Proceedings of the Fourth Australian International Conference on Industrial Engineering and Operations Management, Melbourne, Australia, November 25-27, 2025

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AU04.20250026
Published: November 25, 2025

A Manufacturing Model to Enhance Productivity through Applying SLP, 5S, and TPM in a Textile SME

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Abstract

The Peruvian textile sector faces intense competition, driven by numerous local micro and small enterprises (SMEs) and the presence of international competitors. Given this landscape, the current article proposes a manufacturing model designed to enhance productivity in a textile SME through the strategic implementation of tools such as SLP (Systematic Layout Planning), 5S, and TPM (Total Productive Maintenance). The project's primary objective is to increase business productivity via process optimization. It is anticipated that the application of these methodologies will contribute to mitigating persistent challenges within the sector, including informality and reliance on imports. The study also encompasses the relevant legal and regulatory framework, the design of the proposed solution, and its functional validation. The results revealed improvements in the key indicators of the company analyzed, demonstrating a positive impact on its productivity, as evidenced by the 5S pilot plan. Furthermore, a simulation was conducted using Arena software, ultimately achieving a 4.37% improvement in the productivity indicator. Finally, this research aims to offer other textile companies practical tools to optimize their operations and effectively implement these methodologies. In alignment with its stated objective, the model is highly replicable across other Peruvian textile SMEs and adaptable, given the universal nature of the employed tools, to diverse manufacturing industries.

Keywords
Productivity, Lean Manufacturing, Process Optimization, Textile Sector, Simulation.

1. Introduction
The textile sector in Peru stands as a fundamental economic pillar nationwide. Historically, it has contended with various challenges. In recent years, a discernible decrease in productive efficiency has been observed within enterprises, primarily attributed to the downtime of both operators and the machinery utilized (Annamalai et al., 2020) Despite the sector's significant contribution to employment generation, its performance has been adversely affected by events such as the COVID-19 pandemic, global economic volatility, and intensifying international competition (Mundaca et al., 2023). This sector's share of the manufacturing GDP has declined, representing 6.4% in 2019 and subsequently falling to 0.5% of the total GDP by 2023. This contraction included a 31.8% reduction in GDP and a 21% decrease in employment in 2020 alone. While a gradual recovery has been noted since 2021, sales have yet to reach pre-pandemic levels. Furthermore, both domestic and international demand remain inconsistent, which complicates business planning and capital expenditure.

Reports from industry associations such as the National Society of Industries (SNI) corroborate this sharp decline in 2020 and the subsequent gradual recovery. The prevalence of Small and Medium Enterprises (SMEs) within the sector intensifies local competition, compounded by pressure from international competitors with lower cost structures, such as China, Bangladesh, and India. Despite textile exports being a crucial revenue stream for Peru, they are impacted by political uncertainty and constant shifts in trade policies. Nonetheless, the National Institute of Statistics and Informatics (INEI) reported a 20.9% growth in the export volume of non-traditional textile products in May 2024, indicating potential for reactivation. However, the 9.0% decrease in spinning production in January 2024 suggests fluctuating demand in specific segments of the sector.

Presently, the Peruvian textile sector confronts critical challenges, including low productivity, high informality, and reliance on imports, which collectively impede its competitiveness and sustainability. Despite inherent growth opportunities offered by innovative technologies and a growing emphasis on sustainability, the absence of optimized manufacturing models significantly limits the capitalization of these opportunities and the enhancement of operational efficiency. Although the global textile industry is undergoing transformation with new technologies that bolster effectiveness, the adoption of these tools remains limited within Peruvian SMEs. This scarcity leads to significant issues concerning productive efficiency, primarily due to various forms of waste and extended unproductive cycle times (Alcazar et al., 2023).

Several Peruvian regulations are considered in relation to the proposed model and are directly linked to the tools to be utilized. These include Peruvian Technical Standard NTP 900.030:2018, which pertains to measuring particulate matter concentration, and Supreme Decree No. 085-2003-PCM, which establishes the maximum permissible noise levels in various industrial zones.

1.1 Objectives

The overarching objective is to enhance productivity within a textile sector enterprise through process optimization. This will be achieved by implementing a management model based on Lean Manufacturing, TPM, 5S methodology, and SLP. The aim is to increase overall productivity and market competitiveness.

The specific objectives are related to conducting a complete initial analysis that thoroughly examines the current status of the project and carries out an in-depth investigation of the most relevant background within the textile industry; elaborate a diagnosis of the problem in the spinning process of a textile company, using a combination of TPM, 5S and SLP tools to identify areas of improvement and propose effective solutions; develop and implement technical solutions to improve productivity and ensure compliance; and validate the Lean Manufacturing model and the contribution of the solution in the economic aspect of the company to present the scopes and limitations.

