Production management model to increase productivity through lean manufacturing tools as SMED, TPM and 5S in a SME in the plastic sector

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***Abstract*— The production of plastics has experienced significant growth globally in recent decades. This growth has led to an increase in national demand, which small companies often struggle to meet due to low productive capacity. Various studies show that this low productivity is mainly caused by inefficient use of company resources, extended setup times and low machine availability. This research aimed to address these issues by applying Lean Manufacturing tools, specifically Single Minute Exchange of Dies (SMED), Total Productive Maintenance (TPM), and 5S, in a Peruvian plastics sector company. The project focused on improving productivity in the company's plastic bag production line, which mainly included extrusion, printing, and sealing operations. The model was subsequently validated through simulation in the Arena software, where its effectiveness was verified. Finally, it was demonstrated that implementing these tools could achieve a setup time reduction of 17.09% for extrusion, 26.63% for printing, and 28.84% for sealing. Additionally, regarding machine availability, extruders and printers showed improvements of 1.23% and 4.81%, respectively. All these improvements translated into an overall productivity increase of 33.57% in the production line. Future studies could focus on exploring its application in other production environments or industries to validate its broader impact. Future work could focus on exploring its application in other production environments or industries to validate its broader impact.**

Keywords—Lean Manufacturing, SMED, TPM, 5S, plastic industry, productivity improvement, setup time reduction, machine availability.

I. Introduction

In recent decades, global plastics production has experienced sustained growth, consolidating its position as one of the most dynamic and influential industrial sectors worldwide. In the case of Peru, this sector constitutes a key component of the national economy. According to the National Society of Industries (SNI), it generates approximately 200,000 jobs across the country, underscoring its significance within both the productive and labor spheres [1]. Likewise, data from the National Institute of Statistics and Informatics (INEI) indicate that, in 2022, there were 2,795 companies operating in the plastics industry, representing an increase of 51.6% compared to 2015 — a clear indicator of the industry's expansion in recent years. Additionally, in 2021, this industry contributed approximately 724 million soles in domestic taxes, reaffirming its role as a significant source of public revenue for the State [2].

Despite its economic importance, the sector faces substantial challenges, particularly among small and medium-sized enterprises (SMEs), which account for over 90% of the industry's composition [1]. These businesses often operate with limited financial and technological resources, underdeveloped automation infrastructure, and restricted innovation capacity [3]. Among the primary operational obstacles are constrained production capacity, prolonged setup times, and low machinery availability, all of which adversely affect operational efficiency and market competitiveness [4].

To address these issues, various studies have highlighted the effectiveness of implementing Lean Manufacturing tools, such as SMED (Single-Minute Exchange of Dies), TPM (Total Productive Maintenance), and the 5S methodology. These approaches aim to optimize production processes, minimize waste, and enhance the overall efficiency of operations.

Within this context, the present study focuses on the application of these tools in a Peruvian company specializing in the manufacture of plastic bags. The principal objective is to improve the productivity of its production line — specifically in the extrusion, printing, and sealing operations — through the reduction of setup times and the increase of equipment availability.

This research not only seeks to provide practical, evidence-based solutions to the operational challenges faced by the selected company but also aspires to offer a replicable model for other SMEs within the Peruvian plastics sector confronting similar issues. The adoption of Lean Manufacturing practices may prove instrumental in enhancing the competitiveness, efficiency, and sustainability of these enterprises in an increasingly demanding and dynamic market environment.

This article is structured in five sections: introduction, methodology, validation, results, and conclusions.

II. Literature review

A. *Lean Manufacturing Challenges and Benefits*

The literature review reveals that manufacturing sectors face multiple challenges in their production processes, which require specific solutions to be optimized and reduce inefficiencies. One methodology in this field is Lean Manufacturing (LM), defined as an approach focused at eliminating waste in production systems, including human efforts, inventories, and unnecessary times, which contributes to significant improvements in quality and productivity [5]. Furthermore, LM allows companies to maintain their competitive advantage addressing common challenges such as achieving efficient production with fewer resources and capital while ensuring time and cost reductions [5][6]. Regarding the national plastics sector, the implementation of lean tools such as 5S and improved plan layout on an SME increased productivity by 27% [7]. Similarly, in a Peruvian tire manufacturing company, the integration of lean tools such as VSM, line balancing and layout optimization achieved a 13% increase in equipment efficiency and a 22.5% reduction on setup times [8].

B. *5S: Workplace Organization*

5S is a methodology designed to ensure optimal productivity, safety, and quality within any organization. It serves as the initial step in implementing Lean Manufacturing, tackling and reducing waste within or between processes. Moreover, it creates a more efficient workplace, improves safety, and lays the foundation for Total Productive Maintenance (TPM) [9]. It comprises five key phases: Sort (Seiri), where necessary and unnecessary items are separated, and the latter are eliminated; Set in Order (Seiton), involving systematic arrangement for quick access and return; Shine (Seiso), which focuses on regular cleaning to prevent inefficiencies and accidents caused by dirt and dust; Standardize (Seiketsu), where methods are documented and simplified for easy adherence; and Sustain (Shitsuke), emphasizing discipline through continuous audits, habit-building, and cultural integration of 5S practices [10][11]. In Peru, its application has demonstrated significant success in diverse industries. For instance, in a food processing company, it reduced cleaning and packaging times by 3.19%, streamlining tool search times and enhancing operational efficiency [12]. Similarly, in a Peruvian metalworking company, 5S decreased delays in accessing tools and materials by 60% and increased the workspace available for operators, contributing to a 10% productivity improvement in hinge production processes [13].

