# Lean Tools and Digital Andon under the PDCA Methodology to Increase OEE in a Peruvian's SME Textile

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***Abstract*— This study addresses the problem of low operational efficiency in a Peruvian Small, and Medium-Sized Enterprises (SME) in the textile sector, responsible for the production of knitted fabrics such as piqué and jersey. The textile sector represents approximately 10% of total manufacturing output in the country and contributes 2% to the Gross Domestic Product (GDP), being one of the largest generators of employment. The company studied recorded an overall equipment effectiveness (OEE) of 66.47%, far below the ideal goal of 85%. To close this gap, a continuous improvement model based on the PDCA methodology is proposed, integrating Single-Minute Exchange of Die (SMED), Total Productive Maintenance (TPM), and Work Standardization. The project uses a mixed-method validation strategy: pilot and discrete event simulation. The results show the potential of this approach to improve efficiency, reduce waste, and strengthen operational sustainability.**

***Keywords*— Digital Andon, SMED, Textile Sector, TPM, Work Standardization.**

## I. INTRODUCTION

The Peruvian textile sector is one of the main activities of the national manufacturing industry, with more than 46,000 registered companies and approximately 400,000 direct jobs generated [1]. However, over the past decade, its contribution to the Gross Domestic Product (GDP) and the manufacturing GDP has shown a declining trend. Between 2011 and 2020, the textile GDP fell by an average of 1.6% annually, with a sharp contraction of 31.8% in 2020 [2]. This behavior reflects a sustained loss of competitiveness, especially among micro, small, and medium-sized enterprises (MSMEs), which make up 95% of the sector and face serious limitations in maintaining adequate levels of productivity [3].

In response to this situation, various studies have documented efforts to reverse this trend through the adoption of continuous improvement tools [4], [5], [6]. SMED has significantly reduced setup times in industrial environments by converting internal activities into external ones [4]. TPM, with its preventive and autonomous approach, has contributed to increasing machine availability [5]. Likewise, work standardization ensures uniform and efficient task execution, facilitates staff training, and reduces process variability [6]. These tools have proven effective in manufacturing industries, particularly generating substantial improvements in textile companies across Latin America [7]. Additionally, the integration of digital technologies with Lean methods, such as equipment sensorization for predictive maintenance, has been shown to increase availability by over 90% [5] and reduce defects by more than 20% [8]. However, these approaches may be further strengthened through the integration of digital technologies that enable real-time monitoring and data-driven decision-making in critical textile production processes.

Nevertheless, knitting operations present specific technological challenges that can limit the effectiveness of conventional improvement practices. Recent studies have shown that knitting machines can benefit from the acquisition and analysis of operational data, such as machine speed, operating steps, and machine-stop events, to enable real-time classification of stoppages and support timely maintenance decisions [9]. Similarly, IoT-based monitoring systems have been applied to circular knitting machines to continuously capture operational conditions and identify potential failures [10]. Despite these advances, the limited integration of real-time data acquisition, condition monitoring, and automated traceability in textile production environments may hinder the early detection of equipment abnormalities, the identification of process deviations, and the establishment of relationships between machine conditions and production losses. These limitations are particularly relevant for MSMEs operating with legacy equipment and constrained digital infrastructure. Therefore, integrating digital technologies with Lean practices provides an opportunity to strengthen decision-making, improve equipment reliability, and enable timelier and data-driven interventions in textile production.

Within this context, the present study proposes a methodological model based on the PDCA cycle for a Peruvian textile company. The model combines Lean tools—SMED, TPM, and work standardization—with digital technologies, with the goal of structurally addressing the factors that impact fabric production efficiency. It is expected that the application of this model will contribute to improving operational performance, reducing waste, and serving as a replicable reference for companies with similar characteristics.

## II. LITERATURE REVIEW

### A. Lean Manufacturing

Lean Manufacturing is a management approach focused on maximizing customer value by eliminating waste in processes. Its principles include demand-driven production (pull), continuous improvement, standardization, and efficient workflow [11], [12].

### B. Overall Equipment Efectivenes

OEE is a key indicator that measures equipment efficiency based on three factors: availability, performance, and quality. In this study, it was used as the main metric to identify technical gaps and guide improvements [13], [14], [15]

### C. Evaluación sectorial

The textile sector faces recurring deficiencies in efficiency, setup times, and unplanned maintenance. Recent studies in textile and apparel manufacturing highlight the relevance of OEE and Lean/TPM practices for identifying operational losses and improving equipment performance [11], [13], [14].

### D. Single-minute exchange of die (SMED)

SMED significantly reduces setup times by converting internal tasks into external ones and standardizing procedures. Recent evidence from garment manufacturing shows that SMED can substantially reduce changeover time when responsibilities and production flows are clearly structured [16]. In the diagnosed case, the current setup time is 275 minutes, clearly showing the opportunity to implement SMED and improve equipment availability.

