SSRG International Journal of Industrial Engineering
ISSN: 2349 – 9362 / https://doi.org/10.14445/23499362/IJIE-V12I2P106

Volume 12 Issue 2, 49-59, May-Aug 2025

Original Article

A Structured Lean–TPM Model to Transform Setup and Downtime Management in Flexible Packaging: Evidence from Peru

Diana Carolina Apolinario-Avendano[1], Eleana Carolina Torres-Lima[1], Elmer Luis Tupia-De-La-Cruz[1*]

[1]*Carrera de Ingeniería Industrial, Universidad de Lima, Perú.*

[*]*Corresponding Author : etupiade@ulima.edu.pe*

Received: 06 June 2025 Revised: 08 July 2024 Accepted: 29 July 2025 Published: 18 August 2025

Abstract - *Flexible-packaging firms repeatedly encounter low availability and lengthy setup times, issues that earlier Lean and TPM literature examined in isolation. Yet persistent waste in Small and Medium Enterprises (SMEs) reveals the need for a more cohesive and flexible approach. Therefore, this work blends those philosophies into a staged Lean-TPM framework designed to boost equipment performance and slash downtime. The plan features single-minute exchange of dies (SMED), scheduled preventive maintenance, and clear work standards, while frontline operators lead regular improvement cycles. When a Peruvian SME adopted the model, availability climbed from 75 to 92, mean time between failures rose 58, mean time to repair dropped 38, and setup duration shrank 40. Those metrics delivered steadier production and less scrap. From an academic viewpoint, the evidence highlights the roadmap's usefulness as a realistic option for resource-constrained firms. From a socioeconomic angle, the gains point to replicable pathways for similar plants across emerging markets. Researchers are urged to broaden testing to other sectors and regions.*

Keywords - *Lean-TPM Model, Setup Time Reduction, Downtime Management, Flexible Packaging Industry, Operational Efficiency, Peruvian SME Case Study.*

1. Introduction

The flexible-plastic-packaging industry has become a focal point for manufacturers both overseas and in fast-growing Latin American economies like Peru. Global projections indicate that consumption is set to climb from roughly 31.5 million tonnes in 2021 to more than 35 million tonnes by 2025, a trend powered by expanded e-commerce, a push for greener packaging and the need for streamlined logistics [1]. Before COVID-19, plastic-product output in the region rose by about 4-5 percent a year. Peru emerged as an industrial leader, contributing close to 4 per cent of national GDP and supporting over 200,000 jobs [2].

Flexible-packaging sales abroad now make up nearly 15 per cent of Latin America's total plastic trade, and the trajectory remains encouraging [1][2]. Yet, Peruvian plants run at just 71-73 per cent of their design capacity because of delays tied to maintenance, line changeover and in-house logistics [3].

This capacity shortfall, coupled with the fact that many local firms are small or medium-sized, work on narrow margins and face tougher quality and sustainability rules, highlights an urgent need for process upgrades that align supply with rising market demand [2][3][4].

Flex packaging plants are undeniably agile but still grapple with persistent operational headaches. Chief among these is a poor facility layout, which forces materials and workers to zigzag around the floor and stretches the cycle time longer than necessary. Observations from industry peers show that some batches travel more than 300 meters internally, wasting over 15 percent of the time set as the benchmark [5].

A second hurdle is the absence of agreed standard times for format changeovers or setup. When extruder, printing, and cutting lines lack clear recipes or step-by-step checklists, the switchover can drag on for many minutes; research shows the clock can triple in such cases, leaving machines idle far too long \[6\]\[7\].

A third concern is the rash of surprises: breakdowns and unscheduled stops that shrivel equipment availability. Because most shops still practice mainly reactive maintenance, case studies from across Latin America suggest this approach alone is accountable for 25 percent of downtime, to say nothing of extra losses from defects or rework [6][8]. Taken together, layout, setups, and maintenance deficits pinch capacity, erode reliability, and push costs up, leaving these firms unnervingly exposed in the marketplace [5][6][8].

The benefits of coordinated setup and maintenance upgrades quickly make the case for tackling these issues head-on. To begin with, a better workshop layout speeds material movement, cuts cycle time, and raises productive capacity, especially for steady, high-volume jobs without purchasing extra machines [5][9]. Next, a Smart Single-Minute Exchange of Die SMED process can trim tool-change hours by up to 40 %, giving operators the flexibility to switch between small or mixed orders with far less downtime and far lower work-in-process stock [7]. Adding the two pillars of autonomous and planned care from Total Productive Maintenance TPM helps crews catch faults early, keeps equipment up and running, and can stretch the working life of even older assets [8][6]. In fact, packaging lines that adopt TPM often report 25 % better Overall Equipment Effectiveness OEE, along with fewer defects and shorter stoppages [6][8][10]. Beyond productivity numbers, these initiatives lift the firm's competitive edge by bolstering reputation, cutting waste, and freeing more energy for fresh ideas [4][11].

Yet a sizeable research and practice gap persists, especially in Peru and comparable markets: most improvement programs still tackle SMED or TPM as if they exist in a vacuum [6][7][8]. Insight into how SMED truly aligns with the autonomous and planned-maintenance pillars within flexible-packaging lines is still sparse. Some reports point to gains- a joined SMED-TPM framework lifted productivity by 24% in one Peruvian SME, yet analyses are rarely thorough, replicable, or mindful of sudden downtime and defect rates [12][6]. At present, no solid data show how this integrated route reshapes plant layout, trims changeover duration, or boosts equipment reliability, nor what the full cost and operational picture looks like for the sector [1][6][12]. Finally, no model has been crafted to reflect the realities of extrusion and printing lines, which confront distinct hurdles compared with rigid manufacturing or molding operations [3][8].

This research introduces a unified operations model tailored for a Peruvian flexible-packaging facility to bridge these shortcomings. lity; it merges SMED with both the autonomous and planned-maintenance pillars of Total Productive Maintenance. By customizing Lean–TPM techniques to the realities of extrusion and printing lines in emerging markets, the approach directly confronts the longest-standing issues: excessive changeover durations, erratic material flow, and unforeseen equipment breakdowns. A technical blueprint of the model, the specific performance metrics employed, and the hard data generated will be presented in the Contribution chapter.

