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Implementation of TPM and SMED to increase Productivity in a Brick Manufacturing Company in Lima, Perú

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Abstract

This study focuses on improving the productivity of a brick manufacturing company in Lima, Peru, through the integrated application of Total Productive Maintenance (TPM) and Single-Minute Exchange of Die (SMED). The research was structured in four phases. The first phase involved diagnosing the initial state of the SME to identify critical bottlenecks in the production process. The second phase consisted of systematic data collection on equipment performance, downtime, and setup operations. In the third phase, a maintenance program was implemented to reduce MTBF and MTTR, while SMED principles were applied to convert internal activities into external ones, thereby optimizing setup times. Finally, in the fourth phase, the improvements were validated using a simulation model, and the results before and after the intervention were statistically compared through a pilot study conducted over a defined period. As a result, productivity increased to 10.1 thousand units per machine-hour, representing an 18% improvement. These outcomes demonstrate the effectiveness of combining TPM and SMED in enhancing equipment performance, minimizing downtime, and driving operational efficiency in a medium-sized brick manufacturing context.

Keywords
TPM, SMED, Lean Manufacturing, Brick Productivity, OEE

1. Introduction
The brick industry in Peru has a significant impact on the national economy, contributing approximately 5.3% of GDP (INEI, 2025). This sector benefits from sustained growth in construction, with projected annual expansion of 3.6% through 2030 (CEPLAN, 2025). This outlook drives greater demand for bricks, increasing their production and commercialization. However, the industry faces considerable challenges, including intense competition and the rise of informality. These conditions compel formal companies to optimize their production processes to remain competitive, while ensuring compliance with quality and regulatory standards (Perú Construye, 2019). Within this context, lean manufacturing emerges as a strategic alternative, offering proven improvements in productivity, cost reduction, and efficiency through the implementation of tools such as 5S, Total Productive Maintenance (TPM), Kaizen, and Single-Minute Exchange of Die (SMED) (Valencia et al.,2025).

The central research question guiding this study is: How can the productivity indicator be improved in a brick manufacturing company through the application of Lean tools?

Complementary questions include: How is maintenance currently managed within the company? What failures or root causes contribute most to production downtime? What is the current performance of the productivity indicators?

This research seeks to serve as a reference model for companies in the sector, demonstrating that Lean methodologies represent a viable solution for process improvement in contexts characterized by high informality and intense competition.

Evidence from prior studies reinforces this perspective. For instance, Becerra et al. (2024), in a study conducted within a Peruvian brick manufacturing SME, reported a 40% reduction in setup times through the application of SMED and TPM. This improvement led to a 4% increase in productivity, a reduction in production hours, and enhanced product quality, achieving a return on investment in only three months. Similarly, Flórez et al. (2024) implemented SMED and TPM methodologies in a metallurgical company, achieving a 66.29% reduction in changeover times and increasing equipment availability from 82.2% to 95.6%. Additional improvements were observed in key performance indicators such as Overall Equipment Effectiveness (OEE), Mean Time Between Failures (MTBF), and Mean Time to Repair (MTTR), further confirming the technical and operational effectiveness of these tools. A notable case is presented in the study by Silva et al. (2020), where several measures were implemented to optimize the setup process. These included organizing the workspace, standardizing operator movements, converting internal tasks into external ones, and adapting tools. Although the final setup time recorded was 66 minutes slightly above the initial target it was accomplished with only two operators instead of three, thereby surpassing the project's original expectations. This outcome highlights that, beyond reducing cycle times, the application of SMED also enables more efficient use of human resources, reinforcing its applicability and effectiveness across diverse industrial contexts.

SMED was selected as the primary tool due to its demonstrated effectiveness in extrusion and molding processes. As reported by Thummalukkit and Srithorn (2024), approximately 40% of setup activities can be transformed into external tasks, such as the verification of parts, tools, and molds, without requiring the machine to be stopped. This capability establishes SMED as a fundamental methodology for enhancing the operational availability of equipment.

Availability, performance, and quality are the three fundamental components of Overall Equipment Effectiveness (OEE), each of which can be individually improved to enhance overall productivity. Prakash et al. (2019) note that OEE values are typically 15% to 25% below the required standard, representing one of the main challenges faced by the industry. Ideally, companies should achieve an availability of ≥0.90, a performance efficiency of ≥0.95, and a quality rate of ≥0.99, which together yield an optimal OEE of 0.84 (Tsarouhas, 2019). This benchmark provides a reference point for organizations striving to achieve operational excellence.

Despite the positive results reported from the application of Lean methodologies in the brick industry, their implementation has not yet been specifically explored in each of the critical machines, nor has the problem-solving process provided by tools such as TPM and SMED been examined in large-capacity equipment such as 40 ton-per-hour mixers and extruders. In this regard, the present study proposes an innovative application of these methodologies to improve the productivity of the mixing and extrusion processes in a Peruvian SME within the brick sector.

The novelty of this study lies in the following aspects:

- Specific context of SMEs in Peru: This research is explicitly limited to a Peruvian SME, providing solutions designed according to its unique characteristics and operational constraints.
- Integration of SMED and TPM: The joint application of these methodologies in the context of an SME represents an innovative approach, demonstrating their complementarity in enhancing operational efficiency.
- Practical adaptations: The study produced results validated through a pilot study, including measurable improvements in productivity, efficiency, and setup times.

