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Improvement of productivity by applying Poka Yoke, SMED and TPM in a SME in the brick production sector

Alonso Arturo Becerra-Flores, Bsc[1], Jhonny Sergio Wildo Salas-Sotelo, Bsc[2], Jorge Antonio Corzo-Chavez,Msc[3]
[1,2,3]Universidad de Lima, Perú, 20190235@aloe.ulima.edu.pe, 20193400@aloe.ulima.edu.pe, jacorzo@ulima.edu.pe

Abstract*– By the end of 2022, the construction sector in Peru had experienced a growth of 6.02%, consequently benefiting the brick industry as well. This research focuses on studying a small and medium-sized enterprise (SME) facing productivity challenges that compromise its profitability and competitiveness. Periodic visits were conducted to the company to gather data. The main issues were identified using a Pareto diagram, including excessive production time, human error, unplanned machinery downtime, and reprocessing, with the first three being the most remarkable. Root causes of each problem were identified to link them to solutions based on Lean Manufacturing principles, such as TPM, SMED, Poka Yoke and activity standardization. Improvement proposals were suggested and validated through simulation in Arena, yielding positive results, such as a 7-hour reduction in total production time, a 40% decrease in setup times, a 2% reduction in defective products, and a 75% decrease in the incidence of human errors in some activities, such as mixing. Finally, the profitability of the proposal was evaluated, resulting in a Net Present Value (NPV) of 15,745 USD, an Internal Rate of Return (IRR) of almost 30% and a Payback Period of 3 months.

***Keywords*-- Bricks, Productivity, Lean Manufacturing, TPM, SMED, Poka Yoke.**

I. Introduction

A. Background

During 2022, the construction sector experienced a positive variation of 6.02%, leading to a 2.27% increase in the domestic consumption of cement [1]. This directly influences the growth of the brick manufacturing industry. Informality within this sector has been present for several years, to the extent that only 35% of brick production in Peru was from formal companies in 2019 [2]. It is likely that this percentage has not increased, as this sector remains highly profitable for the entry of clandestine enterprises.

This is probably because in informal businesses, manufacturing costs are reduced due to a lack of exhaustive control or regulation in quality standards. In response, many SMEs (Small and Medium-sized Enterprises) choose to enhance not only their quality standards to retain more customers but also optimize their processes to reduce manufacturing costs and compete against the low prices prevailing in the market. The intention is not to match prices exactly but to avoid distancing to the extent that the price-to-quality ratio remains attractive to consumers.

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Industry 4.0, digitalization, automation, and other similar technologies are becoming increasingly prevalent in the construction industry, contributing to the growing competitiveness of companies in this sector each year. In addition to this, Lean Construction, essentially the application of lean manufacturing principles to the construction industry, plays a significant role [3].

The research question would be: How can productivity in a brick factory be improved using lean tools? Other complementary questions arise from this, such as: What are the main factors that affect productivity? What strategies can be implemented to optimize cycle times in the different stages of the production process? How can reduce the number of defects and losses in brick production? What training programs can be implemented to improve the skills and knowledge of personnel? What strategies can be implemented to increase the competitiveness of the brick factory in the market, among others.

Therefore, this project is relevant, as it aims to present a model for improving productivity that doesn't need massive investments in increasing technological levels or redesigning the plant. Instead, through the implementation of lean tools, the project seeks to enhance process efficiency and boost productivity within the company. Likewise, the research intends to serve as a reference model that contributes to the dissemination of the benefits of the implementation of Lean Manufacturing as a solution to the main problems faced by brick companies in the sector.

Regarding the structure of the paper, first, the state of the art is presented, then the central problem to be treated will be detailed along with its most relevant root causes. Subsequently, the components of the improvement proposal and the results of the experimentation will be described to validate them. Finally, an evaluation will be carried out to determine the economic viability of the project, followed by a discussion of the most significant results and conclusions will be presented.

B. State of the art

Regarding the sources found on the application of lean manufacturing in companies within this sector or similar ones, it was discovered that the most used tools include Value Stream Mapping (VSM), 5S, Total Productive Maintenance (TPM), and Just in Time (JIT). Value Stream Mapping (VSM) enables the visualization and analysis of the production process, identifying issues within the workflow that can be refined through the implementation of 5S, TPM, or JIT. This integration has been shown to result in up to a 6% reduction in lead time [4]. Additionally, other tools such as Kanban, standardization, Kaizen, and Poka Yoke are mentioned. These tools contribute to reducing the number of defects or errors in production, better organizing the workflow, and have the potential to decrease the time without value of all waste by up to 20 days. Their implementation enhances overall efficiency and quality within the production processes [5] [6]. Regarding which processes within the brick production typically apply lean thinking, it was found that lean manufacturing tools are applied in the stages of procurement, storage, transportation, forming and cutting phase, grinding, extrusion, and drying. This is because these processes often generate a significant portion of waste during brick manufacturing.

