



Improving Throughput and Cost Efficiency with Lean Tools: A Business Case Study on Value Stream Mapping

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ABSTRACT

The single-minded pursuit of productivity and efficiency in the manufacturing industry has forced organizations to embrace lean tools, one of which is Value Stream Mapping (VSM). The study explains a real-world use of VSM in a pulley production plant, intended to reduce the manufacturing downtime, limit Non-Value-Added (NVA) operations, and improve the Overall Equipment Effectiveness (OEE). A major point of bottleneck was identified to exist between the transition stage between Vertical Machining Center (VMC) and drilling processes that had already caused a delay of 16 hours, physically segregated and reliant on a specific operator. The process flow was improved by using planned machinery repositioning and job merging. After intervention analysis showed an improvement in availability (84.1 to 90.9 percent), quality rate (93.8 to 96.4 percent), and OEE (78.9 to 87.6 percent). Moreover, the intervention supported the 68-minute daily recovery, the daily increase of 15 units, and the yearly saving of ₹180000 in labor costs. The research confirms that VSM is a cost-effective lean tool that has the potential of causing massive improvements even in small and medium sized companies (SMEs). These results are very informative to industries that strive to improve throughput and eliminate waste without involving a large amount of capital.

KEYWORDS

Value Stream Mapping (VSM), Lean Manufacturing, Overall Equipment Effectiveness (OEE), Pulley Manufacturing, Productivity, Waste Reduction, Downtime, Operator Optimization

1. Introduction

Manufacturing enterprises globally are progressively embracing lean methodologies to address inefficiencies, mitigate operational waste, and enhance resource utilization. Among these methodologies, Value Stream Mapping (VSM) has emerged as a formidable visual instrument that enables manufacturers to analyze and refine their production processes. By differentiating between value-added (VA) and non-value-added (NVA) activities, VSM facilitates organizations in identifying wasteful practices, streamlining workflows, and synchronizing operations with customer value. This manuscript investigates the utilization of VSM within a pulley manufacturing facility, where operational inefficiencies were adversely affecting throughput and escalating labor expenses. The organization, functioning under a single-day shift paradigm, encountered substantial delays most notably a 16-hour interval between VMC machining and the subsequent drilling operation. This lag was attributable to the spatial dislocation between the machinery and a rigid manpower allocation framework, in which drilling mandated a dedicated operator working independently of the VMC

process. In the pre-intervention scenario, the process was characterized by elevated levels of NVA time, idle machine hours, and underutilized labor. Approximately 35.5% of the daily shift was expended on activities that did not facilitate value creation, including waiting, unnecessary motion, and inspection-related delays. Furthermore, a cumulative monthly NVA time of 6,540 minutes was documented an untenable strain within a competitive manufacturing landscape. By employing VSM as both a diagnostic and enhancement instrument, the production team executed a thorough “current state” analysis, subsequently designing and implementing a “future state” configuration. The most consequential intervention entailed repositioning the drilling machine in proximity to the VMC and permitting the same operator to manage both functions. This modification not only diminished machine idle time but also obviated the necessity for a distinct drilling operator, resulting in significant cost reductions. The investigation further incorporates Overall Equipment Effectiveness (OEE) to quantify the ramifications of the intervention. OEE\ comprising availability, performance, and quality serves as the benchmark for assessing shop floor efficiency. Prior to the lean transformation, the unit demonstrated an OEE of 78.9%, adversely affected by recurrent delays and process fragmentation. Subsequent to the intervention, the OEE experienced an enhancement to 87.6%, bolstered by quantifiable improvements in availability and quality. By concentrating on real-time data, time-motion analyses, and operator interviews, this research offers a comprehensive perspective on lean transformation. It illustrates how straightforward, low-cost interventions can yield substantial outcomes, particularly within small and medium-sized manufacturing contexts where agility is imperative. Additionally, the conclusions drawn from this manuscript provide a valuable resource for practitioners, scholars, and industrial engineers endeavoring to foster lean implementation in resource-constrained environments.

