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Original Article

Lean Manufacturing Implementation in Textile Dyeing: A Study of Process Optimization and Waste Reduction in a Peruvian SME

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Abstract *- The textile dyeing industry in Peru faces persistent inefficiencies related to machine stoppages, rework, and inventory mismanagement, which impact productivity and competitiveness. Previous studies have demonstrated the potential of Lean Manufacturing tools, such as 5S, Kanban, and Just-In-Time (JIT), to optimize processes and reduce waste. This research addressed these challenges by designing and implementing a Lean-based production model in the dyeing section of a Peruvian textile company. The model focused on standardizing work processes, optimizing workspace layout, and enhancing material flow through Kanban and JIT. The results showed a 12% improvement in operational efficiency, a 39% reduction in rework hours for shade adjustments, and a 21% decrease in color deviation hours. Additionally, recipe delivery delays were reduced by 52%, minimizing machine stoppages and enhancing production continuity. These findings validate the effectiveness of Lean methodologies in textile dyeing, suggesting further exploration of Lean applications in other stages of textile production to achieve broader operational improvements.*

Keywords *- Lean Manufacturing, Textile Dyeing, Process Optimization, Waste Reduction, Kanban System, Operational Efficiency.*

1. Introduction

The textile industry is a strategically vital sector of the economy due to its impact on international economic development, especially regarding employment opportunities and GDP contribution in developing countries [1]. Within this industry, dyeing is one of the most important processes in that it gives the fabric its final touch and determines its color, texture, and sharpness [2]. From a worldwide perspective, countries like China, India, and Pakistan are at the forefront of manufacturing textiles and, therefore, performing dyeing, as they account for a large share of total exports [3]. However, Latin America has not been absent from this phenomenon, with Brazil, Mexico, and Peru serving as the region's heavyweights in the industry [4]. Peru's textile industry has shown remarkable sustained growth. It has aided the country's economic progress, particularly in Lima, Arequipa, and Gamarra, the hubs of manufacturing activities [5].

Even with its relevance to the economy, dyeing processes face many production problems that stifle efficiency. Perhaps most notable are the machine stoppages caused by the absence of standardized recipes, resulting in prolonged downtimes and backlogs in production scheduling [6]. Moreover, reprocessing owing to color matching and off-tone problems remains a persistent solution-deficient challenge, augmenting operational expenditures while degrading product quality [7]. It has recently been discovered that the lack of adequate planning combined with dysfunctional management of pigments and chemicals inventory contributes significantly to these issues [8]. There is, therefore, an urgency to resolve issues associated with the inefficiency of the processes, incorporating Peru's textile industry within a global competitive framework [9].

In this regard, it has placed greater urgency on addressing operational inefficiencies for companies within the sector. Enhanced competitiveness and lower costs can be achieved by reducing downtimes, minimizing reprocessing, and improving recipe scheduling [10]. The implementation of strategies with a focus on continuous improvement fueled by the elimination of waste and process standardization, such as Lean Manufacturing, might offer fulfilling solutions to these challenges [11]. Nonetheless, there is a considerable lack of scientific literature addressing the specific use of Lean Manufacturing in dyeing processes, as noted in other portions of the textile industry. Most literature centers on the cutting and sewing stages; however, dyeing plants, vital in the value chain, have received scant attention [12]. Moreover, existing research typically examines the application of Lean tools such as 5S, work standardization, or Kanban. However, it lacks studies that evaluate their combined and contextualized implementation in the dyeing operations of SMEs in Latin America. This gap limits understanding of how integrated Lean systems can address operational inefficiencies in recipe management, rework, and inventory synchronization.

In response to this gap, this investigation develops and validates a production model based on Lean techniques, including 5S, work standardization, JIT, and Kanban, tailored to the dyeing section of a Peruvian SME [13]. The model seeks to enhance operational efficiency and global competitiveness by reducing machine stoppages, optimizing recipe scheduling, and minimizing reprocessing caused by tonal errors [14]. This integrated approach offers a novel contribution by demonstrating how the synergistic application of multiple Lean tools can resolve persistent inefficiencies in a production stage traditionally neglected in Lean research.

As outlined in the following sections, we will describe the theoretical rationale justifying this proposal, the methodological design, and the implementation results in real-world settings. These contributions are expected to serve the Peruvian and, more broadly, Latin American textile sectors with novel strategies that strengthen their ability to effectively compete in a more globalized and demanding environment world [15].

2. Literature Review

2.1. Lean Manufacturing Techniques for Dyeing Plants in the Textile Industry

The impact of Lean Manufacturing stretches across various industries, including the textile industry. Within the dyeing plants, the philosophy focuses on eliminating waste, decreasing idle time, and enhancing productivity with the help of specific tools like Value Stream Mapping (VSM) and standardization of processes [16]. One study in an Indian dyeing plant discovered a 20% decrease in cycle times and a 15% reduction in chemicals used after Lean was put into practice [17]. Also, a LEAN-technique-based optimized material flow and recipe design led to a 12% increase in productivity by a Peruvian textile SME. [18] Further, other studies support the 5S implementation and Kanban usage, which resulted in 8% shading defect reduction and 10% plant space optimization due to better distribution of processes. [19] This proves the efficacy of carefully tailored Lean Manufacturing principles for the textile industry, enabling tighter control of the dyeing processes, reduced variability, enhanced competitiveness, and improved adaptability.

