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Smart Manufacturing Model Based on Standard Work, TPM, and SMED with IoT within the Industry 4.0 Framework to Improve Productive Efficiency in a Textile Company

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Abstract— ***In the textile sector, productive efficiency is a critical factor for business competitiveness and sustainability. This study was conducted in a Peruvian garment manufacturing company, where an efficiency level of 31.76% was identified, below the sector average of 50.3%, revealing a technical gap of 18.54 percentage points. The main causes of this problem are the lack of process standardization, high variability in production times, and prolonged changeover times.***

To address this issue, a smart manufacturing model is proposed, integrating Standard Work, Total Productive Maintenance (TPM), and Single-Minute Exchange of Die (SMED), supported by IoT technologies within the Industry 4.0 framework. The model aims to reduce non-productive times by more than 40%, decrease set-up times by at least 35%, and increase overall process efficiency above 50%, aligning with sector standards. The proposal contributes to closing the identified technical gap, improving process traceability, and strengthening the digital transformation of the Peruvian textile industry.

Keywords— ***Standard Work, SMED, IoT, Industry 4.0, textile sector, TPM***

I. INTRODUCTION

Worldwide, the textile industry plays a key role in the economy due to its high employment generation and its participation in international trade. In 2024, this sector reached an estimated value of USD 1.86 trillion, with a projected compound annual growth rate of 4.2% through 2030 [1], [10]. Leading countries such as India, Turkey, Italy, and the United States stand out not only for their production capacity, but also for the adoption of advanced technologies based on the Internet of Things (IoT), automation, and smart manufacturing systems, which are pillars of Industry 4.0 [3]. In this context, India has incorporated smart manufacturing models through process digitalization and predictive maintenance, while Italy promotes textile innovation in Europe through connected machinery and energy efficiency [4], [5].

In Latin America, Brazil, Mexico, and Colombia are positioned as sector benchmarks. Brazil accounts for 44% of regional production and has advanced in smart manufacturing systems through IoT sensors and real-time data analysis. Mexico concentrates 33% of the sector's exports due to its integration with the U.S. market and the implementation of methodologies such as SMED, TPM, and Standard Work, aimed at reducing changeover times, improving operational availability, and standardizing processes [6], [7]. Colombia, in turn, has promoted the "Textile 4.0" program, focused on plant digitalization through quality control, traceability, and digital twins [8], [13]. This difference in the level of technological adoption reveals a relevant gap compared to the Peruvian context.

In Peru, the textile and garment sector maintains a strategic position as one of the main clothing exporters in South America, with a value exceeding USD 1.7 billion in 2023, representing 6.4% of manufacturing GDP and 0.8% of national GDP [9]. In addition, Peru stands out for the production of high-quality fibers, such as Pima cotton and Baby Alpaca, which provides a competitive advantage in international markets. This sector also generates more than 26% of national manufacturing employment, with approximately 900,000 associated indirect jobs [10], [14].

However, despite its economic relevance, the Peruvian textile industry presents significant operational limitations, such as lack of process standardization, high variability in production times, prolonged changeover times, and dependence on unplanned corrective maintenance. These deficiencies affect operational continuity, increase costs, and reduce the ability to respond to market demand.

Despite international advances in Lean tools and digital technologies, in the Peruvian context there is limited implementation of integrated models that articulate Standard Work, SMED, TPM, and IoT in textile production systems. This gap highlights the need to develop solutions that optimize processes and generate real-time information for decision-making [11], [12], [15].

In this context, this research proposes a smart manufacturing model based on Industry 4.0, integrating Standard Work, SMED, TPM, and IoT as a unified continuous improvement system. The model seeks to increase productive efficiency by reducing non-productive times, standardizing operations, and improving equipment availability, supported by real-time data capture and analysis. Furthermore, it aims to contribute to closing technological gaps in the sector and serve as a reference for future research on manufacturing digital transformation.

The article is structured as follows. Section II presents the theoretical review of smart manufacturing and Lean tools applied to the textile sector. Section III describes the proposed model. Section IV details the validation methodology. Section V presents and analyzes the results, and finally, Section VI presents the conclusions of the research.

II. STATE OF THE ART

For the development of the state of the art, scientific articles addressing the application of Lean tools and Industry 4.0 technologies aimed at improving productive efficiency in manufacturing systems were reviewed, with special attention to the textile sector. Studies reporting quantitative results on line efficiency, set-up times, operational availability, and production plan fulfillment indicators were selected. Based on this review, the key concepts and indicators that support the proposed smart manufacturing model were identified.

A. Garment Line Efficiency

Garment line efficiency measures the proportion of available time used for productive output, considering imbalances, waiting times, and idle time between workstations [16]. In textile and assembly lines, studies report that initial configurations with low efficiency can improve by **10 to 20 percentage points** after applying line balancing and task standardization, reducing idle time and stabilizing the workflow [16], [17].