2. Literature Review

A systematic literature review was conducted, analyzing 40 academic articles published within the last five years. A key limitation encountered was the limited availability of open-access reference material. This selection process, detailed in a PRISMA diagram, focused on publications relevant to the textile sector, Lean Manufacturing tools, and productivity improvement in SMEs, as illustrated in Figure 1.

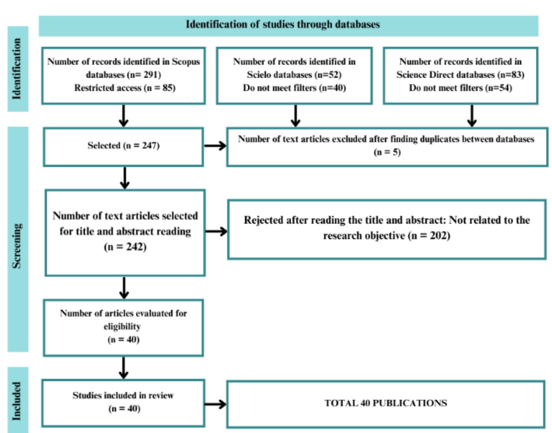


Figure 1. Prisma Flow diagram

The initial typology, "The Importance of the Textile Sector and the Impact of SMEs," reveals a consensus among various authors regarding the global influence and significance of the textile sector as a substantial source of employment and economic revenue (Calderón et al., 2023; Amiel et al., 2022). These sources further agree on the national importance of SMEs within the sector, highlighting their role in employing 26% of the economically active population. Simultaneously, they identify significant challenges such as high levels of competition and lower efficiency when compared to the global market (Torres et al., 2023; Amiel et al., 2022).

The second typology examined, "The Influence of Lean Manufacturing Tools in the Textile Sector," highlights the rationale for proposing Lean Manufacturing tools to address the aforementioned challenges. These tools aim to enhance efficiency and productivity within SMEs in the textile sector. Lean Manufacturing has proven to be a valuable strategy for waste reduction and process optimization, ultimately leading to more effective utilization of available resources. This is empirically supported by studies demonstrating that the implementation of a management model based on Lean Manufacturing tools (like 5S, TPM, and time/motion studies) can yield a significant increase in the hour-man productivity within the textile industry. This advantage is crucial in a rapidly changing sector where production efficiency is key to achieving business success. Furthermore, the systematic design of systems such as Autonomous Maintenance (AM) using a Lean philosophy has shown tangible benefits, achieving an improvement in equipment downtime and in the Mean Time Between Failures (MTBF) in the textile industry (Lista et al., 2021; Kose et al., 2022; Ortiz et al., 2022; Alcazar et al., 2023).

The third typology focuses on "Optimizing Processes to Reduce Errors". Among the various tools available, 5S methodology is frequently cited by authors, emphasizing order, cleanliness, and effective organization within the work environment. Implementing 5S significantly reduces errors and accidents, leading directly to improved product quality (Quiroz et al., 2023; Arteaga et al., 2019; Martínez et al., 2021).

Additionally, Value Stream Mapping (VSM) is a crucial tool for diagnosing factors affecting enterprise efficiency. VSM allows for a comprehensive analysis of the entire production value flow, enabling the identification of improvement opportunities and critical areas (León et al., 2023; Saravanan et al., 2023; Bizuneh et al., 2024).

It's crucial to note that implementing Lean Manufacturing in the textile sector isn't without its challenges. One significant barrier is the requirement for an initial investment in training and process adaptation, which can be an obstacle for some companies, particularly SMEs. However, it's essential to understand that the long-term benefits in terms of efficiency, quality, and competitiveness far outweigh these initial costs. Given this, the implementation of Lean Manufacturing tools is recommended to help textile companies in Peru address sector challenges and capitalize on opportunities to improve their productivity and competitiveness (Candelario et al., 2023; Damian-Garcia et al., 2023).

3. Methods

This research employed a quantitative and applied approach, specifically designed to optimize the operational performance of a SME. Initially, a thorough identification of key operational deficiencies within the company was conducted. This involved analyzing crucial performance indicators such as Overall Equipment Effectiveness (OEE) and machinery availability, along with systematically collecting relevant data through direct observation of production processes and detailed analysis of the company's internal production and maintenance records.

To pinpoint the core problem, on-site visits were conducted, alongside an exhaustive review of the company's internal documentation, meetings with plant management, and surveys distributed to operators. These preliminary stages were crucial for identifying four root causes directly contributing to low productivity in the spinning process. Each cause is aligned with a specific engineering tool selected through a review of specialized literature, including 5S, Total Productive Maintenance (TPM), and Systematic Layout Planning (SLP). This comprehensive approach is detailed in Figure 2.