2.2. Standardized Work in the Textile Industry

Standardized work is one of the most important principles to arise from Lean Manufacturing, aiding in the minimization of deviations from the ‘norm’ of performing work tasks. In textile dyeing industries, applying standard work procedures has been beneficial in maintaining quality control and avoiding errors when applying dyes and chemicals [20]. One case study from a textile company in Vietnam showed that the implementation of standardized work in the dyeing area led to an 18% reduction in reprocessing and a 12% improvement in operational efficiency [21]. Furthermore, other studies reported that these types of standardization in textile SMEs in Brazil and China resulted in a 9% decrease in defects [22]. The standardization of dyeing recipes has reduced setup time and input usage, leading to considerable cost savings [23]. Hence, this evidence shows the importance of process standardization in dyeing for achieving quality control and reducing the variation of processes.

2.3. 5S Methodology in Textile SMEs

The 5S methodology is recognized as a basic strategy for organizing and optimizing the workspace in the textile sector. Its use in dyeing plants has been documented to significantly reduce waste and enhance the flow of materials [24]. A study performed at a dyeing plant in Mexico noted that operational efficiency increased by 7% while the time spent searching for inputs decreased by 10% after 5S was implemented \[25]. Likewise, some cases from Peru demonstrated improvement in the order and cleanliness of the dyeing areas, which enhanced safety, reduced accidents, and improved operational safety [26]. The combination of 5S with other Lean methods enhances the efficient utilization of space and visual control of processes [27]. These findings confirm that 5S provides an efficient framework for the maintenance of cleaner, safer, and more productive work environments in textile dyeing plants.

2.4. Application of the Kanban System in Textile Processes

The Kanban system helps to manage the flow of work and apply inventory control within the dyeing processes to mitigate overproduction and streamline Work-In-Progress (WIP) storage [28]. One study held in Spain showed that using Kanban in a textile company led to a decrease in WIP inventories by 12% and a 15% improvement in the synchronization of materials [29]. Similar studies conducted in Colombia reported an improvement of 10% in the overall management of inventories and an 8% decrease in machine downtimes due to the use of Kanban cards [30]. Also, more recent studies have pointed out that Kanban aids in the maintenance of uninterrupted material flow as well as better interprocess communication in dyeing plants [31]. This demonstrates the effectiveness of Kanban in resolving bottlenecks and enhancing production movement more smoothly through the processes.

2.5. Just-In-Time (JIT) in Dyeing and Similar Manufacturing

The methodology of Just-In-Time (JIT) concentrates on minimization of production processes to what is necessary at the exact required time, thereby reducing inventories and making the best use of available recourses [32]. This method has decreased waiting times and lower inventories in the dyeing industry, thereby improving efficiency [33]. China conducted a case analysis and found that the storage costs in the dyeing JIT sector reduced by 18% [34]. Also, a textile plant in Bangladesh revealed that it improved its delivery times by 22% while at the same time reducing waste by 12%, all after refining processes under a JIT framework [35]. This evidence shows that JIT implementation in textile dyeing plants enhances responsiveness to demand while improving resource utilization and overall product quality.

3. Contribution

3.1. Proposed Model

Figure 1 illustrates the proposed production model, designed under the principles of Lean Manufacturing, which was implemented in the dyeing area of a textile company. This approach focused on optimizing processes by reducing non-value-added activities, eliminating waste, and improving workflow. Key tools such as 5S were applied for the organization and standardization of the area, resulting in a cleaner and more efficient environment that facilitated the detection of anomalies and reduced unproductive times. Moreover, the reallocation of workstations aimed to minimize unnecessary movements and enhance task sequencing, achieving greater synchronization among operations. The integration of Just In Time and Kanban enabled more precise management of inputs, adjusting production to real demand and avoiding unnecessary inventory accumulation. Through this model, the goal was not only to optimize processing times in the dyeing area but also to enhance the quality of the final product by reducing defects and rework. The Lean philosophy served as the foundation to establish an agile and flexible system capable of adapting to production variations, thereby strengthening the company's competitive capacity in a globalized market.