### E. Total Productive Maintenance (TPM)

TPM is a comprehensive preventive and autonomous maintenance approach aimed at increasing equipment availability through staff involvement. Recent evidence in textile manufacturing shows that TPM-based interventions can improve OEE through planned, quality, and autonomous maintenance practices [13], [17]. In the current diagnosis, the company reports losses of up to 3,229 kg of unproduced fabric per month due to needle breakage, highlighting the need to apply TPM as a structural solution.

### F. Work standardization

Work standardization aims to define optimal and repeatable sequences in operations to reduce variability among operators and increase productivity. Recent Lean research identifies standardization, continuous improvement, and process discipline as relevant practices for operational performance [11], [18], [19]. Currently, machine performance stands at 77.15%, below the 90% standard, validating the application of this tool in the plant.

### G. Digital Andon

The Andon system is a visual management tool used to signal deviations in the production process and support timely corrective decision-making. Recent research on Lean and Industry 4.0 emphasizes the role of digital technologies, real-time information, and visual management in strengthening operational control and process improvement [11], [12], [20].

### H. PDCA (Plan-Do-Check-Act)

The PDCA cycle, also known as the Deming cycle, provides a structured basis for continuous improvement by enabling organizations to plan, implement, evaluate, and standardize corrective actions. Recent Lean research continues to use PDCA-oriented improvement cycles and data-driven control mechanisms to sustain operational gains [21], [22].

## III. CONTRIBUTION

### A. Methodology

The PDCA (Plan-Do-Check-Act) cycle provides a structured approach to continuous improvement in industrial processes. In this study, it is used to implement Lean tools aimed at increasing OEE. In the Plan phase, root causes are identified and corrective actions are defined; in Do, solutions such as SMED, TPM, and work standardization are applied; in Check, results are evaluated using operational indicators; and in Act, new standards are adjusted and formalized [23], [24], [25].

### B. Proposed Model

The proposed model is structured around the PDCA methodology with the objective of improving the operational efficiency of a textile SME through an integral and cyclical approach (Fig. 1). It consists of three main tools: SMED, Autonomous TPM, and Work Standardization. Each tool addresses a specific root cause identified during the technical and economic diagnosis.

The model was structured by aligning each root cause with the most appropriate tool, supported by recent empirical evidence. First, historical OEE data were analyzed to identify gaps in availability, performance, and quality. Then, specific interventions were designed for each phase of the PDCA cycle: action planning, operational execution, results evaluation, and process adjustment [26], [27], [28].

### C. Model Components

#### a) Component 1: Work Standardization

This component establishes uniform procedures for critical operational tasks, such as speed calibration and initial adjustments. Current activities will be mapped, the optimal method will be defined, and visual work instructions will be developed. Staff will then be trained to ensure correct execution, and periodic audits will be conducted to verify compliance. This component aims to reduce variability among operators and improve performance, which currently stands at 77.15% [26], [29].

#### b) Component 2: SMED

This component involves a restructuring of the format change process on circular knitting machines. It begins with a detailed analysis of current activities, followed by classification into internal and external tasks. The next step is to convert internal tasks into external ones, optimize both, and document the new standardized procedure. Finally, technical personnel will be trained in the improved process with the goal of reducing setup time by approximately 50% [27], [30].

#### c) Component 3: Autonomous TPM

This component focuses on reducing machine stoppages caused by needle breakage and sinker wear. Machine-specific logs will be implemented, along with daily routines for cleaning and inspection, and wear control based on operating cycles. Operators will be trained to perform basic autonomous maintenance tasks and record every intervention. The goal is to