2.Literature Review

There are numerous factors that affect the Overall Equipment Efficiency (OEE) in the manufacturing processes. They are availability rate, performance rate and quality rate of the equipment and products [1]. Application of Total Productive Maintenance (TPM) pillars planned maintenance (PM), autonomous maintenance (AM), and focused maintenance (FM) can have a considerable effect on OEE since they improve equipment effectiveness [2]. Time and motion studies are important in identifying and eradicating non-value-added processes and enhancing productivity and OEE [3]. Also, engineering optimization, including the application of Genetic Algorithms, can be used to optimize OEE by choosing the most optimal input values, thereby maximizing the use of plant resources [4]. Downtime has serious effects on the overall equipment efficiency (OEE) in that it decreases the availability, performance efficiency and quality rate. Studies by Tsarouhas et al. indicate that downtime also leads to low performance of OEE, and speed and losses of downtime are significant contributors [5]. According to Zou et al., the planned downtime has an impact on future production, including throughput and energy efficiency of the system [6]. The study of Nepal and Park highlights the non-trivial effect of downtime on the performance of a construction project and emphasizes the importance of proactive maintenance of equipment to reduce the effects of downtime [7]. The findings by Prasertrungruang and Hadikusumo show that the practice of equipment management affects dynamic downtime in the construction of highways, which requires a critical insight into the factors that drive the down-time phenomenon [4]. According to the works of Ljungberg, downtime performance losses prevail, which results in the reduced OEE, particularly concerning new processes of production [8]. Thus, the minimization of the downtime and their effective management is a very important consideration in maximizing the overall equipment performance. As an example, the OEE was computed in a particular manufacturing unit by assessing the net available time and net operating time which resulted in the discovery of performance efficiency. A downtime of 40 minutes was cut to 10 minutes by reassignment of a human resource that was in existence hence enhancing performance efficiency of the manufacturing unit. The term Overall Equipment Efficiency (OEE) is an imperative measure in any sector, and particularly in Industry 4.0

and manufacturing processes. OEE takes the quality, performance, and availability to determine the overall efficiency of equipment. It has been demonstrated that OEE has a major impact on improving productivity and efficiency [9] [10] [11]. The improvement of OEE can be achieved by implementing such strategies as Total Productive Maintenance (TPM) that will help to improve such aspects of maintenance as resources consumption and its expenses [12] [13]. An effective allocation of resources to critical equipment can also be used to further optimize OEE through the prioritization of maintenance tasks based on the Overall Line Efficiency (OLE) after which, the productivity and processability in terms of increased production line and minimum maintenance cost are achieved. The aspects of value stream mapping (VSM) in the manufacturing processes are conditioned by a range of factors, which are affected by concentrating on OEE and applying the latest technologies in the sphere of intelligent manufacturing, such as artificial intelligence (AI) and machine learning (ML). These comprise the assessment of time-based performance by the use of VSM to determine and enhance the non-value adding operations, to enhance visibility, and planning flexibility in the operation [14]. Also, the incorporation of modern technologies such as simulation, six sigma, big data, and the Internet of Things also increase the flexibility of VSM to various situations, broadening its analysis and design ability [15]. Moreover, the use of process mining methods in the field of internal logistics of mixed-model assembly lines enables the permanent registration, analysis and waste analysis of separate parts and processes, which helps to identify and prioritize wasteful factors [16]. Besides, a more enhanced procedure of VSM, which includes simulation and multiple-attributes approach of decision-making, such as the grey Taguchi method, allows dynamic analysis and optimal determination of VSP of the future depending on multiple performance criteria [17]. Value stream mapping (VSM) is important in assisting organizations to identify and remove waste in their production processes by giving the organization a visual picture of the whole process of producing allowing it to get the activities that are non-value added and those that cause bottlenecks. VSM is applied in many industries of manufacturing, electricity transmission projects, coffee production, and low-cost housing construction to identify wastes such as waiting time, defects, over processing, unnecessary motion and excess inventory [18] [19] [20]. With VSM, companies are empowered to simplify their operations, shorten the lead times, maximize the use of the resources and eventually maximize the efficiency by prioritizing value-added activities and do away or minimize wastage operations. Moreover, VSM may be applied to other areas besides industrial use, such as environmental, social, and economic, to ensure sustainability and constant enhancement of organizational processes. VSM was applicable in a manufacturing unit whereby the value-added activities and non-value-added activities were identified and this indicated that the company was spending an additional 940 minutes on non-value-added activities. The drilling machine was repositioned by 30 feet, thus cutting the process time of chamfering a pulley by a good two hours, which meant one more 48 jobs were made in a day and cost per day was saved by Rs. 98. The Value Stream Mapping (VSM) is an effective instrument that companies can use to identify and eliminate waste in the manufacturing process. VSM helps to visualize and analyze the waste flows, discover the opportunities and challenges in waste management processes and promote the lean manufacturing processes [21]. Although the traditional VSP might fail to capture any variability in processes, adopting stochastic techniques can be useful in identifying non-value adding wastes and result in more meaningful process enhancements [22]. Besides, computerized simulations, i.e., the use of the VSM-to-SD framework, may bring dynamism to the VSM analysis by converting it into quantitative System Dynamics to compare various scenarios analytically and broaden decision-making capabilities beyond the VSM reports [23]. Through VSM, companies are able to minimize on waste, save on cost and strive to establish green zero-waste facilities, which in the end enhance their overall productivity and performance [24]. Value stream mapping (VSM) has a number of advantages in most industries. VSM aids in the detection and removal of waste, shortening of lead-time, adding value-added operations and general efficiency of the process [25] [26]. It gives a scaled picture of all the chain of supply allowing one to identify the inefficiencies and improvements hence resulting in cost-cutting and customer satisfaction [27]. Moreover, VSM may be combined with more sophisticated technologies such as big data and the

