International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V72I8P114

Volume 72 Issue 8, 128-138, August 2024

Original Article

Increase of the Availability of Machinery in a Food Company Applying the TPM, SMED and RCM Methodologies

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Received: 11 April 2024 Revised: 13 July 2024 Accepted: 31 July 2024 Published: 28 August 2024

Abstract *- The food industry stands as a pivotal contributor to economic and efficient production in contemporary societies. In recent years, Peru has witnessed a notable upswing in the industrial food sector, characterized by the automation of production processes and the consequential shift from manual labor to machinery. Despite these advancements, a pervasive challenge persists – the suboptimal availability of critical machinery due to various failures, leading to operational disruptions and additional costs. This challenge is empirically examined through a case study measuring machinery availability via MTBF and MTTR indicators, revealing suboptimal values according to "World Class" benchmarks, as reflected in the efficiency value measured by the OEE indicator. In response to these findings, a practical and economically viable model adapted to the unique needs of the food sector is proposed. Leveraging fundamental indicators such as MTBF, MTTR, and OEE, deviations from "World Class" standards are identified. The proposed model strategically integrates the second pillar of Total Productive Maintenance (TPM), the Single-Minute Exchange of Die (SMED) methodology, and the third TPM pillar into the Reliability-Centered Maintenance (RCM) tool. This study underscores the inefficiencies stemming from suboptimal machinery availability, highlighted by non-ideal MTBF, MTTR, and OEE values. The proposed model, focusing on TPM and SMED methodologies, demonstrates a tangible enhancement in machinery availability, translating into heightened productivity and reduced operational costs. The proposed improvements, once implemented, are anticipated to deliver enduring benefits, aiming for a sustained positive impact on productivity and cost-efficiency within the food industry.*

Keywords *- Efficiency, Food industry, Machinery availability, SMED, TPM.*

1. Introduction

As a key player in social development, the food industry holds significant strategic importance due to its focus on private consumption, both in producing and processing goods [1]. In recent years, the industrial food sector in Peru has seen notable growth, driven by automation to meet rising demand, replacing manual labor with advanced machinery. However, the impact of increased machine use as a crucial factor in operational processes presents a significant challenge for companies, which require optimal availability to avoid substantial operational and economic losses. According to Pinto et al. [2], 42% of companies in the food sector experience machine failures, which cause production delays and economic repercussions, highlighting the critical need to improve machinery availability to maintain comprehensive productive activities. The industrial dynamism in Peru's food sector has become intricately woven into the nation's GDP, experiencing consistent growth from 2010 to 2019 [2]. Beyond its economic impact, this sector holds strategic significance, shaping the landscape of goods production for private consumption. The increasing market participation of diverse companies in recent years highlights the sector's vitality. However, the growing use of machinery presents a formidable challenge, requiring meticulous attention to ensure optimal availability and to prevent significant losses in production processes. According to the findings of Silva et al. [3], approximately 42% of companies in the food sector face issues due to machine failures. This impacts their operational processes and leads to significant economic losses. Equipment availability emerges as a critical issue that restricts the full achievement of productive activities. This study identifies a technical gap in machinery availability, as evidenced by the company under scrutiny registering a value of 79.06%, falling below the acceptable threshold of 90%. Notably, Pinto et al. [2] demonstrate that the comprehensive application of methodologies in manufacturing companies has yielded favorable results. These methodologies streamline adherence to maintenance plans and underscore the direct correlation between low equipment availability and maintenance challenges. Motivated by the pressing issue of machine accessibility, this study addresses a gap in existing research. At the same time, diverse studies have explored machine availability in agriculture, forest management, and machinery usage [4-8]. None have delved into the intricacies of the food and beverage sector. Furthermore, a dearth of methodological differentiation in addressing the resolution of machine accessibility issues underscores the need for a tailored approach, providing the impetus for this study.