In the literature review, significant impacts were also found when applying lean tools within this industry. For example, a reduction of Takt Time to 7 hours from the initial 24 hours, manufacturing cycle time decreased to 9 hours from the initial 27 hours [7], a 15% reduction in the total project time [8], a 1.5% increase in productivity, an 80% reduction in downtime in the production process, a 30% reduction in costs [9], a 20% reduction in defective products [10], among others. Regarding the most frequent wastes in this sector, it was found that the most recurrent ones in the sources were overproduction, waiting, inventory, and downtime due to machinery failures. It is known that production in large or small quantities commonly ends up affecting the improper delivery of work or goods and an inventory overload [11]. Regarding waiting, it is mentioned that managing pieces of the process waiting to be processed requires the establishment of an automatic stock control process. This would regulate and reduce the accumulation of late stocks [12]. As for downtime due to machinery failures, unnecessary waiting due to the sudden breakdown of the machine while production is already underway can be largely eliminated with improvements in the production process, an area where Lean tools would be of great help [7].

Finally, regarding barriers to implementing lean manufacturing, those mentioned most frequently were a lack of knowledge on the subject and resistance to change. However, the most remarkable facilitator was the commitment of the personnel itself; those workers and supervisors are willing to embrace the new mindset and commit to it to create a culture around this philosophy [13].

II. PROBLEM

The case study for this work was a small and medium-sized enterprise (SME) brick production company located in Lima, Peru. This company produces 57.8 thousand bricks each day, with an average defect rate of 3.7%. Its manufacturing cycle time is 13 days, its unit cost ratio per thousand bricks is 96.8 USD and the bricks per operator ratio is 3,212 bricks per day. When compared to the industry standard, its main weakness lies in productivity, as the sector operates at 143 thousand bricks per day [14], with an average defect rate which ranges between 3.5% to 4% [10], a manufacturing cycle time of 10 days [9], a unit cost ratio per thousand bricks of 152.8 USD [9] and a bricks per operator ratio of 1,300 bricks per day [10], as seen in Fig. 1.

Indicators	Sector	Company under study	Units	Percentage difference
Overall Productivity	143	57.8	Thousand Bricks / Day	-59.57%
Manuf. Cycle Time	10	13	Days	-23.07%
Defective Percentage	3.5 to 4	3.7	%	-0.2% to 0.3%
Unit Cost	152.8	96.8	USD / Thousand Bricks	57.96%
Bricks per Operator	1300	3212	Bricks / Day	147.06%

Fig. 1 Comparative Analysis between Company and Sector

This results in an economic impact of 3,015.12 USD lost per day as gross margin, representing 39.69% of the company's annual gross income.

But why focus only on improving productivity and not on plant capacity? The company's problem is not in not taking advantage of the available capacity but in using resources more efficiently. Increased productivity not only allows the same objectives to be achieved with fewer resources, but also brings with it a series of additional benefits that drive the growth and sustainability of the company in the long term. On the other hand, increasing capacity, which generally involves the expansion of operations or the acquisition of new resources, can be a complementary strategy. However, if productivity is not optimized first, the company runs the risk of increasing its costs and reducing its efficiency, in addition to increasing this capacity on par with the most representative companies in the sector would require a large investment, which given its situation. financial the company cannot afford.

Once the problem to be treated has been defined, periodic visits to the company were conducted to collect data and understand the root causes of low productivity. In Fig. 2, the problem tree illustrates the identified root causes. It was found that the reasons for low productivity include excessive production time due to errors in the mixing stage and non-standardized activities, reprocessing caused by non-standardized work and lack of training, unplanned machinery downtimes due to the absence of preventive maintenance, and finally, human error stemming from the lack of training.

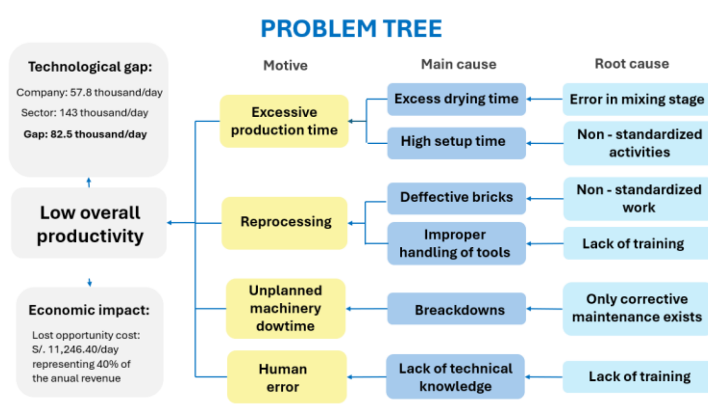

Fig. 2 Problem Tree

To understand which of all these reasons has the greatest impact, a Pareto diagram was made, as shown in Fig. 3, with a slight variation by weighting the significance of each reason based on the days lost per year it generates, rather than using the frequency of occurrences. This is mainly because, for example, human errors may happen more frequently than machinery downtimes, but the latter can cause hours or even days of production interruption, whereas human errors typically result in only a few minutes lost in most cases.

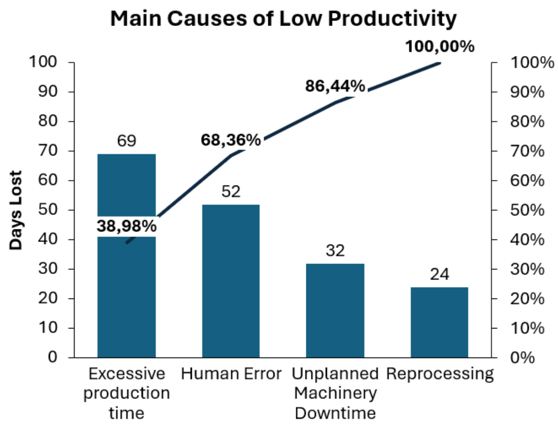

Fig. 3 Pareto Chart

A. Excessive production time

This issue is a result of an extended drying time. The process is done outdoors and can last 7 days, during the summer, or 15 days, during the winter. However, this time can be prolonged due to errors in the mixing stage, such as adding more water to the mixture. Moreover, unnecessary, and non-standardized movements between activities also extend the production time. Overall, it is estimated that around 69 days are lost per year due to these factors.