B. Set-up Time Excess

Set-up time excess is defined as the portion of preparation time that exceeds the target value established for a changeover [17]. The literature uses it as an indicator of system flexibility: a high excess value reflects a significant proportion of the shift devoted to preparation instead of production. Case studies show that, by reorganizing changeover activities and applying SMED principles, this excess can be reduced from high values to ranges close to the target level, implying set-up time reductions of approximately 30% to 60%, depending on the process analyzed [17], [18].

C. Operational Availability of Machines

Operational availability of machines expresses the proportion of time in which equipment is able to operate with respect to the total planned time [19]. This indicator considers stoppages due to breakdowns, maintenance waiting times, and prolonged adjustments. The reviewed studies show that low availability is associated with mainly corrective maintenance strategies; when preventive routines are introduced and stoppage causes are systematically managed, availability tends to increase and stabilize within ranges considered acceptable for continuous manufacturing systems [19].

D. Productive Efficiency Index (PEI)

The Productive Efficiency Index (PEI) is used as a global measure of production plan fulfillment, relating actual production to planned production over a given period [18]. Different studies use it to compare lines or plants and to evaluate the impact of improvement projects. The results show that, when line efficiency, set-up times, and equipment availability are addressed simultaneously, the PEI can increase from low levels to values close to the reference ranges defined by the authors, with improvements of around 15 to 30 percentage points in some cases [18], [20].

E. Standard Work

Standard Work is presented as the best-known way to perform a task, documenting the sequence of activities, target times, and operating conditions [21]. Specialized literature indicates that its application reduces variability among operators, improves repeatability, and creates a stable basis for continuous improvement. Case studies report reductions in cycle time and unnecessary movements when standard sheets are implemented and linked to daily performance indicators, especially in labor-intensive lines such as garment manufacturing [21], [22].

F. Single-Minute Exchange of Die (SMED)

SMED is proposed as the reference methodology for reducing changeover time by separating internal and external activities, converting internal tasks into external ones, and standardizing the set-up procedure [7]. The reviewed studies show that, by following these stages, significant reductions in preparation times are achieved, with typical set-up time decreases ranging from 30% to 60%, while increasing responsiveness to frequent product or model changes [8], [22]. These improvements result in a lower proportion of the shift devoted to changeovers and a higher proportion of time available for effective production.

G. Total Productive Maintenance (TPM)

Total Productive Maintenance is conceived as an integrated approach aimed at eliminating losses caused by failures, unplanned stoppages, and speed reductions, involving operators in the daily care of equipment [3]. The literature highlights that TPM programs combine autonomous maintenance, preventive maintenance, and focused improvement activities targeting recurrent causes of breakdowns. Various studies report reductions in downtime hours and failure frequency, as well as greater process stability; in several cases, a noticeable increase in machine operational availability is observed after consolidating basic inspection, cleaning, and lubrication routines [19], [23].

H. Internet of Things (IoT)

The Internet of Things (IoT) is recognized as an enabling technology for smart manufacturing, as it allows sensors to be installed on machines and workstations to automatically record operating times, set-up times, stoppages, and processed quantities [4], [14]. In industrial applications, sensor-captured data are used to identify bottlenecks, quantify non-productive times, and prioritize improvement initiatives [14], [15]. Several studies indicate that replacing manual records with IoT-based systems reduces data capture errors and improves process traceability; furthermore, when this information is connected to maintenance planning, reductions in waiting times and micro-stoppages are observed, along with an additional improvement in operational continuity [15], [24]. These experiences consolidate IoT as a recurring component in smart manufacturing models reported in recent literature.

Based on the literature review, Lean tools such as Standard Work, SMED, and TPM have been widely used to improve operational efficiency in production systems, while IoT technologies have strengthened real-time data capture and analysis. However, there is limited integration of these tools into unified models applied to the textile sector, especially in contexts such as Peru. Therefore, the model proposed in this research seeks to articulate these approaches into an integrated system aimed at improving productive efficiency.

III. CONTRIBUTION

The main contribution of this research lies in the development of a smart manufacturing model applied to a textile garment production line, which integrates Lean tools and Industry 4.0 technologies in a structured manner to address the main sources of productive inefficiency.

Fig. 1 shows the proposed model, organized into phases that allow the identified problems in the production process to be addressed in a sequential and systemic way, such as low line efficiency, prolonged set-up times, machine breakdowns, and the lack of activity standardization. This approach facilitates the understanding of the improvement flow, as well as the relationship between the model stages and the expected results.

Unlike traditional approaches, the model integrates Lean tools and IoT technologies into a unified system, which makes it possible not only to optimize operational processes, but also to capture and analyze real-time information for decision-making, generating a simultaneous impact on multiple performance indicators.

A. *Fundamentals*

The proposed model is based on the integration of smart manufacturing and continuous improvement tools, specifically Standard Work, SMED, TPM, and IoT technologies, with the objective of improving the productive efficiency of the garment production line.

Standard Work reduces operational variability through the definition of standardized methods; SMED is aimed at decreasing changeover times; TPM seeks to reduce losses caused by breakdowns and unplanned stoppages; and IoT enables the automatic recording of times, equipment status, and stoppages to support real-time decision-making.