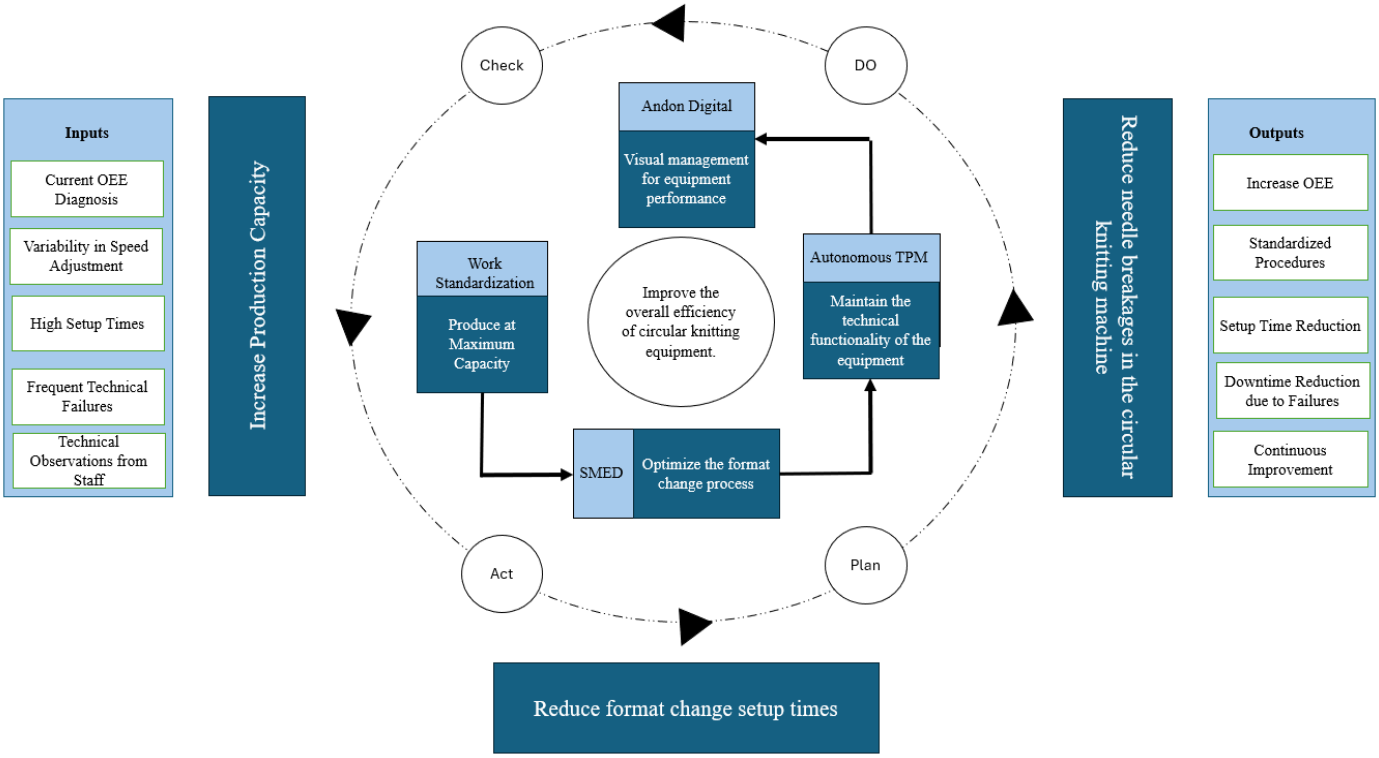



Fig. 1 Proposed Model

prevent failures that cause losses of over 3,200 kg of fabric per month [23], [28].

*d) Component 4: Digital Andon*

This component facilitates visual management of incidents during the knitting process on circular machines. The system uses visual and audible signals to alert maintenance or supervisory personnel of issues such as needle breakage or sinker wear without stopping production. Its integration improves operational coordination, enables rapid responses to unplanned events, and significantly reduces downtime, thereby increasing equipment availability [31].

## *D. Model Design*

This section outlines how the practical implementation of the three main components was designed to improve operational efficiency in a company from the textile sector. Lean Manufacturing tools such as work standardization, the SMED methodology, and autonomous TPM were used. The main objective is to optimize key processes identified in a previous analysis: production variability, long machine setup times, and frequent needle breakage that causes production stoppages.

*a) Component 1: Work Standardization*

Standardization applied to the SMED process:

This component involved the development of clearly defined and specific protocols for each type of fabric, detailing step-by-step how to carry out essential technical configurations (such as speed settings, cam setup, and needle inspection).

These protocols include pre-change inspections to ensure that the machine is completely clean and free of debris. For example, in Jersey production, configurations were set to reduce thread tension due to the fabric's elasticity, while in denser fabrics such as 24/1 Piqué, the cams were configured to provide greater tension, avoiding quality issues.

*b) Component 2: SMED*

The implementation of the SMED methodology in the format change process of circular knitting machines began with a detailed activity analysis, identifying a total setup time of 275 minutes. In the first stage, tasks were classified as internal or external, revealing that all initial activities were performed with the machine stopped, leading to significant downtime.

In the second stage, several internal activities were converted to external ones, identifying 10 tasks that could be performed while the machine was running. This allowed for a reorganization of the workflow and laid the groundwork for improvements in the third stage, such as the incorporation of a second operator, which reduced total setup time to 198 minutes.

The fourth stage involved optimizing the time specifically associated with internal tasks, reducing it to 123 minutes. In parallel, external tasks were performed while the machine was running, achieving a total improvement of 152 minutes compared to the original process.

The fifth stage focused on standardizing the new format change procedure, documented in a series of technical annexes. This standard includes the preparation of materials, disassembly and assembly of cams and carriers, adjustment of

the feed system, lubrication of components, configuration of operating parameters, and visual verification of fabric before startup. The entire procedure was designed to ensure order, precision, and traceability, regardless of the operator.

Finally, in the sixth stage, a technical training program was implemented to ensure proper application of the new method by the operators. The training included guided practices and control criteria, reinforcing the sustainability of the implemented system and its alignment with continuous improvement.

