Operators After (person)	Productivity Before (pcs/man/day)	Productivity After (pcs/man/day)	Defect Rate Before (%)	Defect Rate After (%)
TAS Line	38	30	1,684	2,432	0.23	0.23
TAS–Grease Line	18	14	1,333	1,971	0.09	0.09
Dust Seal Line	20	16	1,600	2,280	0.33	0.33
Mix Line SAT	34	35	1,000	1,102	0.92	0.92
Big Size Line Manual	6	5	600	820	0.64	0.64
Total	**116**	**100**	**1,359**	**1,799**	**0.39**	**0.39**

These results indicate that the main source of inefficiency in the current system was not machine capacity, but the lack of synchronization between process stages and operator workload. By reallocating task responsibilities and aligning cycle flows, the production system was able to increase throughput and labor productivity while maintaining consistent product quality.

3.4 Cost Time Profile (CTP) Evaluation

The Cost Time Profile (CTP) analysis was carried out to evaluate how process duration relates to cumulative production cost in each manufacturing line (Families A–F). By integrating process time, waiting time, and cost-rate data (labor, machine, energy, and overhead), CTP provides a clear picture of how value and cost accumulate throughout the production flow. This approach allows the company to measure not only efficiency in time but also how every improvement step affects the financial performance of the process.

The analysis compared the current state and future state after implementing Lean Manufacturing improvements such as reducing lot size, shortening curing time, and re-sequencing work operations. The summary of the findings for all families is presented in Table 3.

Table 3. Summary of CTP Results (Families A–F)

Family	Lead Time Before (sec)	Lead Time After (sec)	Cost Added Before (Rp/pcs)	Cost Added After (Rp/pcs)	Change	Key Improvement Result
A1	31,860	10,916	1,777.31	1,582.52	↓ 11% Cost & ↓ 65.7% LT	Lot-size reduction, curing time reduction, operator rebalancing
A2	31,860	10,832	1,777.31	1,676.26	↓ ~5–6% Cost & ↓ 66% LT	Reduced waiting between curing → post-cure → trimming
B	14,433	~31	1,930.58	1,710.86	↓ 11.4% Cost & ↓ 99.8% LT	Waiting-to-greasing eliminated; +4 grease machines integrated into flow
C1	29.4	27.06	1,777.31	1,582.52	↓ 11% Cost & ↓ ~8% LT	Screening + trimming synchronization; cycle alignment
C2	29.4	26.8	1,777.31	1,715.03	↓ 3–4% Cost & ↓ ~9% LT	Improvement limited by curing batch & machine allocation
D	78,388	79,854 *(↑ slight)*	2,074.83	≈ 2,018.00	↓ ~2.7% Cost, LT ↑	Higher utilization ↑ throughput → LT slightly increased but cost improved
E	71,886	74,965 *(↑)*	2,850.19	2,627.60	↓ ~7–8% Cost, LT ↑	Increased capacity raised WIP duration but improved VA efficiency
F	31,842	10,839	1,777.31	1,715.04	↓ ~3–4% Cost & ↓ ~66% LT	Lot-size halving + manual cycle sequencing improved flow continuity

The results of the CTP evaluation indicate that the Lean Manufacturing initiatives implemented at PT XYZ successfully improved efficiency and reduced cost, though the scale and pattern of improvement varied among families. The most significant reductions occurred in Families A1 and A2, where curing time was shortened, lot size was reduced, and operator workloads were redistributed. These changes effectively removed the accumulation of work-in-process between curing, post-cure, and trimming, resulting in a decrease in total lead time of approximately 66% and a reduction in cost per unit ranging from 5% to 11%.

Family B demonstrated the most dramatic shift, particularly because the waiting-to-greasing activity, which previously contributed the largest portion of total lead time, was entirely eliminated after the integration of additional greasing machines into the main line. This modification transformed the production flow from batch-based processing to continuous processing, reducing lead time from 14,433 seconds to approximately 31 seconds and lowering the cost per unit by 11.4%.

Families C1 and C2 experienced moderate yet stable improvements. The synchronization of curing, screening, and trimming reduced idle variations and improved flow consistency. Although Family C1 recorded a notable cost reduction of around 11%, Family C2 showed a smaller reduction of approximately 3–4%, primarily due to equipment allocation constraints that limited further lot-size optimization. Meanwhile, Families D and E exhibited a slight increase in total lead time after improvement. However, this increase corresponded with higher machine utilization and greater throughput, leading to a reduction in cost per unit by approximately 2.7% in Family D and 7–8% in Family E. In these cases, the rise in lead time did not signify inefficiency; rather, it reflected a production condition in which more units were being processed concurrently.

Family F (Big Size Manual) also recorded substantial improvements due to the reduction in lot size and better control of manual pacing sequences. These changes shortened lead time by approximately 66% and reduced cost per unit by around 3–4%.

Overall, the CTP results confirm that Lean-based improvements successfully reduced unnecessary waiting, improved resource utilization, and enhanced cost performance without compromising productivity or product quality.