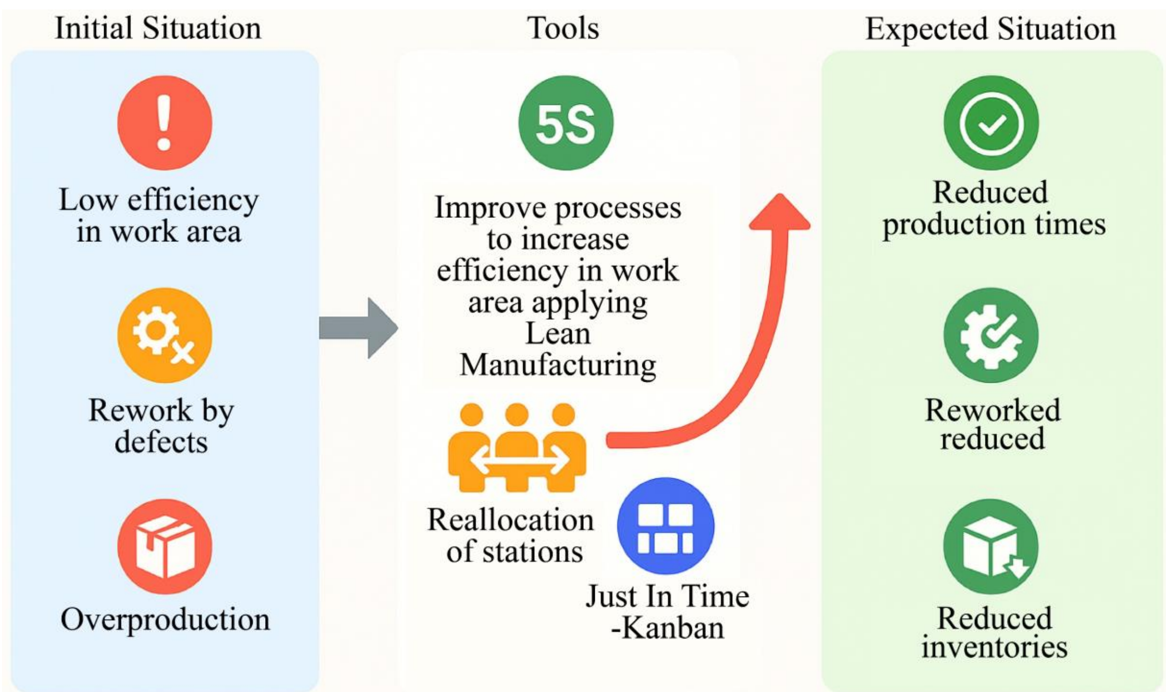

Fig. 1 Proposed Model

3.2. Model Components

The outlined production model in Figure 1 depicts a systematic approach to optimizing efficiency and productivity in the dyeing section of a textile firm. This model is aligned with the guidelines of Lean Manufacturing, which considers the avoidance of waste, improvement of the workflow, and systematic refinement of all processes as critical to achieving operational excellence. Lean tools foster the refinement of processes, reduction of non-value-adding activities, and the establishment of a culture of high efficiency and production quality in the workplace. Its use regarding the dyeing section solves rework problems, inventory management, and workflow integration, greatly enhancing processing time and product quality.

3.2.1. Standardization and Organizational Structure via 5S

The proposed model's implementation starts with applying the 5S approach. This tool helps organize the workplace, regulates operations, and maintains cleanliness. The five steps of 5S—sort, set in order, shine, standardize, and sustain—are applied systematically to remove waste, increase the visibility of tools and materials, and optimize workflows. In the dyeing section, the application of 5S ensures that no more than essential materials are labelled, accessible, and kept at hand. Such order significantly reduces time wastage in searching for items, minimizes work interruptions, and improves productivity.

The sorting phases focus on removing everything unnecessary—materials, items irrelevant to production goals, and the workspace, where everything is cleared. Following this is the setting in order “Set” stage, where tools and equipment are organized to match sequential steps in the production process. The effective “Shine” phase concerns cleanliness and equipment upkeeping to avert possible malfunctions. “Standardize” establishes that all shifts must document all actions within the turn to boost discipline and order. Lastly, the last phase, ‘sustain,’ reinforces these habits through periodic checks and strategies for change dynamics, whereby 5S becomes part of the organizational culture.

3.2.2. Reallocation of Workstations and Layout Improvements

After implementing 5S, the focus shifts to strategic workstation reallocation to improve the workflow and remove redundant and unnecessary movements. In the dyeing section, workstations are moved to reflect better the sequential transfer of materials to lower transport distances and possible stagnation points. The new layout enhances control; operators can supervise every process, monitor progress, and easily see what requires attention. This change consumes less time to complete work cycles and increases the throughput of the dyeing process.

The layout optimization considers the Lean Manufacturing philosophy concerning safety, efficiency, and ergonomic workplace design considerations. The dyeing operation becomes more reliable and less susceptible to variation-induced disruptions because eliminating unnecessary handling makes predicting the processes easier. Furthermore, the orderly arrangement of workstations affords better operator-to-operator communication, improving coordination and reaction time during production operations.

3.2.3. Integration of Just in Time (JIT) and Kanban Systems for Effective Inventory Management

The model suggested uses Just in Time (JIT) methods integrated with Kanban systems to improve inventory control and synchronize production with demand. Within the dyeing area, JIT concentrates on ‘making’ only what needs to be ‘made,’ when the “make” is required and in the precise quantities needed. This approach limits the holding of excess stock and the waste associated with overproduction. Kanban cards are used as indicators to control the flow of materials through the production segments so that materials are supplied on time, neither too early nor too late.

The combination of JIT and Kanban supports lean production whereby each subsequent process initiates action based on the previous one’s demand. This system addresses the issues of material starvation and excess WIP and makes operations more predictable and efficient. The dyeing section improves responsiveness and agility to demand changes, enhancing service levels and reducing lead times.

3.2.4. Waste Elimination and Continuous Improvement

The commitment to continuous improvement and waste elimination is a core characteristic of the proposed model. Within the framework of Lean Manufacturing, there is a push towards eliminating all activities that do not add value to a given process. In the dyeing department, waste is classified into the following seven categories: overproduction, waiting, transport, extra processing, inventory, motion, and defects. This model aims to address these issues through continuous iteration and improvement.

Improvement drives are open to all staff, who can submit comments and recommendations for improving productivity and reducing waste. Administrations perform regular checks for a given process's efficiency to detect any bottleneck and refine further. Such an initiative guarantees that changes in demand or operational difficulties do not compromise the flexibility and robustness of the dyeing process.