The combination of these tools makes it possible to simultaneously address the main sources of inefficiency, stabilize the workflow, and strengthen the productivity, traceability, and responsiveness of the textile production system [25].

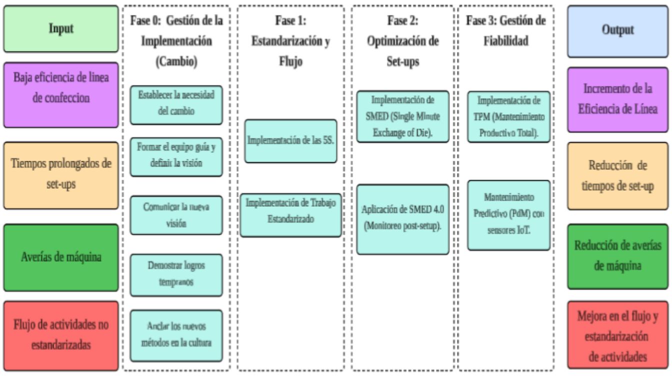

Fig. 1 Proposed model

B. Proposed Model

Based on the diagnosis carried out, the need to address the low productive efficiency of the garment production line in the company under study is identified. This problem is reflected in limited use of installed capacity, high non-productive times, and difficulties in meeting production plans, directly affecting operating costs and the organization's competitiveness in the textile market [25], [26].

In this context, a smart manufacturing model is proposed, integrating Standard Work, the Single-Minute Exchange of Die (SMED) methodology, Total Productive Maintenance (TPM), and Internet of Things (IoT) technologies in an articulated manner. Standard Work allows the best sequence of operations to be defined and documented, reducing cycle time variability and aligning work with takt time. SMED is aimed at reducing changeover time and set-up excess through the reclassification and simplification of internal and external activities. TPM seeks to reduce losses associated with breakdowns and unplanned stoppages, increasing equipment operational availability through autonomous and preventive maintenance. IoT, in turn, enables the automatic capture of operating times, stoppages, and set-up events, providing reliable real-time data for decision-making.

Recent literature supports that the combination of these tools can generate significant improvements in line efficiency, preparation times, and operational availability when applied under an integrated smart manufacturing approach [27]–[30]. In this sense, the model does not address the causes of inefficiency in isolation, but rather articulates the tools into a sequential system aimed at stabilizing the workflow, reducing non-productive times, and improving process control.

The model takes as inputs the main indicators diagnosed in the company: garment line efficiency, set-up time excess, machine operational availability, and the Productive Efficiency Index (PEI). Based on these elements, intervention phases are structured, including the design and implementation of standardized work, the redesign of changeovers through SMED, the implementation of a TPM program supported by IoT monitoring, and the consolidation of an indicator tracking system.

As expected outputs, the model seeks to increase line efficiency, reduce set-up time excess toward ranges close to the standard, improve equipment operational availability, and raise the PEI to values aligned with references reported for production systems that have adopted Lean practices and Industry 4.0 technologies [31]–[33].

C. Initial Diagnosis

The initial diagnosis is based on indicators that make it possible to evaluate the productive efficiency of the garment production line. The main indicator considered is line efficiency, since it reflects the actual use of installed capacity. In addition, supporting indicators are used: set-up time excess, machine operational availability (AR), and the Productive Efficiency Index (PEI). These indicators make it possible to measure whether the proposed improvements in work methods, changeover times, maintenance, and IoT integration generate a tangible impact on system performance. Table I presents the initial (AS-IS) values.

TABLE I

INITIAL STATUS OF THE INDICATORS

Indicator	**AS-IS**
Garment line efficiency (%)	31.76%
Set-up time excess (%)	33.4%
Machine operational availability (AR %)	67.6%
Productive Efficiency Index (PEI %)	50.71%

Fig. 2 presents the operational sequence of the model, from data collection and analysis to the application of 5S, Standard Work, SMED, TPM, and IoT, culminating in indicator validation and the final evaluation of improvement.

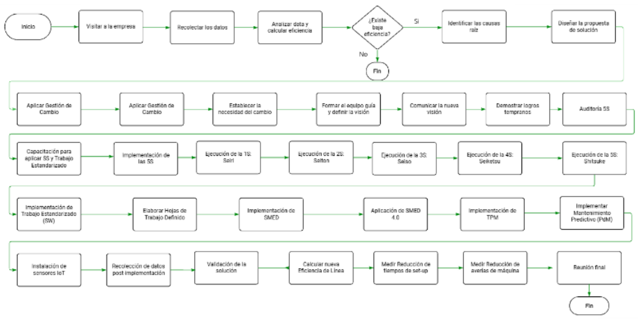

Fig. 2 Flow Diagram

D. Development

The proposed solution is structured into four phases aimed at addressing the critical causes of low productive efficiency in the garment production line. Based on the diagnosis, it was identified that non-productive times and unplanned stoppages account for nearly 93% of the problem's impact. Therefore, the model is focused on reducing set-up times, stabilizing workflow, and improving operational availability through the integration of 5S/Standard Work, SMED, TPM, and IoT technologies.