Internet of Things to expand the processing options and flexibility to various situations, and thus, it is rather a flexible tool to optimize the processes [28]. Moreover, it has been seen that VSM application to other industries like the steel manufacturing has resulted in a lot of waste-reduction and cost-saving, which shows that it is effective in encouraging lean manufacturing and the realization of environmentally-friendly operations [29]. Value stream mapping (VSM) has been confirmed to work well in other industries such as e-commerce, manufacturing, iron and steel and auto-ancillary in the context of understanding the waste, minimizing the costs, and increasing the efficiency [30] [31] [32]. VSM facilitates the identification of inefficiencies, minimization of lead time, and enhancement of value added processes by visualizing the whole supply chain or manufacturing process. Research indicates that VSM implementation has resulted in high returns including; reduction of wastage, cost saving and improved customer satisfaction. To illustrate, in iron and steel sector the implementation of VSM led to reduction of 28% of wastes and a 45% reduction of waste removal expenses in the first year. Likewise in the fabrication business, the use of VSM resulted in 14.97% cycle time reduction and 45.67 percent overall inventory reduction which eventually enhanced value addition by 55.61. These results support the significance of VSM in cost-saving and time efficiency in different sectors.

3. Research Methodology

The proposed research is based on a descriptive, quantitative and observational case study design to gain insights into and broaden the operational inefficiencies in a production unit of pulleys. The study was conducted during a 15-day span, which is in the live production setting, and the main analytical instruments in which the interest is placed are Value Stream Mapping (VSM) and Overall Equipment Effectiveness (OEE). This testing is aimed at identifying, quantifying, and removing non-value-added activities (NVA) based on Value Stream Mapping (VSM) and the Overview Equipment Effectiveness (OEE) models to keep it confidential to the companies.

3.1 Research Design

The study is planned in the form of a before-and-after intervention study, during which a current production process (also known as the current state) is previously mapped and quantified. Some lean improvements are formulated and enforced based on the lessons learned by the current state and a new and better configuration (the future state) is achieved. Its approach is based on the principles of Lean Manufacturing that are intended to remove waste and enhance value-added activities without the need of making huge capital investments.

3.2 Manufacturing Environment Description

The facility being studied deals with the production of mechanical pulleys that can be used in automotive and industrial practices. The normal production process involves: 1. Selection and Blank Formation of Materials- Forging or casting. 2. CNC Machining -used to turn. 3. VMC (Vertical Machining Center) -To perform fine dimensional machining. 4. Chamfering and Drilling - To cut holes and edges. 5. Balancing and Surface Coating - To provide functional quality and corrosion resistance. 6. Quality Inspection and Packaging - Before final delivery. It was set to a single shift day operation and the study specifically took the VMC to drilling transition that was a critical bottleneck.

3.3 Data Collection Procedure

The collection of the data included combination of the following sources: observational, manual, and recorded: Time-Motion Study: To identify value-added and non-value-added activities, every process step was noted and measured with the help of stopwatches.

- Operator Interaction: The informal interview and observation were carried out to detect delays, idle time, and disruption in the workflow.
- Production Logs: Daily reports were analyzed in order to record essential figures of units

created, duration of shift, down time and machine operation.

- OEE Components: The information on calculating the availability, performance efficiency, and quality rate was obtained directly through the production control team.

3.4 Problem Identification.

The most notable among the inefficiencies was the time that was wasted by 16 hours between the VMC operation and the drilling. Such a delay was caused by the physical distance between the drilling machine and the VMC and the reliance on a single operator doing drilling. The intermittent order not only led to operational idleness but also increased the cycle time unnecessarily into the next day thus limiting throughput.