This research not only validated the techniques mentioned in previous studies but also contributed new perspectives and context-specific adaptations for the Peruvian brick sector, thereby enriching both the academic literature and practical applications in industrial engineering.

1.1 Objectives

The general objective of this research is to increase productivity in the brick manufacturing process, measured in thousands of units per machine hour, through the implementation of Lean Manufacturing tools, specifically Total Productive Maintenance (TPM) and Single Minute Exchange of Die (SMED), in a brick production and commercialization company. To achieve this, the study pursues specific objectives such as improving the Overall Equipment Effectiveness (OEE) of the plant from 36% to 85% by increasing the availability of the kneading and extrusion machines through the application of TPM to optimize equipment availability and SMED to reduce changeover times. In addition, the research aims to increase daily production from 85,6 thousand to 100 thousand units by minimizing unproductive time in the critical machines.

2. Literature Review

Discrete event simulation has emerged as a valuable methodology across multiple industries, as it enables the evaluation of projects and processes without requiring significant upfront investments to test feasibility. Case studies documented in the literature highlight how simulation supports decision-making and enhances organizational productivity, with applications ranging from process optimization to strategic planning (Zahraee et al., 2016; Medvedev et al., 2020). In a representative example, Krishnan et al. (2017) applied simulation techniques in a pneumatic manufacturing company to reduce non-value-added activities, alleviate bottlenecks, and shorten processing times. Their findings revealed that by adjusting scheduling constraints it was possible to eliminate a major bottleneck, which led to a productivity increase of 15.81%. This evidence reinforces the role of simulation not only as an analytical tool but also as a driver for practical interventions in industrial environments.

Productivity optimization in manufacturing environments is generally approached from two complementary fronts: improving equipment availability through Total Productive Maintenance (TPM) and reducing setup times through Single Minute Exchange of Die (SMED).

TPM focuses on maximizing equipment availability by engaging operators, implementing preventive maintenance, and strengthening training programs. Reviews and case studies consistently report improvements in Mean Time Between Failures (MTBF), reductions in unplanned downtime, and increases in Overall Equipment Effectiveness (OEE) when key TPM pillars are adopted (Ahuja et al., 2008).

Similar contexts show operational improvements when maintenance plans and workforce training are integrated (Canahua, 2022) with critical success factors highlighted in the literature such as management commitment, spare parts management, operator training, and performance monitoring ((Campos et al., 2023).
On the other hand, SMED improves labor allocation and enhances production flexibility (Antosz & Pacana, 2018), making it especially relevant in processes with frequent mold changes, where it eliminates bottlenecks caused by format adjustments and cleaning.

Importantly, TPM and SMED are not mutually exclusive; rather, their combined implementation generates a synergistic effect, with TPM minimizing failures and variability that lead to long stoppages, and SMED reducing downtime associated with setup changes. Case studies and implementation frameworks demonstrate that the combined strategy produces greater improvements in OEE than when each tool is applied individually. In the brick industry and in SMEs, integrated interventions have shown significant reductions in setup times, increased availability, and notable productivity gains, often with rapid returns on investment when complemented with 5S and workforce training (Aka et al., 2019).

Evidence from TPM implementations has reported OEE improvements (Canahua, 2022), while studies integrating SMED and Lean Six Sigma have achieved reductions in defects and idle times (Quiroz et al., 2023). In brickmaking processes, where mold cleaning and pallet/extruder changes are frequent, SMED directly reduces internal setup time, while TPM ensures operational continuity.

Reported improvement percentages vary depending on the sector and the depth of the intervention; however, the literature highlights representative ranges such as setup time reductions between 25% and 66% (Antosz & Pacana, 2018) and OEE improvements from low levels (<50%) to over 80% following TPM+SMED implementation (Campos et al., 2023). Specifically in brick manufacturing, time reductions and productivity increases tend to be substantial when interventions include changeover kits, pre-staging, cleaning tools, and technical training (Canahua, 2022).

3. Methods

This is applied research, as it seeks to generate practical knowledge on optimizing the production process in a brick manufacturing plant. The scope is descriptive explanatory, as it seeks to explain the factors affecting productivity and to understand the relationship between failures, setups, and equipment performance. The research design is quasi-experimental, as it will measure the impact of applying improvement tools such as TPM and SMED on the operational efficiency of the clay mixer and extruder, key machinery in clay preparation and shaping.

The research approach is quantitative, since data collection and analysis will enable the evaluation of the current situation and the measurement of the results obtained after the intervention. The independent variable has been defined as "maintenance and format change management," with indicators such as MTBF (Mean Time Between Failures), MTTR (Mean Time to Repair), availability, and internal and external setup times, in accordance with the SMED methodology. The dependent variable considered was "productivity," measured by machine-hour output. For data collection, techniques such as direct observation, interviews with technical and operational staff, and detailed timing of setup and maintenance activities were employed. Finally, it was decided to use the FMECA (Failure Mode, Effects, and Criticality Analysis) tool, which enabled the identification of critical failures and the optimization of equipment availability.

Likewise, a 95% confidence level was used for the sample calculation, with a critical value (Za) of 1.96. The probability of occurrence of the event under study is represented by p and q, both set at 50% as the most conservative assumption. The maximum allowable error (e) was defined as 5%. Based on these parameters, the minimum required sample size was calculated to be 319,000 bricks, which corresponds to approximately four days of production.