In Phase 0, change management is developed to facilitate the implementation of the model. At this stage, the diagnostic results are shared, the improvement team is formed, roles and responsibilities are defined, and quantitative targets are established for the selected indicators. Likewise, a scheme based on five of Kotter's steps is applied in order to strengthen the culture of continuous improvement and support the adoption of the proposed tools in the garment area [34].

In Phase 1, work standardization is carried out in the critical operations of the line. To do so, the current process is documented, time studies are performed, and the work method is redesigned based on the identification of non-value-added activities. As a result, Standard Work sheets are developed, including the optimal sequence of activities, time per operation, minimum WIP, and quality control points. This phase is complemented by the application of 5S, with the purpose of improving order, cleanliness, and the availability of tools, materials, and equipment.

In Phase 2, the reduction of changeover times is addressed through the SMED methodology supported by digital recording. First, the current set-up procedure is documented and activities are classified as internal or external. Then, tasks that can be externalized are converted, internal activities are simplified, and the new method is standardized. In addition, timers or sensors connected to an IoT module are incorporated to automatically record the start and end of each set-up. Fig. 3 presents the proposed architecture of the SMED 4.0 system for the textile workshop.

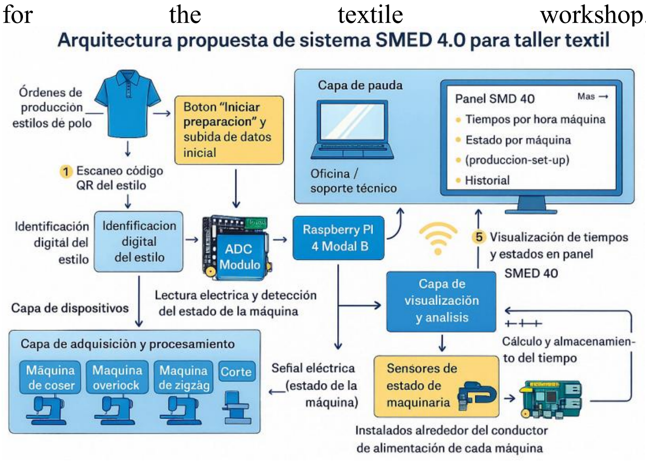

Fig. 3 Proposed architecture of the SMED 4.0 system

In Phase 3, the Total Productive Maintenance (TPM) component is implemented, complemented by predictive maintenance supported by IoT, with the objective of increasing the operational availability of the machines and reducing unplanned stoppages. To this end, autonomous maintenance routines, a preventive maintenance plan, and a monitoring system based on sensors to record operating hours, stoppages, and condition variables are established. The captured information is centralized in a monitoring dashboard that allows events to be tracked, alerts to be generated, and interventions to be prioritized. Fig. 4 shows the proposed architecture of the predictive maintenance system with IoT.

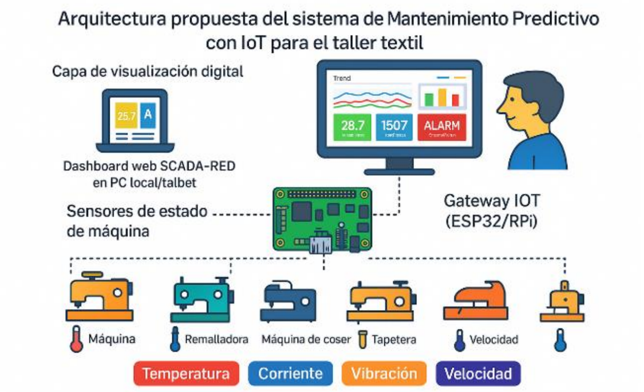

Fig. 4 Proposed architecture of the PdM system with IoT

E. Final Diagnosis

The final diagnosis establishes the TO-BE scenario of the proposed model, taking as reference the target values identified in the literature and the indicators defined in the initial diagnosis. For garment line efficiency, a reference value of 50.30% is considered; therefore, the model seeks to increase the current value of 31.76% by 18.54 percentage points.

Likewise, for set-up time excess, the initial value of 33.40% is expected to be reduced to a level close to 5.00%, representing a decrease of 28.40 percentage points. Regarding machine operational availability (AR), the objective is to increase the indicator from 67.60% to 80.00%, with an estimated improvement of 12.40 percentage points. Finally, for the Productive Efficiency Index (PEI), a target value of 81.93% is adopted, seeking to increase the current value of 50.71% by 31.22 percentage points.

These values make it possible to quantify the expected improvement gap and serve as the basis for the validation stage. Table II summarizes the AS-IS indicators, the TO-BE values, and the expected variation for each case [32]–[34].

TABLE II

EXPECTED INDICATOR RESULTS

Indicator	AS-IS	TO-BE	Variation
Line efficiency (%)	31.76%	50.30%	+18.54 p.p.
Set-up excess (%)	33.40%	5.00%	−28.40 p.p.
(AR %)	67.60%	80.00%	+12.40 p.p.
(PEI %)	50.71%	81.93%	+31.22 p.p.