3.2.5. Conclusions Regarding the Proposed Model

The production model of Figure 1 implements Lean Manufacturing principles, specifically in the dyeing section of a textile company. With the application of 5S, reshuffling of workstations, JIT and Kanban, a smooth workflow together with better control of inventory and reduction of wastes considerably has been achieved.

The approach enables self-improvement within the system, ensuring improved performance will be maintained over time. This model can be used directly as a guideline for improving production processes in the textile industry, providing flexible, responsive options to varying demands and complexity levels. It further allows many lean-inspired future modifications, confirming the versatility and robustness of the model in highly competitive markets.

3.3. Model Indicators

The operational efficiency of the textile dyeing process was evaluated through a Lean-based production model designed to enhance process performance. This approach utilized customized measurement criteria specifically adapted to the dynamics of dyeing operations. These metrics enabled a comprehensive efficiency analysis, supporting the assessment of critical factors impacting process flow and waste reduction.

The systematic application of Lean principles facilitated continuous monitoring and control, ensuring workflow synchronization and resource utilization improvements. This structured evaluation contributed to more agile and efficient dyeing processes, reinforcing the factory's competitiveness in the textile sector.

3.3.1. Rework Hours Due to Shade Adjustment

This indicator measures the total number of hours spent on rework due to discrepancies in the dyeing shade. It reflects inefficiencies in the colour-matching process and aims to track the time required to achieve the desired colour consistency.

$$\text{Rework Hours Due to Shade Adjustment} = \sum_{i=1}^{n} T_i$$

Where:

- T_i = Time spent on rework for each batch
- n = Total number of batches requiring rework

3.3.2. Rework Hours Due to Colour Deviation

This indicator quantifies the hours dedicated to reprocessing fabrics that did not meet the expected colour specifications. It monitors inconsistencies in the dyeing process that lead to off-shade results.

$$\text{Rework Hours Due to Colour Deviation} = \sum_{i=1}^{n} T_i$$

Where:

- T_i = Time spent on rework for colour correction
- n = Total number of batches with colour deviations

3.3.3. Downtime Hours Due to Recipe Delivery Delays

This indicator calculates the total downtime caused by delays in the delivery of dyeing recipes. It reflects disruptions in the workflow that impact production continuity and process efficiency.

$$\text{Downtime Hours Due to Recipe Delivery Delays} = \sum_{i=1}^{n} T_i$$

Where:

- T_i = Time of inactivity due to recipe unavailability
- n = Total number of delayed recipe events

3.3.4. Operational Efficiency

This indicator represents the ratio between the actual and maximum possible output, adjusted for production time. It is a key performance metric to evaluate the effectiveness of the dyeing process.

$$\text{Efficiency (\%)} = \frac{\text{Actual Output}}{\text{Theoretical Maximum Output}} \times 100$$

Where:

- Actual Output = Amount of fabric successfully dyed
- Theoretical Maximum Output = Maximum capacity based on machine and time availability

4. Validation

4.1. Validation Scenario

The validation scenario was carried out in a case study of a medium-sized company in Lima, Peru, dedicated to the textile sector. This organization focused its operations on producing and commercialising yarns and fabrics, covering spinning, weaving, dyeing, and finishing. In the dyeing area, the dyeing processes were carried out in machines called "barcas," with variable capacities of 200 kg, 400 kg, 600 kg, and 800 kg, allowing different volumes of fabric to be processed according to production requirements. However, the area showed significant deficiencies in its performance, with an efficiency of 65.7%, below the technical standard identified in the literature, which was set at 75%. These gaps in operational efficiency reflected problems in process management, directly impacting production times and the quality of the final product, highlighting the need to implement improvements in workflow organization and inventory control.

4.2. Initial Diagnosis

The diagnosis conducted in the case study revealed low efficiency in the dyeing area, reaching 65.7% effectiveness in the TSR and 75% globally, representing an economic impact of USD 1,093,121.00 annually, equivalent to 3.64% of the total revenue. This deficiency was mainly attributed to two factors: process stoppages, accounting for 18% of the identified reasons, and rework, which reached an alarming 82%. Among the process stoppages, 54.15% were due to delayed recipe deliveries from the laboratory, while 45.85% corresponded to other causes. The second-level analysis identified that delays in material delivery from PCP, disorganization in the laboratory area, and the lack of standardization in work methods significantly contributed to this issue. On the other hand, rework was divided into three categories: colour matching (48.08%), off-shade fabric (35.19%), and others (16.73%), where root causes included unclean and disorganized environments, non-standardized work methods, and unbalanced workloads. These findings reflected a lack of control over key processes, directly affecting the operational efficiency of the dyeing area.

4.3. Validation Design

The proposed production model, based on Lean Manufacturing principles, was validated through a structured pilot implementation in the dyeing process of a textile factory. This validation spanned four months, encompassing the application of key Lean tools, including 5S for workspace organization, Kanban for inventory control, and work standardization to reduce variability. The primary objective of this initiative was to enhance the operational efficiency of dyeing processes, minimizing waste and optimizing resource utilization. The validation followed a data-driven approach, enabling a comprehensive evaluation of workflow, productivity, and process stability improvements, ensuring economic and operational feasibility.