4. Model Application

4.1 The Formulation Problem

This research is carried out in a brick manufacturing company, classified as a medium-sized enterprise (SME), located in Lima, Peru. The company has an installed capacity of 12.2 thousand bricks per machine-hour, which would allow it to reach a daily production of more than 120 thousand bricks. However, its current output is 85.6 thousand bricks per day, reflecting a limited utilization of its installed capacity (Figure 1).

Figure 1. Initial state of equipment

When compared with the brick industry standard, a significant performance gap is evident. According to the sectoral construction analysis report, companies with similar capacities reach production levels exceeding 100 thousand bricks per day, with a production cycle time of 10 days (Tsarouhas, 2019). These data highlight that the company's main weakness lies in its low productivity level, which is directly related to the low OEE of its equipment, currently at 36%, far below the optimal standard of 85% (PUCP, 2017). This productivity gap results in an estimated economic loss of 306 thousand dollars, representing approximately 10.4% of the company's annual revenue (Table 1)

Table 1. Comparative Analysis Between the Company and the Sector

Indicator	Current Value	Reference Value	Formula	Technical Gap
Productivity	8,5 t/h-m	10 t/h-m	thousand/h-m	15%
OEE	36%	85%	(AxPxQ)%	58%
Availability	47%	90%	((TD-P-SU-TPR)/TD)*100	48%
Performance	77,66%	95%	(Real Production/ Theoretical production) *100	18%

The analysis revealed that the company's main problem does not stem from a lack of installed capacity but rather from the inefficient utilization of available resources. Improving productivity enables the achievement of the same objectives with fewer resources, which not only reduces costs but also strengthens long-term competitiveness. Once the problem was defined, plant visits and interviews with maintenance operators were conducted to collect qualitative information and diagnose the main causes. Subsequently, this information was contrasted with historical production and maintenance records, identifying the central issue as the low performance of the machines, explained by low availability (66%) and low efficiency (34%).

The prioritization of causes was carried out through a FMEA analysis. For each cause identified in the problem tree, frequency (F), severity (S), and detection (D) were evaluated on a scale of 1 to 5. Using these values, the Risk Priority Number (RPN) was calculated, and the causes were ranked from highest to lowest criticality Table 2).

Table 2. Failure Mode and Effects Analysis (FMEA)

Causa Raíz	Origen	Efecto en el proceso	Pilar OEE afectado	F	G	D	NPR
Long machine downtime	Recurring failures due to lack of a plan	Unscheduled downtime	Availability	4	5	4	80
Long setup times	Mold change/Paddle cleaning	Setup downtime	Availability	4	5	3	60
Lack of routine inspection and monitoring	Unexecuted checklists	Undetected avoidable failures	Availability	3	4	4	48
Accumulation of dirt/residues	Unsufficient mold cleaning , paddles	Reduced speed, blockages	Performance	4	4	3	48
Internal wear of parts	Bearings, bushings, nozzles	Vibrations, speed loss	Performance	3	4	3	36

Regarding availability, long setup times were identified, caused by the lack of instructions for mold changes in the extruder and for cleaning the clay mixer (Figure 2). Unplanned stoppages were also detected due to the absence of a preventive maintenance plan. In terms of performance, deficiencies in inspection and monitoring were observed, leading to component wear, calibration misalignments, and residue accumulation, which significantly reduced operating speed.

Complementary to the FMECA, an analysis was conducted based on the impact of lost production days per year. This approach demonstrated that, although certain incidents such as human errors occur more frequently, their effect on overall productivity is limited when compared to machine stoppages, which can result in losses of several hours or even entire days of production. The integration of both approaches, Risk Priority Number and production loss analysis, allowed for an objective prioritization. The problem tree is presented below in Figure 2:

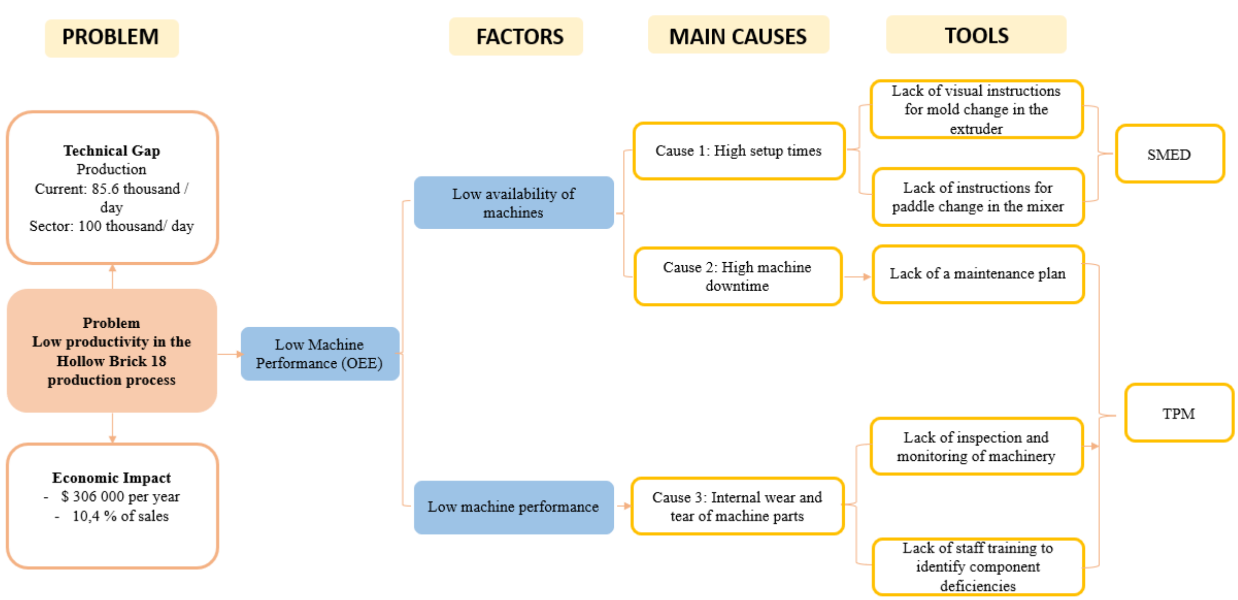

Figure 2. Problem Tree Analysis

4.2 Solution

4.2.1 Component 1: Time Setup Management

Following a preliminary analysis of the equipment, it was determined that the extruder (600-C, model 981/996) represented the main bottleneck of the production process, as it recorded the lowest OEE across the entire line (36.10%) and concentrated an average of 21 die changes per month. Prior to the implementation of SMED, each die change required 139 minutes. While the plant makes use of different machines, the extruder showed the highest losses attributable to setup times. The lack of dies for each product type, along with the need to manually adjust the die during each change, resulted in prolonged setup times and a high risk of defects. Accordingly, the extrusion and clay mixing stages were prioritized for improvement, leading to the application of SMED principles aimed at transforming internal activities into external ones.

4.2.1.1 Observing Setup Time

The first stage in the implementation of the SMED methodology was the analysis of setup time during the die change of the extruder, as well as the cleaning of the clay mixer paddles. From the completion of the previous production cycle, all activities carried out until the effective start of the new batch were documented. To this end, the analysis was complemented with direct observation. Thanks to this methodological approach, the following aspects were clearly identified: the activities performed, the sequence in which they were performed, and the personnel responsible for each task (maintenance staff), consisting of a specialized technician and a support assistant. It should be noted that, during the process, if other machines presented failures, the technician could be required to attend them, generating delays in both the die change and the clay mixer cleaning.

The analysis allowed for the classification of activities into internal and external tasks, as well as the quantification of the times associated with each. It was determined that the average total time for die change in the extruder was 139 minutes, while the setup of the clay mixer reached 75 minutes, both involving the participation of two main operators. In this way, the total setup time in the line was 214 minutes, as shown in Figure 3. After conducting time measurements through chronometry, the following distribution was obtained (Figure 3):

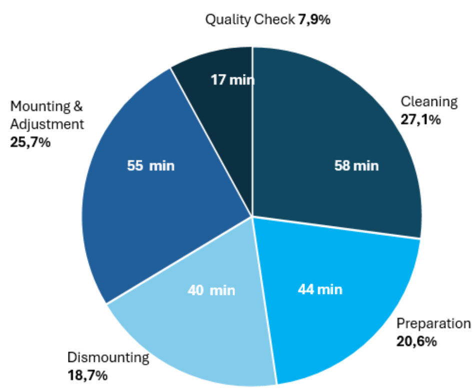

Figure 3. Pie Chart of Activities in the Extruder and Mixer

4.2.1.2 Identification of Internal and External Tasks

The results of the analysis revealed that approximately 18.2% of the total setup time corresponded to external setup, while the remaining 81.8% was internal setup. This high proportion of non-productive time evidenced a significant improvement opportunity through the conversion of internal tasks into external ones, which would reduce the total changeover time and thus increase machine-hour productivity, particularly in the extruder.

4.2.1.3 Conversion of Internal Activities to External

After classifying the activities into internal and external, improvements were implemented following the SMED methodology. First, tool preparation in both the extruder and the clay mixer was reduced from 39 to 25 minutes by introducing a quick-change kit and applying color coding to wrenches and couplings, which facilitated the immediate identification and use of each tool. This approach, documented by Cakmakci (2008) and replicated in European brick plants, has proven effective in eliminating downtime associated with searching for tools and minimizing errors during assembly.

To address delays related to machine components, a welding unit was incorporated, responsible for grinding and conditioning machine components. Thanks to this preliminary work, molds and critical parts arrived ready and in optimal condition for assembly. Six operators were trained to perform this operation. Likewise, the transfer of molds and tools, which was initially a fully internal task, was transformed into an external activity through pre-positioning on a scheduled loading cart. This practice, recommended by Shingo (1985) within pre-staging techniques, represents one of the most effective mechanisms for reducing setup times.

Furthermore, manual cleaning of molds was one of the major bottlenecks (34 minutes), as it was carried out during machine downtime. After applying SMED, different cleaning tools (metal brushes, nylon brushes, etc.) were evaluated. Ultimately, the use of long-handled stainless-steel brushes was standardized, allowing operators to access narrow mold cavities and remove accumulations of wet clay, thereby reducing direct operator intervention. This improvement reduced the cleaning time to 24 minutes and increased mold durability. In the clay mixer, controlled pressure washing and compressed air were implemented. These studies confirmed that metal-bristle brushes provide greater removal efficiency than nylon ones in clay molds, while compressed air serves as a complementary method for hard-to-reach areas.

4.2.1.4 Optimization of Setup Operations:
Although assembly and disassembly activities correspond entirely to internal tasks, additional improvement opportunities were identified. The analysis revealed that both machines (the clay mixer and the extruder) used a total of 76 bolts, approximately 38 per machine, which were manually tightened with combination wrenches. This procedure was slow and physically demanding for the two operators in charge.