IV. VALIDACIÓN

To validate this research, the aim is to ensure that the proposed results are consistent, reproducible, and reliable through the proper development of the improvement model. For this purpose, the evaluation scenarios, the implementation phases of the model, and the updating of the indicators defined in the initial diagnosis are described.

A. Description of Scenarios

The solution model is based on the implementation of four development phases, which are validated using different methods depending on the nature of each component. Phase 0, corresponding to change management, is considered a preparatory stage for the implementation of the model. Phase 1, focused on 5S and Standard Work, is validated through a pilot test in the garment production line. Finally, Phases 2 and 3, associated with SMED 4.0 and TPM 4.0 with IoT, respectively, are validated through simulation in Arena Simulation Software. This validation makes it possible to compare the current AS-IS scenario with the improved TO-BE scenario, assessing the impact of the model on productive efficiency indicators.

B. Model Implementation

1) Change Management Validation Model

For the validation of change management, awareness and internal communication activities were carried out to align the operational team with the objectives of the model. As part of this phase, visual material was used to reinforce the new vision of the project and promote worker commitment. Fig. 5 shows representative evidence of this activity.

To this end, awareness meetings were held with the work team, in which the initial diagnosis, the technical efficiency gap, and the objectives of the improvement model were presented. Likewise, roles, responsibilities, and commitments associated with the implementation of 5S, Standard Work, SMED 4.0, and TPM 4.0 were defined. This stage made it possible to establish an organizational basis for the application of the model and to ensure that the proposed improvements were understood by the operators and those responsible for the garment production area.

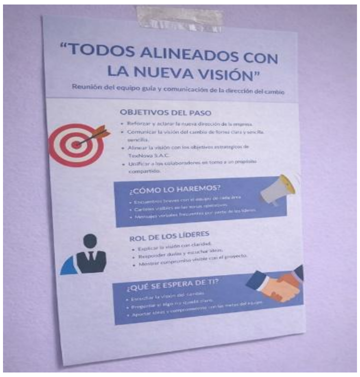

Fig. 5 Visual material used in the change management phase

2) 5S Validation Model

The validation of the 5S methodology was carried out through a pilot test in the garment production area. First, an initial audit was conducted to identify the level of compliance with the criteria of sorting, order, cleanliness, standardization, and discipline. Based on the results obtained, improvement actions were implemented to remove unnecessary items, reorganize tools and materials, mark work areas, establish cleaning routines, and reinforce a culture of order through visual communication.

As evidence of the implementation, red tags were used to identify unnecessary or misplaced items, along with visual material to reinforce order and cleanliness practices in the production area. Fig. 6 shows representative evidence of the pilot implementation of 5S.

Fig. 6 5S Evidence

After the intervention, a final audit was conducted using the same evaluation criteria applied in the initial diagnosis. The results show improvement in all 5S dimensions, especially in Seiso, Seiketsu, and Shitsuke, which reflects better working conditions, improved workplace organization, and a more stable basis for the standardization of operations.

TABLE III

5S AUDIT COMPARISON

5S Dimension	Initial	Final	Improvement
Seiri	9	19	+10
Seiton	11	22	+11
Seiso	7	23	+16
Seiketsu	9	23	+14
Shitsuke	5	23	+18
Total	**41**	**110**	**+69**

Fig. 7 presents the graphical comparison between the initial and final 5S audits. This comparison makes it possible to observe the increase in the level of compliance in each evaluated dimension, confirming that the intervention generated a visible and measurable improvement in the conditions of the garment production area.

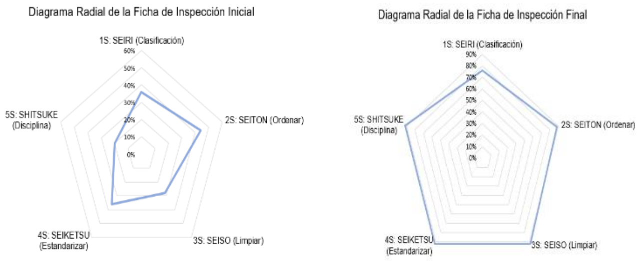

Fig. 7. Initial/Final 5S Radial Comparison

Overall, the results confirm that the pilot application of 5S improved order and cleanliness conditions in the garment production area, providing a more stable operational basis for the subsequent implementation of Standard Work and the reduction of non-productive times.

3) Standard Work Validation Model

The validation of Standard Work was carried out through a pilot test in the critical operations of the garment production line. Initially, variability was observed in the way the same operation was performed, since operators did not follow a single work sequence and the arrangement of materials did not respond to a fixed criterion. This condition generated differences in cycle times, unnecessary movements, and difficulties in maintaining a stable production flow.

Based on this information, a standardized method was designed to define the optimal sequence of activities, operation times, control points, and the minimum conditions of the workstation. Likewise, a visual instruction was used to facilitate the correct execution of the method by the operator.