This intervention focuses on implementing a Lean Manufacturing-based production model in the dyeing division, a textile company segment. In the initial stage, a holistic blueprint was crafted wherein Lean techniques (5S, standardization of processes, Kanban, etc.) were systematically aimed at resolving the underpinning concerns of subpar efficiency in recipe production and the proportioned of materials to the Production Planning and Control (PPC) department. The engineering team drew up a detailed timeline to execute the improvement phases, organized workshops with participants (laboratory technicians, supervisors, and management), and delegated roles to spearhead each phase. This strategy resolved the excess control issues in the laboratory and the lack of JIT (Just-in-Time) PPC collaboration that had previously counter productively lagged the entire process. Therefore, the workflow for producing recipes was redesigned to align with Lean guidelines, focusing on eliminating waste in terms of movements, idling, and redundant work and standardizing these operations to improve efficiency in the dyeing area.

4.3.1. Phase 1: Application of the 5S Methodology

The project's initial phase was 5S implementation in the laboratory to achieve order cleanliness and ease of operations. For this purpose, the engineering team developed a Gantt chart with the sequence of activities and the relevant responsibilities. With this plan in hand, the deployment of the 5S phase commenced: 5S was first introduced in an initial talk to the people directly concerned (the laboratory technicians, the supervisor, and the area manager) conducted by the engineering team. As it was “5S for Everybody,” this session aimed to achieve the 5S system goals and preset leaders and facilitators of the defined teams for each “S”. Figure 2 illustrates the layout transformation before and after the 5S application. The improved design optimized workstation distribution, minimized unnecessary movements, and enhanced visual management, leading to more efficient material flow and reduced travel distances. The reorganization facilitated smoother operations and better workspace utilization in the dyeing process.

Let us execute the Sort (1S) phase: employees engaged in material classification sessions that lasted 3 hours within the workspace. The team marked redundant components such as waste, obsolete samples, and misplaced items for removal or relocation. Directly after, the phase Set in Order (2S) was done, and the laboratory layout was modified. The recipe preparation area was subdivided into subzones labelled by colours so that each machine, instrument, or supply had a clear designation to a specific unit. This restructuring improved object identification and reduced ambiguity. Furthermore, re-evaluating operator routes reduced internal travel distances: the layout study showed the average distance was reduced from 17 meters to 12 meters, a decrease of approximately 29% in the distance during recipe preparation. This quantitative result showcases the preliminary impact 5S had on reducing transportation time and improving the workflow within the laboratory.

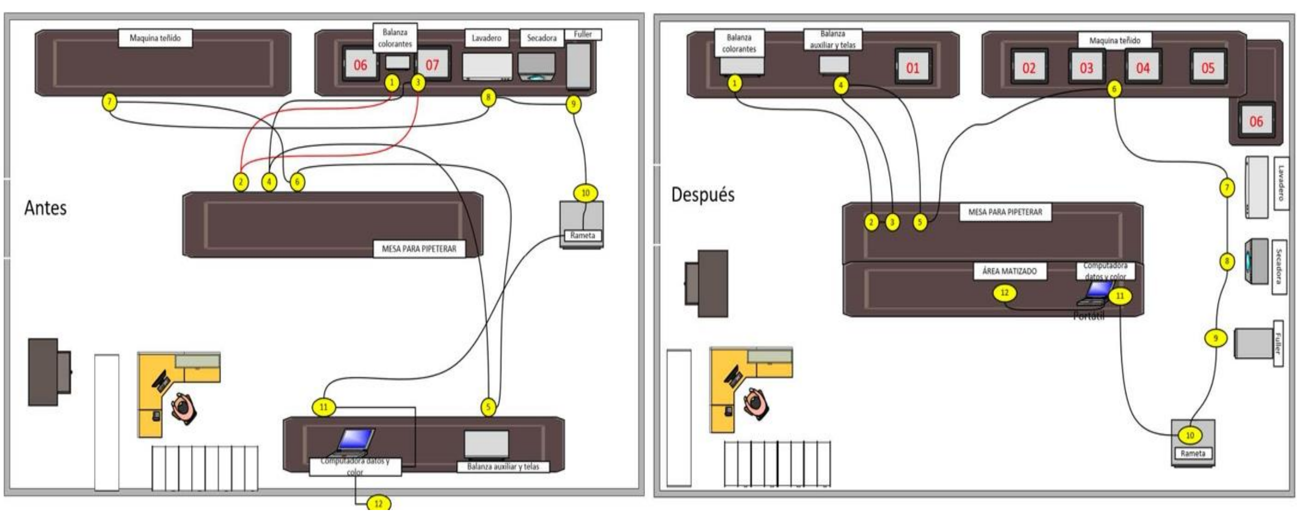

Fig. 2 Layout before and after the 5S application

Ultimately, while the document does not specify how the last two phases were accomplished, it is possible to infer that routine cleaning (3S) was instituted, standards for visual order (4S) were set, and (5) regular audits to sustain improvements were instituted. In summary, Phase 1 developed a more streamlined and controlled laboratory operation, a foundation for the subsequent Lean improvements. In Figure 3, the radar chart illustrates the performance levels achieved in each of the 5S stages: Sort, Set in Order, Shine, Standardize, and Sustain.