*c) Component 3: Autonomous TPM.*

This component focused on significantly reducing unplanned stoppages due to needle breakage. To achieve this, a detailed autonomous maintenance model was implemented, structured into well-defined four phases:

- *Phase 1: Daily Needle Monitoring.* Clear routines were established for daily visual inspection at the beginning and end of each shift. A specific protocol was defined to detect early signs of wear, damage, or deformation in the needles, allowing for timely replacement before breakage occurs.
- *Phase 2: Preventive cleaning.* Operators perform thorough daily cleaning using compressed air blowers to remove accumulated lint, which could cause damage or additional tension on the needles and other moving components.
- *Phase 3: Needle replacement procedure.* A detailed process was documented for the correct removal and installation of damaged or worn needles. This procedure includes post-replacement verification steps to ensure the machine operates properly after intervention.
- *Phase 4: Comprehemsive training.* A complete training program was implemented to ensure that operators fully understand how to perform preventive tasks, correctly use maintenance tools, and interpret the Andon visual system to accelerate response times in the event of issues.

*d) Component 4: Digital Andon*

The implementation of the Andon system on a circular knitting machine is based on a six-step sequential architecture. The process begins with configuring specific operating conditions for four critical sensors: one optical yarn break sensor, two mechanical stop motion sensors (upper and intermediate), and one needle drop sensor. Each sensor has defined activation parameters, which are translated into visual signals (green, amber, red) depending on the detected status.

These conditions are programmed into a Programmable Logic Controller (PLC), which interprets the signals input and executes responses through digital outputs. The programming includes filters and hierarchies to ensure reliable activation, avoiding false positives. For instance, the needle drop sensor requires one signal per machine revolution; if the signal is missing, a critical alarm is triggered, and the machine stops automatically.

The physical activation connects the PLC with devices such as indicator lights and stop relays, ensuring immediate response to failures. Additionally, the system allows alerts to be sent to external platforms over a network, notifying maintenance personnel about the type, location, and nature of the failure. Finally, operational response protocols are established based on the Andon signal color, standardizing the technical staff's actions for each event. This system improves fault traceability and enables fast, effective, and well-documented interventions.

The general logic of the system's operation is presented in Fig. 2, which summarizes the complete flow of detection, interpretation, and response.

### *E. Process Proposal*

Fig. 3 shows the complete cycle for the implementation of continuous improvement methodologies such as Work Standardization, SMED, and Autonomous TPM.

### *F. Model Indicators*

Table I presents the main indicators that must be evaluated to monitor the progress of the implementation and improve it continuously.

TABLE I
MODEL INDICATORS

| KPI | Critical | Risk | Adequate |
|---|---|---|---|
| OEE | < 67% | [67% to 73%] | > 73% |
| Availability | < 88% | [88% to 93%] | > 94% |
| Performance | < 61% | [61% to 66%] | > 66% |
| Setup time | > 4.5 h | [4.5 h to 3.5 h] | < 3.5 h |
| MTBF | < 25.94 h | [25.94 h to 29 h] | > 29 h |

## IV. VALIDATION

The validation of the proposal was structured based on a mixed approach that combines plant Pilot and Discrete Event Simulation (DES), selected according to the nature of each Lean tool. Work Standardization was validated through a pilot test, since variability among operators can affect operation times if modeled only with historical data [32], [33]. Similarly, Autonomous TPM required experimental validation, as its effectiveness depends on the level of compliance with inspection, cleaning, and lubrication routines carried out by operators [34], [35]. In contrast, the SMED tool was validated through simulation, as it allows precise representation of the reduction in setup and changeover times within the system [36], [32]. Finally, the digital Andon system was also validated through simulation, focusing on the systemic impact of communication and the reduction of notification and response times to incidents [31], [37]. This mixed approach ensures a comprehensive validation that combines direct observation of human performance with the evaluation of the overall effects on the system.