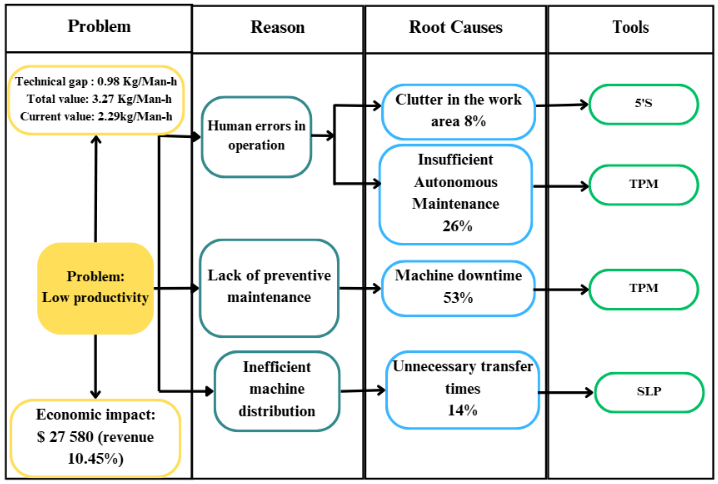


Figure 2. Problem tree

Root cause analysis, including the Ishikawa diagram, facilitated a thorough understanding of the underlying factors impacting productivity. Three primary issues were identified: human errors during operation, the absence of preventive maintenance, and inefficient machinery layout. Subsequently, during the improvement phase, solutions were designed and implemented based on three key Lean Manufacturing tools, each directly linked to these identified root causes:

- The 5S methodology was implemented in the preparation area to optimize workplace organization, cleanliness, and standardization.
- Additionally, TPM and SLP were evaluated using Arena Simulation software. This simulation modeled plant operations based on empirical time data, allowing for the validation of the projected impacts of these tools in a controlled environment. This approach enabled the prediction of changes in Productivity prior to large-scale physical implementation.

The final phase focused on verifying and sustaining the implemented improvements. This involved a closing audit of the 5S implementation. Additionally, a comparative analysis of key performance indicators was conducted both before and after the intervention. This allowed for the quantification of the positive impact of the proposed manufacturing model. Simulation continued to be a vital tool for modeling operations and evaluating projected changes in key indicators, as illustrated in Figure 3.

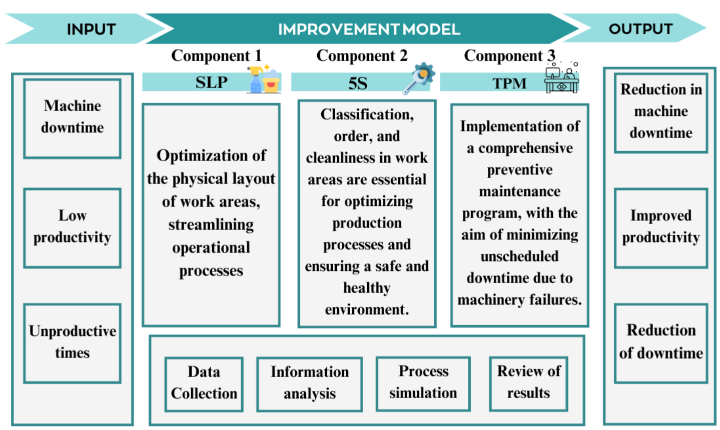


Figure 3. Proposed Model

For the purpose of conducting a comprehensive analysis of the production process, the Value Stream Mapping (VSM) tool was utilized to analyze the material flow. To this end, a visual map of the process was developed, documenting key metrics at each stage, such as inventory levels, cycle time, and machine availability (Uptime). As a result, this methodology allowed for the identification of critical deficiencies and bottlenecks in the preparation phase, which includes the mixing, scutching, carding, and drawing processes.

The first component of this research focuses on optimizing workspace organization using SLP methodology. This process begins with an in-depth analysis of material and information flows to identify bottlenecks and unnecessary movements. Activity relationship diagrams are then employed to study the connections between different work areas. Subsequently, various layout options are proposed with the aim of reducing travel distance and improving workflow. These options undergo evaluation based on critical factors such as cost, safety, and ergonomics. Finally, the selected layout is implemented, and its effectiveness is continuously monitored.

The second component involves applying the 5S methodology to optimize organization, cleanliness, and standardization within the workspace. This process commences with Sort, where items are classified, distinguishing the necessary from the unnecessary, and superfluous articles are eliminated. Next, during Set in Order, essential items are organized, assigned specific locations, and labeled for easy access. Following this, the Shine stage entails a thorough cleaning of the area, removing dirt and clutter. The Standardize phase involves documenting and visually displaying procedures and standards to maintain order and cleanliness. Finally, Sustain fosters discipline to ensure adherence to established standards and supports the continuous improvement of the 5S system.