To optimize the operation, pneumatic impact wrenches (maximum torque of 2000 Nm) were introduced, enabling faster tightening and loosening of bolts. As a result of this improvement, setup time was reduced by approximately 21 minutes. Additionally, operators did not have a clear record of the time spent on each task. To address this, an hour meter was installed in the area, allowing precise monitoring and control of the time dedicated to each activity.

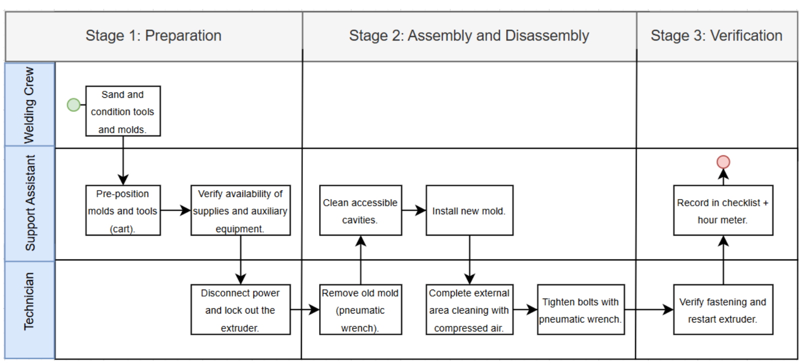

Figure 4: Standardized Mold Change Procedure Flow

The development of standardized work instructions, activity flowcharts, and the pre-arrangement of tools were proposed as measures to facilitate the reduction of non-productive times while also strengthening employee engagement (as shown in Figure 4).

Upon the completion of SMED implementation in the company, the total setup time was reduced from 214 minutes to 160 minutes, representing an improvement of approximately 25.23%. The details of the optimizations achieved are presented in Table 3. Among the most significant advances, the conversion of internal activities, such as tool searching, area cleaning, and mold transportation, into external tasks stands out, as it effectively eliminated unnecessary movements.

Table 3. Activities Improved through the Application of SMED

Applied Improvement	Before SMED (min)	After SMED (min)	Improvement
Tool preparation: quick-change kit with color coding	39 min	25 min	14 min
Transfer of molds and tools converted to external activity (pre-positioning on a loading cart)	5 min	2 min	3 min
Manual mold cleaning: use of long-handled wire brushes combined with compressed air.	58 min	42 min	16 min
Mold and paddle assembly/disassembly: incorporation of pneumatic impact wrenches	95 min	74 min	21 min

4.2.2 Component 2: Preventive Maintenance

In this phase, MTTR and MTBF data were collected for both the extruder and the clay mixer, defining a list of causes that delay operations along with their corresponding average times (Table 4). Based on this information, the total lost time was determined.

Table 4. Record of Failures and Downtimes of the Extruder and Mixer before TPM Implementation

Order	Breakdowns in the Extruder	MTTR (min)	MTBF (min)	Order	Breadkdowns in the Mixer	MTTR (min)	MTBF (min)
1	Lateral Wear	159.36	275.47	1	Motor Failure	50.69	258.32
2	Shaft Wear	137.18	36.81	2	Drum Wear	58.8	34.51
3	Drive Belt Wear	134.26	30.94	3	Pin Wear	50.6	29.02
4	Sprocket Wear	128.38	31.24	4	Blade Wear	56.92	29.3
5	Chain Wear	173.1	55.94	5	Shaft Wear	51.22	52.45
6	Piston Wear	168.71	114.71	6	Bearing Wear	53.39	107.57
7	Gear Wear	155.53	87.21	7	Dirt	54.32	81.78
8	Shaft Misalignment	132.68	53.08	8	Lack of roller replacement	59.1	49.77
9	Dirt	145.17	145.93	9	Insufficient Piston Pressure	54.24	136.85
10	Lack of lubrication in bearings	163.42	23.17	10	Expired Rubber components	58.13	21.72
11	Conveyor Belt Wear	169.95	53.28	11	Paddle Wear	59.11	49.96
12	Hammer replacement not performed	160.76	70.36	12	Lack of Lubrication in Gears	59.02	65.98

Subsequently, a Pareto diagram was developed based on the total lost time, where the identified causes accounted for 80% of the downtime in each machine (Figures 5 and 6). The analysis revealed that the most critical factor affecting the extruder's availability was the lack of lubrication in the bearings, while in the clay mixer, the main issue was the use of worn-out rubber components.