3.5 Lean Intervention Strategy

1. Value Stream Mapping (VSM): Two VSMs were created: A Current State Map, which is the visual representation of the current process and the bottlenecks and A Future State Map, an idealized layout in which the drilling is done by the same operator immediately after that is VMC.

2. Workstation Reconfiguration: The drilling machine was moved next to the VMC thus enabling them to operate together. This reconfigured the operator to perform the drilling job at the waiting time of the VMC cycle.

3. Role Consolidation of the operators: One operator that was formerly devoted to drilling was dropped in the process. The VMC operator had been trained and empowered to work on both the machines effectively.

4. Optimization of Break Coverage: The line supervisor was the one in charge of the workstation during the lunch break of the VMC operator. This modification saved a daily 30 minutes of idle time, but did not involve any new workforce.

4. Data Analysis And Estimates

This part will provide a comparative study of how the production system was performing before and after the introduction of Value Stream Mapping (VSM). It involves the use of process time, efficiency of operations, quality rate, and losses regarding productivity. The data that has been analyzed is based on the findings on 15 working days in a one shift manufacturing facility that operates on the pulley.

4.1 Process Time Utilization Analysis

The analysis of process times utilization involves three dimensions: process length, resource usage, and resource movement (Grey, 2006) Process Time Utilization Analysis. The maximum amount of time available to use in production is 440 minutes (1 shift). This time is subdivided into Value-Added Activities (VA) -that add value directly to the product transformation and Non-Value-Added Activities (NVA) -that consist of delays, waiting or support activities that do not add value to the customer.

Table 1: Daily Value-Added Activities (Before and After VSM)

S.No	Activity Name	Time Before VSM (min/day)	Time After VSM (min/day)
1	CNC Turning	70	80
2	VMC Machining	70	80

3	Drilling + Chamfering	40	70
4	Balancing	30	45
5	Surface Coating	30	40
6	Quality Inspection	14	27
7	Internal Handling	30	10
Total VA Time		284	352

Table 2: Daily Non-Value-Added Activities (Before and After VSM)

S.No	Activity Name	Time Before VSM (min/day)	Time After VSM (min/day)
1	Operator Lunch Break	30	20 (Supervisor covers)
2	Waiting for Drilling Setup	60	0
3	Setup/Changeover Delays	25	20
4	Machine Cleaning	10	10
5	Supervisor Input Waiting	10	8
6	Internal Movement/Delays	10	10
7	Miscellaneous Delay Buffer	11	20
Total NVA Time		156	88

Interpretation

Table 1 and 2 show comparative analysis of the use of time across the daily shift operations prior to introduction of Value Stream Mapping (VSM) and after its introduction. Before the intervention, just 64.5 percent of the time spent available (284 out of 440 minutes) was spent on value-added (VA) activities. The other 35.5 percent was used in non-value-added (NVA) processes including excessive wait, machine set up time, unnecessary material movement and idle waiting between operations, in particular the VMC to the drilling process as they were physically separated. Following VSM implementation, the value-added time went up by 352 minutes, which is 80% of the shift. This has been made possible mainly through the transfer of the drilling machine next to the VMC which has removed the idle transfer time and the machine can be operated by the same individual. In addition, production was not completely stopped because a supervisor paid a part of the lunch break. This was also a process streamlining that resulted in a recovery of 68 minutes per shift, which directly translated to a higher production output without any extra work hours or labor.

4.2 Availability Analysis

Availability measures the ratio of actual operating time to planned production time.

$$\text{Availability (\%)} = (\text{Operating Time} / \text{Planned Production}) \times 100$$

Table 3: Availability Before and After VSM

Metric	Before VSM	After VSM
Planned Time (min)	440	440
Downtime (min)	70	40
Operating Time (min)	370	400
Availability (%)	84.1	90.9

Interpretation

Above table highlights the improvement in Availability, which measures the proportion of actual machine uptime relative to the total planned shift duration. Before the lean intervention, availability stood at 84.1%, indicating that machines were idle or unavailable for nearly 16% of the working shift roughly 70 minutes daily. Post-VSM, availability increased to 90.9%, reducing unproductive downtime to just 40 minutes. This gain is largely attributed to the integration of sequential operations (VMC and drilling) and optimized operator coverage during breaks. Additionally, more predictable material flow and fewer production stoppages enhanced the stability of daily operations