The third component involves implementing TPM, which aims to eliminate production losses stemming from equipment breakdowns or malfunctions. The process begins with identifying and analyzing the root causes of machinery failures. A comprehensive preventive maintenance plan is then developed, encompassing periodic inspections, lubrication, cleaning, and adjustments. An autonomous maintenance system is established, actively engaging operators in the fundamental care of their equipment. Focused improvement is encouraged to resolve chronic issues and enhance equipment reliability.

The final project phase focuses on development and validation. This involves simulation using Arena Simulation software, followed by the review and evaluation of key performance indicators. If the results are satisfactory, the process proceeds; otherwise, adjustments are made, and the cycle is repeated to ensure the program's effectiveness. , as illustrated in Figure 4.

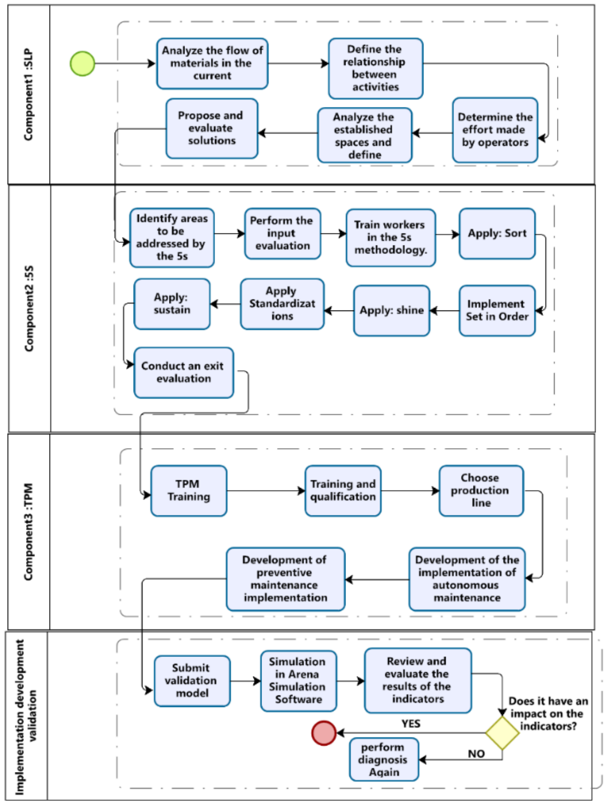


Figure 4. Implementation of the component Plan

4. Data Collection

Data collection was a fundamental step for the successful implementation and validation of the proposed model, as it allowed for the establishment of a baseline and the evaluation of improvement progress. Various techniques were employed for data collection, including direct observation, the use of checklists, photography, and surveys administered to operational personnel. Cycle times served as the primary unit of analysis to obtain the essential information required for key performance indicators (KPIs). Furthermore, to ensure data representativeness, the sample size was calculated using the specific formula for finite populations.

$$n = \frac{N*Z^2*p*q}{e^2(N-1)+Z^2*p*q} \tag{1}$$

The optimal sample size, denoted as 'n', was determined to be 383 cones from a finite population 'N' of 120,412 cones. To ensure high reliability, a critical 'Z' value of 1.96 was used, corresponding to a 95% confidence level. The proportions 'p' and 'q' were conservatively set at 0.5 (50% each), representing the presence or absence of the characteristic of interest. Finally, the maximum acceptable margin of error 'e' was fixed at 5%, indicating the desired precision for our research findings.

The data collected was then analyzed to calculate and measure the following key indicators:

- **Productivity**: Measured in pounds produced per man-hour.
- **OEE (Overall Equipment Effectiveness)**: Machine efficiency will be measured, considering performance, availability, and quality.
- **Travel Time:** The spatial distribution and machine layout will be analyzed.
- **5S Index**: The level of organization and order in the preparation area will be evaluated using the 5S

methodology.

5. Results and Discussion
5.1 Numerical Results
Table 1 presents the results for the key indicators.

Table 1. Measurement of the improvement proposal

Cause	Indicator	As is	To be	Results
Machine downtime/ Inefficient Autonomous Maintenance	OEE	60%	>85%	72%
Unnecessary routes/walks	Time per route/walk	18 h/month	< 18	10 h/month
Disorganization in the work area	5S Audit	18%	75%	76%
Productivity	Kg / Man-Hour	2.29	3.27	2.39

5.2 Graphical Results
Regarding the final 5S audit results, we observed significant improvements across all sections, bringing the total score to 76%, slightly exceeding our target indicator of 75% (Quiroz et al., 2023). This 5S audit indicator validates not only the effectiveness of the initial implementation but also the consolidation of a culture of discipline and maintenance that directly impacts productivity, safety, and the quality of the work environment. A graphical representation of the before-and-after audit scores for each step of the 5S methodology is provided below, with a maximum score of 25 points per category, blue is "before," orange is "after" implementation as shown in Figure 5.