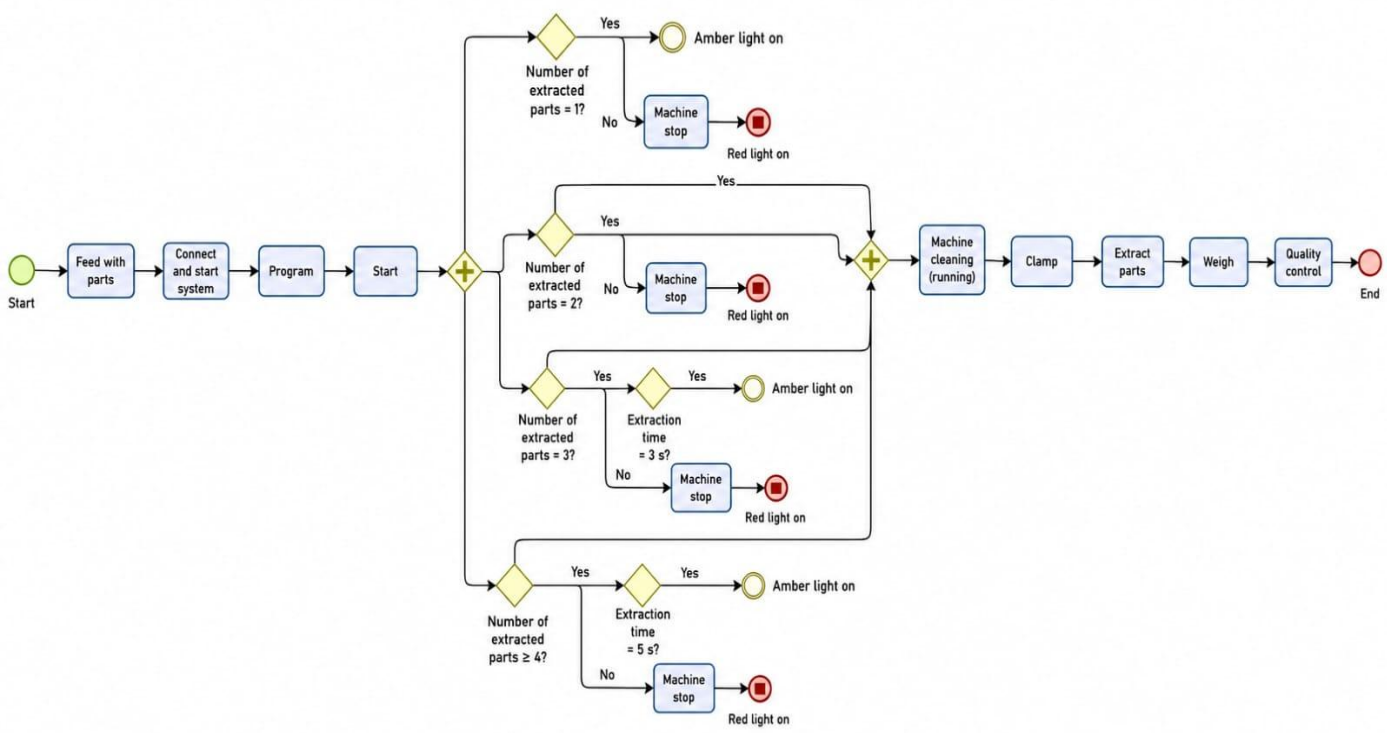



Fig. 2 Flowchart for Digital Andon System Operation

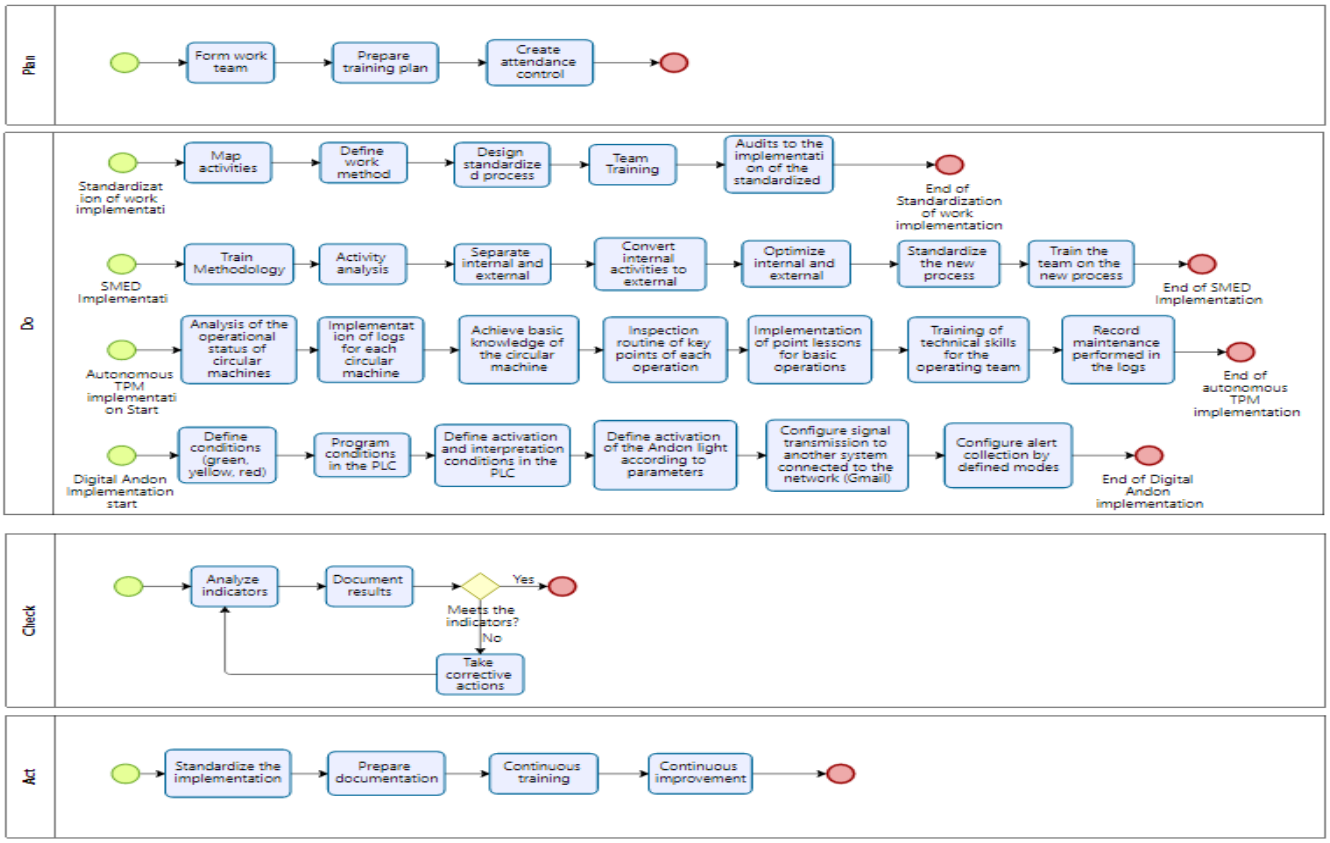



Fig. 3 Bizagi Diagram of the Proposed Process

### A. Pilot

The experimental pilot was carried out in the plant with the aim of validating, under real operating conditions, the effectiveness of the Work Standardization and Autonomous TPM tools, both selected due to their high dependence on human factors. The intervention was developed following the PDCA cycle, establishing performance indicators, applying inspection and standardization routines, and comparing the results obtained with the baseline of the process.

In the case of Work Standardization, operational manuals were developed and implemented, which served as a practical guide for operators in the uniform execution of tasks. Meanwhile, for Autonomous TPM, inspection forms were designed and implemented, with the aim of reinforcing preventive maintenance routines and encouraging active participation of the staff in the care of the equipment.

The results obtained during the three-week pilot, conducted on three machines, showed an overall positive performance. During this period, a total production of 574.87 kg was achieved, allowing the evaluation of process stability and efficiency. Likewise, a total accumulated downtime of 15.75 hours was recorded.

### B. Discrete Event Simulation

The validation through simulation was performed using the Discrete Event Simulation (DES) approach, with the purpose of analyzing the behavior of the textile production system under two scenarios: the current state (AS-IS), as shown in Fig. 4, and the improved scenario (TO-BE), as shown in Fig. 5. This methodology made it possible to virtually reproduce the production flow and evaluate the effects of the SMED and digital Andon tools on process efficiency, without interfering with real production.

The improvement parameters used in the model were not obtained from experimental tests in the plant but from a systematic literature review and documented case studies. Based on the improvement percentages reported in previous studies on the application of SMED and Andon systems in the textile and manufacturing industries, reference values were established for the simulation. In this way, a model was built capable of estimating the potential impact of the proposed design under controlled and comparable conditions.

### C. Results

The results (TO BE) derived from pilot and the simulation methods that are summarized below in Table II, highlighting the variation in the main process indicators.

OEE increased from 66.47% to 83.68%, representing a 17.21 percentage-point improvement and bringing the indicator close to the 85% reference target [38]. Similarly, availability increased from 87.56% to 93.41%, approaching the 94% benchmark [39], while performance increased from 77.15% to 91.95%, exceeding the 84% reference value reported in previous research [40]. In addition, setup time was reduced from 4.80 to 2.29 h, outperforming the 3.20 h reference target [27], whereas MTBF increased from 25.94 to 28.62 h, although remaining below the 31.86 h benchmark [38]. Overall, these results indicate that the proposed intervention has the potential to substantially improve equipment effectiveness, availability, production performance, and setup efficiency in the analyzed SME textile.