Beyond the industrial landscape, the research is driven by the dual importance of maintaining competitive advantages and strategic market positioning. Integrating one of the main pillars of TPM (the third one) into the RCM tool aims to enhance the current preventive maintenance system, contributing to operational efficiency and economic sustainability. Concurrently, applying the SMED methodology and implementing the second pillar of TPM focus on economic and social contributions, addressing issues such as reducing configuration time and improving responses to unforeseen failures. This article serves as a reference for future research, advocating the implementation of these engineering tools to augment efficiency and machinery availability in the industrial sector.

In addition to contributing to the scholarly discourse on machinery availability, this study explores the intricate relationship between the industrial sector, economic growth, and societal development. The subsequent sections of this article include a comprehensive literature review, a detailed explanation of the methodology employed, an in-depth exploration of a case scenario and analysis, a presentation and discussion of the results, and a conclusive summary.

2. Literature Review

2.1. The Availability of Machinery

Based on the literature review, five distinct studies focusing on machine availability have been identified. These studies provide a diverse range of research on machine availability, offering extensive insights into agriculture, forest management, and the use of machinery. The availability of agricultural machinery and services significantly impacts farmer decisions, forest management, and sustainable development. The findings from these studies offer valuable insights for developing strategies to enhance productivity and sustainability in the agriculture and forestry sectors.

Srihari et al. [9] emphasized enhancing machine availability by diagnosing gearbox faults. Using Artificial Neural Networks (ANN) in the MATLAB environment, the authors developed a system trained with optimal parameters to simulate worn-out and broken teeth conditions in gearboxes. The study utilized vibration signals to extract five feature parameters as inputs to the ANN-based fault detection system. Employing a backpropagation algorithm, the three-layered feed-forward network was systematically trained and tested with varying parameters. The study determined the optimal learning rate to be 0.15, and the number of hidden layer neurons was found to be 9. Additionally, it revealed that using two or three hidden layers provided the best detection accuracy.

In the context of agrarian development, Greig's [10] research focused on indigenous knowledge concerning crop choice in the Kibamba Ward of Tanzania. Employing point score analysis, the study investigated farmers' decision-making processes, highlighting the influence of the physical environment, machinery availability, and economic factors on crop choice [10]. Notably, subsistence farmers prioritized crop taste, while commercial farmers were more market-oriented. The study identified challenges related to water resources, machinery access, and the absence of formal extension services, emphasizing the need for further research in diverse geographical contexts.

Vicente and Perez [11] explored the connection between family characteristics and individual forest management among Non-Industrial Private Forest Owners (NIPFOs) in northern Spain. Conducted through personal interviews with 103 forest landowners, the study identified factors such as bequests, household income, logistics, and professional assistance that influence planting, silvicultural, and harvesting practices. Understanding family dynamics and their impact on forestry decisions is crucial for advancing sustainable forestry and rural development objectives.

Fletcher et al. [12] investigated the influence of machinery availability on sowing practices in Western Australia. The study explored the adoption of technologies like minimum tillage and new herbicides, enabling early and dry sowing. Results indicated that larger farms tended to begin sowing earlier and were more likely to dry sowing due to the extended time required for sowing. The research emphasized the need for understanding agronomic management interactions with changes in sowing practices, including cultivar traits, weed management, and water-repellent soil considerations, which emerges as a crucial insight.

Finally, Liu et al. [13] examined the impact of the increasing availability of agricultural machinery services on smallholders' participation in farmland rental markets in rural China. The study employed a price band model to analyze responses from 2041 smallholders in Handan Prefecture. Results revealed that machinery services significantly influenced land rental decisions, with implications for policies promoting agricultural machinery services and farmland rentals among smallholders. In summary, the identified studies in the literature have examined various sectors focusing on machine availability. Each study shares the goal of optimizing machine accessibility sustainably and efficiently. While these studies have provided valuable insights, the present study distinguishes itself by concentrating on the food sector and employing diverse statistical analysis methods. Consequently, this study will make theoretical and practical contributions to the literature by addressing its specific topic, sector, and analytical approach.