The following sections outline the integrated model's step-by-step diagnosis, design, and rollout and summarize the operational gains that ensued. Those gains are benchmarked against global averages and examined from both a managerial and scholarly angle, with particular attention to productivity, environmental impact, and the ease of scaling such initiatives across small-to-medium enterprises in the flexible-packaging industry. In this sense, the study delivers a realistic playbook for businesses ready to elevate their efficiency and dependability through readily deployable, Lean-and-TPM-based tools.

2. Literature Review

2.1. Lean Maintenance Integration in Flexible Packaging

Recent investigations into the flexible plastic packaging industry indicate that Lean Manufacturing methodologies can meaningfully enhance both maintenance oversight and broader operational performance. Frameworks that merge 5S, Single-Minute Exchange of Dies (SMED), and Total Productive Maintenance (TPM) in particular have been linked to shorter downtimes and improved rates of equipment up-time. For example, Ames et al. designed a Lean-oriented maintenance model for a small-to-medium-sized enterprise in the Peruvian plastics sector, producing a 20-percent boost in production capacity by cutting idle periods and raising machine use [13]. Quiroz-Flores and Vega-Alvites adapted that model in an injection-molding facility and recorded a 13-percent climb in Overall Equipment Effectiveness (OEE) [2]. Supporting evidence comes from Miranda-Castro et al., who layered Johnson's Rule, SMED, and the TPM pillars inside a flexible-packaging plant and observed a 24.4-percent gain in productive efficiency [5]. Finally, Allca-Chauca et al. noted that pairing 5S, TPM, and SMED in another plastics SME pushed efficiency scores as high as 73 percent, highlighting the collective advantages created when maintenance functions are tightly knitted into Lean operations [14].

2.2. SMED Methodology in Plastic and High-Mix Industries

The Single-Minute Exchange of Die (SMED) methodology has been adopted across manufacturing systems to shorten changeover intervals and curtail non-productive time, and the advantages are especially clear in plastic and high-mix factories. In a pipe-making plant, Shinde et al. trimmed setup times by 40%, thereby enabling the operation to switch jobs on shorter notice without sacrificing output volume [15]. On an injection-molding line, Marcella and Widjajati recorded a 17% drop in changeover duration, a gain they linked to steadier operator focus and clearer pre-start checklists [16]. Sahin and Kologlu studied a turning cell that handled various plastic parts and noted a 45% reduction in setup time after the disciplined SMED drills were put in place, an improvement that visibly raised overall line availability [17]. Ribeiro et al. worked with a small-to-medium Peruvian firm and combined SMED with TPM tactics, yielding a useful 30% gain in machine utilization and illustrating the method's compatibility with broader continuous-improvement systems [18]. Collectively, these investigations affirm that SMED minimises wasted minutes and boosts flexibility, making it a powerful tool for high-mix operations such as plastic-packaging production.

2.3. Autonomous Maintenance and Operator Empowerment

Autonomous Maintenance (AM), a core pillar of Total Productive Maintenance, invites machine operators to handle everyday equipment care, and evidence shows that this ownership boosts reliability in the packaging and plastics sectors. Pinto et al. tracked a clutch-bearing facility and found that AM cut breakdowns by 23% on lathes and by 38% on milling machines, lifting Overall Equipment Effectiveness by 5% [19].

Morales and Rodriguez noted similar gains on a bottleneck machining line, where operator-led checks eased minor stoppages and nurtured a forward-looking maintenance mindset [20]. Callan-Villanueva et al. documented 25% higher output and 30% lower repair bills after AM routines were entered a plastics-molding plant [21]. Calderón-Gonzales et al. merged Lean tools with TPM and credited AM for steady production flows and better machine condition in a flexible-packaging small-to-medium enterprise [22]. These studies show that pairing AM with visual boards and standard checklists reliably shrinks equipment variation and sustains a culture of continuous improvement.

2.4. Planned Maintenance as a Strategic Preventive Tool

Planned Maintenance (PM) provides firms a structured way to resolve moderate equipment problems before they escalate, a practice that matters nearly everywhere but is crucial in plastic packaging, where line reliability is treated as a quality guarantee. Pinto et al. traced the effect of weekly, documented service charts in a high-output mechanical plant and found that unscheduled stops fell by almost a third while process consistency across several workstations rose [19].

Arroyo and Obando reported similar gains in extruder-heavy facilities after adding month-long check semi-nars, noting that average machine life doubled and output flicker tamed [21]. Arroyo and Obando also observed a forty-percent drop in Mean Time To Repair (MTTR) and a twenty-two-percent increase in Mean Time Between Failures (MTBF) after one year of PM in a Peruvian packaging SME [22]. Ames et al. put the payback in profitability terms, showing that Lean-driven calendars alone raised output capacity by twenty percent, all without fresh capital equipment [13]. Together, these results indicate that PM not only curbs emergency bills but also tightens alignment among operators, maintenance staff, and spare-parts suppliers.

2.5. Integrated Lean-TPM Strategies for Sustainable Results.

Combining Lean Manufacturing with Total Productive Maintenance (TPM) now appears as a single approach aimed at boosting productivity, product quality, and machine uptime in plastic-processing plants. Allca-Chauca and colleagues built a common framework featuring 5S, Single-Minute Exchange of Dies (SMED), and core TPM tasks, and in a small-to-medium enterprise found gains in flexibility, cut cycle times, and dropped defect rates [14]. Miranda-Castro added Johnsons sequencing rule to SMED and TPM in a different line and recorded a sharp rise in output and responsiveness in flexible-packaging work [5]. Sánchez and Pérez showed that pairing SMED with TPM yields steady gains, especially where firms routinely change setups and produce mixed-sized batches [18]. Quiroz-Flores and Vega-Alvites argued that Lean-TPM fusion suits smaller companies because it demands little upfront spend and quickly pays back through ongoing process tuning [2]. These studies imply that deploying Lean alongside TPM can lift overall equipment effectiveness (OEE), deepen employee commitment, and widen customer approval for the long haul..