B. Reprocessing

Regarding reprocessing, it is due to defective bricks resulting from non-standardized work, as sometimes the mixture does not have the correct proportion of inputs (fragile or poorly formed bricks). Another reason here is the improper handling of tools due to a lack of training, as it often happens that when transporting or removing bricks from the mold, they suffer cracks that can compromise their strength, rendering them defective. It is estimated that these problems cause a loss of 24 days to the company each year.

C. Unplanned Machinery downtime

This problem arises from spontaneous breakdowns that occur during the workday because there is no preventive maintenance plan in place, only corrective maintenance. The estimated annual downtime due to this issue is approximately 32 days.

D. Human error

Regarding this last issue, human error is due to a lack of technical knowledge in some activities, and this deficiency is a result of insufficient training. These errors can be exemplified when the operator, due to a lack of time, empirically mixes the fuel during baking, resulting in the fire not being sufficiently high to burn the bricks within the expected time. In total, around 52 days are usually lost each year due to this problem.

The Pareto results revealed that excessive production time, human error, and machinery downtimes are the primary reasons for low productivity. Reworks also have some influence but will not be relevant for this research work as they fall outside the 80% cumulative frequency.

With all this in mind, the objectives of the following work would be the elaboration and development of solution proposals for the root causes identified using lean tools, to subsequently quantitatively validate the proposed model through simulation in the Arena software. Once it has been demonstrated that the project is feasible, its economic viability and its impact on the corresponding stakeholders would be evaluated.

III. METHODOLOGY AND INNOVATIVE PROPOSAL

The root causes were linked to three lean manufacturing tools, considering what was found in the state of the art. The SMED tool was chosen to address the problem of non-standardized activities since it is a good alternative to make processes more efficient and optimize setup times. There was a case where a 38% reduction in time was achieved [14]. TPM would take care of addressing the absence of corrective maintenance to avoid unplanned stops during production. In fact, it is known that by applying this tool, a 17.69% increase in machine availability can be achieved [15]. Finally, Poka Yoke is included to address human errors in the mixing stage, the absence of non-standardized activities, and the lack of knowledge and training. In some cases, an increase in productivity of 1.5% or a 30% reduction in operating costs was achieved [9].

To collect the necessary data to develop the proposed solutions, it was considered that the company produces an average of 1734 thousand bricks per month, equivalent to 694 production lots, which was chosen as the population. Therefore, we calculated the sample size with the following formula:

$$n = \frac{N * Z_a^2 * p * q}{d^2 * (N-1) + Z_a^2 * p * q} \quad (1)$$

In formula (1), “N” means Population, which is equivalent to 694, “Za” refers to the Security Value. Since a Confidence Level of 95% was considered, the value of "Za" is equivalent to 1.96. The probability of occurrence of the studied event is represented by “p" and "q" and is 50% given that it is the safest option and "e" is the maximum accepted error, which is 5%. Using these variables, reaches a minimum sample size of 248 lots of King Kong 18-hole bricks. The study variables defined are setup time, total production time, incidence of errors and percentage of defectives. These will serve as a basis for the development of indicators that will allow us to quantify the improvement of the proposal in each component.

Considering the mentioned tools, the following model was developed as an improvement proposal, as seen in Fig. 4.