2.2. Increased Availability of Machinery in Companies in the Food Sector

Successful cases were summarized where machinery availability was increased in companies within the food sector. It is the basis for identifying the technical gap and various ways to address the improvement of this problem. In other words, it allows us to design strategies, identify alternatives, and decide on actions to be taken. Introducing the SMED methodology as a viable tool regarding reduction factors in change times and speeding up the process of changing machines [3]. According to Pinto et al. [2] likewise, two of the pillars of the TPM, On the one hand, detailed that autonomous maintenance presents beneficial improvements in the losses generated by the misuse of equipment and human resources and, on the other hand, planned maintenance that provides a strategic methodology to prevent and correct breakdowns in equipment and facilities through daily, periodic and predictive routines [14] [15]. In the same way, the RCM tool offers an approach capable of helping in decision-making regarding selecting relevant maintenance actions [16] [17].

On the other hand, it is detailed that autonomous maintenance eliminates nonconformities and develops, through the operators, minor and continuous local improvements [8]. This guarantees fewer breakdowns, stops and defects while reducing operating costs [7]. In addition, the SMED tool considerably reduces change times and streamlines the processes of making changes to machines and facilities [3] [18]. Moreover, the RCM methodology positively and directly impacts equipment availability and prevents losses and failure modes [16].

2.3. Application of the TPM Tool

Maintenance is a vital operation function related to all manufacturing processes and focuses on preventing equipment failure and improving business performance. Total Productive Maintenance (TPM) is a maintenance strategy widely used to gain a competitive advantage in the industry [8] [19]. In addition, it is a strategy that aims to eliminate the loss of equipment in the manufacturing process since the supervision of manufacturing systems for maintenance helps to identify the status and failures of the equipment before it breaks down [7] [8] [20]. On the other hand, the principles of the TMP are, ultimately, to achieve zero defects, zero failures and zero accidents in all company processes, involving from top management to front-line operators; reduce the incidence of defects and equipment maintenance by providing different equipment and activities working as a system [2] [8] [19]. Therefore, TPM is not a temporary activity but a continuous improvement and implementation program [7]. Likewise, its implementation guarantees fewer breakdowns, stops, and defects while reducing operational cost overruns [2] [7].

The second pillar of TPM (Autonomous Maintenance): Among the various aspects of the TPM program, one of the main pillars is Autonomous Maintenance, which focuses mainly on eliminating losses caused by the misuse of equipment and human resources, eliminating non-conformities and developing, through the operators, minor and continuous local improvements [21]. Likewise, it can be understood as a change from "I manufacture, you repair" to "I take care of my equipment myself" [22]. Faced with this premise, the complete elimination of the six significant losses related to the equipment is achieved: failures, configuration and configurations of the machine, downtime, reduced speed, process defects and reduced performance [14] [22].

The third pillar of TPM (Planned Maintenance): Planned maintenance, also known as scheduled or preventive maintenance, is the third pillar of TPM and corresponds to the incremental and sustainable improvement of equipment, facilities and the system to achieve zero failures [23]. Likewise, it provides a strategic improvement methodology based on activities to prevent and correct breakdowns in equipment and facilities through daily, periodic and predictive routines [14] [15]. In addition, events aimed at improving the characteristics of the equipment, eliminating maintenance actions, updating work orders, and updating the list of spare parts to establish a reliability analysis [14].

2.4. Application of the SMED Tool

Manufacturing companies have continuously high installation and configuration times for their equipment, which causes low availability. Therefore, reducing the changeover time and the increase in the reliability of the changeover process in the machines is crucial to improving their availability [6] [18]. On the one hand, the SMED methodology makes it possible to considerably reduce changeover times and speed up the processes for making changes to machines and facilities [3] [14] [24]. In addition, the tool makes it possible to perform equipment setup in less than 10 minutes by quickly providing conversion from current product processing to following product processing in the manufacturing process [24] [25]. On the other hand, to correctly implement the SMED methodology and obtain significant results, the change process must be first analyzed in detail [18] [24]. In the same way, the measurements of the process in question must be carried out in order to understand and identify where the losses of time occur [3] [14] [24] since this will increase the optimization of the process, which will reduce the risk of breakdowns in it.