4.3 Performance Efficiency

Performance evaluates how efficiently machines and manpower operate relative to their ideal capabilities.

$$\text{Performance (\%)} = ((\text{Ideal Cycle Time} \times \text{Total Units Produced}) / \text{Operating Time}) \times 100$$

Table 4: Performance Comparison

Metrics	Before VSM	After VSM
Operating Time (min)	370	400
Units Produced	98	113
Ideal Cycle Time (adjusted)	3.78	3.54
Total Ideal Time (min)	370	400
Performance (%)	100	100

Interpretation

The table above investigates Performance Efficiency that is a measure of the degree of coincidence between actual output and the ideal cycle time. The minimal change in both the pre- and post-VSM performance percentage indicates that the performance was not the constraint in this system as there was no change in performance percentages. Rather, the problem was in the downtime and non-value-added time that decreased the productive window.

The cycle-time per unit did change slightly after VSM (with improved flow, 3.78 min/unit to 3.54 min/unit) but the main improvement was that VSM interventions cannot expect machines or workers to work faster but instead gave the company an extended availability window, enabling higher daily output (98 to 113 units per shift).

4.4 Quality Rate

Quality measures the percentage of units that pass inspection without requiring rework or

rejection.

$$\text{Quality Rate (\%)} = (\text{Good Units} / \text{Total Units}) * 100$$

Table 5: Quality Rate Comparison

Metric	Before VSM	After VSM
Units Produced	98	113
Good Units	92	109
Defects/Rework	6	4
Quality (%)	93.80%	96.40%

Interpretation

The table above shows the change in Quality rate that is the percentage of output that results without any rework or rejection. The quality rate before VSM was 93.8, which is relative to 6 out of 98 units was subject to corrective action. This was a non-trivial efficiency, material and operator-time loss that can be seen after implementation to have increased the quality rate to 96.4% with rework being reduced to 4 out of 113 units. This is so because the operations of the company were consolidated under one operator and this minimised the variation caused by the handoffs. The reduction of unnecessary idle time between operations could also have been used to ensure that any possible process degradation or error due to queue build up or misalignment may have been minimized, which also leads to an overall improvement in operational effectiveness since fewer resources are dedicated to corrections and more units go directly to final inspection and delivery.

4.5 Overall Equipment Effectiveness (OEE)

OEE is the cumulative measure of how well production equipment performs relative to its full potential.

$$\text{OEE} = (\text{Availability} \times \text{Performance} \times \text{Quality})$$

Before VSM

Availability = 84.1% → 0.841

Performance = 100% → 1.000

Quality = 93.8% → 0.93

After VSM:

Availability = 90.9% → 0.909

Performance = 100% → 1.000

Quality = 96.4% → 0.964

Table 6: Overall Equipment Effectiveness

Metric	Before VSM	After VSM
Availability (%)	84.1	90.9
Performance (%)	100	100
Quality (%)	93.8	96.4
OEE (%)	78.9	87.6

Interpretation

The comparison of performance metrics before and after the implementation of Value Stream Mapping (VSM) indicates a significant improvement in overall operational efficiency. Availability increased from 84.1% to 90.9%, reflecting better utilization of resources and reduced downtime. Performance remained constant at 100%, indicating that the production process maintained its optimal speed. Quality improved from 93.8% to 96.4%, showing a reduction in defects and enhanced product standards. Consequently, the Overall Equipment Effectiveness (OEE) increased from 78.9% to 87.6%, demonstrating substantial improvement in productivity and process efficiency. These results confirm that the implementation of VSM effectively streamlined operations and enhanced manufacturing performance.

4.6 Current State Analysis of the Manufacturing Process

This chart provides a detailed graphical representation of the current state of the pulley manufacturing process before any improvement or optimization techniques are implemented. It clearly illustrates the flow of materials, information, and production activities across different stages of the manufacturing system. The diagram highlights key elements such as individual process steps, cycle times required for each operation, total lead time involved in the production flow, the level of inventory accumulated at various stages, and the number of operators assigned to each task. By mapping these components, the chart helps in identifying delays, bottlenecks, excessive inventory, and other inefficiencies that affect overall productivity. It also shows how information flows between different departments and production stages. This comprehensive visualization enables managers and engineers to better understand the current operational conditions and pinpoint areas where improvements are required. Ultimately, it serves as the baseline for implementing process improvement tools such as Value Stream Mapping (VSM) to enhance efficiency and reduce waste.