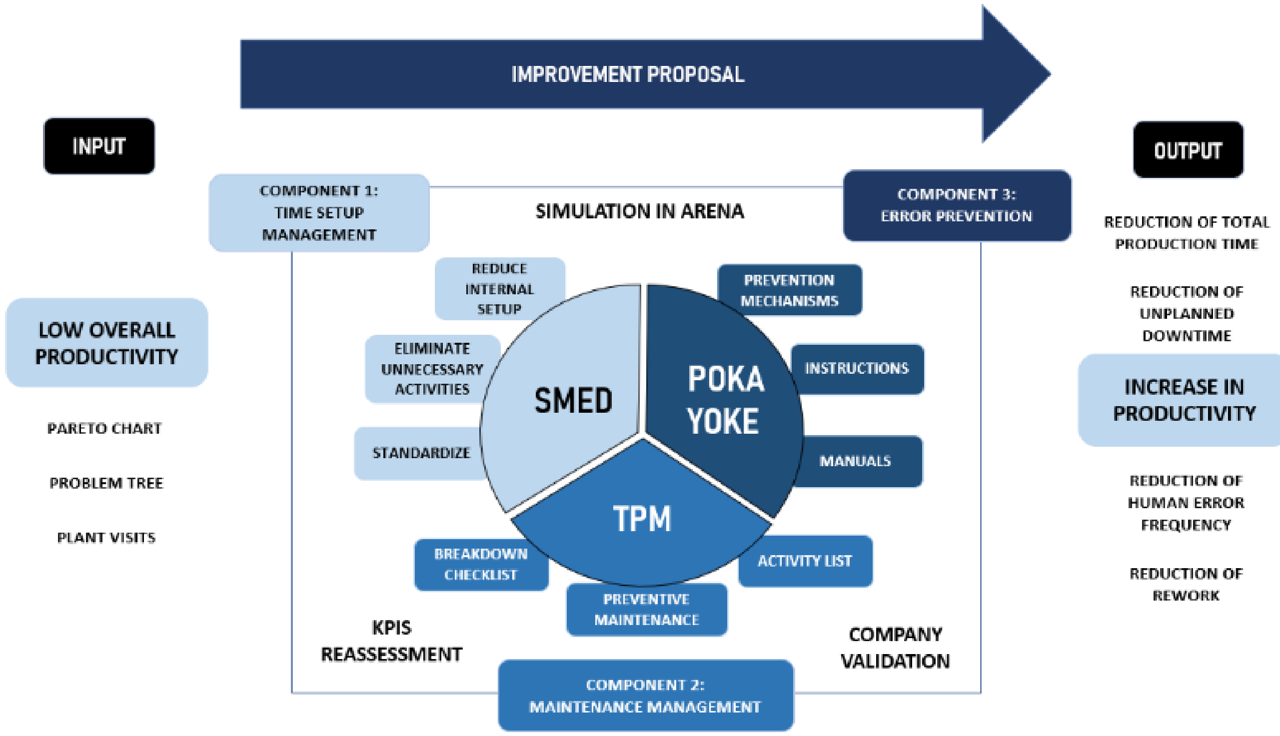

Fig. 4 Proposed Model

A. *Component 1: Time Setup Management*

The first component of the proposal is the SMED tool. It began with the identification of production preparation activities through field visits and consulting with the responsible operators about the intrinsic characteristics of its work. The activities were classified as: machinery review and conditioning, machinery ignition, mold change, and raw material loading. Next, information on times was gathered, and the preparation activities were classified as internal (performed during downtime) and external (performed during production time), as seen in Fig. 5.

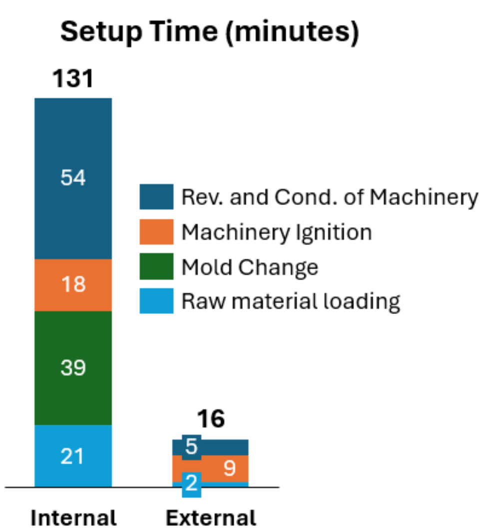

Fig. 5 Setup Time

All of this was done to select which internal activities could be converted to external, which activities are unnecessary and should be eliminated, which activities can be performed in parallel, and which activities can be simplified to reduce times.

In Fig. 6, these activities were defined in a flowchart. The expected outcome for this proposed solution is to reduce internal preparation times by almost 39%.

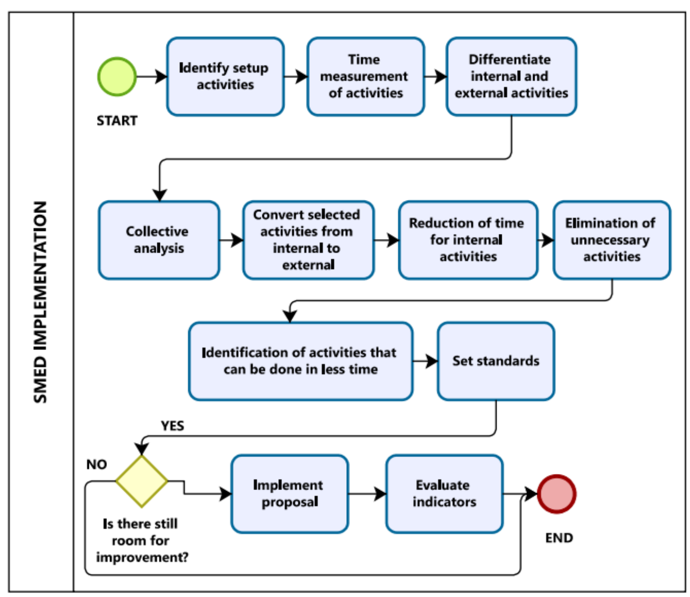

Fig. 6 Time Setup Management Flowchart

B. *Component 2: Preventive Maintenance*

The second component involves the implementation of the Total Productive Maintenance tool. Regarding the implementation flow of the improvement, it began with an assessment of the current state of maintenance policies within the company, along with an analysis of historical machinery failure information provided by the company. The results can be seen in Fig. 7.