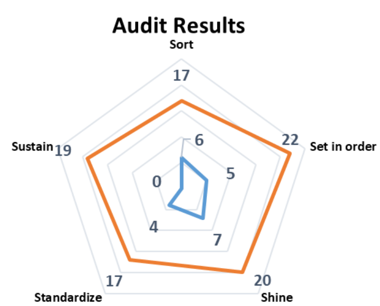


Figure 5. 5S Results

The 5S implementation in the preparation area yielded substantial improvements in operational efficiency and workspace organization. This is evidenced by a dramatic reduction in average tool localization time, from 12 to 3 minutes, coupled with a significant increase from 24% to 68% in the percentage of correctly sorted and organized tools. Furthermore, the training of 5 employees underscores a crucial investment in human capital, essential for sustaining these practices, as shown in Table 2.

Table 2. 5S Results

Indicators 5S	Before the improvement	After the improvement
Average time to locate and access the necessary tools	12 minutes	3 minutes
Percentage of tools correctly classified and organized	24%	68%
Number of trained employees in the preparation area	0	5
Cleaning time in the preparation area	1h	30 minutes
5S Audit Indicator	19%	76%

Also, the proposed new layout, detailed below, considers factors such as material flow efficiency, worker safety, ergonomics, and implementation cost as shown in Figure 6.

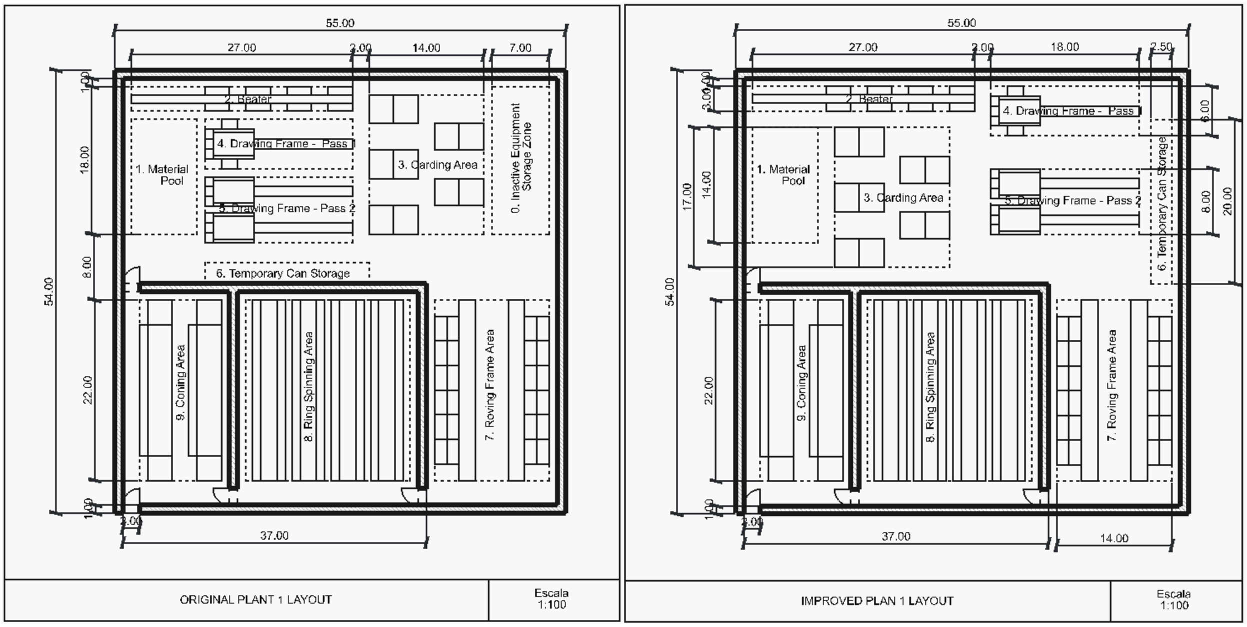


Figure 6. Original and Improved Layout

5.3 Proposed Improvements

SLP implementation begins with a thorough analysis of material flows in the production area, identifying bottlenecks and unnecessary movements. The first step involves Value Stream Mapping (VSM) to visualize the entire process, recording activity times to facilitate sample selection for the implementation of the proposed tools. Based on this analysis, the preparation stage—including blending, blow room, carding, and drawing frame processes—was chosen due to observed deficiencies in production available time and its criticality in determining final product quality. Accordingly, various alternative layouts for machinery and work areas were proposed, considering material flows, machine interactions, and space requirements. A detailed plant layout analysis, represented by a relationship matrix, outlines areas such as "Material Pool," "Blow Room Zone," "Carding Zone," and other distinct areas (numbered 1 to 10). Values within the cells (numbers, "X", "U") indicate the degree of relationship or importance between these zones, guiding desired proximity. The objective of the proposed layout is to consolidate the designated space for drawing frame sliver cans to reduce transport time and mitigate potential collision risks with other cans or drawing frame machines present in the current layout.