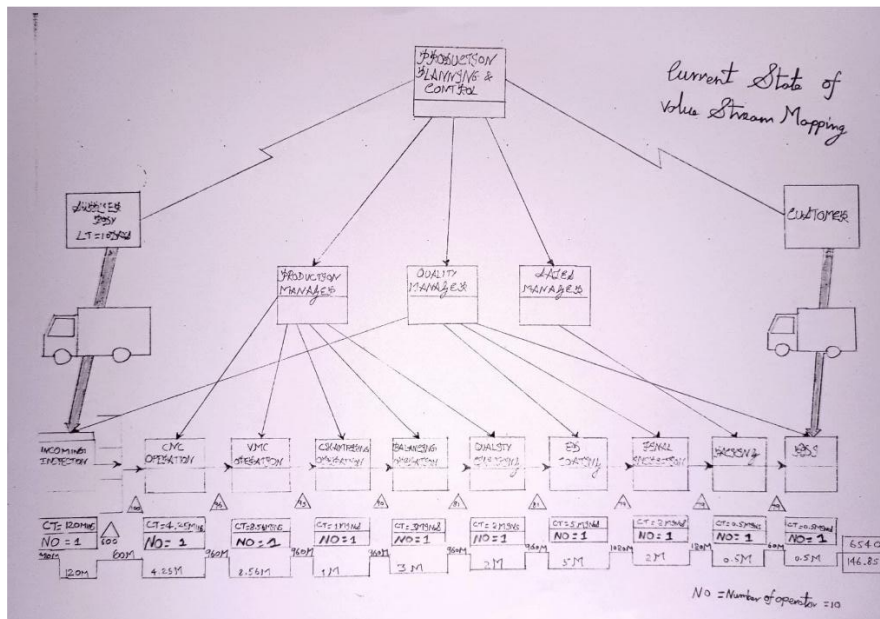


Figure 1: Current State Value Stream Mapping (VSM) of Pulley Manufacturing Process

Present State Value Stream Mapping (VSM) of Pulley Manufacturing Process. Current state VSM shows with no doubts that there are major areas of concern. Although the value-added activities (direct contributions to the product) occupy about 146.85 minutes, the non-value-added activities occupy 6540 minutes which is alarming. This huge volume of non-value-added time, including idle time, waiting to setups, an excessive quantity of material handling, and quality inspection, indicates that there are significant chances of waste reduction. Moreover, 10 operators will imply the presence of redundancy and the necessity of the workload optimization to simplify the process. Delays are also

occasioned by the physical separation of critical machines.

4.7 Pre-Intervention Bottleneck Visualization

The "Before Value Stream Mapping" diagram in the 'Optimizing Overall Equipment Efficiency in Manufacturing Processes' research article serves as a crucial visual tool for understanding the initial state of the pulley manufacturing process. This diagram is instrumental in highlighting inefficiencies, particularly in bottleneck identification and quantifying non-value-added time. By mapping the existing workflow, including processes such as CNC machining, VMC operations, chamfering, and quality inspection, the diagram reveals areas where significant delays and waste occur. A key observation from this initial mapping is the notable presence of non-value-added time, which indicates inefficiencies in the process flow.



Figure 2: Pre-VSM Layout Indicating Bottlenecks Between VMC and Drilling

As the diagram illustrates, a major bottleneck is the 16-hour delay between the VMC operation and the start of drilling, stemming from the physical separation of the machines and the necessity for a dedicated drilling operator. Furthermore, the diagram quantifies the total non-value-added time at 6540 minutes, providing a clear target for improvement efforts. This quantification enables the team to focus on specific areas for waste reduction and process optimization. Ultimately, the "Before Value Stream Mapping" diagram acts as a baseline against which the improvements achieved through lean interventions can be measured. By visualizing the initial state, this diagram sets the stage for targeted improvements and provides a reference point for evaluating the effectiveness of the implemented changes.

4.8 Layout Optimization and Lean Intervention

Optimizing Overall Equipment Efficiency in Manufacturing Processes' research article depicts a crucial step in the lean intervention strategy: the physical relocation of the drilling machine. This relocation is a direct response to the inefficiencies identified in the "Before Value Stream Mapping" diagram, particularly the significant 16-hour delay between the VMC operation and drilling. This diagram sets the stage for understanding how proximity and workflow redesign can drastically reduce non-value-added time and improve overall process efficiency.