C. *SMED: Reducing Changeover Times*

This tool focuses on recognizing and optimizing internal and external setup activities. Internal activities, which can only be performed when the machine is stopped, are minimized or converted into external ones that can be carried out while the machine is operating, reducing inefficiencies and downtime [14]. Thus, this methodology addresses the reduction of equipment preparation, tuning, and replacement times, aiming to decrease the efficiency loss caused by production reference changes [15]. Its implementation typically follows this sequence: measuring the total mold change time, identifying internal and external operations, converting internal activities into external ones, optimizing internal activities that cannot be converted, and standardizing the changeover procedure [16]. In the reviewed articles, it was observed that SMED consistently delivers positive outcomes, with reductions in setup times exceeding 30% in most cases [16][17].

An example of its success can be seen in a Peruvian microenterprise in the textile and clothing sector. By transforming downtime into parallel activities, the company increased its productivity index from 0.38 to 1.16 and significantly boosted production capacity by reducing delays that caused major inefficiencies [18].

D. *TPM: Maximizing Equipment Efficiency*

TPM is a methodology that integrates all levels of a company, from management to operators, with the goal of maximizing equipment effectiveness throughout its lifecycle and, by involving all members of the organization, it seeks to prevent breakdowns, speed losses, and quality defects, fostering reliability, cost savings, and continuous improvement [19][20]. Furthermore, it is structured around eight foundational pillars: autonomous maintenance, planned maintenance, focused improvements, training and education, early management, quality maintenance, office TPM, and safety, health, and environment [21]. However, implementing all eight pillars may not always be practical, especially in PYMEs, where challenges such as the absence of structured maintenance systems or lack of historical intervention data are common. In such cases, it is advisable to prioritize pillars like autonomous and planned maintenance, focusing first on data collection and establishing a maintenance foundation [19].

In Peru, TPM has demonstrated its impact in the plastics sector. For instance, one plant increased its Overall Equipment Effectiveness (OEE) from 64% to 78% by implementing autonomous maintenance and training programs [22]. Similarly, another Peruvian plastics plant achieved a 13% improvement in OEE over two months, with expectations for

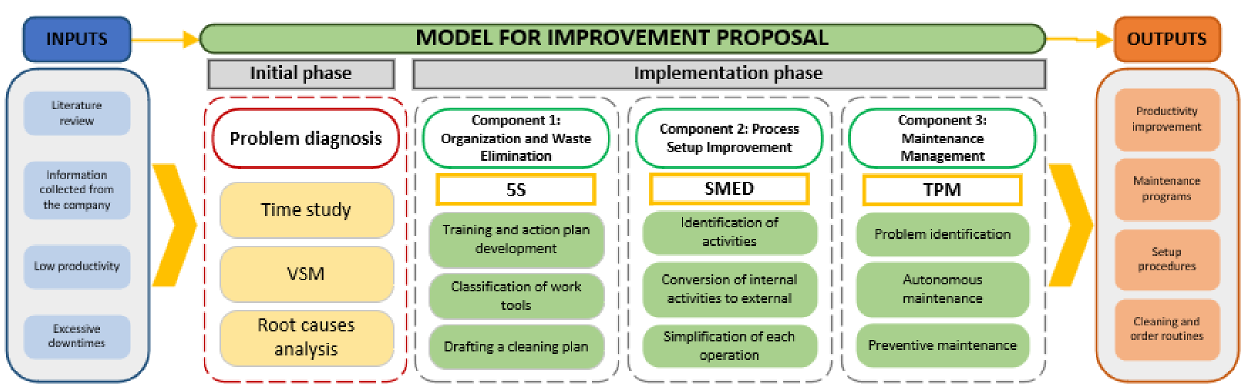

Fig. 1 Baseline model simulating production order flow

further growth as personnel adapted to the changes [4]. Beyond plastics, TPM also contributed to a 10.82% productivity increase in a food manufacturing company, demonstrating its versatility across industries [23].

III. Methodology

A. Proposed model

The proposed solution model illustrated in Fig. 1 was designed by integrating structured methodologies to identify, analyze, and address key operational inefficiencies. It is organized around three essential components: inputs, two distinct phases (initial phase and implementation phase), and measurable outputs. The model begins with the inputs, which include the literature review to provide theoretical support, data collected from the company to highlight operational challenges, and key issues such as low productivity and excessive downtime to guide the subsequent phases of the model.

The Initial Phase, or problem diagnosis, focuses on systematically identifying the root causes of inefficiencies. This phase employs three key tools. The time study analyzes the time required for tasks to pinpoint bottlenecks and delays. Value Stream Mapping (VSM) maps the production process to differentiate between value-adding and non-value-adding activities, allowing for better process visualization. Lastly, root cause analysis explores underlying issues that contribute to productivity losses.

The implementation phase applies three tailored tools to address the root causes identified in the previous phase. The 5S methodology improves tool management and organization, resolving inefficiencies in sorting and storage. SMED reduces high setup times by streamlining equipment preparation and eliminating non-value-adding activities. Finally, TPM addresses unplanned downtimes by implementing autonomous and preventive maintenance practices to enhance equipment reliability and performance.