The 5S methodology was implemented over nine weeks in the yarn preparation area, following an initial audit that revealed a low 18% compliance rate. The first phase, Sort, involved removing obsolete or unused tools and materials, as well as reviewing stock using "Red Tags" to identify essential or expiring items. Subsequently, in the Set in Order phase, specific locations were designated with clear labeling, shadow boards were utilized for tools, machine layouts were optimized, and containers for spare parts were organized. Shine included detailed cleaning plans for machines, floors, and surrounding areas, with particular attention to fiber waste and dust, establishing maintenance schedules and acquiring waste containers. For Standardize, procedures were documented in a 5S manual for the production area, checklists were implemented, and "before-and-after" photographs were used. Finally, Sustain was fostered through operator training, periodic audits, and a recognition system to ensure active participation and continuous adherence. This final phase proved to be the most challenging, as maintaining consistency in the application of standards required a shift in habits and the establishment of a culture of discipline, which took time to solidify. Therefore, it was essential to continuously reinforce the importance of the 5S methodology through visual reminders. The implementation of the 5S process is reflected in the actual photographs presented in Figure 7.

TPM implementation focused on reducing machine downtime and increasing availability. This involves training operators to perform basic equipment maintenance tasks, such as cleaning, lubrication, and visual inspection. During plant visits, maintenance personnel collaboratively identified activities suitable for operators to proactively prevent

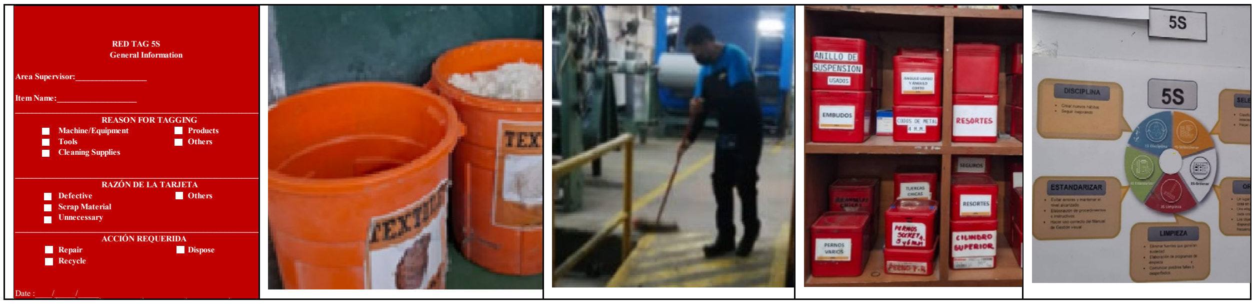


Figure 7. 5S implementation

and detect potential machine failures. A comprehensive maintenance policy was also developed, serving as both an instruction manual and a training tool for operators. This policy aims to ensure operators satisfactorily perform maintenance activities and are capable of identifying warning signs, such as unusual noises or vibrations, which could indicate internal machine issues like friction, lack of grease, or component wear. Finally, two procedures were created: the first detailing cleaning activities per machine, including location and necessary tools; and the second outlining the correct lubrication process for machinery.

5.4 Validation

For validation, the process was modeled using Arena Simulation software to simulate one month's production and evaluate the indicators with the implemented improvements. Executing the model in a single replica allowed us to observe the flow of a single entity, simulating the arrival of a blended fiber pool. This entity is consumed through a sequence of modules, with its attributes modified, competing for resources, being processed with varying durations, dividing, grouping, and making decisions based on defined rules. The enhancements achieved through the tool implementations are reflected in the increased uptime of the carding, ring spinning, and cone winding machines, as well as the reduction in Roving Frame Preparation and drawing frame drafting times. as shown in Figure 8.