Fig. 8 shows the comparison between the initial situation, characterized by variability in execution and the absence of defined criteria for material arrangement, and the proposed situation, in which the workstation incorporates a visual process guide and a more stable organization of the operational flow.

Fig. 8 Current Method vs. Standardized Method

After defining the proposed method, the times associated with the current process and the standardized process were compared. Table IV presents a comparative summary of the results obtained.

TABLE IV

COMPARISON OF STANDARD WORK TIMES

Indicator	Current situation	Standardized method	Variation
Observed time per polo shirt	14.15 min/shirt	11.60 min/shirt	-18.02%
Standard time per polo shirt	16.27 min/shirt	13.34 min/shirt	-18.01%

The results show that the pilot implementation of Standard Work made it possible to define a single method for garment production, reducing variability in the execution of operations and improving workstation organization.

4) 0SMED 4.0 Validation Model

The validation of SMED 4.0 was carried out through simulation in Arena Simulation Software, comparing the current scenario (AS-IS) with the improved scenario (TO-BE). For this stage, the overlock machine and the straight sewing machine were selected due to their representativeness within the garment production process and their impact on preparation times. This selection makes it possible to evaluate the effect of the model on critical production flow operations without unnecessarily extending the analysis to all the equipment on the line.

In the AS-IS scenario, the actual set-up times recorded for both machines were considered and fitted using Input Analyzer to select the most appropriate probabilistic distribution in Arena Simulation Software. In the TO-BE scenario, the proposed improvements were incorporated through the classification of internal and external activities, task simplification, and the standardization of the changeover procedure. In addition, the SMED 4.0 approach complemented the reduction of preparation times with the digital recording of set-up events through sensors or timers connected to an IoT module, improving the traceability and reliability of measurement.

Fig. 9 presents the TO-BE simulation model developed in Arena Simulation Software for the straight sewing machine, selected as a representative case of the SMED 4.0 procedure. In this scenario, external preparation activities, a digital checklist, standardized adjustments, controlled testing, and IoT-based set-up recording were incorporated to evaluate the reduction in changeover time compared with the AS-IS scenario. The comparative results for the selected machines are summarized in Table V.

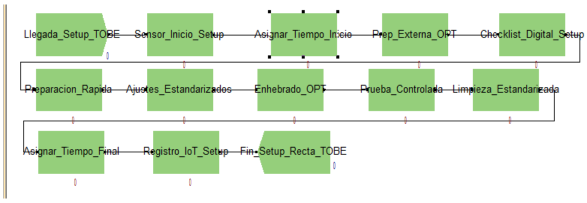

Fig. 9 SMED 4.0 Simulation in Arena

Table V presents the comparative summary of the current and proposed set-up times for the selected machines. This comparison makes it possible to demonstrate the reduction in preparation excess and its contribution to increasing the time available for production.

TABLE V

AS-IS AND TO-BE SET-UP COMPARISON

Machine	AS-IS Set-up (min)	Simulated TO-BE Set-up (min)	Reduction
Overlock machine	18.67	12.50	6.17 min / 33.05%
Straight sewing machine	27.67	17.48	10.19 min / 36.83%

The simulated results make it possible to analyze the impact of the SMED 4.0 method on reducing preparation times and set-up excess. Overall, this validation confirms whether the reclassification of activities, the standardization of changeover procedures, and the use of digital recording contribute to improving the availability of productive time in the garment production line.

5) TPM 4.0 / PdM with IoT Validation Model

The validation of TPM 4.0 and predictive maintenance with IoT was carried out through simulation in Arena Simulation Software, comparing the current scenario (AS-IS) with the improved scenario (TO-BE). For this stage, the most critical machines within the garment production line were selected, considering their failure frequency, downtime, and impact on production continuity.

In the AS-IS scenario, the current behavior of unplanned stoppages was represented using failure records, repair times, and downtime of the selected machines. These data were fitted using Input Analyzer to identify the most appropriate probabilistic distributions for the simulation. In the TO-BE scenario, the improvements associated with TPM 4.0 were incorporated, including autonomous maintenance routines, preventive maintenance, and alerts generated by IoT sensors for the early detection of abnormal conditions.

Fig. 10 shows the simulation model developed in Arena to evaluate the impact of TPM 4.0 and predictive maintenance with IoT on machine operational availability and the reduction of unplanned stoppages.

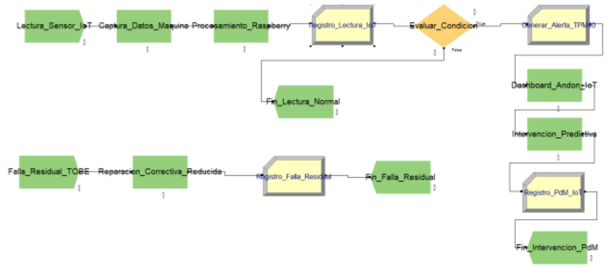

Fig. 10 TPM 4.0/PdM Simulation in Arena

Table VI presents the comparison between the AS-IS and TO-BE scenarios for the main maintenance-related indicators. This comparison makes it possible to evaluate whether the incorporation of TPM routines and IoT monitoring contributes to improving operational availability and reducing non-productive times caused by failures.