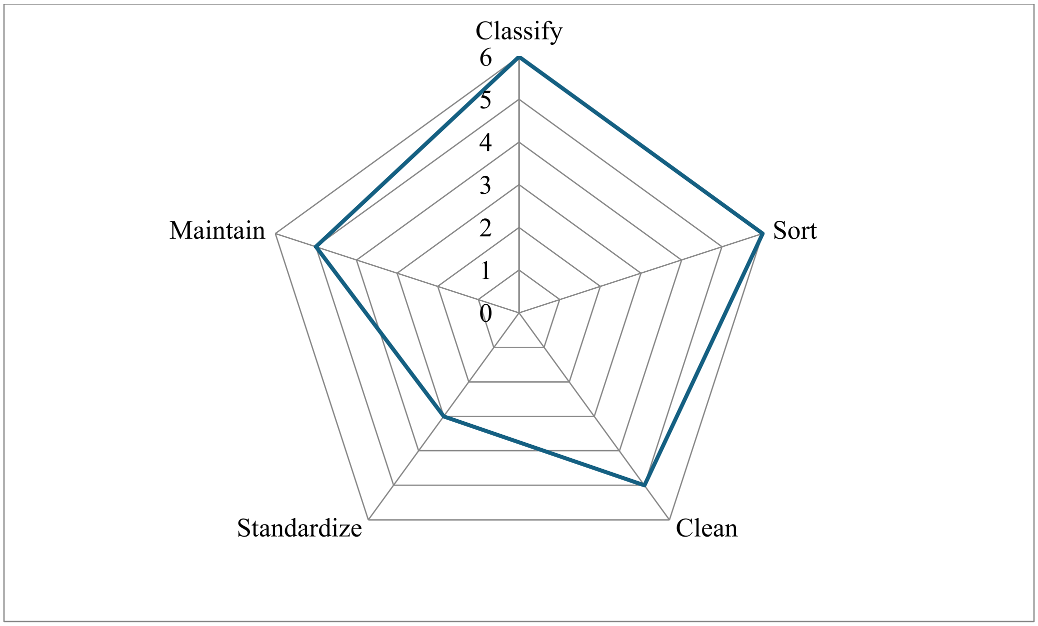

Fig 3. 5S Assessment Radar Chart

4.3.2. Phase 2: Study of Work Methods and Standards

In this second phase, work methods and time study were done with the area management for the central laboratory process. The goal was to distinguish all recipe creation activities, identify those processes that provide value, and eliminate or rectify those that do not. For this purpose, the overall process was captured and divided into its respective components; 24 activities were identified, and it was determined that 2 of them were unnecessary. By eliminating these unnecessary tasks, the process route was streamlined. Likewise, some poorly applied procedures (substandard application of methods) that influenced the dyeing quality were corrected. After deriving the optimal operational sequence, the resultant workflow was standard, and times were established.

The findings from this analysis were notable because the average standard time for the recipe preparation process was cut down by 5.4 minutes. This reduction was equivalent to a 28.9% improvement over the previously recorded time, as shown in the original comparative graphs (Figure 4). This supports the claim that standardization helped accelerate the operation. This was a proving point in how Lean impacted the processes: after pruning redundant steps and standardizing tasks, the operational efficiency in the laboratory streamlined by close to a third. Concurrently, clear formal documentation of the corrected procedures was developed, ensuring that operators had aligned, standardized instructions, thus reducing failures identified in earlier processes. Hence, Phase 2 ended with processes that are straightforward yet structured, faster, and directly reduced costs associated with rework while improving the quality of the dyed fabric.