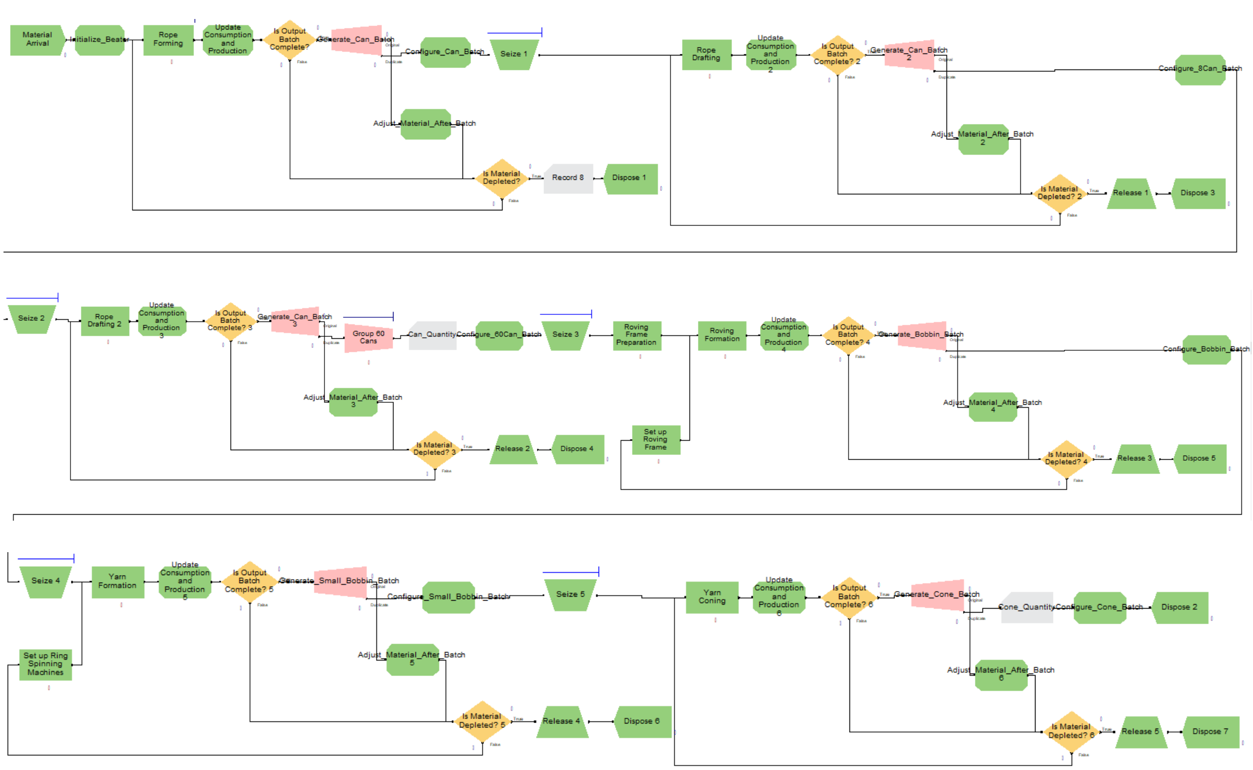
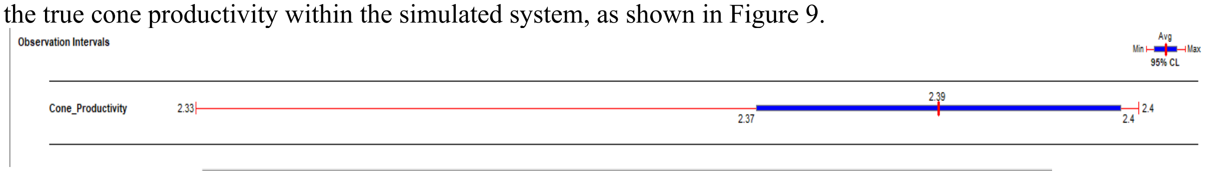


Figure 8. Improved Arena Model

The statistical validity of the model's variables (95% Confidence Intervals) shows that the "Cone_Productivity" metric in the model exhibits excellent statistical validity and high precision in its average estimation. This indicates that the 13 replications produced exceptionally consistent results for this metric. The HALF-WIDTH represents a minuscule percentage of the average, signifying high confidence that the average value of 2.39 is a highly accurate estimate of the true cone productivity within the simulated system, as shown in Figure 9.

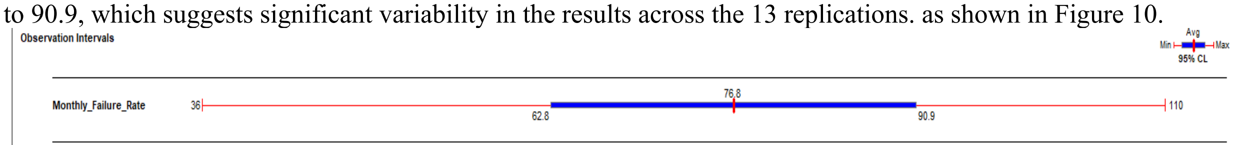


Classical C.I. Intervals Summary

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
Cone_Productivity	2.39	0.0214	0.0129	2.33	2.4	13

Figure 9. Cone Productivity results

The "Monthly_Failure_Rate" in the model exhibits statistical validity that could be improved and an average estimate with limited precision. The 95% confidence interval for the monthly failure rate is relatively broad, ranging from 62.7 to 90.9, which suggests significant variability in the results across the 13 replications. as shown in Figure 10.