3. Contribution

3.1. Proposed Model

In the plastic sector, a framework for maintenance (Figure 1) shows management in a flexible packaging plant. This was initiated in response to a pragmatic problem of the infrequent machine availability, which obstructed production continuity and eroded reliability. The framework incorporates concepts of Lean Manufacturing together with Total Productive Maintenance (TPM), forming a hybrid model that leverages reliability and minimizes unplanned downtime. Machine operators were empowered to perform basic daily care as a centrepiece in the deployment, which fostered deeper organizational commitment to equipment health. Preventive emerging defect inspection and correction were concurrently structured into a fixed calendar to mitigate surprising failures. To further enhance speed and agility, the team adopted SMED techniques that quickly shortened setup times and enabled quicker inter-batch transitions.

These initiatives have shifted the maintenance of an overwhelmingly reactive and crisis-driven function to a disciplined routine anchored in daily practice. As a result, production flows have been stabilized, and the long-term sustainability of the equipment base has become a more manageable objective.

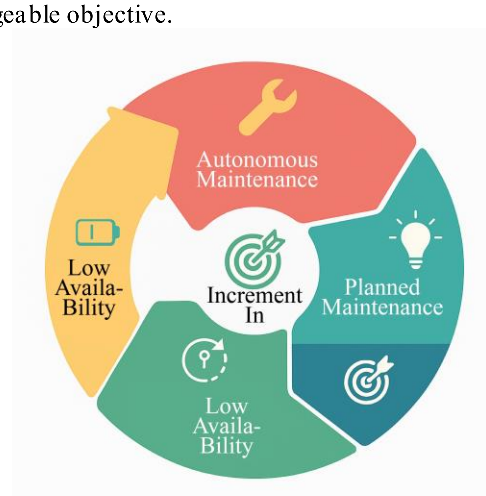

Fig. 1 Proposed model

3.2. Model Components

The graphic presented here sketches a straightforward improvement pathway aimed squarely at a persistent shop-floor headache: machines parked idle far longer than they actually run. Drawing heavily from the Total Productive Maintenance (TPM) philosophy and the spirit of continuous improvement, it puts forward three connected actions—Autonomous Maintenance, Planned Maintenance, and the quick-change discipline known as SMED—and lays out a sensible order in which to introduce them. When used together, these practices chip away at the same target: higher equipment uptime, the bedrock of any lean operation.

What distinguishes the model is its clear, step-by-step road map that moves teams away from a world of surprise shutdowns and minimal operator ownership toward a setting where machines run nearer to their designed capacity. Instead of allowing separate departments to chase fixes in their own corners, the framework weaves the tactics into a single plan that can be written down, taught, and rolled out from one production line or factory to the next. That simplicity especially appeals to small and medium-sized enterprises (SMEs) that cannot afford costly overhauls yet stand to gain a great deal when maintenance shifts from reactive to genuinely preventive.

By presenting the step-by-step process in straightforward terms, the framework bridges the gap between classroom theory and real-world practice, giving researchers and industry professionals a playbook they can follow repeatedly. Its charm is that it is uncomplicated, easy to trace, and closely matched to established reliability and lean-maintenance rules, so teams spend less time learning and more time seeing quick results on the shop floor.

3.2.1. Initial Diagnosis: Identifying Low Equipment Availability

The opening phase of the assessment model zeroes in on low equipment availability and treats it as the principal constraint slowing the entire operation. By placing this condition front and centre, practitioners secure a clear justification for the improvement actions that follow. In many active production environments, operators encounter machines that break down with surprising regularity, almost always require reactive maintenance, changeovers that consume excessive minutes or hours, and cleaning or inspection activities that lack written steps and meaningful audit trails.

Evidence of low availability shows up quickly in the metrics: unplanned stoppages multiply, effective run-time remains disappointingly small, and the overall technical state of the fleet remains largely hidden from supervisors. Consequently, overall equipment effectiveness, or OEE, declines, and the factory's ability to ramp up or scale back in response to orders is severely hampered. When repair knowledge resides in only a few specialists, waiting for their availability creates yet another choke point and deepens the operation's reliance on a narrow skill pool.

Awareness of these symptoms paves the way for a tailored, step-by-step plan to restore higher availability. The framework targets root causes through a balanced mix of hardware fixes and changes to how teams organise their work. Central to the approach is empowering shop-floor staff, codifying preventive tasks, and aligning production leaders with maintainers so that actions are coordinated, timely, and visibly tracked.

3.2.2. Pillar 1: Empowering Operators Through Autonomous Maintenance

The opening pillar, Autonomous Maintenance, asks frontline workers to take charge of basic tasks such as cleaning, lubricating, and inspecting machinery while recording early warning signals. By handing these responsibilities to the people who face the equipment shift after shift, the company gains faster alerts to small faults and cultivates a deeper sense of ownership on the shop floor.

The initiative starts with practical workshops covering how to conduct a visual check, interpret equipment health indicators, and follow the steps in a daily routine. As days go by, operators not only learn the drill but also begin to identify nearby improvement opportunities that lie beyond routine care. That shift from a passive to an engaged mindset hinges on steady coaching from maintenance mentors paired with visible support from senior leaders.

Immediate gains appear in fewer small stoppages and less downtime caused by dirt, misalignment, or dry bearings. Over the longer term, each completed checklist produces consistent data that will guide the model's future phases with evidence drawn from daily work. When everyone relies on the same visual boards and standard forms, the workplace stays cleaner, safer, and better organized—a solid foundation for the deeper changes that lie ahead.

3.2.3. Pillar 2: Enhancing Reliability through Planned Maintenance

Once autonomous maintenance is bedded in, many firms transition to planned maintenance, systematically tightening machine reliability with pre-scheduled tasks. The primary aim is to avert catastrophic failures by tackling wear, misalignment, and slow material fatigue before they escalate. Unlike reactive maintenance, which springs into action only after a breakdown, planned maintenance leans on historical data, manufacturer's instructions, and real usage metrics to plan each service.

A criticality matrix then ranks every asset according to its influence on production, giving managers a clear starting point for attention. With high-impact machines singled out, maintenance calendars map firm dates for inspections, parts swaps, and condition checks, guiding technicians to work when their time yields the greatest return. Scheduling in advance also smooths the delivery of spares, tools, and specialist labour, turning what could devolve into a frantic hunt into a measured rhythm.

Standard work instructions, backed by consistent documentation, round out the system. Every task, no matter how routine, is logged so staff can later review what was done, spot recurring patterns, and refine the procedure in a continuous, evidence-based loop.