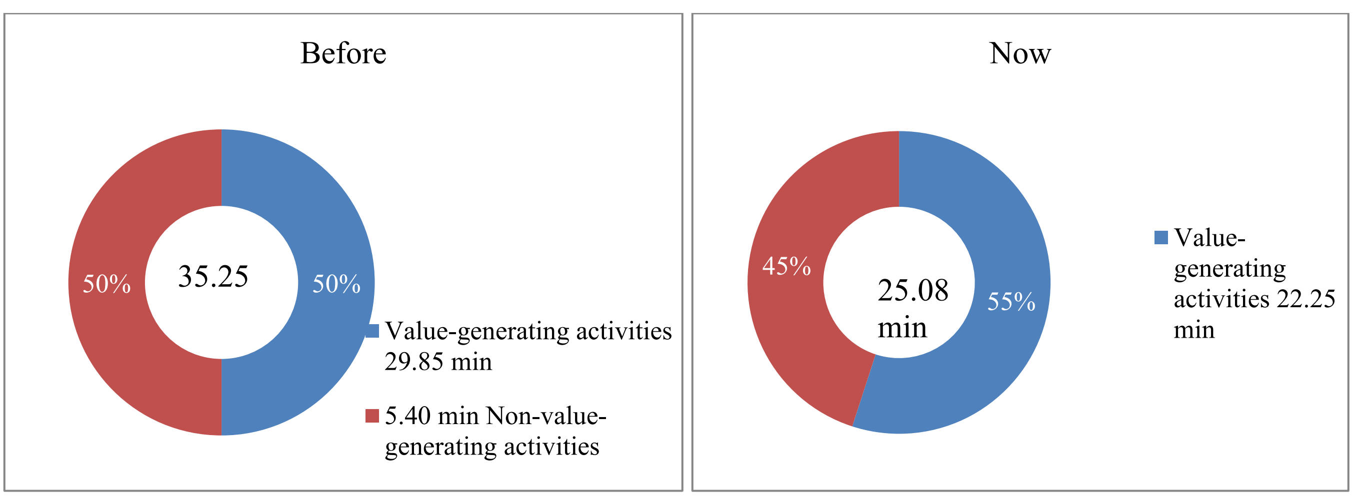

Fig. 4 Comparison of Recipe Standardization Process

4.3.4. Phase 3: Redesign of Process with Focus on Fabric Request and Integration of Kanban Scheduling System

In the fourth part of the iterative design process, the macro process of fabric request from weaving to dyeing was redesigned with the integration of Kanban boards for further optimization of Just-In-Time scheduling. For this, we mapped the entire process, from the creation of the batch in weaving up to the fabric's arrival at the dyeing boat. This analysis pointed out two major issues. The lead time to deliver the fabric to the laboratory was 10 days, whereas the target was 24 hours. This issue stemmed from a bottleneck caused by the PPC area delaying material requisition at the start of weaving. Secondly, the existing method of strategic planning was suboptimal. Scheduling was based on three-hour coordination meetings with chronic information delays regarding critical data and high uncertainty concerning lab needs.

To solve these issues, two tailored Kanban systems were created. A visual control board containing twenty spaces, one for each weaving machine, was installed in weaving. This control board was focused on monitoring the section so the supervisor and a controller could refresh it as production progressed. Each space represented a request for a fabric lot. Thus, after completing a weaving run, the operator only needed to fill the corresponding space to notify the laboratory. The new kanban board guaranteed that all requests in the queue were noticed simultaneously, which compelled PPC to resolve them. This practically eliminated uncertainty: the system requires that if any request space is unchecked (reset to zero), the supervisor must resolve it immediately to comply with the 24-hour rule.

Also, a Kanban board was created for the dyeing PPC area to mitigate machine stoppages caused by a lack of recipes. This second board, part of the production control system, shows the need for recipes based on the number of dyed lots. As a result, the PPC area of dyeing can synchronize recipe generation with the weaving process more effectively. Both Kanban boards work in tandem: the first ensures the right fabric is at the laboratory on time, while the second avoids recipe delivery delays that cause machine stoppages. With these Kanban visual control tools, the flow of raw materials approached the just-in-time system, idle times were minimized, and the fabric production was better timed with the dyeing operation.

Figure 5 shows the weaving areas of the Kanban board, illustrating the fabric requests' visual scheduling. This system enabled efficient monitoring of production demands, reducing lead times from 10 days to 24 hours, aligning the material flow with Just-In-Time (JIT) principles and minimizing bottlenecks.

In Figure 6, the Kanban board for PCP in the dyeing area is presented. This tool facilitated precise recipe planning, preventing machine stoppages due to recipe unavailability. Its visual cues allowed real-time adjustments, improving workflow synchronization and enhancing process efficiency in textile dyeing

Fig. 5 The Kanban Board for Weaving Operations

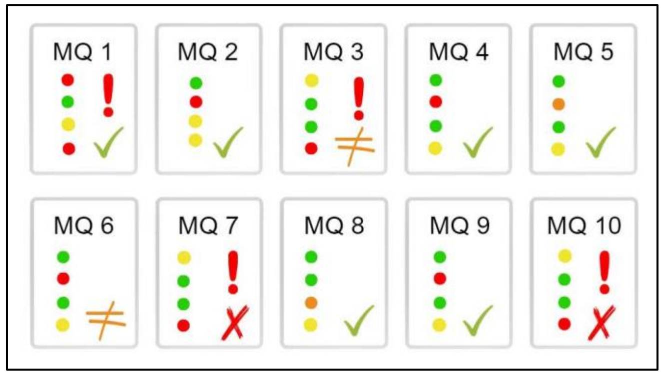

Fig. 6 The Kanban Board for PPC Dyeing

4.4. Results

Table 1 presents the impact of the production model based on Lean Manufacturing tools on process optimization within the textile dyeing area. The results showed a significant reduction in rework hours, highlighting a 39% decrease in hours dedicated to shade adjustment and a 21% reduction in those generated by colour deviation. Furthermore, there was a 52% decrease in downtime related to late recipe delivery, contributing to greater operational availability. Overall process efficiency increased from 65.70% to 73.60%, reflecting a 12% improvement after the implementation of the model. These results confirmed the effectiveness of Lean methodologies in eliminating waste and optimizing workflows in industrial environments, strengthening the operational capacity of the dyeing area and improving performance in terms of time and product quality.

5. Discussion

The novelty of this study lies in its integrated application of Lean Manufacturing tools in the dyeing section—a stage less explored than the cutting and sewing processes [1][2]. Unlike previous studies that apply 5S, JIT, or Kanban individually [16][17][28], this model combines these tools in a systematic manner tailored to the operational reality of a Peruvian textile SME. This integration addressed recipe delivery delays, excessive rework, and poor inventory flow, achieving an overall efficiency improvement of 12% and a 39% reduction in rework due to shade issues and 52% less downtime from recipe delays. These results extend the findings of Silva et al. [12] and Sharma and Gupta [17], who reported the benefits of Lean tools applied separately by demonstrating the cumulative effect of tool integration. Moreover, the dual Kanban system represents an original contribution by aligning production between weaving and dyeing, reducing lead times and improving coordination—an aspect not addressed in existing literature.