Error Name	Average Down Time	Down Time Unit	Error Name	Average Down Time	Down Time Unit
Mill.hamer overheating.1	54	minutes	Extruder.disc wear	21	minutes
Mill.belt wear.1	42	minutes	Extruder.spindle wear	20	minutes
Mill.bolt wear.1	45	minutes	Mixer.bearing wear	69	minutes
Mill.blade overheating.1	16	minutes	Mixer.drum wear	39	minutes
Mill.shaft overheating.1	28	minutes	Mixer.belt rupture	123	minutes
Mill.bearing wear.1	28	minutes	Mixer.bolt wear	40	minutes
Mill.screen wear.1	40	minutes	Mixer.blade wear	57	minutes
Mill.beltv breakage.1	118	minutes	Mixer.shaft overheating	28	minutes
Mill.hamer overheating.2	54	minutes	Mixer.motor overheating	23	minutes
Mill.belt wear.2	42	minutes	Cut.disc wear	58	minutes
Mill.bolt wear.2	45	minutes	Cut.motor overheating	20	minutes
Mill.blade overheating.2	16	minutes	Cut.misalignment	18	minutes
Mill.shaft overheating.2	28	minutes	Cut.dirt	23	minutes
Mill.bearing wear.2	28	minutes	Cut.bolt wear	33	minutes
Mill.screen wear.2	40	minutes	Cut.bearing wear	38	minutes
Mill.beltv breakage.2	118	minutes	Cut.belt failure	113	minutes
Extruder.shaft miscalibration	36	minutes	Kiln.duct dirt.1	75	minutes
Extruder.bolt wear	43	minutes	Kiln.wall wear.1	95	minutes
Extruder.motor overheating	23	minutes	Kiln.dirt hoppers.1	53	minutes
Extruder.chain slack	21	minutes	Kiln.duct dirt.2	75	minutes
Extruder.gear wear	21	minutes	Kiln.wall wear.2	95	minutes
Extruder.belt wear	37	minutes	Kiln.dirt hoppers.2	53	minutes
Extruder.piston wear	25	minutes	Mixing error in fuel	1	days

Fig. 7 Main machinery failures

In this stage suggestions were proposed to change the current maintenance approach. The third step involved defining the new maintenance activities, such as preventive maintenance, and updating the process for the current corrective maintenance. Once that was completed, designs for recording data from breakdown checklists and preventive maintenance were developed. Additionally, proposed maintenance activities for each element (mill, extruder, mixer, open kiln, cutter) were listed with the tool and the frequency with which they should be performed. All these stages were defined in a flowchart, as seen in Fig. 8.

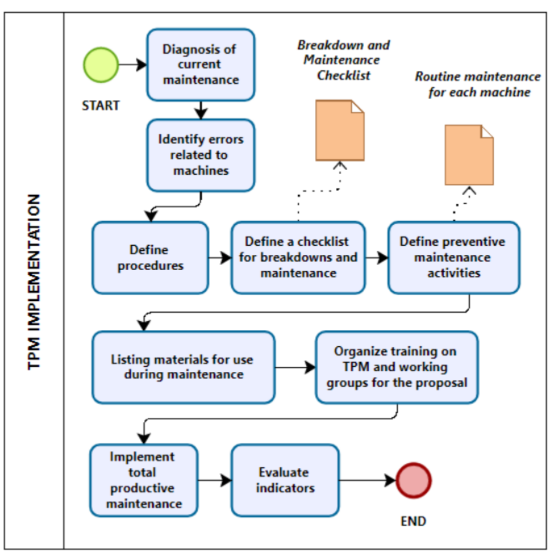

Fig. 8 Preventive Maintenance Flowchart

Finally, training presentations were developed for all personnel within the company so they could become familiar with this new philosophy. The expected outcome for this tool is a reduction of 10 hours in the total production time.

C. *Component 3: Error Prevention*

The third component involves the implementation of the Poka Yoke tool. It begins with the diagnosis of the operators' activities, identifying the most common errors, which included incorrect proportioning of inputs during mixing, excess water in the mixture, excessive stacking of bricks during transportation to the drying area, failures in fuel preparation, and inadequate control of the furnace temperature.

Subsequently, historical information regarding the frequency and consequences of these errors is requested to conduct an analysis of the root causes. An assessment is also made to determine if effective solutions to the problem are possible. Mechanisms for preventing failures for each error are developed, including the implementation of a gate system to control the entry of soil and kaolin, the installation of a spraying system for uniform water distribution, the use of a conveyor belt to transport bricks to the drying area, the creation of instructions and signage for fuel preparation, the installation of a thermocouple along with the use of a digital thermometer to control furnace temperature, and the development of a training plan for operators, as seen in Fig. 9.

Error Name	Proposed Solution	Reference Image
Incorrect proportion between kaolin (30%) and dirt (70%)	Gate System Control	
Excess of water in the mixture	Pump, Filter and Water Spray System	
Stacking more bricks than necessary during storage	Conveyor Belt System	
Incorrect fuel proportion	Procedure and Visual Aid	
Poor temperature control in kiln	Thermocouple Installation	

Fig. 9 Solution proposals to reduce errors.

In Fig. 10, The proposed activities were organized in a flowchart.

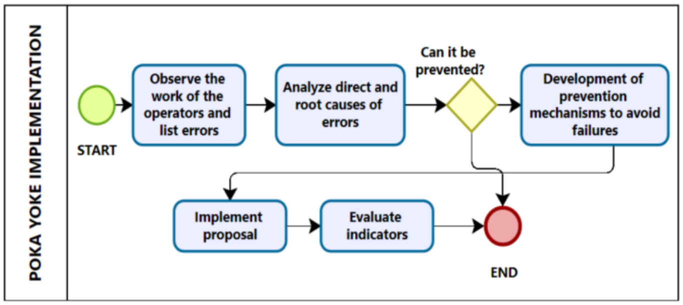

Fig. 10 Error Prevention Flowchart

The expected outcome of this tool was a 2% reduction in defective products, a 75% decrease in errors during the mixing stage, and a 37.5% reduction in errors during the baking stage, as seen in Table 1.