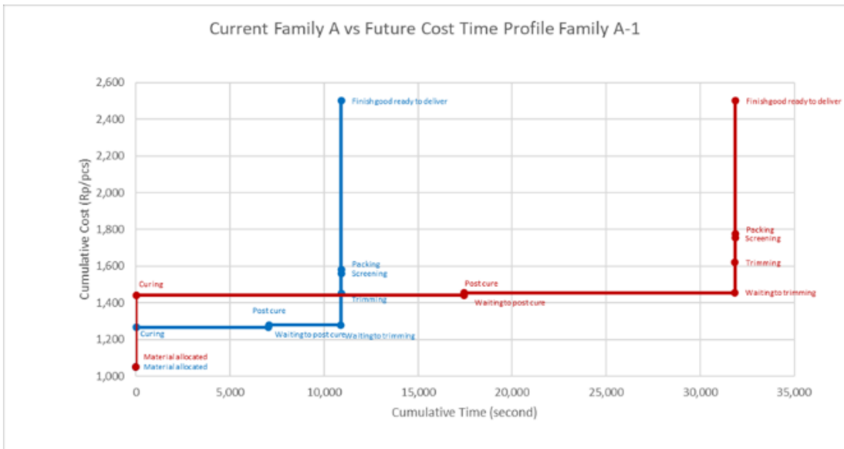

Figure 2. Comparison of Current and Future State CTP — Family A1 (Representative)

The future-state curve (blue) is flatter and shifts downward compared with the current-state curve (red), indicating faster cost accumulation and reduced waiting across post-cure and trimming stages. The Cost Time Profile analysis confirmed that Lean-based improvements at PT XYZ effectively reduced cost accumulation and enhanced process stability. Even in lines where lead time increased (Families D and E), the improvement came from greater throughput and higher machine utilization rather than inefficiency. This proves that a well-balanced production system can achieve better productivity and cost efficiency simultaneously. The integration of Value Stream Mapping, Line Balancing, and Cost Time Profile therefore provides a powerful framework for continuous improvement in oil-seal manufacturing.

3.5 Comparison of Before and After Conditions

Table-based comparisons between current state and future state VSM and CTP results show that all families experienced measurable improvements. The lead time decreased substantially in four family lines, while the other two achieved higher throughput at constant cost. Overall production efficiency improved by approximately 32.4%, with productivity increasing from 1,359 pcs/man/day to 1,799 pcs/man/day, while the defect rate remained stable at approximately 0.39%. This confirms that the improvement efforts enhanced flow continuity and unit cost performance without compromising product quality.

The Future State VSM illustrated a smoother flow of materials and reduced waiting periods, while CTP graphs verified that the cost accumulation slope became flatter, indicating lower cost build-up during production. This integration of time–cost visualization allowed management to clearly observe where improvement contributed most to performance gains.

4. Discussion

The integration of Lean Manufacturing tools (VSM and Line Balancing) with Cost Time Profile analysis provides a holistic framework for productivity improvement. VSM helped visualize the problem, Line Balancing optimized human and machine allocation, and CTP translated efficiency into measurable financial results. The results also validate previous findings by Vijay and Prabha (2021) and Kenedy & Widyadana (2024), who emphasized that combining process-based and cost-based perspectives enhances decision-making in manufacturing optimization. In the case of PT XYZ, this integrated method not only reduced waste and cycle time but also supported better production planning and cost transparency.

The study demonstrates that Lean and CTP synergy is highly applicable to small and medium-sized manufacturing environments where limited capital investment must still yield significant productivity improvement.

5. Conclusion

This study demonstrates that the integration of Lean Manufacturing tools—Value Stream Mapping (VSM) and Line Balancing—together with the Cost Time Profile (CTP) approach, effectively improves production performance in oil seal manufacturing at PT XYZ. Across the six product families, the implementation of curing-time reduction, lot-size adjustment, and operator workload restructuring led to a decrease in lead time of up to approximately 66%, primarily through the reduction of waiting and WIP accumulation between process stages.

In addition, the unit cost per piece decreased by approximately 3–11%, depending on the process characteristics of each family, supported by improved flow continuity and more efficient utilization of machine and labor resources. At the system level, overall production efficiency increased by 32.4%, rising from 1,359 pcs/man/day to 1,799 pcs/man/day, while the defect rate remained stable at approximately 0.39%, indicating that productivity gains were achieved without compromising product quality.

The use of CTP provided a financial perspective to complement Lean flow analysis, enabling management to understand not only where time was wasted but also how time reduction translated into cost savings. More importantly, the combined use of VSM, Line Balancing, and CTP proved essential in bridging the gap between operational and financial performance evaluation. Each method alone provides a limited view—VSM highlights process flow inefficiencies, Line Balancing optimizes manpower distribution, while CTP quantifies cost-time relationships. When integrated, these tools deliver a holistic framework that enables data-driven decision-making and ensures that lean improvements are both technically effective and economically justified.

This integrated methodological approach is therefore not only a technical solution but also a strategic imperative for modern manufacturing systems. It provides managers with a replicable, evidence-based model to pursue continuous improvement that sustains competitiveness, profitability, and operational excellence. Overall, the integrated VSM–Line Balancing–CTP framework offers a comprehensive and replicable improvement model for manufacturing systems seeking to reduce non-value-added time, increase throughput, and improve cost efficiency.

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