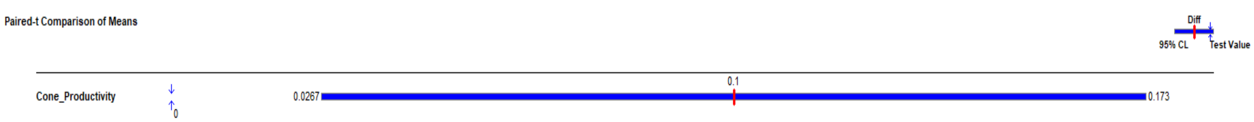


Classical C.I. Intervals Summary

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
Monthly_Failure_Rate	76.8	23.3	14.1	36	110	13

Figure 10. Monthly Failure Rate Results

In the statistical comparison utilizing paired-sample t-tests, the Output Analyzer indicated an estimated average difference of 0.1 between the two scenarios. The 95% confidence interval for this difference ranges from 0.0267 to 0.173. Since this interval does not encompass zero, the test suggests that the mean "Cone_Productivity" in both scenarios are not statistically equal at a significance level of 0.05. This allows for the conclusion, with 95% confidence, that the modification introduced in the second scenario had a statistically significant impact on cone productivity, resulting in a increase of 0.1 units. as shown in Figure 11.



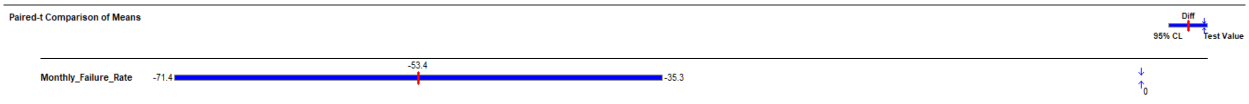
Paired-T Means Comparison :

IDENTIFIER	ESTD. MEAN DIFFERENCE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS
Cone_Productivity	0.1	0.121	0.0733	2.33	2.4	13
				1.97	2.38	13

REJECT H0 => MEANS ARE NOT EQUAL AT 0.05 LEVEL

Figure 11. Paired-t Comparison Results – Cone Productivity

In the Paired-T Means Comparison for the "Monthly_Failure_Rate," the Output Analyzer yielded an estimated average difference of -53.4 between the two compared scenarios. The 95% confidence interval for this difference spans from -71.5 to -35.3. As this interval does not include zero, the test indicates that the mean "Monthly_Failure_Rate" in both scenarios are not statistically equal at a 0.05 significance level. This allows for the conclusion, with 95% confidence, that the modification introduced in the second scenario had a statistically significant impact on the monthly failure rate, resulting in a reduction of approximately 53.4 failures per month. as shown in Figure 12.

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        Paired-T Means Comparison :

     IDENTIFIER         ESTD. MEAN   STANDARD  0.950 C.I.    MINIMUM     MAXIMUM  NUMBER
                        DIFFERENCE  DEVIATION  HALF-WIDTH      VALUE       VALUE  OF OBS
--------------------------------------------------------------------------------------
Monthly_Failure_Rate          -53.4       29.9        18.1         36         110      13
                                                                   79         146      13
        REJECT H0 => MEANS ARE NOT EQUAL  AT  0.05 LEVEL
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Figure 12. Paired-t Comparison Results – Monthly Failure Rate Productivity

6. Conclusion

A thorough initial diagnosis of the spinning mill revealed significant weaknesses in efficiency and productivity. Through plant visits, observation, time studies, and interviews, key indicators were identified, and the technical gap and economic impact were quantified, leading to clear objectives for solution implementation. Consequently, the combined application of SLP (Systematic Layout Planning), 5S methodology, and TPM (Total Productive Maintenance) tools resulted in a comprehensive improvement of operational processes, enhancing cone productivity by 4.37%, can productivity by 28.32% and OEE by 12%. This OEE improvement was constrained to 12% primarily due to the advanced age of the machinery, which limited the potential gains in the Availability component.

First, Systematic Layout Planning (SLP) optimized the plant layout, reducing bottlenecks and enhancing material flow and interrelationships. Subsequently, the 5S methodology established a more organized, clean, and disciplined work environment, serving as a foundation for standardization and increased efficiency, achieving a 76% audit score. Finally, Total Productive Maintenance (TPM) transformed the maintenance approach by engaging operators and implementing autonomous and preventive maintenance, leading to a significant reduction in failures, increased equipment availability, and ultimately, higher productivity.

The integrated approach of SLP, 5S, and TPM establishes a robust foundation for Operations Management and Lean Manufacturing. This methodology is universally applicable to environments involving physical flows and equipment, optimizing logistics layout, cultural standardization, and asset availability. The diagnostic framework is transferable, requiring only the adjustment of sector-specific Key Performance Indicators (KPIs).

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