Effective coordination between maintenance teams and production staff is critical; planned activities should blend smoothly into everyday operations, avoiding interruptions or conflicting priorities. Maintenance evolves from a disruptive chore into a continuous process that adds tangible value when this alignment is achieved.

Concurrently, central reliability metrics like Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) are tracked carefully, providing managers with concrete, transparent evidence they can consult when shaping budgets and balancing performance goals with cost constraints.

3.2.4. Pillar 3: Reducing Setup Losses with Focused Improvement (SMED)

The third pillar zeroes in on a common bottleneck in high-mix settings: long changeover times. By following Single-Minute Exchange of Die (SMED) principles, cross-functional teams shave precious minutes off product switches, freeing machine hours and boosting overall agility.

SMED begins with a stopwatch and a notebook; observers record each motion in the setup routine. They then sort tasks as internal—those requiring the machine to stop—and external—those that can happen while production is running. The first improvement push moves as many steps as possible to the external side and trims any action that adds no real value.

Standardized changeover guides now tame unwanted variation, reduce human error, and protect operator posture by giving every group a steady plan to follow. Faster and more predictable setups mean machines sit idle for fewer minutes between runs, allowing firms to lower the minimum profitable batch size, cut excess inventory, and still respond to demand swings.

Realizing these productivity gains hinges on collaborative work across all departments and on a readiness to modify hardware or software, whether by raising a guard rail, installing a locator pin, or writing a simple sensor routine, so that many operations feel natural and some steps can be handed off to a machine. The capital required for these tweaks is nearly always modest, yet the boost in product-mix flexibility, throughput speed, and order-response time regularly outstrips the yield from much larger investment programs.

3.2.5. Outcome: Sustaining Higher Machine Availability

When maintenance activities, operator training, and design-for-change principles are introduced in the planned sequence and at the right pace, overall machine availability climbs steadily and can be forecast with confidence. This gain is not the result of a single sprint; it builds week after week and month after month as engineering, production, and service teams take small, coordinated steps.

The lift in equipment uptime makes scheduling smoother, expands the order backlog that can be handled, and enables quicker shifts whenever customer priorities change. Autonomous Maintenance prompts operators to conduct everyday inspections, Planned Maintenance schedules deeper reviews before small problems grow, and SMED trims the hours lost each time tools or fixtures are swapped. These practices set up a reinforcing loop of forward-looking care and gradual fine-tuning.

The joint strategy delivers quantifiable efficiency gains and strengthens the organization's overall knowledge repository. By empowering teams, recording critical procedures, and tracing sources of waste, the approach cultivates a nimble kaizen culture that tracks with changing shop-floor layouts. Such preparation equips the firm for future leaps and positions it to compete steadily in markets that demand vigilant stewardship of every minute and every asset.

3.3. Model Indicators

The proposed maintenance management model, built on Lean and Total Productive Maintenance principles, was evaluated using a custom set of performance indicators that matched the day-to-day reality of a flexible plastic-packaging plant. These tailored metrics directly speak to the plant's unique maintenance problems and made it possible to assess how well the new system is working in a clear, step-by-step manner. This approach allows managers to track core operational areas over time and gain an evidence-based view of how equipment availability changes. The resulting measurement framework thus anchors ongoing decision-making and continuous improvement drives focused on boosting the reliability of assets across the production line.

3.3.1. Availability (%)

This indicator reflects the proportion of time that equipment was operational and available for use. It helps assess the impact of downtime on production capacity.

$$\text{Availability (\%)} = \left(\frac{\text{Operating Time}}{\text{Total Time}}\right) \times 100$$

3.3.2. Excess Repair Time

This metric quantifies the amount of time spent on equipment repairs beyond acceptable standards, offering insight into inefficiencies in corrective maintenance.

$$\text{Excess Repair Time} = \text{Total Repair Time} - \text{Standard Repair Time}$$

3.3.3. MTTR (Mean Time to Repair)

MTTR measures the average time required to perform repairs after equipment failure. Lower values indicate faster recovery and better maintenance responsiveness.

$$\text{MTTR} = \frac{\text{Total Downtime}}{\text{Number of Failures}}$$

3.3.4. MTBF (Mean Time Between Failures)

This indicator calculates the average time between two consecutive equipment failures, reflecting reliability. A higher MTBF suggests fewer interruptions.

$$\text{MTBF} = \frac{\text{Operating Time}}{\text{Number of Failures}}$$

3.3.5. Average Setup Time

It measures the typical time required to prepare equipment for production, including changeovers. Reducing this time enhances flexibility and productivity.

$$\text{Average Setup Time} = \frac{\text{Total Setup Time}}{\text{Number of Setups}}$$

4. Validation

4.1. Validation Scenario

The validation study occurred at a medium-sized manufacturer of flexible packaging serving food and non-food sectors in Lima, Peru. With more than thirty years in the field, the company runs production plants across Latin America, enabling it to supply over twenty national and regional markets. Its local facility operates a five-step line—extrusion, printing, lamination, cutting, and sealing—and considerable downtime has been traced to the cutting stage, where machinery availability falls far below target levels. Such frequent stoppages and inadequate preventive maintenance have depressed overall throughput and generated heavy financial losses, explaining the urgent need for a detailed root-cause analysis of the department's performance.

4.2. Initial Diagnosis

The diagnostic performed in the case study uncovered a serious flaw in the cutting process, with operational availability sitting at just 75.3%, well below the desired 90% benchmark. That performance dip translated into an estimated cost of S/ 613,235, or 4.6% of the company's yearly revenue. A closer look at the root drivers revealed that 65.9% of the lost hours stemmed from maintenance-related stops, split between 47.4% coming from the absence of a formal maintenance schedule and 18.5% arising because repairs took too long. Another major source of downtime, accounting for 27.4%, was linked to setup delays, prompted by a missing standard work document (16.9%), technicians occasionally ignoring technical protocols (7.3%), and operators receiving only minimal training (3.3%). The final 6.7% fell into a miscellaneous category whose exact causes remain unidentified. This data spelled out how large the gap really is and pointed managers toward priority actions, namely tightening maintenance planning and clarifying setup steps, so equipment availability can improve across the board.