TABLE VI

TPM 4.0 AS-IS AND TO-BE INDICATORS

Indicator	**AS-IS**	**Expected TO-BE**	**Simulated TO-BE Result**
Machine operational availability (AR %)	67.60%	80.00%	76.85%
Downtime due to failures	544.32 h/year	336.00 h/year	388.92 h/year
Failure frequency	216 failures/year	130 failures/year	155 failures/year

The simulated results make it possible to analyze the effect of TPM 4.0 on the operational continuity of the garment production line. Overall, this validation confirms whether the combination of autonomous maintenance, preventive maintenance, and IoT monitoring contributes to reducing unplanned stoppages, improving equipment availability, and strengthening the reliability of the production system.

C. Indicadores del modelo

As previously presented, the model validation was carried out through a pilot test in the garment production line and simulation in Arena Simulation Software. The pilot test made it possible to validate the application of 5S and Standard Work, while the simulation allowed the improved scenarios of SMED 4.0 and TPM 4.0 with IoT to be evaluated.

After applying the validation methods, the model indicators showed a favorable evolution compared with the initial scenario. Line efficiency increased from 31.76% to 48.60%; set-up time excess was reduced from 33.40% to 7.65%; machine operational availability increased from 67.60% to 76.85%; and the Productive Efficiency Index increased from 50.71% to 78.35%.

TABLE VII

COMPARISON OF MODEL INDICATORS

Indicator	**AS-IS**	**Validated result**	**TO-BE**	**Variation**
Line efficiency (%)	31.76%	48.60%	50.30%	+16.84 p.p.
Set-up excess (%)	33.40%	7.65%	5.00%	−25.75 p.p.
Machine operational availability (AR %)	67.60%	76.85%	80.00%	+9.25 p.p.
Productive Efficiency Index (PEI %)	50.71%	78.35%	81.93%	+27.64 p.p.

As shown in Table VII, all indicators show improvements compared with the AS-IS scenario and approach the TO-BE values defined for the model. This confirms the technical and operational feasibility of the proposal, provided that indicator monitoring and continuous improvement are maintained during implementation.

V. DISCUSSION

A. New Scenarios vs. Results

After obtaining favorable results in the indicators defined for the model, new scenarios are proposed in which the integrated application of 5S, Standard Work, SMED 4.0, and TPM 4.0 with IoT could generate similar or greater benefits. These scenarios correspond to sectors with high operational variability, frequent changeovers, intensive machinery use, and the need for continuous monitoring of productive performance.

1) Textile and Garment Industry

In textile and garment companies, the model can be applied to lines with high style variability, repetitive manual operations, and non-productive times associated with disorder, lack of standardization, and machine stoppages. The integration of Lean tools, TPM, standardization, and data analysis makes it possible to improve productivity in textile SMEs and strengthen operational decision-making [35].

2) Garment Industry with High Model Rotation

In garment lines with frequent changes in model, size, or design, the proposed model can contribute to reducing changeover times, stabilizing workflow, and improving process visibility. The application of digital technologies in sewing lines makes it possible to represent system behavior, analyze bottlenecks, and support improvement decisions in high-variability environments [36].

3) Discrete Manufacturing with Frequent Changeovers

In manufacturing companies with batch production or frequent product changeovers, the SMED 4.0 component can be applied to reduce preparation times and improve changeover traceability. The evolution of conventional SMED toward SMED 4.0 allows Industry 4.0 technologies to be incorporated to reduce set-up times, prevent defects after changeovers, and improve process sustainability [37].

B. Results Analysis

The results obtained show a favorable improvement in the four indicators defined to evaluate the performance of the proposed model. Each indicator is analyzed below.

1) Line Efficiency

Line efficiency increased from 31.76% to 48.60%, achieving an improvement of 16.84 percentage points. This result shows that the integrated application of 5S and Standard Work improved the use of installed capacity and stabilized the operational flow of the garment production line.

2) Set-up Time Excess

Set-up time excess decreased from 33.40% to 7.65%, equivalent to a reduction of 25.75 percentage points. This improvement confirms the impact of SMED 4.0 on reducing changeover times, increasing the time available for effective production.

3) Machine Operational Availability

Machine operational availability (AR) increased from 67.60% to 76.85%, achieving an improvement of 9.25 percentage points. This result reflects the positive effect of TPM 4.0 and IoT monitoring on reducing unplanned stoppages and improving process continuity.

4) Productive Efficiency Index

The Productive Efficiency Index (PEI) increased from 50.71% to 78.35%, with an improvement of 27.64 percentage points. This increase demonstrates greater production plan fulfillment and confirms that the integration of the proposed tools contributes to the progressive closure of the technical gap identified in the company.

Based on the technical results obtained, an economic analysis was developed considering an initial investment of USD 10,952.93, associated with training, implementation of Lean tools, acquisition of IoT sensors, technological components, materials, and technical support. The economic cash flow considers the benefits derived from the reduction of non-productive times, set-up reduction, improved operational availability, and greater production plan fulfillment.