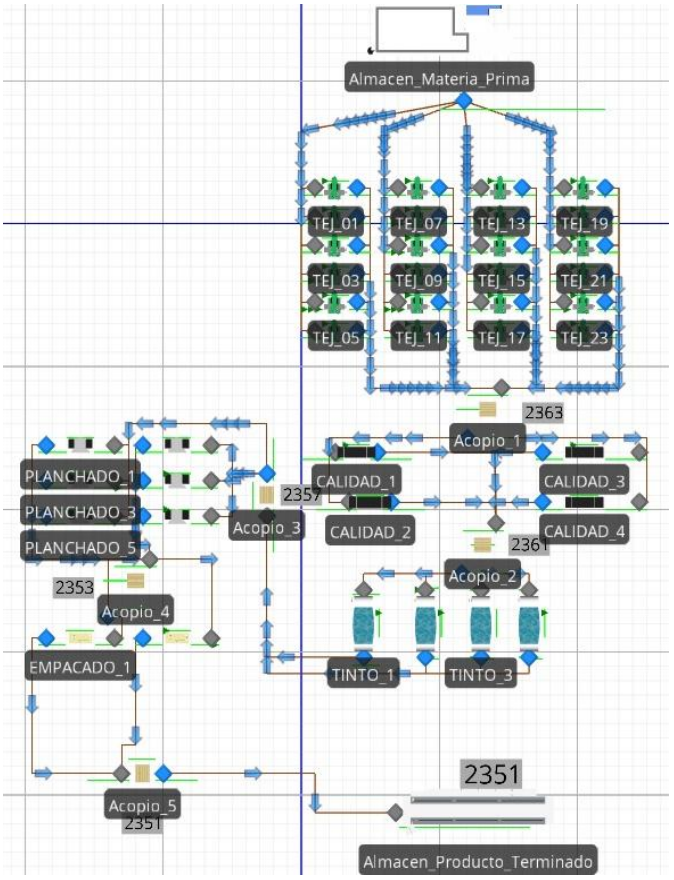



Fig. 4 AS-IS Model in Simio

Nevertheless, because the TO BE values were obtained through a mixed-method: pilot implementation and simulation rather than full-scale longitudinal deployment, these findings should be interpreted as empirical evidence of improvement potential under the evaluated operating conditions rather than as definitive evidence of generalizability across the textile industry.

TABLE II
INDICATORS

| KPI | AS IS | TO BE | Reference Target |
|---|---|---|---|
| OEE | 66.47% | 83.68% | 85% [38] |
| Availability | 87.56% | 93.41% | 94% [39] |
| Performance | 77.15% | 91.95% | 84% [40] |
| Setup time | 4.8 h | 2.29 h | 3.2 h [27] |
| MTBF | 25.94 h | 28.62 h | 31.86 h [38] |
| MTTR | 1.17 h | 0.70 h | 0.50 h [38] |

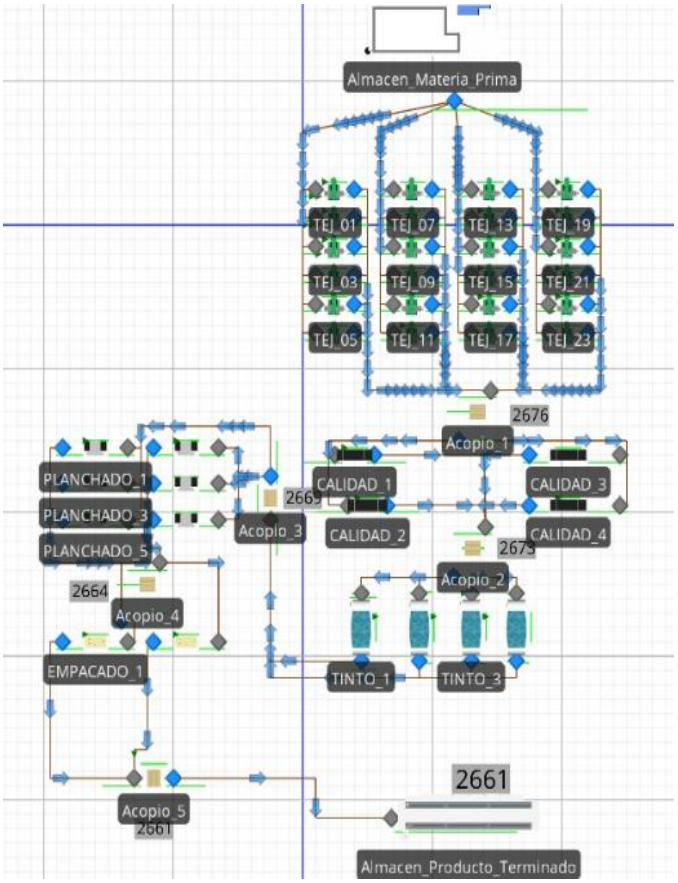



Fig. 5 TO-BE Model in Simio

### D. *Economic Evaluation*

Respect to the economic evaluation, the Cost of Capital (COK) used as the discount rate was 25.79% per year, a value determined through the Capital Asset Pricing Model (CAPM). In the optimistic scenario, the Internal Rate of Return (IRR) reached 111%, with a positive Net Present Value (NPV) and a Payback Period (PP) of 0.90 years, equivalent to approximately 10.8 months, indicating a rapid recovery of the initial investment. In the moderate scenario, the IRR was 82% and the PP 14.2 months, while in the pessimistic scenario, the IRR was 51% with a PP 20.6 months. All three scenarios (Table III) showed a positive NPV, demonstrating that the project generates benefits greater than the cost of invested capital.