2.5. Application of the RCM tool

Towards a solution to improve the availability of the equipment, it is vital to identify the possible causes that can cause a failure in the same [4] [5]. It is relevant to highlight that the RCM tool allows for the classification of the main dimensions and failure modes of the system [16] [17] [25]. Likewise, it facilitates the determination of the risk weightings of all the failure modes to proceed, later, to their classification, according to their relevance [5] [16]. In addition, the RCM methodology contributes to optimizing the design and management of processes since it offers an approach capable of helping in decision-making regarding selecting relevant maintenance policies and actions [16] [17].

On the other hand, the importance of the application of the RCM tool is emphasized through three main phases: Definition of the limits of the system under study and its mode of operation, identification of functional failures and determination of their causes, and the effects of these [5] [17]. Based on these previous phases, you can create the RCM tool's implementation plan, in which the best maintenance technique to be established will be selected, which has a positive and direct impact on the availability of the equipment and frequently prevents losses and failure modes [16], ensuring optimal planning and production strategy for companies [16] [17].

3. Methodology

3.1. Foundation of the Model

The proposed model is supported through the sequential scheme of applying the first pillar of TPM [22], where the implementation is addressed as an improvement tool that is not intended to be restrictive, so it is feasible to use in any industry. This tool was implemented in a company within the food sector and is successfully improving the availability of its machines. Second, the implementation of the SMED tool focused on considerably reducing changeover times and streamlining the processes for making machine changes [18]. Similarly, integrating planned maintenance with RCM establishes a methodology standardising maintenance-related activities [14] [25]. Additionally, MTBF and MTTR have been identified as crucial indicators for assessing equipment availability [17]. For this reason, it was utilized in the model as the main validation method to gather and compare data on the company's current situation with the expected outcomes. Furthermore, the combined use of the proposed tools has demonstrated more favourable results—by at least 25%—in successful cases compared to other tools.

3.2. Proposed Model

The improvement proposal model is divided into three components (see Figure 1). The first component covers the certainty of preventive maintenance, initially addressing the integration of planned maintenance with the RCM tool. Subsequently, the machines belonging to the process are determined. Similarly, the criticality analysis is carried out in the respective machines. Subsequently, the company's leading critical equipment under study is selected, as well as the functionalities of the equipment. Subsequently, an assessment of the current state of the machines is conducted, and their main failure issues are identified. Similarly, a thorough analysis of these failures is carried out, followed by examining the failure history. Subsequently, the training schedule and the improvement of the current preventive maintenance schedule are prepared. In addition, the current maintenance methodologies and the information system are improved. Finally, the activities are monitored, and their progress is evaluated. It should be noted that two key activities are carried out within its development: criticality analysis and equipment failure analysis. On the one hand, the criticality analysis allows us to focus the improvement on the two primary machines with the highest criticality level. On the other hand, the failure analysis provides information for the primary care of the most common failures in the machines and specific equipment components.

The second component is reducing equipment preparation time and identifying machinery preparation activities within the line under study. The sequence of activities carried out in this section is detailed below. First, the process is observed to take note of what is observed. After that, the activities within the process are identified; this is detailed in a list of activities. Similarly, the team is assembled and trained. Next, the schedule for activities is set, and each activity is categorized to identify areas for improvement and opportunities.In the same way, certain previously selected internal activities are transformed into external activities. These activities are then assessed to determine if they can be removed, combined, or modified.

Additionally, activities with long durations are identified to optimize their development time. Finally, the process is standardized, and a format that endorses these activities is prepared. A work team is assembled by selecting personnel within the company and training them to perform optimally and develop the required activities effectively. Activities are timed and classified into internal and external categories. Subsequently, internal activities are evaluated to determine if they can be converted into external activities, thereby not directly impacting equipment preparation. The value-added analysis identifies whether the activities contribute value to the process. Based on the results of this analysis, decisions are made on which activities to integrate, modify, or eliminate.

Finally, the third component refers to optimising the failure response plan. Regarding the implementation of the autonomous maintenance pillar to solve machinery failures and operational errors, 8 phases are proposed to follow.As a zero-step measure, accidents are prevented by isolating the types of energy in the equipment before performing tasks such as cleaning, modifications, or testing. Subsequently, through a thorough diagnosis, various anomalies are identified to stabilize the equipment's operation. This is achieved through cleaning and inspection, guided by the findings from the initial cleaning diagnosis.