TABLA VIII
ECONOMIC CASH FLOW OF THE PROJECT

Period	Economic cash flow	Present value cash flow	Cumulative
Year 0	USD -10,952.93	USD -10,952.93	USD -10,952.93
Year 1	USD 6,980.54	USD 6,035.41	USD -4,917.52
Year 2	USD 13,400.90	USD 10,017.76	USD 5,100.24
Year 3	USD 14,000.52	USD 9,048.96	USD 14,149.20
Year 4	USD 16,520.07	USD 9,231.77	USD 23,380.97
Year 5	USD 19,497.07	USD 9,420.21	USD 32,801.18

After developing the project's economic cash flow, the main economic feasibility indicators were calculated. The results are presented below.

TABLE IX
RESULTS OF THE ECONOMIC FEASIBILITY ANALYSIS

Indicator	Value	Criterion
NPV	USD 32,801.18	> 0, accept
IRR	93.99%	> COK, accept
B/C ratio	3.84	> 1, accept
DPP	1.49 years	Payback period less than 2 years

The economic results show that the proposal is feasible. The NPV of USD 32,801.18 indicates that the project generates benefits greater than the initial investment. Likewise, the IRR of 93.99% exceeds the opportunity cost of capital, confirming the profitability of the proposal. The benefit/cost ratio of 3.84 indicates that, for every dollar invested, approximately USD 3.84 in updated benefits is obtained. Finally, the discounted payback period of 1.49 years indicates that the investment could be recovered in approximately 18 months.

Based on the technical and economic results obtained, it is confirmed that the proposed model is feasible for increasing the productive efficiency of the garment production line. The reduction of non-productive times, the decrease in set-up excess, the improvement in machine availability, and the increase in PEI demonstrate that the integrated application of 5S, Standard Work, SMED 4.0, and TPM 4.0 with IoT has a positive impact on the company's productivity and profitability.

C. Future Work

Once the proposed model has been validated, it is recommended to extend its application to other production lines within the textile company. In this research, the model focused on the polo shirt production line due to its high participation in production and its impact on operational efficiency. However, adapting it to other products, such as crew neck shirts, V-neck shirts, sweatshirts, shorts, or pants, would make it possible to evaluate the scalability of the model and obtain additional improvements in production management.

Likewise, it is proposed to expand the use of IoT technologies toward a more comprehensive plant monitoring system. In this study, the digital approach is mainly focused on recording set-up times, stoppages, and maintenance-related variables. As future work, a real-time dashboard could be incorporated to integrate line efficiency, operational availability, production plan fulfillment, and predictive maintenance alerts. This would strengthen data-driven decision-making and improve process traceability.

Finally, it is recommended to validate the model in textile companies with different production levels, product variety, and technological availability. This extension would make it possible to compare the model's performance in different scenarios, identify methodological adjustments, and strengthen its applicability in the Peruvian textile sector.

VI. Conclusions

This research aimed to improve productive efficiency in a textile company through a smart manufacturing model based on the integration of 5S, Standard Work, SMED 4.0, and TPM 4.0 with IoT. The model made it possible to address the main causes of low efficiency identified in the garment production line: non-productive times, prolonged set-up times, unplanned stoppages, and lack of standardization in operations.

The results obtained show a favorable improvement in the defined indicators. Line efficiency increased from 31.76% to 48.60%, achieving an improvement of 16.84 percentage points. Likewise, set-up time excess decreased from 33.40% to 7.65%, representing a reduction of 25.75 percentage points. Regarding machine operational availability, it increased from 67.60% to 76.85%, with an improvement of 9.25 percentage points. Finally, the Productive Efficiency Index increased from 50.71% to 78.35%, reaching an improvement of 27.64 percentage points.

These results demonstrate that the integrated application of the model contributes to the progressive closure of the identified technical gap. The implementation of 5S and Standard Work improved workplace conditions, reduced operational variability, and established a more stable sequence of activities. In turn, SMED 4.0 reduced changeover times, while TPM 4.0 with IoT contributed to improving machine availability through the monitoring of stoppages and operating conditions.

From an economic perspective, the proposal requires an initial investment of USD 10,952.93. The feasibility analysis shows an NPV of USD 32,801.18, an IRR of 93.99%, a benefit/cost ratio of 3.84, and a discounted payback period of 1.49 years. These results confirm that the model is economically feasible, since the expected benefits exceed the required investment and allow the capital to be recovered in approximately 18 months.

In conclusion, the proposed model is technically, operationally, and economically feasible for improving productive efficiency in the evaluated textile company. However, its full implementation requires maintaining indicator monitoring, strengthening operational discipline, continuously training personnel, and ensuring the sustainability of the IoT monitoring system. Therefore, a progressive implementation is recommended, accompanied by periodic result reviews and continuous improvement, in order to consolidate the benefits obtained and facilitate its application in other production lines within the textile sector.

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