Finally, the outputs of the model represent the tangible results achieved through its application. These include an improvement in productivity, maintenance programs to ensure equipment reliability and longevity, while standardized setup procedures streamline equipment preparation processes. Cleaning and organization routines, developed through 5S, foster sustained workplace discipline and continuous improvement.

Based on the components previously described, a flow of activities was designed to detail how the proposed tools will be developed and implemented as shown in Fig. 2

B. Initial Phase: Problem Diagnosis

The first phase involved diagnosing the problem to establish a comprehensive understanding of the company's initial situation as it forms the foundation for the development of the proposed solution model described later. A productivity assessment was conducted using production records of plastic bags from December 2023 to March 2024. The analysis revealed a significant gap compared to the industry standard, with an average performance of 143.20 bags per man-hour, which is 26.92% below the expected level of 181.76 bags per man-hour [24].

The diagnosis began with a time study focused on the main processing activities: extrusion, printing, rewinding, and sealing, as well as the duration of its equipment setup times, providing a detailed breakdown of time consumption across operations.

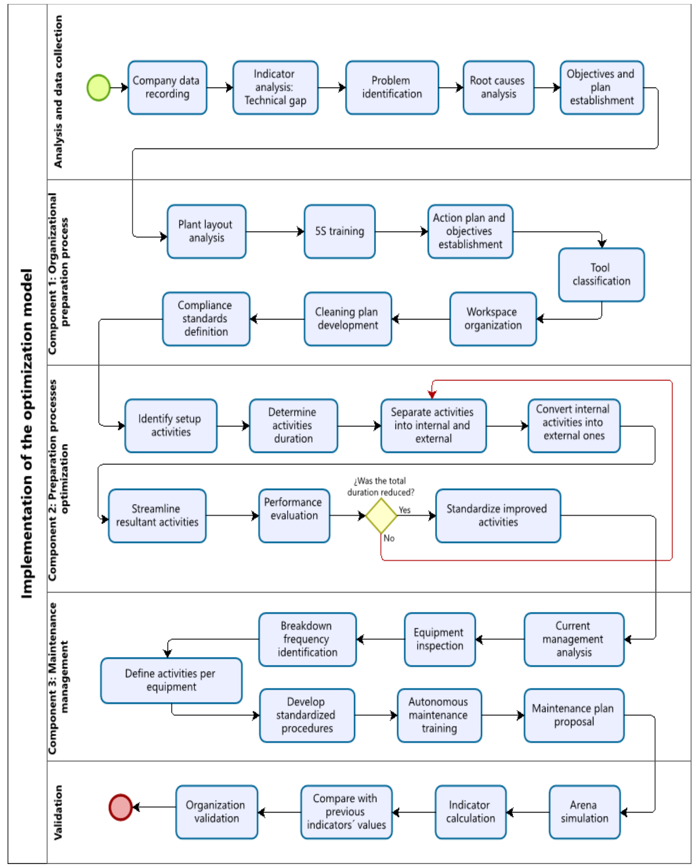

Fig. 2 Optimization model implementation flowchart

Using this data, along with additional information from the company, a Value Stream Mapping (VSM) analysis was developed. The VSM shown in Fig. 3 revealed a lead time of 8.87 days and a TAKT time of 66.55 minutes, which was lower than the cycle times and setup times recorded for extrusion, printing, and sealing operations. This discrepancy between TAKT time and the actual cycle and setup times indicated potential difficulties in meeting customer demand within the required timeframe.

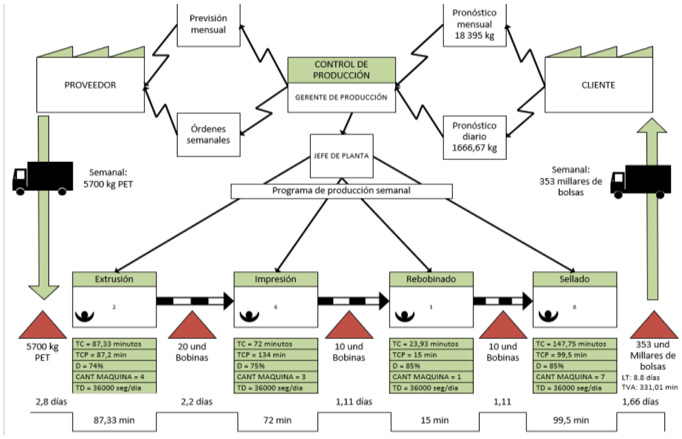

Fig. 3 Current Process Value Stream Mapping

Root Cause Analysis was then conducted using engineering tools such as the 5W2H method and the Ishikawa diagram, which were instrumental in identifying and categorizing the main problems contributing to the productivity gap. The Ishikawa diagram, shown in Fig. 4, classified the causes into five categories: materials, methods, workforce, machinery, and environment.

Key issues identified included equipment failures, insufficient training, and poor operational conditions. After conducting the analysis on both tools, it was determined that the main factors affecting the plant's production were high setup times and recurring unplanned downtimes, with their respective impacts calculated as 32.05% and 67.95%.