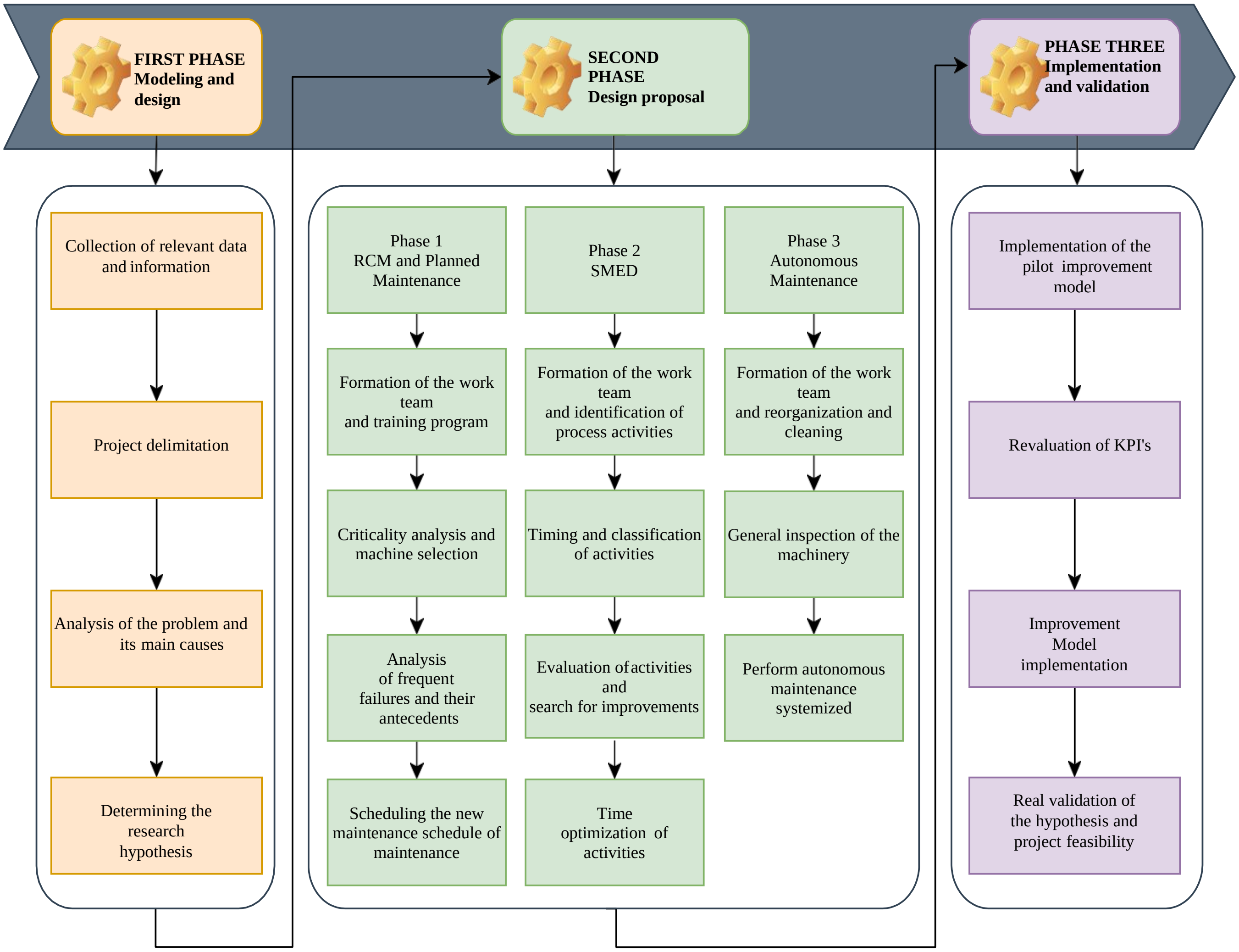

Fig. 1 General view of the proposed model

Similarly, the senses are employed to identify and detect anomalies by touching and examining components and parts during cleaning. Next, sources of contamination that have been detected are removed. Eliminating contamination sources (FDC) ensures that equipment remains free from contaminants originating from materials used in the machine, thereby simplifying the cleaning, inspection, lubrication, and tightening processes. The ECRS matrix was utilized to achieve this. The fourth phase is standardization, aimed at implementing the LALI standard to ensure uniformity in the activities technicians perform on each machine, thereby preventing accidents, breakdowns, defects, or losses. Additionally, general inspection aims to enhance understanding of the equipment's function and mechanism, enabling daily inspections based on knowledge and logic. The subsequent phase is autonomous inspection, which involves the creation of inspection checklists. The final two phases, systematized autonomous maintenance, focus on comprehensively systematizing maintenance control, including developing company policies and goals.

3.3. Model Details and Indicators

The measurement of the results of the model will be obtained through the following operational indicators:

3.3.1. Mean Time to Repair

Seeks to optimize unplanned maintenance activities.

$$MTTR = \frac{Total\ stop\ time}{number\ of\ failures}$$

Due to machine failure repair, downtime is expected to be reduced to 8.72 hours.

3.3.2. Mean Time Between Failures

Consists of increasing the availability of machine operation.

$$MTBF = \frac{Total\ operating\ time}{number\ of\ failures}$$

Factors are estimated to increase to 34.94 hours as the mean time between failures.

3.3.3. OEE

A leading indicator that measures the efficiency of the study company's bottling process.

$$OEE = Availability \times Performance \times Quality$$

Currently, there is 70.48% and its parameters of availability (78.05%), performance (94.86%) and quality (95.19%); and it is intended to reach an equal value of 85.02% (availability (94.15%), performance (94.86%) and quality (95.19%)) as an efficiency level.

3.3.4. Process Time

Consists of increasing the availability of machine operation.

$$TP = \sum Time\ of\ programming\ activities$$

Factors are estimated to be reduced to 113.89 hours as time for programming activities.