4.3. Validation Design

Over four months, a flexible plastic packaging firm tested the maintenance management model to boost equipment availability through Lean principles and Total Productive Maintenance (TPM) tools. Validation entailed applying step-by-step methods designed to cut unplanned stoppages and strengthen asset reliability in everyday production. The framework merged preventive scheduling, standardized routines, and operator-led upkeep to tackle persistent performance gaps. Guided by a data-centric approach, the team measured gains consistently and revealed both operational trends and the financial impact of each improvement step.

4.3.1. Implementation of the Proposed Model in the Case Study

The proposed model was rolled out in a Lima, Peru, flexible plastic-packaging SME that had suffered from persistently low equipment availability. In the absence of a formal maintenance program, the firm endured frequent unscheduled shutdowns and protracted periods when machines remained idle. To remedy this, a stepwise Lean-TPM framework, built around standardized procedures, preventive tasks, and streamlined setup operations, was introduced with the goal of steadily raising overall availability.

Deployment was organized into clearly defined stages—marketing, diagnosis, intervention, and sustain—to facilitate a logical and gradual transition toward continuous improvement. Throughout the project, availability rate, mean time to repair (MTTR), mean time between failures (MTBF), and setup time were tracked in real time to gauge progress against baseline conditions. After twenty months, the system's availability climbed from 75.2 percent to 84.5 percent, aided by a 76 percent drop in excessive repair labour and marked enhancements in reliability. This shift rested on four interlocking pillars—strategic standard work, scheduled preventive care, data-driven decision-making, and adaptive learning—which together constituted a coherent evidence-based intervention framework.

4.3.2. Comprehensive Assessment of Maintenance Needs

The first step was to trace the main reasons the equipment went offline by carefully reviewing past maintenance work and the pressures production teams faced. Analysis of operational records showed that the organization had spent an extra 4585.01 hours repairing machines over the reference year alone. Alongside this, a Mean Time to Repair of 41.72 hours and a Mean Time between Failures of 214.36 hours pointed to slow service and weak machine reliability. The numbers clearly called for a more disciplined maintenance regime and the introduction of Lean and TPM tools. Reviewers also found no regular preventive checks and erratic changeovers, both of which fed frequent breakdowns and unpredictable workflow. The study set a performance benchmark and guided managers in picking the right methods and instruments for the coming improvement cycle.

4.3.3. Implementation of Autonomous and Planned Maintenance

Because the organization lacked a structured maintenance schedule, management chose to make autonomous and planned maintenance the centre of its improvement initiative. Autonomous maintenance gives frontline personnel the tools they need to spot problems early, carry out routine checks, and look after their own machines. Guided by step-by-step training modules, operators learned to clean, read the wear indicators, and apply the right amount of lubricant, an effort that built pride and cut the little breakdowns that cost hours. At the same time, planned maintenance tackled the heavier repairs by skilled technicians who worked from data rather than guesswork. Interventions were booked at steady intervals that matched inspection records with the history of machine failures. Together, these maintenance layers lowered the number of emergency call-outs and trimmed the mean time to repair: MTTR fell from 41.72 hours to 25.23 hours, or a drop of roughly 40 percent. Such gains showed that engaging operators and following a clear schedule are both vital for keeping the equipment running smoothly.

Fig. 2 Cutting Machine Used for Initial Inspection and Cleaning

Figure 2 shows the cutting machine where inspections are carried out to assess the actual condition of each component. The observations are documented using the checklist presented in Figure 3. Additionally, the machine is cleaned initially to ensure optimal operating conditions.

Figure 3 presents a visual checklist designed to guide the initial inspection of cutting equipment. It includes six key tasks focused on mechanical integrity and abnormal conditions. The checklist improves maintenance routines by standardizing evaluations and recording observations, supporting early fault detection and operational safety across the cutting area.

COMPANY LOGO	INITIAL INSPECTION CUTTING EQUIPMENT			
	Area: CUTTING	Equipment Name:		
CHECKLIST FOR EQUIPMENT INSPECTION				
EM	TASK DESCRIPTION	YES	NO	COMMENT
1	Inspect condition of structure	☐	☐	
2	Inspect anchor bolts	☐	☐	
3	Inspect winder rollers	☐	☐	
4	Inspect winder shafts	☐	☐	
5	Inspect winder felt belts	☐	☐	
6	Inspect abnormal noises	☐	☐	
COMMENTS:				
PERFORMED BY:		APPROVED BY:		
SIGNATURE:		DATE:		

Fig. 3 Initial inspection checklist for cutting equipment

Figure 4 outlines the autonomous maintenance standard for the cutting machine, detailing daily and monthly cleaning and lubrication tasks. It specifies the method, frequency, and expected condition for each component, ensuring equipment reliability and cleanliness through structured routines carried out by operators.

LOGO DE LA EMPRESA	TPM Mantenimiento autónomo	ESTANDAR DE MANTENIMIENTO AUTONOMO Limpieza - Inspección - Lubricación			
PROCESO CORTE MÁQUINA CORTADORA PROSLIT	No.	Actividad	Método	FRECUENCIA	Estandar
	1	Limpieza del área de trabajo	Con una escoba roja se limpia el piso del área de trabajo.	Diaria	Área Libre de polvo
	2	Limpieza de rodillos embobinadores	Usar trapo industrial y alcohol	Diaria	Rodillos limpios
	3	Limpieza de polines embobinadores	Usar trapo industrial y alcohol	Diaria	polines limpios
	4	Limpieza de ejes embobinadores	Usar trapo industrial y alcohol	Diaria	ejes limpios
	5	Limpieza de las felpas del eje rebobinador	Usar trapo industrial	Cada mes	eje rebobinador limpio y lubricado
	6	Lubricación felpas	Utilizar aceite del grado	Cada mes	felpas del eje

Fig. 4 Standard for autonomous maintenance

4.3.4. Streamlining Setup Operations to Minimize Changeover Times

The setup process quickly emerged as a pressing target for efficiency gains. Originally, changeovers consumed 6813.73 hours each year, averaging 0.97 hours per transition; that volume limited machine availability and hampered production agility. The engineering group adopted the Single-Minute Exchange of Dies (SMED) framework in response.

Each step of the changeover was mapped, activities were sorted into internal and external categories, and the team focused on moving as many tasks as possible to the external phase. Supervisors supplied visual guides, standard checklists, and hands-on training for operators to reinforce those changes. Once the new practices were in place, average setup time fell to 0.46 hours—a 52.58 percent drop—while yearly setup hours shrank to 3812.3. The reduction opened valuable extra capacity, leaving equipment available for production for far more of the working day.