Fig. 4 Ishikawa diagram

High setup times were primarily caused by inadequate equipment preparation and poor tool management. The lack of specific calibration procedures and insufficient staff training often resulted in repeated adjustments to machines, particularly during the handling of complex orders requiring additional configurations. These inefficiencies were recorded in time-tracking logs, which highlighted delays such as repeated alignment of cylinders in flexographic printers. Additionally, poor tool management, characterized by inadequate classification, organization, and storage, was confirmed through a 5S self-assessment. Compliance rates for the first two S's were alarmingly low, with only 44% for "sorting" and 28% for "organizing," well below the desired 60%. Operators frequently wasted time searching for tools, as evidenced by excessive time logs for locating wrenches and pliers, further exacerbating setup delays.

Unplanned downtimes, which represented the larger share of the impact at 67.95%, were primarily caused by the lack of preventive maintenance. This issue was reflected in breakdown logs from the first quarter of 2024, showing frequent interruptions in critical operations such as sealing, printing, and extrusion. Recurring issues with components like resistances, rollers, and dies significantly disrupted production. These findings were visualized in the problem tree shown in Fig. 5

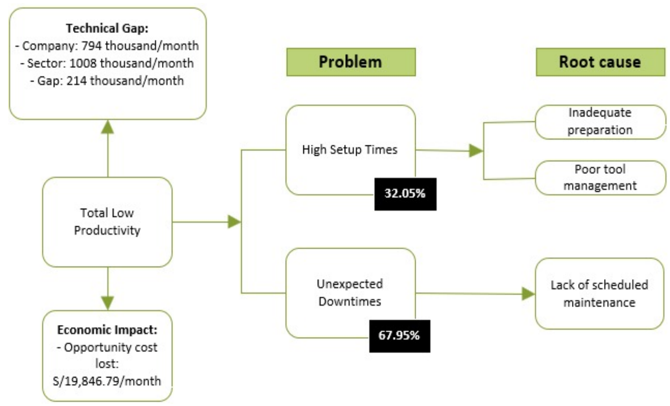

Fig. 5 Tree problem diagram

After analyzing these problems and their root causes, the company's key indicators were established and compared to industry standards to provide a foundation for improvement efforts. This is presented on the table below.

TABLE I
INDICATOR ANALYSIS

Indicator	*Initial diagnostic*	*Expected*	*Company metric Used*	*Source*
Productivity	0.143	0.181	Thousands of plastic bags / Man-hours	[24]
Tool search time	710	190	Seconds	[25]
Extrusion setup times	87.2	54.06	Minutes	[15]
Printing setup times	133.7	82.89	Minutes	[15]
Sealing setup times	99.5	61.69	Minutes	[15]
Extrusion availability	74.09	80	Percentage (%)	[26]
Printing availability	75.47	80	Percentage (%)	[26]

C. Implementation Phase

Building on the insights from the initial diagnosis, the implementation phase focuses on applying tailored tools to address the root causes of inefficiencies identified earlier

The first component addresses poor tool management by implementing the 5S methodology, which improves organization and cleanliness while fostering continuous improvement [27][9]. Through its five principles, 5S reduces delays in material searches, improves workspace conditions, and boosts productivity [4][28].

The second component tackles inadequate equipment preparation through SMED, which reduces setup times, enhances production flexibility, and optimizes workflow by eliminating non-value-adding activities and standardizing processes [18][4].

The third component addresses the lack of scheduled maintenance using TPM's pillars of autonomous and preventive maintenance to maximize equipment effectiveness by empowering operators to perform routine maintenance and implementing structured maintenance plans [20][29].

Below, the implementation of each tool is detailed, highlighting its integration into the production processes to address the identified inefficiencies.

1) Organization and waste elimination

The implementation of the 5S methodology involved a structured approach across five phases. Initially, a self-assessment was conducted using a customized evaluation format tailored for manufacturing environments. This format, comprising 25 questions, revealed an overall compliance rate of 32.8%, highlighting significant areas for improvement in classification, organization, cleanliness, standardization, and discipline. The results underscored the necessity of adopting the 5S methodology to optimize the plant's operations.

To address this, training sessions were organized to ensure the workforce understood the principles and benefits of 5S. These workshops combined theoretical instruction with practical examples relevant to the plant, fostering employee engagement and commitment to the methodology. Subsequently, unnecessary items were identified, categorized, and managed using a visual tagging system as shown in Fig. 6.

Fig. 6 Visual tagging system for 5s implementation

Subsequently, tools and equipment were reorganized, with designated storage locations and lists of essential tools were created for each workstation in collaboration with the operators. Storage systems, such as organizers for tools and equipment as shown in Fig. 7, were introduced to ensure quick access and proper categorization. In addition, tools were labeled with their names and corresponding area codes.

Fig. 7 Organized storage systems for tools and equipment

In the next phase, cleanliness and standardization efforts were implemented. Regular cleaning routines were introduced, targeting key areas such as workstations and storage zones as shown in Fig. 8. A format was created as shown in Fig. 9 to document and regulate the use of standards such as the proper placement of yellow tape to define workstations and machinery. Labels on tools, equipment, and areas were maintained to facilitate easy recognition and retrieval, reducing search times and minimizing disorder.