The efficiency outcomes resulting from this research indicate improvement concerning the specific operational efficiency of the dyeing section within one of the Peruvian textile firms. This is also corroborated by existing literature. The operational efficiency improvement of 12% from 65.70% to 73.60% corresponds with the findings of Silva et al. [12], where an increase in resource utilization and reduction in cycle time was achieved during the dyeing process optimization using Lean tools. Moreover, a % reduction in rework hours of 39% for shade adjustments and 21% for color deviation analyses supports Sharma and Gupta's [17] work on process defect reductions through standard work and visual control. On the contrary, a combination of Kanban and JIT led to a 52% reduction in downtime hours attributed to recipe delivery, which is consistent with Roy and Singh's [28] findings on the use of Kanban in dyeing processes where production flow was optimized along with waiting time reduction. This underlying analysis reinforces the argument that Lean techniques should be integrated with dyeing areas, which other segments in the textile chain have traditionally neglected. This integration contributes towards trimming waste and optimizing workflows while sharpening the competitive edge in operational productivity within the sector [16].

5.1. Study Limitations

Even with the productive outcomes attained, this research has a specific set of boundaries to consider for deeper future analysis. Firstly, the production model based on Lean Manufacturing principles was implemented in a controlled setting within the dyeing section of a textile company. This scope could limit other contexts considered within the industry. In addition, a validation period of four months was assigned to the study. While observing initial improvements is plausible within this timeframe, deeper observing and long-term effects, such as wearing lean practices or acclimatising operators to new work methods, may not be as apparent. Lastly, the absence of specific benchmarks to measure the ecological footprint concerning waste reduction in the dyeing process showcases an opportunity for refinement in future studies.

Table 4. Results of the pilot

Indicator	Unit	As-Is	To-Be	Results	Variation (%)
Rework Hours Due to Shade Adjustment	Hours	4254	1659	2595	-39%
Rework Hours Due to Color Deviation	Hours	3113	653	2459	-21%
Downtime Hours Due to Recipe Delivery Delays	Hours	736	385	351	-52%
Efficiency	%	65.70%	85%	73.60%	12%

5.2. Recommendations for SMEs Based on Results

The study's results particularly provide significant practical consequences for the textile industry in Peru. The increase in operational efficiency and reduction in downtimes in the dyeing section indicates that Lean approaches like Kanban, 5S, and JIT streamline not only production but also lower costs related to rework and idle inventory. This strengthens the competitive position of textile firms in international markets where responsiveness and agility in dealing with changing customer demands are critical. Additionally, it is possible that the model adopted could be applied in other regions of the textile industry, thereby fostering a culture of benchmarking within the organization focused on continuous improvement and the relentless pursuit of process refinement and waste elimination at every level of production.

5.3. Future Works

Further investigations may concentrate on applying the Lean Manufacturing-based production model to other major activities within the textile value chain, like cutting and sewing, to assess their impact on the operational efficiency of manufacturing plants. Also, integrating tools from Industry 4.0, including the IoT and real-time data streams, to enhance KPI tracking and expedite evaluation and action during decision-critical moments would be helpful. Finally, looking into the ecological effects of reduced waste creation in the dyeing process could provide further insights into how sustainable Lean practices are within the textile industry.

6. Conclusion

The application of the Lean Manufacturing approach in the dyeing section of a textile firm from Peru yielded remarkable gains in operational efficiency alongside waste minimization. The findings indicated an increase in efficiency by 12%, with a 39% reduction in rework hours for shade adjustments and a 21% decrease in colour deviation hour losses. Moreover, the adoption of Kanban and Just-In-Time (JIT) methodologies reduced recipe delivery lags by 52%, which subsequently aided in maintaining production flow and reducing downtimes. These results underscore the sharpened focus Lean frameworks provide for working toward more efficient process design in the dyeing department, which has traditionally received less attention to Lean paradigms, resource-focused process improvement, and non-value-adding activity elimination. The regimented application of 5S, work standardization, and inventory control through Kanban improved process variability and streamlined production flow. This confirms the model's broader industrial applicability.

This study emphasizes the importance of adopting Lean Manufacturing concepts into the textile dyeing industry, which is often neglected when informing process improvement frameworks. The findings validate that applying Lean techniques can enhance productivity, minimize waste, and improve resource utilization, making businesses more competitive globally.

Moreover, the thorough application of visual controls and work regulation brought about uniformity, leading to better cross-stage synchronization, which was smoother. This showcases how operational outcomes, as well as the production practices of textile firms, are improved through Lean strategies.

In contrast to existing literature focusing on cutting and sewing as the primary application areas, this study expands the body of knowledge by applying Lean Manufacturing to dyeing processes and demonstrating its positive impacts. This study proves that dyeing, like cutting and sewing, can benefit from applying Lean tools. In addition, the successful adoption of Kanban and JIT reinforces the role of material circulation in alleviating bottlenecks and enhancing production cycles. This evidence proves that the other textile sectors aiming for high efficiency can adopt the suggested model without restriction.

The proposed model's implementation in other vital processes of the textile supply chain, like cutting and finishing, remains to be evaluated and should be explored in future research to assess its broader implications. Furthermore, including IoT and real-time data analytics as part of the frameworks' vision of Industry 4.0 could improve process transparency and make decisions more efficiently. Lastly, assessing the sustainability of production in the textile industry by applying Lean principles and estimating the ecological effects of waste reduction would certainly yield important conclusions.

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