Figure 5 illustrates the time reduction achieved in the format change process after applying SMED methodology. The total time decreased from 58.43 to 24.14 minutes, clearly differentiating internal and external activities. This visual comparison highlights the effectiveness of the intervention in optimizing setup procedures and minimizing production downtime.

4.3.5. Enhancement of Equipment Reliability through Standardization

In addition to overhauling maintenance schedules, the firm rolled out standardization practices designed to cut variation and make every repair more predictable. Each task was captured in a formal standard operating procedure (SOP) that spells out step-by-step actions, how often the work should happen, and who is accountable. Visual management boards now sit in the workshop, letting team members see at a glance what is overdue and what tools or parts are needed, so delays disappear as quickly as possible. The initiative strengthened cross-team communication by establishing clear norms and planted the seeds for a discipline-centered culture of continuous improvement. The hard numbers tell the story: mean time between failure (MTBF) rose from 214.36 hours to 257.9 hours, a gain of 20.31 percent, confirming that equipment is running longer and more reliably than before.

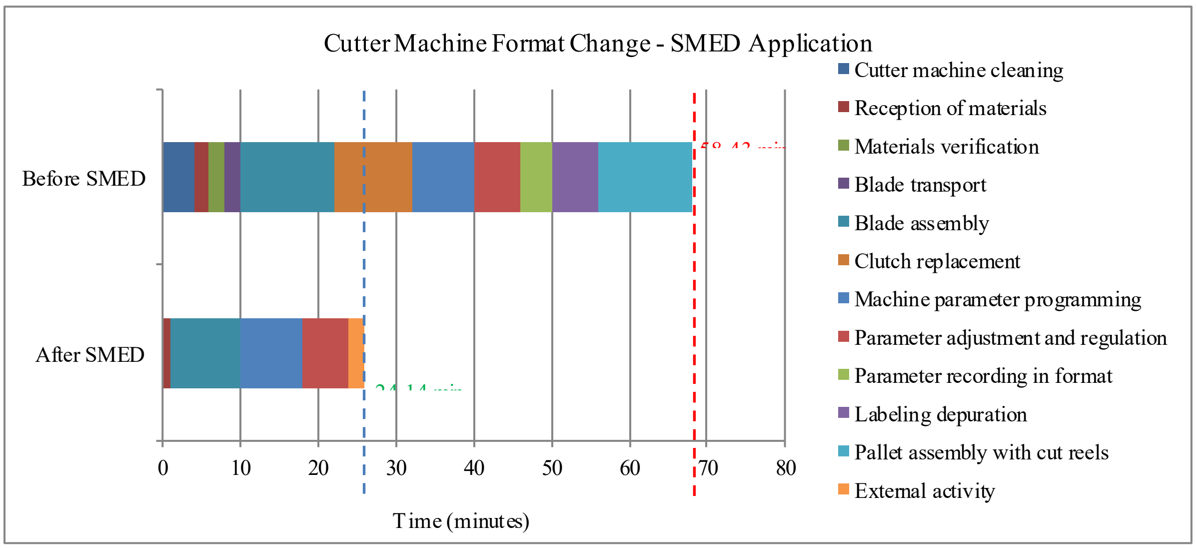

Fig. 1 Comparison of Format Change Times Before and After SMED Implementation

Figure 6 outlines the Tentative Planned Maintenance Standards, highlighting visual improvements in equipment condition before and after maintenance. It includes staffing requirements for execution and supervision, operational personnel estimates, and work shifts. Additionally, it records observations, task completion, and formal approval by the maintenance supervisor and mechanical leader.

4.3.6. Embedding Lean Thinking to Sustain Maintenance Gains

To lock in the gains from the TPM rollout, the firm embedded Lean thinking throughout the maintenance function. Visual performance boards now track key indicators in real time, and daily stand-up meetings give teams a quick forum to spot and address any drift. 5S was rolled out across maintenance bays, cutting the time spent hunting for tools and creating a more disciplined workplace. Personnel also routinely map wastes and dig into root causes using Ishikawa diagrams and the 5 Whys, turning analysis into a habit rather than a one-off drill. This structured, daily cadence feeds a continuous loop that fine-tunes schedules, SOPs, and operator responsibilities as new insight emerges. The cultural shift proved crucial for holding onto the early wins and positioned the organization to chase even bigger improvements.

4.3.7. Evaluation of Results and Operational Impact

The final stage of the project involved a rigorous, number-driven assessment of how the new system performed relative to the targets we set at the outset. Equipment availability climbed by 12.37 percentage points, arriving at 84.5% in the first full year after rollout. Hours spent on excessive repairs dropped from 4,585.01 to 1,099.72, a cut of 76.01%. This dramatic fall in mean time to repair and longer mean time between failures, as well as shorter setup intervals, shows that we tackled the root problems identified in the diagnostic phase. As a result, production scheduling flows more smoothly, customer orders are filled on time, and the threat of late shipments has decreased noticeably. Reduced unplanned stoppages also trim maintenance bills and free up labour for value-adding tasks. In sum, the Lean and total productive maintenance blend has proven both technically sound and financially sensible for small-to-medium manufacturers competing in tight markets.

4.4. Results

Table 1 shows the outcomes from validating the maintenance management model using Lean and TPM tools alongside all KPI metrics showing improvement. The availability rate has improved from 75.2% to a near 86% target, which represents a positive variation of 12.37%. There was also a sharp reduction of 76.01% in excess repair time and a 39.53% reduction in MTTR, signifying more efficient maintenance operations. Concurrently, MTBF improved by 20.31%, indicating improved reliability in equipment. The mean setup time for setup operations greatly improved from 0.97 to 0.46 hours, totalling a 44.05% decrease in total setup time. All these results confirmed the model's actionable potential towards improving equipment availability by eliminating various downtime triggers and streamlining corrective and preparatory maintenance tasks.