3.3.5. Scheduled Maintenance Index

It seeks to reduce the time spent on preventive maintenance activities.

$$IMP = \frac{Hours\ dedicated\ to\ scheduled\ maintenance}{Total\ hours\ dedicated\ to\ maintenance}$$

It is expected to reduce current preventive maintenance times by at least 64.72%.

4. Validation

4.1. Scenario Description

The company under study belongs to the food industry in Lima, Peru. It has five production lines: Chocolate Line, Confectionery, Instant Products, Cereals and Milling. The key area is the Confectionery line, where a gap in machinery availability has been identified, with the company under study reporting a value of 79.06%; however, the industry reflects that the value is acceptable greater than 90%. This generated an economic impact that increased total annual sales to 3.81%. Therefore, the availability of the machinery will be increased with the implementation of TPM, SMED and RCM to obtain favourable results.

4.2. Validation Method

The type of validation method that will be addressed for the improvement proposal consists of applying the TPM, SMED, and RCM tools, which consist of a pilot plan. This type of validation refers to developing the research proposal on a small scale (pilot). In addition to enhancing the experience and confidence of the personnel, which facilitates implementation, the pilot implementation of the tool enabled a more targeted use of both human and material resources. This approach resulted in more significant savings even before understanding the full impact of the proposal through preliminary results.

Table 1. Technical gap of the scenario

Indicator	Real Value	Valor World Class	Difference
OEE	78.05%	90.00%	11.95 pp

Table 2. RCM and MP training dates

Work week	Training date	Duration
Week 1	February 20	3 hours
Week 2	February 27	2 hours
Week 3	March 03	2 hours

The improvement indicators will be monitored to validate the proposal and evaluate its development throughout implementation. For proposal validation, it is essential to properly document the data generated during the improvement proposal's development and ensure the results' reliability. Consequently, documenting the process involves mapping out all activities involved. The validation will evaluate the improvements of the solution tools since these directly impact the improvement indicators that will be evaluated.