ÁREA DE LIMPIEZA	ELEMENTOS/OBJETOS A LIMPIAR	FRECUENCIA	RESPONSABLE	OBSERVACIONES
Impresión	Maquinaria de impresión	Diario	Operario de impresión en turno	Inspeccionar por acumulación de tinta o suciedad
	Superficies de trabajo/ Suelo y alrededores	Diario	Ayudante de impresión en turno	Revisión final al terminar cada turno. Limpieza profunda de los alrededores del área
	Rodillos de impresión	Semanal	Operario de impresión en turno	Limpieza a fondo para evitar fallos de impresión
Sellado	Máquina de sellado	Diaria	Operario de sellado en turno	Verificar limpieza de residuos plásticos.
	Superficie de trabajo/ Suelo y alrededores	Diaria	Ayudante de sellado en turno	Limpieza profunda de mesas de trabajo y alrededores del área
Área de tucos	Superficies de almacenamiento	Semanal	Encargado de tucos	Clasificar y eliminar tucos dañados o inservibles
	Vías de tránsito de operarios	Diaria	Encargado de tucos	Asegurarse que las vías estén libres de tucos y residuos para evitar accidentes

Fig. 8 Cleaning routines for workstations and storage zones

ESTÁNDAR	DESCRIPCIÓN DEL USO DEL ESTÁNDAR	RESPONSABLE	OBSERVACIONES
Cinta amarilla	Delimitación de estaciones de trabajo	Operario Carlos	Responsable que la cinta amarilla se encuentre en buenas condiciones
	Delimitación la maquinaria		Ubicación de cinta correctamente ejecutada.
Rótulos	Rótulos en herramientas	Operario Eyner	Herramientas y maquinaria de cada área perfectamente identificadas por cada operario.
	Rótulos de áreas y maquinaria		

Fig. 9 Standardized format for workplace organization and labeling

Finally, discipline and sustainability were prioritized to maintain the improvements. A 5S Panel was established to centralize relevant documents and monitor progress as shown in Fig. 10. An action plan was developed to address identified inefficiencies, such as excessive search times for tools and inadequate workspace organization. Regular audits and photographic comparisons of before-and-after conditions were used to track improvements and maintain employee accountability.

Fig. 10. 5S panel for document centralization and progress monitoring

2) Improvement of preparation processes

For the development of the component, preparation activities in the extrusion, printing, and sealing processes were identified through interviews with personnel and direct observation. The times taken by operators for these activities were timed and classified into internal activities and external activities. This analysis revealed inefficiencies and improvement opportunities, highlighting delays caused by disorganization, redundant movements, and unclear processes as shown in Fig. 11.

HOJA DE ESTUDIO DE TIEMPO					
Máquina	Extrusora	Fecha: 20/07		Responsable	Irvin, Adrián, Hugo
No	**Actividad**	**Tiempo (min)**	**Operación Interna/Externa**	**Herramientas**	**Observaciones**
1	Configurar temperatura	3	Interna	Panel de control	
2	Calentar equipo	45.7	Interna	Sistema de calentamiento	El calentamiento demoró más de lo esperado debido a la temperatura ambiente.
3	Verificar la disponibilidad y estado de los materiales	5	Externa		
4	Preparar material en un cilindro	15	Externa	Cilindro de preparación	
5	Preparar tuco para bobina	10	Externa	Bobinadora	Se encontró dificultad al ajustar la bobina, se requiere revisión.
6	Inspeccionar la boca (filtro) de la extrusora	4	Interna	Llave de ajuste circular (tipo llave inglesa pequeña)	
7	Verter el material en tolva	8.5	Interna	Tolva de carga	
8	Configurar motor	2	Interna	Panel de control	
9	Arrancar equipo	3	Interna	Panel de control	
10	Pegar globo a globo anterior	2	Interna	Cinta adhesiva	Se observó dificultad en la adhesión inicial, revisar el tipo de cinta.
11	Configurar velocidad de tiro	1	Interna	Panel de control	
12	Prender tiro (jala el globo hacia arriba)	1	Interna	Sistema de tiro	
13	Ingresar aire comprimido en el globo de acuerdo a medida	7.5	Interna	Sistema de aire comprimido	
14	Acomodar globo arriba	4.5	Interna	Herramientas de ajuste manual y soporte de alzador	

Fig. 11 Time study format for extrusion process activities

Subsequently, internal activities were converted into external ones to reduce machine downtime. Then, an analysis of internal setup activities was carried out, and standardized procedures were implemented, along with the introduction of quick-release mechanisms for frequently used tools and components. These changes facilitated smoother transitions, minimized interruptions, and reduced manual handling, significantly improving operational efficiency.

Quick setup checklists were developed for all equipment based on the data collected. These checklists provided the essential steps for the startup of equipment, such as the extruder, including the selection of the PET combination with its specific temperatures, activation of heating, confirmation of stability, and recording of the final setup, ensuring an efficient and safe process, as shown in Fig. 12.