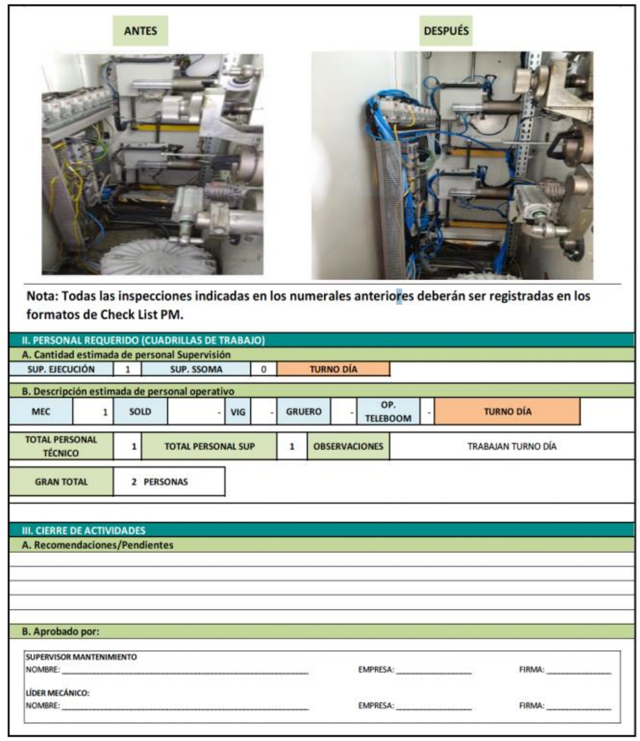

Fig. 6 Tentative Planned Maintenance Standards

Table 2. Validation Results of the Lean-TPM Maintenance Model

Indicator	Unit	As-Is	To-Be	Results	Variation
Availability	%	75.2	86%	84.5	12.37%
Excess Repair Time	Hours	4585.01	1000	1099.72	-76.01%
MTTR (Medium Time To Repair)	Hours	41.72	24.5	25.23	-39.53%
MTBF(Mean Time Between Failures)	Hours	214.36	251.5	257.9	20.31%
Average Setup Time	Hours	0.97	0.4	0.46	-52.58%
Total Setup Time	Hours	6813.73	3750	3812.3	-44.05%

5. Discussion

This study's results indicate a continuous improvement in equipment availability, which increased by 12.37% alongside a 76.01% reduction in excessive repair time, a 39.53% decrease in MTTR, and a 20.31% increase in MTBF. These results have a considerable degree of similarity with the literature reported on the integrated Lean–TPM systems. For example, Miranda-López et al. reported 24.4% efficiency gain because of a combined SMED and TPM model in a flexible packaging SME [5], and Ames et al. showed a 20% increase in productive capacity through planned maintenance performed at no capital cost [13]. In the same manner, Quiroz-Flores and Vega-Alvites reported a 13% increase in OEE with the implementation of Lean–TPM strategies in an injection molding facility [2], and Allca-Chauca et al. reported that implementing 5S, SMED, and TPM drove efficiency levels to 73% [14]. In addition, Ribeiro et al. verified that the integration of SMED and TPM practices brought machine utilization up by approximately thirty percent, correlating well with the 52.58% decrease in average setup time in the current study [18]. Collectively, these findings continue to support the validity of the model, emphasizing that its implementation even in resource-constrained settings can yield remarkable and enduring advancements in operational performance.

5.1. Study Limitations

The study's findings are promising, but a few limitations require some attention. The validation was performed in one flexible packaging plant, which remains a bounding constraint for other industries or production environments. Moreover, the scope of this study was limited to a twenty-month period for implementation and monitoring, leaving long-term resilience in the face of high staff turnover, variable demand, or other technological shifts unexamined. Some aspects, such as active organizational resistance to change or unaccounted-for hidden costs, were not captured in the study, which would have deepened the understanding of the model's applicability across diverse operational or structural organizational attributes.

5.2. Practical Implications

On a practical level, this research is particularly important for small- to mid-sized companies in the plastics industry that are dealing with maintenance and operational performance issues. The proposed model vividly illustrates that significant improvements in important performance metrics such as availability, MTTR, MTBF, and setup time can result from the combined application of autonomous maintenance, planned maintenance, and SMED.

More importantly, these gains were not driven by extensive new machinery investments but rather by disciplined management of tasks, standardized procedures, and empowering frontline workers. This suggests the model is a useful benchmark for performance optimization in resource-constrained firms while maintaining operational agility. It also adds further support to the premise that integrating Lean–TPM tools improves technical efficiency and fosters an engaged, proactive culture capable of agile market responsiveness.

5.3. Future Works

Future research may broaden the scope of this model to include other production systems like injection molding, rigid extrusion, and multilayer packaging to evaluate its versatility and resilience in different technological domains. Moreover, it would be interesting to include ecological factors such as energy use, emissions, and waste production to evaluate the model's contribution towards sustainability and assess the model's impact towards wider sustainability objectives. Another promising approach concerns the integration of IoT sensors and real-time analytics software as digital predictive maintenance frameworks to augment traditional TPM and SMED systems with advanced oversight capabilities.

Finally, it is suggested that further research focus on longitudinal studies exploring the long-term durability of the benefits attained and the primary factors for maintaining a Lean–TPM culture over time in rapidly changing environments characterized by high product variety and pressure from short lifecycles.

6. Conclusion

By systematically applying a Lean–TPM framework, the study records marked gains in operational performance at a flexible packaging plant. Key metrics show pronounced improvements in equipment availability, a longer mean time between failure (MTBF), and shorter mean time to repair (MTTR) and setup durations. These results reflect tighter technical oversight and a culture of empowerment, driven by clear, standardized work procedures for shop-floor personnel. Adopting a staged rollout—preparation, introduction, full application, and ongoing monitoring—enabled gradual absorption of each improvement, proving that resource-limited firms can realistically target and achieve operational excellence. The research is particularly timely because it confronts deep-rooted inefficiencies that plague many small and medium-sized plastic converters. By linking preventive maintenance, quick-change techniques, and frontline participation, the model offers a pragmatic route for reducing chronic downtime and setup bottlenecks. It thus answers an urgent demand for solutions that marry analytical rigor with on-the-ground feasibility, a need often voiced by companies unable to invest in costly automation or expansive consultancy. The model's success in a real production environment lends further credibility and underscores the substantial gains possible through deliberate, stepwise transformation. From an academic standpoint, the work advances knowledge by presenting a cohesive model that links theory directly to on-the-ground practice. It supplies new data to the Lean-TPM conversation, especially within small and medium-sized firms, and offers a clear, repeatable guide for others seeking similar results. The findings also underscore how systematic methods and collaborative projects drive lasting performance gains. Researchers are invited to apply the model in sectors that use different production technologies, thus testing its broader relevance. Integrating digital predictive maintenance and energy tracking solutions could further expand and modernize the framework. In addition, investigating the cultural and organizational factors that sustain continuous improvement would deepen understanding of how to achieve durable success.