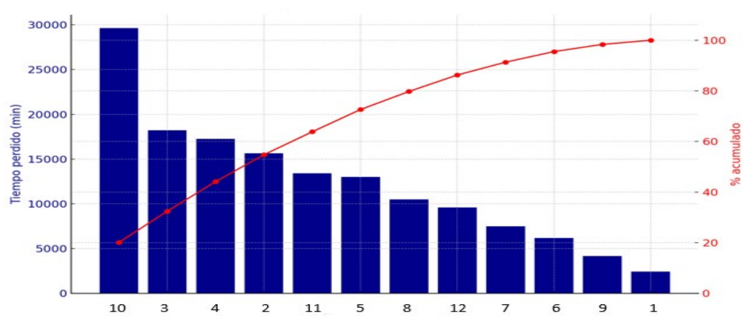

Figure 5. Pareto Diagram of Total Lost Time in the Extruder

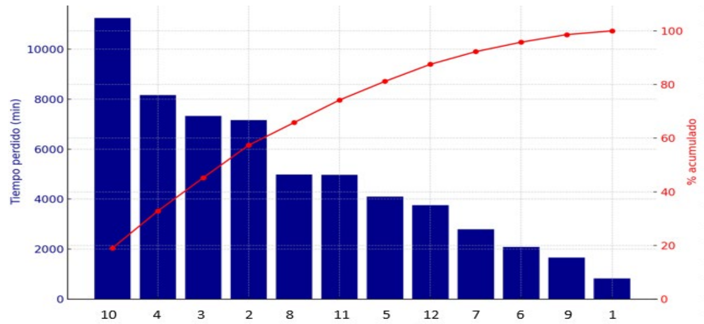

Figure 6: Pareto Diagram of Total Lost Time in the mixer

To improve the situation, the implementation of Total Productive Maintenance (TPM) was initiated, focusing exclusively on two pillars: planned maintenance and personnel training and education. Based on the Pareto analysis, the critical activities for the extruder were grouped and organized according to their mechanical or verification nature, considering the level of intervention required. As shown in Figure 8, five groups were defined, each with an assigned responsible operator, execution frequency, and an associated indicator for monitoring (Sardar et. al,2023). In addition, the mean time between failures (MTBF) was recorded after the improvement was implemented (Table 5- Table 6).

Table 5. Preventive Maintenance and Record Plan – Extruder

Activity Group	**Frequency**	**Responsible**	**Average Repair Time (min)**	**Indicator**
General inspection of the shaft, gears, bushings, bearings, and belt/chain system.	Daily	Maintenance Technician	75	MTBF
Lubrication of the pinion, chain, pillow blocks, bearings, and gears.	Monthly	Operator	68	MTBF
Internal cleaning (vacuum system, screw conveyor, barrel) and external cleaning of the extruder (motor, reducers, control panel, chains, pillow block).	Quarterly	Line worker	72	OEE
Alignment and verification of the central shaft, along with inspection of bearings and shaft pillow blocks.	Monthly	Specialist Technician	80	MTBF
Replacement of critical components such as hammers, belt, pistons, nozzle, and pillow block	Quarterly/Se miannual	Mechanical Technician	88	MTBF / MTTR

Table 6. Preventive Maintenance and Record Plan – Mixer

Activity Group	**Frecuencia**	**Responsable**	**Tiempo promedio de reparación(min)**	**Indicador**
General inspection of the motor, drum, pin, shaft, bearings, gears, and pinion.	Monthly	Maintenance Technician	36	MTBF
Lubrication of gears, pinions, bearings, couplings, bushings, and primary and secondary shafts.	Daily	Lubricator	40	MTBF
Internal cleaning (blades, kneading arms, kneading shaft, gates, and mixing chamber) and external cleaning (safety guards, bearings, pillow blocks, electrical panel, and reducer).	Quarterly	Plant Operator	41	OEE
Verification of pressure and rollers.	Weekly	Hydraulic Technician	37	MTBF
Replacement of components such as blades, rubbers, pressure rollers, and paddles.	Monthly	Mechanical Technician	39	MTTR

To address the lubrication deficiency in the extruder bearings, the corresponding activity group was first identified. Each group was provided with a specific action guide; for example, for the lubrication group, the procedure involved disassembling the bearings, cleaning the components, and removing any residual lubricant before applying Valvulina 90 to a properly conditioned surface. The fit between the bearing and the shaft was then verified to ensure adequate adjustment and prevent excessive friction. Finally, the machine was started to complete the lubrication process and confirm the proper functioning of the components (Figure 7).

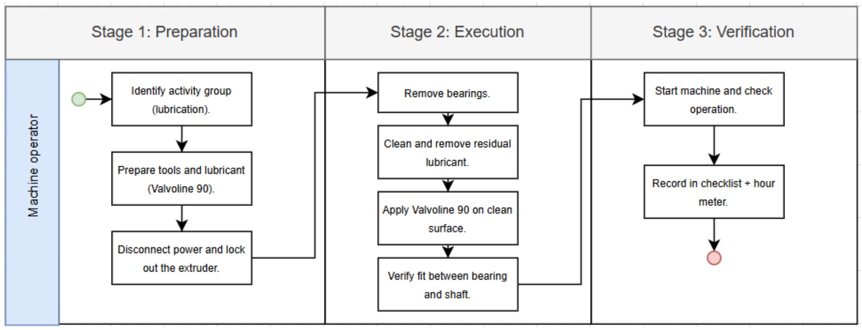

Figure 7. Standardized Flow of the Lubrication Activity

With the support of top management, a TPM-focused training strategy was implemented to empower operators. Combining theory with detailed machine diagrams, the sessions improved understanding of recurring failures, strengthened preventive maintenance, and fostered ownership among staff. This case also shows how TPM can serve as a steppingstone toward digital transformation in manufacturing. Gradual adoption of Industry 4.0 tools, such as predictive maintenance sensors, real-time monitoring, and data driven diagnostics can further boost equipment reliability and ensure sustainable productivity gains.

4.3 Validation of Improvements

In this section, the improvements were validated using Arena software, where the brick production process was modeled under a batch production system. The model incorporated the stages of dosing, grinding, sieving, mixing, extrusion, and cutting, considering a 10-hour shift and 125 replications to ensure robust statistical reliability.

To construct a representative model, quantitative data were collected to determine the statistical distributions of the processes, which were validated through tests such as Kolmogorov-Smirnov and Chi-square. The data wasa gathered through a methods and time study, which involved breaking down the processes performed at each workstation into more specific activities to obtain the required samples and ensure reliable information. For each activity, a probability distribution was defined using the Input Analyzer tool.