No	Paso	Descripción	Verificación
1	Encender la extrusora	Verificar la conexión y encender la extrusora desde el panel de control.	☐
2	Seleccionar combinación de PET	Elegir la combinación de materiales y configurar la temperatura:	☐
		PET de baja densidad lineal + PET de uso pesado: 225°C	☐
		PET de baja densidad lineal + PET de uso general: 220°C	☐
		PET de baja densidad lineal + PET de uso liviano: 215°C	☐
		PET de baja densidad lineal + PET de alta densidad: 240°C	☐
		PET de baja densidad lineal + material recuperado: 210°C (monitorear cuidadosamente por impurezas).	☐
3	Activar el calentamiento	Iniciar el sistema de calentamiento y monitorear la temperatura en el panel.	☐
4	Confirmar estabilidad	Esperar a que la temperatura se estabilice en el nivel configurado por al menos 5 minutos.	☐
5	Registrar y verificar	Anotar la temperatura final y revisar indicadores de seguridad.	☐

Fig. 12 Quick setup checklist for extruder operations

Then, operators were trained in the new SMED procedures to ensure their consistent application. Detailed guides and visual aids were developed, providing clear instructions for efficiently executing setup processes as shown in Fig. 13. This training not only secured the proper implementation of the changes but also fostered a culture of continuous improvement and responsibility among the workers, strengthening their commitment to operational optimization.

Fig. 13 SMED procedure training

Finally, the implementation of the improved setup processes included the reconfiguration of procedures, the assignment of assistants, and the use of more efficient tools, which optimized internal activities and converted several into external ones as shown in Fig. 14. As result of these efforts, the implementation of SMED led to a significant reduction in average setup times, improving overall production efficiency.

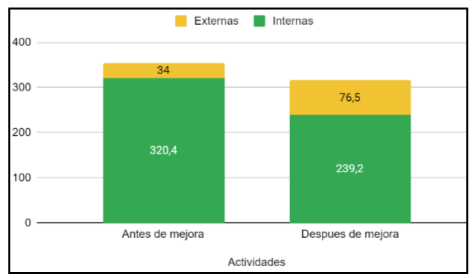

Fig. 14 Comparison of current state and improvement proposal in minutes

3) *Maintenance management*

The implementation of TPM began with an evaluation of existing maintenance practices. This diagnostic included inspecting equipment in the critical areas of extrusion, printing, and sealing, assessing both the physical condition and performance of the machines. Data was collected through interviews with operators and maintenance personnel, as well as direct observation, to identify deficiencies and improvement opportunities as shown in Fig. 15.

Fig. 15 Evaluation of maintenance practices in critical equipment

Breakdowns and their frequency were monitored and recorded to obtain a detailed understanding of critical components and common failures. The collected data allowed the creation of a summary table, which outlined breakdown characteristics, occurrence frequency, and average intervention time. This information served as a foundation for prioritizing maintenance activities and planning preventive measures to enhance equipment availability. Fig.16 shows an example for extruder´s breakdowns

Componente	Característica de la avería	Frecuencia (vez/mes)	Min/vez
Extrusión	-	-	-
Tratadora	Desgaste	2	175
Rodaje	Desgaste	2	182
Termocuplas	Desgaste	3	126
Potenciometro	Desgaste	3	124
Fallo en rodillos	Rotura	2	722
Motor	Rotura	1	2170
Rodamientos	Desgaste	3	130
Sistema de control	Cortocircuito o fallo de sensores	2	248
Husillo	Desgaste	2	367
Calentadores	Desgaste o falla eléctrica	3	155
Sistema de alimentación	Bloqueo o fallo del transportador	2	150

Fig. 16 Summary of extruder breakdowns and intervention times

Then, maintenance activities were defined with specific details regarding their frequency and duration. These tasks were established through collaboration with the maintenance team to optimize practices for the equipment in extrusion, printing, and sealing areas. A preventive maintenance plan was developed, outlining specific tasks tailored to each machine to ensure efficient operations through scheduled activities. An example of printer´s activities is shown in Fig. 17.

ACTIVIDADES DE MANTENIMIENTO PREVENTIVO PARA IMPREOSRA FLEXOGRÁFICA				
Componente	**Actividad**	**Herramienta/material**	**Tiempo (min)**	**Frecuencia**
Piñones	Lubricación	Mobilgrease XHP 222	7	Semanal
Piñones	Reemplazo	Piñon de repuesto	60	Semestral
Rodajes	Lubricación	Mobilgrease XHP 222	7	Semanal
Rodajes	Reemplazo	Extractor de rodaje, rodaje de repuesto	60	Semestral
Fajas	Reemplazo	Faja de repuesto	25	Trimestral
Prisioneros	Reemplazo	Prisionero de repuesto	15	Mensual
Rodillos porta clichés	Lubricación	Shell OMala S2 G 220	10	Semanal
Anilox	Lubricación	Shell OMala S2 G 220	7	Semanal
Cámaras	Limpieza	Limpiador industrial	10	Diaria
Anilox	Limpieza	Limpiador industrial	14	Semanal
Viscosimetro	Limpieza	Limpiador industrial	9	Semanal

Fig. 17 Preventive maintenance plan for the printer

Training sessions were conducted to explain TPM objectives to operators and maintenance staff. These sessions emphasized the importance of increasing equipment availability and reducing unplanned downtime. Operators were trained in autonomous maintenance, problem identification, and their collaborative roles in executing the maintenance strategy. The sessions ensured that all personnel understood their responsibilities and the value of their contributions to the success of TPM as shown in Fig. 18.

Fig. 18 Training sessions for TPM implementation and operator involvement

Finally, the maintenance activities were implemented across all areas following the detailed plan as shown in Fig. 19 and Fig. 20 Maintenance procedures were carried out, and breakdowns were systematically recorded using predefined formats. Operators and maintenance staff maintained comprehensive logs to track activities and validate the effectiveness of TPM, achieving significant improvements in equipment reliability and operational efficiency.