TABLE I
EXPECTED OUTCOMES FOR THE IMPROVEMENT PROPOSAL

Component	Indicator	Units	As Is	To Be
Lean philosophy	Overall productivity	Thousand Bricks /day	57.8	58.8
SMED	Internal setup	minutes	131	79.5
TPM	Defective percentage	hours	330	320
Poka Yoke	Total production time	%	3.70%	2%
	Frequency of errors in mixing	errors/months	40	10
	Error frequency in the firing process	errors/months	16	10

The three improvement proposals were evaluated on the Arena Simulator. All stages were included in the process design, as seen in Fig. 11, for which the times of each stage were measured. Machinery downtimes were simulated with the help of the failure module, and various records were used to obtain the target values of the indicators.

IV. RESULTS

A. Simulation Results

After the simulation in Arena, results were obtained in relation to the 5 indicators initially defined. These values were compared with the target goal for each indicator. First, the main indicator was Overall productivity, with an initial value of 57.8 thousand bricks per day. The simulation showed an increase of 4%, setting the value to 60.3%, as shown in Fig. 12.

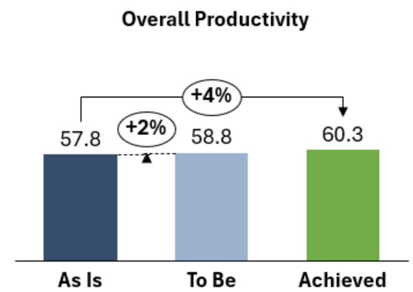

Fig. 12 Overall Productivity Indicator

In the case of the setup time indicator, there was an initial value of 131 minutes, with a target of 79.5 minutes. The experimentation exceeded expectations, as shown in Fig. 13, by reducing the setup time to 78 minutes, a reduction of 40%.

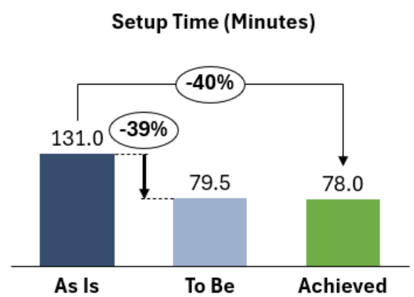

Fig. 13 Setup Time Indicator

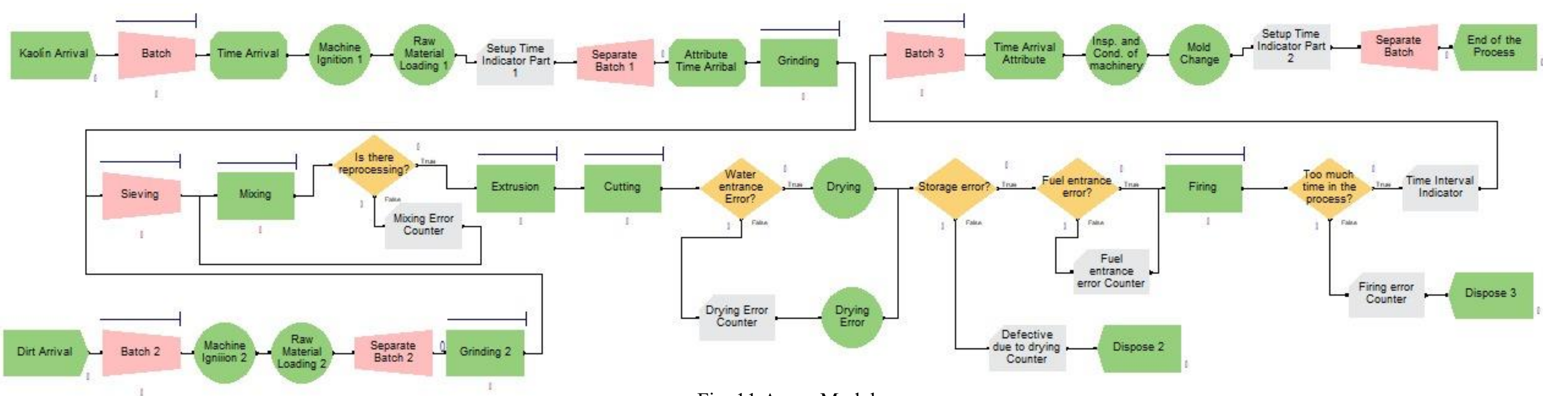

Fig. 11 Arena Model

In the total production time indicator, as shown in Fig. 14, there was initially a value of 330 hours, and the objective was set to reduce it to 320 hours. After experimentation, a reduction of 7 hours, setting the value to 323 hours.

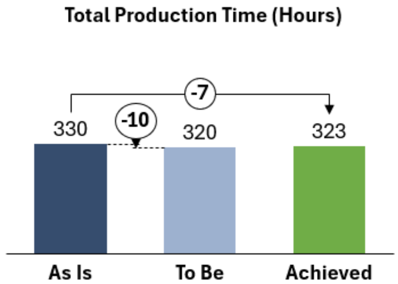

Fig. 14 Total Production Time Indicator

In the Defective Products indicator, as shown in Fig. 15, the initial value was 3.7% and the objective was set to reduce it to 2%, achieving a reduction to 1.94%.