Once the model was validated, the subsequent step was to determine the number of replications required to ensure reliable results. To this end, an initial set of 30 replications was considered, a value commonly adopted in simulation studies based on the Central Limit Theorem. This theorem states that as the sample size increases, the distribution of the sample mean converges toward a normal distribution, regardless of the underlying distribution of the data. For this purpose, the following approach was used:

$$n \equiv n_0 \times \left(\frac{h_0}{h}\right)^2$$

$$124 \equiv \left(\frac{3098.8}{3096}\right)^2$$

$$124.224 \equiv 125$$

Where n_0 represents the initial number of replications, h_0 denotes the initial mean range obtained from the pilot run with n_0 replications, and h corresponds to the desired mean range. Based on this equation, the optimal number of replications was calculated to ensure the reliability of the data.

To calculate the optimal number of replications, four iterations were performed. In the first run, a total of 120 replications were obtained, which allowed for a reduction of the Half-Width, although not to the expected value. In the second run, 122 replications were reached, followed by 124 in the third. Finally, in the fourth run, 125 replications were obtained, a value that brought the Half-Width within the desired range, thereby ensuring the reliability of the results (Figure 8).

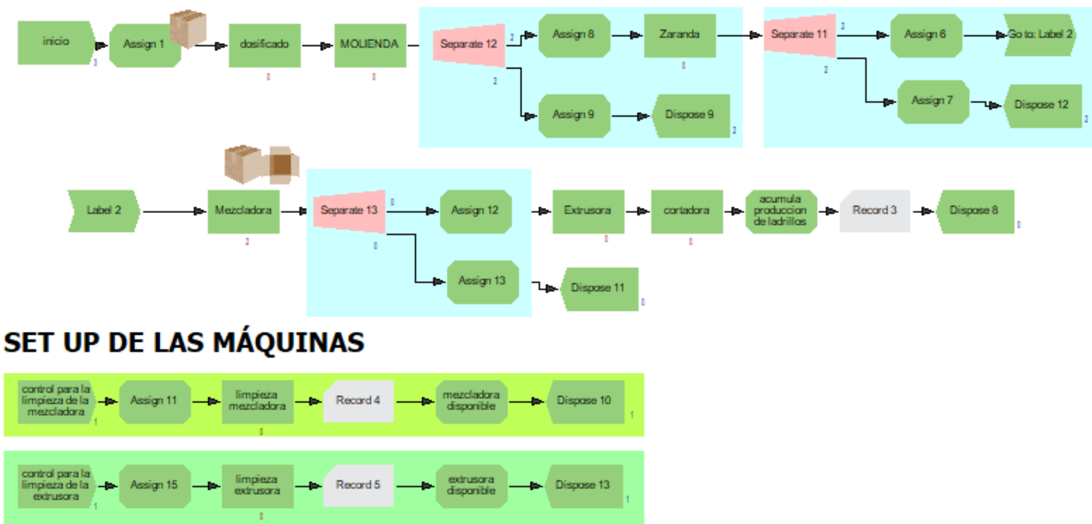

Figure 8. Simulation model

The outputs of the simulation corresponded to the study's key variables: average setup time, mean time between failures (MTBF), mean time to repair (MTTR), and weekly production. Once the model was built with the collected inputs and variables, the base and improved scenarios were compared. The results, summarized in the Table 7 below, show a clear reduction in setup times as well as an increase in MTBF and MTTR, reflecting the positive impact of TPM and SMED on the production system.

Table 7. Relationship Between Outputs and Indicators As Is and To Be

Nombre de indicador	Extruder		Mixer	
	Before	After	Before	After
Mean Time Between Failures (MTBF)	Expo (2,57) hours	Expo (14) hours	Expo (2,41) hours	Expo (15) hours
Mean Time To Repair (MTTR)	Unif (2,3) hours	Unif (1,1.5) hours	Unif (50,60) min	Unif (35,41) min
Mean Setup Time (MST)	139 min	100.3 min -104.6 min	75.1 min	60.4 min - 63.7 min
Internal set up	175		142	
External set up	39		18	

5. Results and Discussion

The simulation demonstrated significant improvements after the application of Lean Manufacturing tools to the brick factory's production process. Key indicators, such as productivity, availability, and OEE, were evaluated using the reports obtained on Arena.

First, the frequency and duration of stops were significantly reduced, as daily failures decreased from 9.34 to 1.71 on the extruder and from 9.96 to 1.60 on the clay mixer, directly contributing to the reduction in downtime. Regarding setup times, significant optimization was observed. In the extruder, the average time was reduced from 139.0 to 100.45 minutes, representing an improvement of approximately 27.7%. Similarly, in the mixer, the time decreased from 75.1 to 60.55 minutes, equivalent to an approximate 19.4% reduction.

Likewise, equipment availability showed notable progress. In the case of the extruder, availability increased from 50.7% to 91.8%, while for the mixer it rose from 72.4% to 95.9%. These results are attributed to the reduction in unscheduled downtime, the conversion of internal activities to external ones, and the ongoing training of personnel. Consequently, total productivity increased from a range of 8.5–8.9 thousand units per day to 10.1–10.8 thousand units per day, representing an 18% increase. Additionally, the overall equipment effectiveness (OEE) increased from 36% to 88%, reflecting a nearly 50% overall improvement (Table 8).