Fig. 19 Implementation of maintenance activities and breakdown tracking

Actividad	Frecuencia	Equipo	Semanas de realización de las actividades de mantenimiento											
			1	2	3	4	5	6	7	8	9	10	11	12
Lubricación de rodajes	Semanal	Extrusora	x	x	x	x	x	x	x	x	x	x	x	x
Inspección y calibración de termocupla	Mensual	Extrusora		x						x				x
Lubricación de ejes	Trimestral	Extrusora												x
Lubricación de tratadora	Semanal	Extrusora	x	x	x	x	x	x	x	x	x	x	x	x
Inspección y calibración de la tratadora	Mensual	Extrusora				x				x				x
Lubricación de piñones	Semanal	Impresora Flexográfica	x	x	x	x	x	x	x	x	x	x	x	x
Inspección y limpieza de prisioneros	Mensual	Impresora Flexográfica		x				x						x
Reemplazo de fajas	Trimestral	Impresora Flexográfica				x								x
Lubricación de rodillos porta clichés	Semanal	Impresora Flexográfica	x	x	x	x	x	x	x	x	x	x	x	x
Inspección y calibración de resistencia	Mensual	Selladora		x				x						x
Lubricación y limpieza de rodillos	Semanal	Selladora	x	x	x	x	x	x	x	x	x	x	x	x
Limpieza y lubricación del sello	Semanal	Selladora	x	x	x	x	x	x	x	x	x	x	x	x
Inspección y lubricación del balancín	Mensual	Selladora			x			x			x			x
Inspección y calibración del tablero	Mensual	Selladora				x				x				x

Fig. 20 Preventive maintenance program for implementation

IV. VALIDATION

Following the structured implementation of the three tools, a pilot test was carried out to evaluate the effectiveness of the proposed improvements under real production conditions. This pilot phase was conducted over several weeks, during which performance data were systematically collected for key operational indicators. The objective was to quantify the direct impact of the improvements before proceeding to model their long term effects via simulation.

The results of the pilot test revealed significant gains across all targeted areas. Tool search times were reduced by 73.24%, confirming the effectiveness of the workplace organization measures. Setup times for extrusion, printing, and sealing processes decreased by 28.84%, 22.66%, and 23.68%, respectively, validating the SMED based optimizations. Moreover, equipment availability increased from 74.09% to 75.32% in extrusion and from 75.47% to 76.70% in printing, supported by the introduction of preventive and autonomous maintenance routines. These results were reinforced by operator feedback through satisfaction surveys and on-site audits, which also demonstrated improvements in orderliness and task efficiency.

Based on these empirical outcomes, a simulation model was developed in Arena to extrapolate the potential impact of the improvements on a larger scale. The model replicated the plant’s operations using updated parameters derived from the pilot test. This allowed a robust comparison between the initial state and the optimized scenario, enabling a comprehensive validation that combined both experimental data and simulated projections.

A. *Baseline model*

The baseline model, as shown in Fig. 21 simulates the flow of production orders through extrusion, printing, and sealing processes. Decision modules determine the timing of order launches, the need for extruder material changes, and the probability (58%) of requiring printing for each production order. Processing modules include “delay” components that simulate preparation times for extrusion, printing, and sealing equipment before the main processing steps. Additionally, a "Failure" section was included to model the real behavior of equipment breakdowns in extrusion, printing, and sealing. This module incorporated parameters for "Up Time" (operational periods between failures) and "Down Time" (repair durations), derived from probabilistic distributions determined using Arena’s Input Analyzer tool. These parameters accurately reflect the current state of equipment reliability, providing a realistic baseline for evaluating production performance.

To ensure the statistical validity of the simulation results, the number of replications was calculated using (1), based on the initial estimates obtained from 10 replications. The analysis, performed with the Output Analyzer tool, identified productivity as the indicator requiring the largest sample size, approximately 69 replications, to meet a 95% confidence level with a 5% error margin. Therefore, 70 replications were executed to ensure the reliability and representativeness of the results, following the approach described in [30].

$$N \geq \left(\frac{t_{\alpha/2,n-1} \times S(n')}{E}\right)^2 \qquad (1)$$

B. *Improvement model*

The improvement model incorporates changes based on the implementation of 5S, SMED and TPM strategies in the plant. Preparation times for extrusion, printing, and sealing were reduced by adjusting delay parameters, reflecting the improvements achieved through SMED and 5S, such as converting internal activities to external ones and optimizing internal tasks. For TPM, the "Failure" module was updated with new "Up Time" and "Down Time" parameters based on preventive maintenance strategies implemented in the plant as shown on the previous section. These changes reflect the transition from reactive maintenance to planned maintenance schedules, derived from new MTBF and MTTR values.

All updated parameters were determined using data collected during their implementation in the plant. Arena’s Input Analyzer tool was again employed to establish the probabilistic distributions for the new parameters, ensuring that the improvement model accurately represented the enhanced operational efficiencies achieved through these tools.

V. Discussion

The final 5S compliance achieved was 68%, as illustrated in Fig. 21, the radar chart showing the progress across the five dimensions of the methodology.