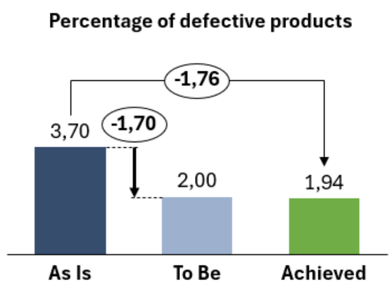

Fig. 15 Percentage of defective products Indicator

Before implementation, the error frequency indicator in the mixing process was 40 errors/month, as shown in Fig. 16. A goal was set to reduce it to only 10 errors/month, but a reduction to 11 errors/month was finally achieved (73% reduction).

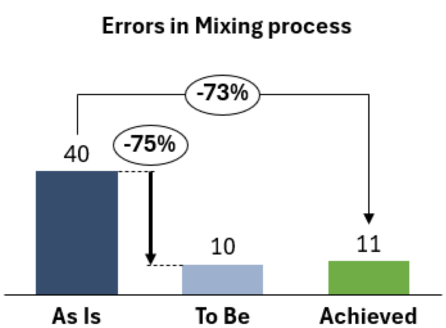

Fig. 16 Errors in Mixing Process Indicator

Finally, as seen in Fig. 17, in the error frequency indicator in the baking process, there was an initial value of 16 errors/month and the objective was set to reduce it to only 10 errors/month. Experimentation in Arena yielded a result of 9 errors/month, which exceeded expectations by representing a reduction of 44%.

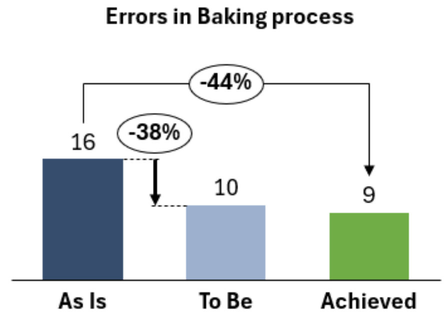

Fig. 17 Errors in Baking process Indicator

B. Economic Evaluation

For the analysis of financial indicators, the Opportunity Cost of Capital (COK) was calculated with the financial asset valuation model (CAPM), which was calculated with the following formula:

$$COK = Rf + \beta \times (Rm - Rf) + Rp \qquad (2)$$

In formula (2), "Rf" means Risk Free Rate, "B" refers to the Systematic Risk of the project industry, "(Rm - Rf)" refers to the Risk Premium and "Rp" refers to the Risk Country. According to the Central Reserve Bank of Peru, the risk-free rate in 2023 was 4.46%, and the Country Risk is 1.65%. The systematic risk of the brick industry is 1.2 and 7% was used for the risk premium. With these values a monthly COK of 1.14% is obtained.

Subsequently, the profitability indicators of the incremental flow of the improvement project were calculated, considering 12 months as the project horizon, as visualized in Fig. 18.

Economic Evaluation Overview	Value
Capital Investment (CAPEX)	7,654 USD
Anual Investment (OPEX)	37,033 USD
Net Present Value (NPV)	15,745 USD
Internal Rate of Return (IRR)	29.90%
Cost-Benefit Analysis	3.06 USD
Payback Period	3 months

Fig. 18 Summary view of the economic evaluation

From the results, it can be concluded that the project is economically viable, because the VANE is positive, the IRR exceeds the value of the COK (1.14%), the Benefit / Cost ratio is greater than 1 and the payback period is less than the project horizon (12 months).

C. Sensitivity Analysis

To carry out the sensitivity analysis of the improvement proposal, the @Risk tool was used, which allows quantifying the impact of beneficial or harmful scenarios on the economic indicators of the project. For this, the following 3 scenarios were proposed:

- Variation in the average number of defective products: The percentage of defective products of the company under study has an average value of 3.7%. An optimistic scenario is considered where the percentage of defectives decreases to a value between 1% and a pessimistic one where it only decreases to 3%.
- Production Cost Variation: In the economic flow of the improvement project, Production Costs represent on average 59% of total income. Given that these costs are subject to the purchase of raw materials, which may suffer an increase or decrease in prices, an optimistic scenario is considered where the proportion is reduced to 50% and a pessimistic one where it increases to 70%.
- Variation in Distribution Expenses: Sales expenses represent 7.5% of the total income in the economic flow of the project. An increase or decrease in distribution expenses could generate a variation in sales expenses. For this reason, an optimistic scenario is considered where the proportion is reduced to 6.5% and a pessimistic one where it increases to 8.5%.

Once the variables were defined, the variations in the flows were included independently to see their impact on the profitability indicators. Likewise, a scenario with the 3 variables was considered. As demonstrated in Fig. 19, the results were the following:

Variable	Type	Value	NPV	IRR	Cost / Benefit Analysis	Payback Period
% Defective Products	Pessimistic	3%	9,743	22%	2,31	4,14
	Moderate	2%	14,079	28%	2,88	2,92
	Optimistic	1%	18,398	33%	3,47	2,62
Production Cost / Sales	Pessimistic	70%	-2,202	-1%	0,75	11,94
	Moderate	60%	13,454	34%	2,8	4,26
	Optimistic	50%	28,408	138%	4,78	1,01
Distribution Expenses / Sales	Pessimistic	8,5%	-3,166	-8%	0,61	7,85
	Moderate	7,5%	14,198	28%	2,91	3,41
	Optimistic	6,5%	31,820	50%	5,25	1,98
3 variables	Pessimistic	-	-13,846	-37%	-0,89	11,94
	Moderate	-	13,573	35%	2,82	3,97
	Optimistic	-	43,716	153%	6,66	1,01