References

[1] Arenas Mayerli, and Murillo Esthefani, "Improvement in a Flexible Packaging Company through Standardization and Preventive Maintenance," *Proceedings of the International Conference on Industrial Engineering and Operations Management*, pp. 943-954, 2024. [CrossRef] [Publisher Link]

[2] Juan Carlos Quiroz Flores, and Melanie Lucia Vega-Alvites, "Review Lean Manufacturing Model of Production Management Under the Preventive Maintenance Approach to Improve Efficiency in Plastics Industry Smes: A Case Study," *South African Journal of Industrial Engineering*, vol. 33, no. 2, pp. 143-156, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[3] S.C. Nwanya et al., "Optimization of Machine Downtime in the Plastic Manufacturing," *Cogent Engineering*, vol. 4, no. 1, pp. 1-12, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[4] Lina Gozali et al., "Lean Manufacturing Approach to Increase Packaging Efficiency," *Proceedings of the 4th Tarumanagara International Conference of the Applications of Technology and Engineering*, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[5] Yrwing Miranda – López et al., "Optimization Model to Increase the Efficiency of the Flexible Packaging Production Process Applying the Johnson Method, SMED and TPM in a SME in the Plastics Sector," *20th LACCEI International Multi-Conference for Engineering, Education, and Technology*, pp. 1-8, 2022. [CrossRef] [Publisher Link]

[6] Omar Bataineh et al., "A Sequential TPM-Based Scheme for Improving Production Effectiveness Presented with a Case Study," *Journal of Quality in Maintenance Engineering*, vol. 25, no. 1, pp. 144-161, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[7] Jagdeep Singh, Harwinder Singh, and Inderdeep Singh, "SMED for Quick Changeover in Manufacturing Industry - A Case Study," *Benchmarking: An International Journal*, vol. 25, no. 7, pp. 2065–2088, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[8] Zhang Tian Xiang, and Jeng Feng Chin, "Implementing Total Productive Maintenance in a Manufacturing Small or Medium-Sized Enterprise," *Journal of Industrial Engineering and Management*, vol. 14, no. 2, pp. 152-175, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[9] Nassim Ghondaghsaz, Asadollah Kordnaeij, and Jalil Delkhah, "Operational Efficiency of Plastic Producing Firms in Iran: A DEA Approach," *Benchmarking: An International Journal*, vol. 25, no. 7, pp. 2126-2144, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[10] Rafał Drewniak, and Zbigniew Drewniak, "Improving Business Performance through TPM Method: The Evidence from the Production and Processing of Crude Oil," *Plos One*, vol. 17, no. 9, pp. 1-15, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[11] Fabiula Danielli Bastos de Sousa, "The Role of Plastic Concerning the Sustainable Development Goals: The Literature Point of View," *Cleaner and Responsible Consumption*, vol. 3, pp. 1-24, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[12] Nohemy Canahua Apaza, "Implementation of the TPM-Lean Manufacturing Methodology to Improve the Overall Equipment Effectiveness (OEE) of Spare Parts Production at a Metalworking Company," *Industrial Data*, vol. 24, no. 1, pp. 49-76, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[13] Victor Ames et al., "Maintenance Management Model based on Lean Manufacturing to Increase the Productivity of a Company in the Plastic Sector," *17th LACCEI International Multi-Conference for Engineering, Education, and Technology*, pp. 1-10, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[14] Valeria Allca-Chauca, Ana Yauri-Mendoza, and Martin aenz-Moron,, "Improvement Model to Increase Efficiency through the Use of 5S, TPM and SMED Tools in a Plastic SME Company," *21st LACCEI International Multi-Conference for Engineering, Education, and* Technology, vol. 1, no. 8, pp. 1-8, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[15] Shashikant Shinde et al., "Set-up time Reduction of a Manufacturing Line using SMED Technique," *International Journal of Advance Industrial Engineering*, vol. 2, no. 2, pp. 50-53, 2014. [Google Scholar] [Publisher Link]

[16] Sania Marcella, and Endang Pudji Widjajati, "Analysis of Lean Manufacturing Implementation through the Single Minute Exchange of Dies (SMED) Method to Reduce Setup Time in the Injection Molding Machine Process," *Journal of Applied Science, Engineering, Technology, and Education*, vol. 6, no. 1, pp. 17-26, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[17] Ramazan Şahin, and Aycan Koloğlu, "A Case Study on Reducing Setup Time Using SMED on a Turning Line," *Gazi University Journal of Science*, vol. 35, no. 1, pp. 60-71, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[18] Murilo Augusto Silva Ribeiro et al., "Analysis of the Implementation of the Single Minute Exchange of Die Methodology in an Agroindustry through Action Research," *Machines*, vol. 10, no. 5, pp. 1-15, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[19] G. Pinto et al., "TPM Implementation and Maintenance Strategic Plan – A Case Study," *Procedia Manufacturing*, vol. 51, pp. 1423-1430, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[20] Jonathan David Morales Méndez, and Ramon Silva Rodriguez, "Total Productive Maintenance (TPM) as a Tool For Improving Productivity: A Case Study of Application in the Bottleneck of an Auto-Parts Machining Line," *International Journal of Advanced Manufacturing Technology*, vol. 92, no. 1-4, pp. 1013-1026, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[21] Cristian Sebastián Arroyo Vaca, and Romel Fabian Obando Quito, "Importance of Implementing Preventive Maintenance in Production Plants to Optimize Processes," *E-IDEA Journal of Engineering Science*, vol. 4, no. 10, pp. 59-69, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[22] Angela Johana Callan-Villanueva, Sebastián Alejandro Núñez-Gonzales, and Wilson David Calderón-Gonzales, "Addressing Operational Challenges in Plastic Manufacturing SMEs: A Lean-TPM Model for Improved Efficiency and Quality," *SSRG International Journal of Economics and Management Studies*, vol. 12, no. 2, pp. 1-10, 2025. [CrossRef] [Publisher Link]