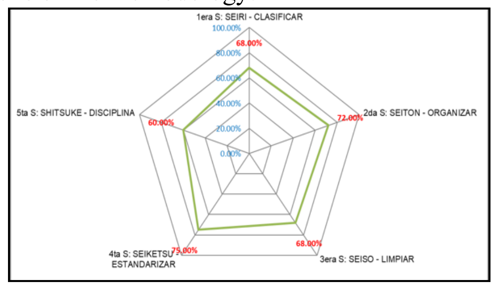

Fig. 22 Final 5S compliance radar chart

Table II summarizes the results of key performance indicators from the validation of the improvement model. "Validation" reflects simulation results, and "Expected" projects outcomes from the literature. Notably, tool search time reductions for 5S were calculated from the pilot test.

TABLE II
FINAL INDICATOR ANALYSIS

Indicator	*Initial diagnostic*	*Validation*	*Expected*	*Source*
Productivity	0.143	0.191	0.181	[24]
Tool search time (s)	710	190	240	[25]
Extrusion setup times (min)	87.2	72.30	54.06	[15]
Printing setup times (min)	133.7	98,10	82.89	[15]
Sealing setup times (min)	99.5	70,80	61.69	[15]
Extrusion availability	74.09%	75%	80%	[26]
Printing availability	75.47%	79.10%	80%	[26]
Average cycle time	2270	1900	1674	[24]

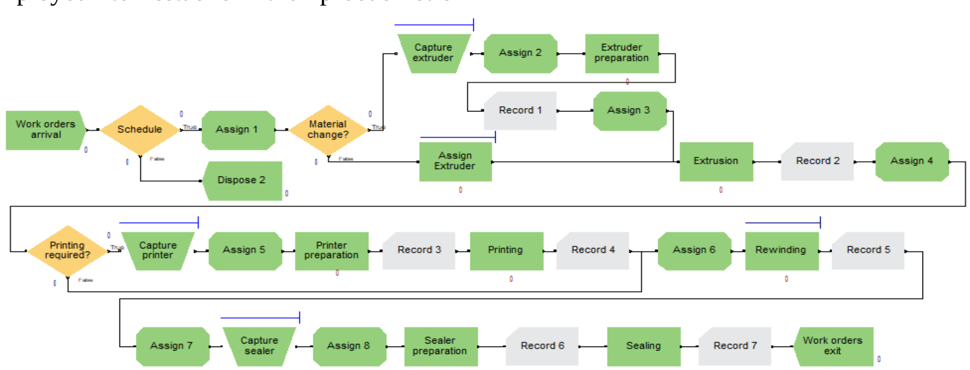

Fig. 21.Baseline model simulating production order flow

The implementation achieved significant improvements in operational efficiency. 5S increased compliance to 68% and reduced tool search times by 73.24%, validating its effectiveness. These results align with [4], who highlight its role in minimizing delays.

In SMED, preparation times for printing and sealing processes were reduced by up to 28.84%, nearing the 30% improvement for equipment that undergoes frequent material or configuration changes. These machines are adjusted more often compared to extruders, which get prepared with less frequency. While the reductions achieved are below the 38% improvement reported in the literature, they demonstrate the effectiveness of SMED in optimizing processes that are critical to daily operations, with potential for further improvement in efficiency [15].

TPM moderately improved equipment availability (1.23% for extruders and 4.81% for printers), consistent with [31], who note the inherent limitations of this indicator. However, autonomous and preventive maintenance enhanced operational reliability. Lastly, the average cycle time was reduced by 16.30%, from 2270 to 1900 minutes, reflecting an increase in productive time, although still above the benchmark of 1674 minutes [24]. Overall, the applied tools justified significant gains in productivity and efficiency, establishing a solid foundation for future optimizations.

VI. Conclusions

This study demonstrated the effectiveness of Lean Manufacturing tools (5S, SMED, and TPM) when implemented within a production management model in a plastic manufacturing plant in Perú. The implementation of the model improved the productivity of the plastic bag production line from 0.143 to 0.191 thousand bags per man-hour by optimizing processes and reducing waste. The 5S methodology significantly enhanced workspace organization, reducing tool search times by 73.24%. Similarly, SMED reduced equipment setup times by up to 30%, streamlining operations and minimizing downtime. Additionally, TPM improved equipment availability to 75% for extrusion and 79.10% for printing, highlighting the importance of proper training and maintenance planning. These findings confirm the value of Lean tools in improving productivity and fostering continuous improvement, particularly in SMEs within the plastics sector.

Regarding the economic impact, the proposed improvement plan achieves an NPV of 272,406 soles and an IRR of 41.27%, significantly exceeding the Cost of Capital (COK) of 13.67%, confirming the project’s profitability. Financially, the NPV rises to 307,672 soles with an Internal Rate of Return (IRR) of 54.67%, far above the Weighted Average Cost of Capital (WACC) of 12.11%. These results highlight the plan's strong economic and financial viability, ensuring substantial returns and value generation over the five-year period.

To sustain and expand these results, future projects are recommended to invest in industrial shelving and organizers to maintain an even more organized workspace. Additionally, further studies should analyze the impact of Lean Manufacturing on other production lines or sectors and explore the integration of real-time monitoring technologies to obtain precise data that enable continuous process improvement and adaptability.

Overall, the main objective of this research was fulfilled by demonstrating that the integration of Lean Manufacturing tools within a structured production management model contributes effectively to optimizing resources and boosting productivity, offering a replicable framework for similar companies seeking operational excellence.

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