Fig. 19 Sensitivity Analysis

Finally, the minimum, moderated and maximum values of the variables were analyzed to see their impact on the profitability indicators. Thus, it is concluded that, in the worst case (pessimistic scenario), a negative variation in defective products would not affect the economic viability of the project, contrary to the other 2 variables. From an optimistic point of view, in the best scenario, the maximum value of the NPV is 43,716 USD, the maximum IRR is 153%, the maximum B/C ratio is 6.6 USD, and the period Minimum recovery is 1.01 months.

V. DISCUSSION

In general, the use of lean tools applied as a solution proposal has generated positive impacts on productivity, reduction of preparation times, reduction of defective products and lower frequency of errors by the operators of the company under study. In the main indicator of total productivity, the initial objective was to go from 57.8 to 58.8 thousand bricks per day (1.7% increase), a reduction like the goal proposed by Arevalo in his research, which was 1.5% [9]. In the Arena simulation, a value of 60.3 thousand bricks per day was obtained, exceeding the proposed goal with a percentage increase of 4.3%.

Regarding the first component (Preparation Time Management), preparation activities of the production process were identified and classified, to be able to analyze which could be simplified, grouped, and eliminated, to finally achieve a set of standardized activities. The initial objective was to reduce the internal preparation time from 131 to 79.5 minutes (39% reduction), because it was a reduction like the goal proposed by Pertuz in his research, which was 38% [14]. In the Arena simulation, a value of 78 minutes was obtained, which translates into a 40% reduction in preparation time, exceeding the proposed goal. Regarding the economic impact, the budget contemplates an initial investment of 725 USD, as well as an increase in direct labor (hiring of 4 operators) and an increase in administrative expenses for training.

In the second component (Maintenance Management), a diagnosis of the maintenance activities of the company under study was carried out, to propose the procedures, instructions, checklists, lists of materials and training necessary for the implementation of the improvement, with the objective to reduce the Total Production Time indicator from 330 hours to 320 hours (3% reduction). This is in line with the percentage of improvement proposed by Gamarra which was 5% [16]. In the Arena simulation, a value of 323 hours was obtained, which translates into a reduction of 2.1%, which is slightly below expectations. Regarding the impact of the component on economic flows, the budget contemplates an initial investment of 926 USD, as well as an increase in indirect labor (hiring of a maintenance supervisor) and a decrease in expenses for spare parts from 2,632 USD per month to only 448 USD, approximately.

For the third and last component (Error Prevention), the most common errors of operators were listed, and prevention mechanisms were proposed to reduce their occurrence. The objective was to reduce the Percentage of defectives from 3.7% to 2%, according to the 3% recommended by Murmu and Patel (2018). Additionally, the goal was set to reduce the frequency of errors in mixing (40 errors/month) and baking (16 errors/month) to 10 errors/month (reduction of 75% and 37.5%, respectively). Both indicators were based on Arevalo's research, which proposed an 80% reduction in errors [14]. In the Arena simulation, a defective percentage of 1.94% was obtained (reduction of 1.76%), an error frequency of 11 errors / month in mixing (reduction of 72.5%) and 9 errors / month in baking (43.8% reduction). For this reason, it can be concluded that expectations were exceeded in all indicators, except for the frequency of errors in mixing. The impact of the component on flows was reflected in an initial investment of 5,802 USD, as well as an increase in administrative expenses for training.

Regarding the economic evaluation of the project, an analysis was carried out using an Opportunity Cost of 1.14% monthly. According to the results obtained, the NPV reflects that the return on investment is 15,745 USD over a period of 12 months. The IRR has a value of 29.9%, which is positive because it exceeds the Opportunity Cost. The Benefit/Cost ratio is 3.06 USD (positive as it is after 1) and the investment is fully recovered in the third month, which indicates that the proposal is economically viable. The sensitivity analysis showed that there is little probability (less than 10% in all cases) that an increase in the number of defective products, production costs or sales expenses alone will affect the profitability of the project.

Finally, the most notable limitations during the development of the work were the lack of records on the processes that the company under study carries out, as well as the difficulties in carrying out pilot tests of the improvement tools. For this reason, we consider that, for the development of future research on the same problem, we could opt for the use of alternative simulation software, or apply pilot tests focused on specific processes, to obtain a more precise sample of the impact. of lean tools on company productivity.

VI. Conclusions

In general terms, the use of lean tools applied as a solution proposal achieved an increase in productivity supported by the reduction of preparation times, a decrease in defective products and a lower frequency of errors by the operators of the company under study.

Regarding the results obtained through the simulation, it can be concluded that the proposed expectations were exceeded in the indicators of overall productivity (increase of 4%), set up time (reduction of 40%), percentage of defectives (reduction of 1.76%) and frequency of errors in baking (44% reduction). Regarding the indicators of total production time and frequency of errors in mixing, results very close to those proposed were achieved.

Regarding the economic evaluation of the project, the proposal is economically viable. The sensitivity analysis showed that there is little probability (less than 10% in all cases) that an increase in the number of defective products, production costs or sales expenses will affect the profitability of the project.

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