Table 8. Results of the As-Is vs. To-Be Model

Indicators	As Is	To Be	Results
Productivity	8.56 machine-hour	10.1 machine-hour	17.99 %
Availability Mixer	72.4 %	95.9 %	32.42 %
Availability Extruder	50.7 %	91.8 %	41.1 pp
Mold Change Time	139 min	100.45 min	27.73 % (reduction)
Paddle Change Time	75.10 min	60.55 min	19.35 % (reduction)
OEE	36 %	88 %	52 pp

It was demonstrated that both methodologies, acting in a complementary manner, directly influence the increase in equipment availability by raising the MTBF. The increase in production at a medium-sized company reveals the profound impact it has on all types of industries, especially the brick industry.

Overall, the use of Lean tools as a proposed solution generated positive impacts on productivity and reduced the frequency of errors by the company's operators. In the main total productivity indicator, the initial goal was to increase from 8.5 thousand units per hour-machine to 10 thousand units per hour-machine. In the simulation conducted in Arena, a value of 10.1 thousand units per man-hour per day was obtained, exceeding the target.

Regarding SMED, the mold and pallet changeover activities were identified and classified to analyze which ones could be simplified, grouped, or eliminated, ultimately standardizing a set of activities. The initial objective was to reduce the internal setup time to 175 minutes. The simulation yielded a value of 142 minutes, which corresponds to an 18.8% reduction. From an economic standpoint, this component entailed an initial investment of USD 712 for cleaning supplies, tools, and training for the welding team. These results align with those reported by Becerra and Salas (2024), who, by applying SMED in a brick-manufacturing SME, observed a 40% reduction in setup times and a 4% increase in productivity, confirming the positive impact of this methodology on process optimization in the sector.

Regarding TPM, a preventive maintenance plan was defined for the extruder and mixer, specifying the frequency, the personnel responsible for each inspection, and the grouping of activities for the respective checks. It is important to highlight the emphasis placed on personnel training, which was one of the main causes of the machines' low performance. Based on the framework proposed by Sardar et al. (2023), the aim was to achieve an OEE increase of more than 25% through the implementation of TPM, which successfully broadened the exponential distribution of MTTR and MTBF, exceeding the benchmark value with an improvement of nearly 50% encompassing the integration of TPM and SMED. In terms of economic impact, the budget included an initial investment of USD 825 for spare parts and an increase in indirect labor (hiring a maintenance supervisor).

The results also highlight the importance of operator involvement, as the training sessions and scheduled talks led them to note the change in the production area: tasks were carried out more quickly and in a more organized manner, and interruptions and delays were reduced. However, these results should be analyzed in light of the implementation's maturity stage, as the benefits may evolve over time depending on staff turnover, managerial commitment, and the consolidation of the Lean culture. Risks such as the turnover of maintenance personnel, which may lead to the loss of technical expertise, and resistance to adopting standardized practices, which can slow down cultural change, must be considered. Another potential barrier is the dependency on continuous training: without recurrent sessions, newly hired operators may not internalize the practices needed to sustain TPM and SMED. Despite these risks, the combination of both methodologies produces a synergistic effect that enhances overall efficiency. This aligns with the findings of Aguilar et al. (2022), who emphasize the importance of planning preventive maintenance activities to maximize machine performance. Establishing periodicity, frequencies, and proper spatial layout is fundamental to achieving better results. Additionally, studies such as that by Ortiz et al. (2025) reinforce the improvement of OEE through the incorporation of preventive maintenance records, considering the distributional behavior of reliability variables. Even in the study by Carrasco et al. (2022), a model for implementing the Lean system is provided that reinforces operator involvement as proposed.

To support future research in other mixing and extrusion processes, the following planned improvements are proposed:

- First, it is important to assess the feasibility of applying this approach in companies of different sizes, considering both machine count and installed capacity. Evidence from medium-sized firms indicates that the proposal is viable.
- Regular training sessions and simplified process diagrams are also recommended to help operators maintain standardized work methods and integrate the implemented improvements. For future studies, pilot projects should incorporate factors such as worker disposition, learning curves, and resistance to change.
- Before implementing improvements, a structured plan of meetings with all relevant areas should be established. Keeping operators informed and actively involved is essential to ensure successful adoption and minimize resistance.
- It is proposed to explore the integration of TPM and SMED with IoT technologies and predictive maintenance. By leveraging connected sensors and real-time data analytics, anomalies can be detected before leading to major failures, thereby optimizing both mold changeovers and maintenance activities. Recent studies indicate that combining TPM with IoT-based condition monitoring improves equipment availability, shortens repair times, and enhances Overall Equipment Effectiveness (OEE).

6. Conclusion

The joint application of TPM and SMED methodologies to the mixing and extrusion line of a Peruvian brick manufacturing company led to substantial improvements in productivity and efficiency. A 18% increase in productivity was achieved, accompanied by a notable reduction in setup times and failure frequency, which raised the OEE from 36% to 88%. The results of this research validate its contribution when compared with relevant prior studies. The 25% reduction in setup times falls within the ranges reported by Antosz and Pacana (2018), while the 18% increase in productivity exceeds the 4% reported by Becerra et al. (2024). Likewise, the improvements in MTTR and MTBF are consistent with the findings of Campos et al. (2023) regarding the benefits of TPM. Taken together, these outcomes confirm the effectiveness of the applied methodologies and underscore the novelty of their adaptation to the Peruvian brickmaking sector, particularly in high-capacity mixers and extruders, an area scarcely addressed in the literature.

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