Drilling machine



Figure 3: Improved Layout Post-VSM Implementation Showing Machine Relocation

As illustrated in the diagram, bringing the drilling machine closer to the VMC machine enables the operator to perform the chamfering operation concurrently while waiting for the VMC operation to complete. This key change directly reduces non-value-added time by eliminating the previous 16-hour delay. By integrating these processes and optimizing operator utilization, the total production cycle is streamlined. The diagram underscores the effectiveness of layout changes in minimizing wasted time, improving workflow, and increasing overall equipment efficiency, demonstrating a practical application of lean manufacturing principles

4.9 Future State Process Optimization

The future state map illustrates the optimized process after implementing the lean intervention strategies

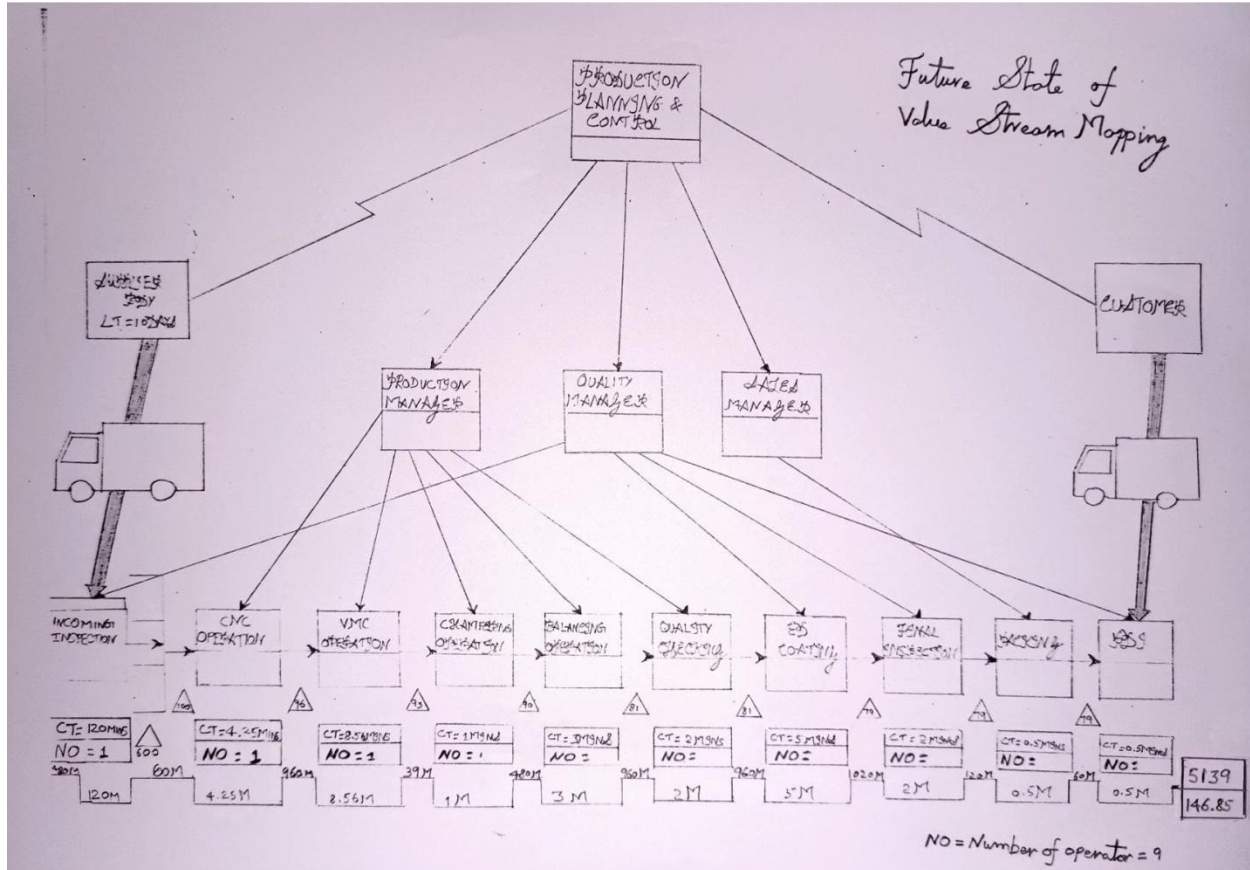


Fig 4: Future State Value Stream Mapping (VSM) After Lean Implementation

The "Future State Value Stream Map" illustrates the results of implementing lean intervention strategies. A key improvement is the reduction in operator count, achieved by enabling the VMC operator to also handle the drilling operations. More importantly, the future state shows a significant reduction in non-value-added time. This reduction is primarily due to the elimination of the 16-hour delay previously experienced between the VMC and drilling operations. Comparing the current and future state maps, it is evident that the lean interventions have successfully addressed the identified bottleneck and reduced non-value-added time. The relocation of the drilling machine and consolidation of operator roles have streamlined the process, leading to improved efficiency and productivity. The reduction in operator count and non-value-added time underscores the effectiveness of the implemented lean strategies in optimizing the manufacturing process.