TABLE III
ECONOMIC EVALUATION

| KPI / Scenario | Optimistic | Moderate | Pessimistic |
|---|---|---|---|
| NPV (S/.) | 1’633,204 | 1’041,821 | 450,438 |
| IRR (%) | 111% | 82% | 51% |
| PP (years) | 0.90 | 1.18 | 1.72 |

### E. *Non-economic Impact*

The experimental pilot was conducted in the plant with the purpose of validating, under real operating conditions, the Work Standardization and Autonomous TPM tools. For this, the Technology Acceptance Model (TAM), which evaluates staff perception of the usefulness and ease of use of a new methodology [41], [42], and the Organizational Change Questionnaire (OCQ), which measures staff attitude and readiness toward organizational change, were applied. [43].

These instruments, widely used in industrial environments [44], [45], made it possible to analyze the perception of operational and technical personnel regarding the new standardization and maintenance routines. The results, presented in Table IV for TAM (Operators) and Table V for OCQ (Supervisors and Maintenance Technician), show a moderate level of acceptance with a positive trend, highlighting perceived usefulness (3.6) and communication and participation (3.6) as the best-rated dimensions. Overall, the findings confirm the initial effectiveness of both tools and reflect a progressive adaptation process toward operational stability and continuous improvement of the textile system.

TABLE IV
RESULTS – TECHNOLOGY ACCEPTANCE MODEL (TAM)

| Evaluation Dimension | Average Score | Perception Level |
|---|---|---|
| Perceived usefulness | 3.6 | High |
| Perceived ease of use | 3.1 | Moderate |
| Attitude toward use | 3.0 | Moderate |
| Intention to adopt | 3.0 | Moderate |
| General TAM average | 3.2 | Moderate |

TABLE V
RESULTS – ORGANIZATIONAL CHANGE QUESTIONNAIRE (OCQ)

| Evaluation Dimension | Average Score | Perception Level |
|---|---|---|
| Communication and participation | 3.3 | Moderate |
| Confidence in technical management | 3.6 | High |
| Readiness for continuous improvement | 3.5 | High |
| Preparación para la mejora continua | 3.2 | Moderate |
| General OCQ average | 3.4 | Moderate |

## V. CONCLUSIONS

The results of the study showed that the coordinated implementation of Lean tools had a significant impact on the performance of the weaving area. The comparison between the

initial scenario and the improved scenario revealed an increase in OEE from 66.47% to 83.68%, confirming the effectiveness of the proposed model in addressing process inefficiencies. Additionally, each specific objective was successfully met. First, the optimization of the product changeover process reduced setup time to 2.29 hours, increasing operational availability and improving the use of installed capacity. Second, strengthening autonomous maintenance reduced both the frequency and duration of breakdowns, reflected in a higher mean time between failures and more timely maintenance. Third, the standardization of calibrations reduced variability between shifts, which boosted performance from 77.15% to 91.95%, resulting in a more stable and predictable process.

Furthermore, the active participation of the operational staff in the pilots demonstrated that the proposal is sustainable from the human component, a key factor to ensure the continuity and consistency of the improvements. From an economic perspective, the financial evaluation showed that the project is profitable, achieving a Net Present Value (NPV) of S/. 1'041,821 and an Internal Rate of Return (IRR) of 82% in the moderate scenario, results that support the feasibility of the required investment. Overall, the proposed improvement model constitutes an effective strategy to increase productivity, reduce operational variability, and strengthen system reliability, positioning the weaving area in better conditions to respond to future demand increases.

## VI. RECOMMENDATIONS

Based on the results and limitations of the study, several recommendations are proposed to enhance and expand the scope of the proposed model. First, it is suggested to implement plant pilots for the SMED and Digital Andon tools, as these were only validated through simulation in this research. This step will allow for the evaluation of how the system behaves under real conditions, as well as observing the interaction of the staff with the alert flow and the operational redesign.

Second, it is recommended to establish a formal system for tracking learning, which includes periodic evaluations, field verification, and regular updates of standards. This mechanism will ensure knowledge retention, maintain operational consistency, and prevent regressions in the implemented improvements. Additionally, it is proposed to incorporate additional variability indicators that were not initially considered, such as micro-stops, minor thread tension deviations, or quality fluctuations. Their integration will help refine process control and improve the accuracy of future analyses.

Finally, it is suggested to adapt and replicate the improvement model in other production areas of the company. This expansion would allow for the benefits achieved in the weaving area to be leveraged and foster a culture of continuous improvement with a cross-cutting impact across the entire organization.


## ACKNOWLEDGMENT

A la Dirección de Investigación de la Universidad Peruana de Ciencias Aplicadas por el apoyo brindado para la realización de este trabajo de investigación a través del incentive UPC-EXPOST-2026-2.

## FINANCING

Universidad Peruana de Ciencias Aplicadas / UPC-EXPOST-2026-2.


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