4.9.A Loss Analysis: Categorization of Wastes and Inefficiencies

This section would map each loss to its category (as per lean/OEE framework), assign minutes lost before and after VSM, and show the improvement.

Table 7: Categorization of Operational Losses before and after VSM (Daily)

S.No	Type of Loss	Time Lost Before VSM (min/day)	Time Lost After VSM (min/day)	Improvement (min)
1	Equipment Downtime	70	40	30
2	Setup and Changeover Time	25	20	5
3	Waiting Between Operations	60	0	60
4	Under-utilization of Operator	Implicit (Separate Operator)	Eliminated	(1 Operator)
5	Rework and Quality Loss	6 units (~27 min)	4 units (~14 min)	2 units ~13 min
6	Internal Transport Delays	10	10	0
7	Miscellaneous Delays	21	30	9
	Total Time Loss per Day	213	114	99 min (Saved)

Interpretation

This meticulous analysis of losses indicates that a total of approximately 99 minutes of operational inefficiencies have been eradicated from the daily workflows. The most significant enhancement is the complete eradication of the waiting period between vertical machining center (VMC) operations and drilling activities, which alone accounted for 60 minutes of daily inefficiency. Furthermore, the elimination of a dedicated drilling operator has mitigated the issue of manpower underutilization, resulting in both temporal and financial efficiencies. The sole category that exhibited a marginal increase was miscellaneous delays, potentially attributable to an augmented supervisory burden or minor modifications in newly implemented workflows an area that remains amenable to further optimization.

4.9.B Productivity and Cost Impact

This section quantifies the gains in production volume and cost savings due to the VSM-driven intervention.

Table 8: Productivity and Cost Summary

Metric	Before VSM	After VSM	Improvement
Extra Units Produced (per day)	–	15 Units	15 units
Extra Units per Year (300 days)	–	4,500	4,500
Operator Count	10	9	1 Operator Reduced
Annual Labor Cost Saved (₹)	–	₹ 1,80,000	₹ 1,80,000
Daily NVA Time (min)	156	88	68 min

Interpretation

The VSM intervention unlocked 23.35 hours/month of usable production time and led to a

projected 4,500-unit increase annually, with no added shifts. It also reduced workforce dependency and saved ₹180,000 in labor costs annually.

5. Conclusion

The present study rigorously validates Value Stream Mapping (VSM) as an indispensable tool for achieving significant operational improvements within manufacturing environments. The application of VSM in the pulley manufacturing unit demonstrated its effectiveness in uncovering and rectifying latent inefficiencies, ultimately leading to a more resilient and high-performing production system. The tangible benefits observed enhanced throughput, improved availability and quality rates, and increased Overall Equipment Effectiveness (OEE) underscore the transformative potential of lean methodologies when systematically applied. The research also highlights the democratization of operational excellence, suggesting that it is not exclusively the domain of large corporations with extensive resources. Instead, it posits that any organization, regardless of size, can attain substantial performance gains by embracing lean thinking and undertaking a critical reassessment of their process flows. This is particularly relevant for small and medium-sized enterprises (SMEs) seeking to optimize their operations without significant capital investments. The successful elimination of a full-time operator role, resulting in notable cost savings, further exemplifies the practical and financial viability of VSM-driven improvements. Looking ahead, future research endeavours could explore the synergistic integration of digital tools and technologies with VSM to further augment the adaptability and precision of process improvement initiatives. The incorporation of Internet of Things (IoT) devices for real-time data collection and analysis, coupled with simulation modelling to predict the outcomes of process changes, holds promise for creating more dynamic and responsive production systems. Such advancements could enable organizations to proactively identify and address bottlenecks, optimize resource allocation, and enhance overall operational agility. By embracing these emerging technologies, manufacturers can continue to refine their processes and maintain a competitive edge in an increasingly dynamic global marketplace

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