4.3. Validation of the Proposed Model

4.3.1. Validation of the RCM and MP Application

Phase 1-Organization and Status

The work team comprised six operators, two technicians, the head of the confectionery line and the production manager. The company in charge of the training on RCM and MP is GRUPO CAPACITAR, who, according to the training file, scheduled the first three training sessions on these tools during working hours. In the third week of work, the collaborators belonging to the work team led, together with us, the criticality analysis of the two primary machines within the confectionery line. The value of the variables such as Frequency and Consequence was found. With this, the value was crossed using the Criticality category matrix and, after that, the status of the intervening machines within the line. The results showed that the critical machines within the line were the Doser / Cutter and the Packer.

Phase 2-Failure Analysis

By identifying the Packer and the Dispenser / Cutter, the most frequent failures were seen with the application of the AMEF analysis. The analysis showed that the most common failures are the Movement of the transversal direction of the cutting laminator, the Misalignment of the rollers of the dough flattener, failure in the heat seal, which does not close the packaging well, and the motor of the conveyor belt is not working correctly. So here are the following values. The results obtained are assimilated to the approximate times of failures in previous years due to the same failures. These have been repetitive for approximately two and a half years and have not been given proper care due to lack of time and the pandemic crisis, which did not allow them to take advantage of the time or the staff that could be in charge of it. In addition, a rigorous analysis of the technical data sheets of each machine under study was conducted to improve the quality of maintenance and the optimal waiting time between one maintenance unit and another.

Phase 3-Establishment of Schedules

Under the previously established, a new preventive maintenance schedule is carried out considering the most frequent errors within the machines where the AMEF analysis was carried out and verifying that the time between each moment of maintenance is adequate by the technical sheets of the machine. In addition, a small training session led by the work team is established to explain and consider the correct application of the activities for the proper functioning of each machine.Finally, it was suggested that this schedule was pending to continue updating and improving the process to standardize it within the two machines analysed and expand it to the other machines within the line and the other production lines in the distant future.

4.3.2. Validation of the SMED application

Phase 1-Start of the Process

To initiate the implementation of this tool, a new team is also confirmed to ensure the proper functioning of the activities. Likewise, the training on the SMED tool was scheduled in the same way as the training on the RCM and MP tools. After the training, together with the work team, all the most outstanding activities for the production process of the confectionery line were identified and will be extended.

Phase 2-Timing and Classification of Activities

As the following activity, a time study was carried out, timing each of them and classifying them as internal or external, obtaining the following results shown in Table 4.

Phase 3-Transformation of Activities

The need to reduce the time of internal activities was efficiently sought to transform activities so that they are external. The team, together with the collaboration of the operators within the line, brainstormed ideas based on what they see every day. They raised various ideas to solve the issue in question, and eight were approved, which were applied to reduce internal activities and obtain the following results shown in Table 5.

Phase 4-Reduction and Optimization of Activities

To optimize and cut the times of each activity, an AVA analysis was carried out to identify the activities that generate value and those that do not. Here, it is identified that two activities do not add value within the process, so it was necessary to eliminate them to reduce production times. Additionally, adding an operator and a conveyor belt was proposed to reduce time and facilitate some of the activities within the process. At the end of the activities, a final process time of 105.69 minutes was obtained, with eight internal and 25 external activities, each with a time of 25.62 and 80.07 minutes, respectively.Finally, a summary table is made within a file so that the improvement process is recorded in a document and thus maintained until a new way to reduce production times is found.

Table 3. SMED training dates

Work week	Training date	Duration
Week 3	March 06	2.5 hours
Week 4	March 14	2 hours

Table 4. Timing of the process and classification of activities

Time Total Production (min)	Classification of activities		Time by type of activity	
	Internal	External	Internal	External
147.54	15	23	63.22	84.32

Table 5. Result of the reduction of internal activities

Time Total Production (min)	Classification of activities		Time by type of activity	
	Internal	External	Internal	External
138.14	9	29	40.72	97.42

4.3.3. Validation of the TPM application

Phase 1-Formation of Teams and Reorganization of the Cleaning

To start the application of this tool, a new work team must be formed to ensure the proper functioning of the activities. Likewise, training on the TPM tool is scheduled, specifically on the first pillar, Autonomous Maintenance, in the same way as the training on the RCM, MP and SMED tools were scheduled. During the training, specific characteristics were detailed, such as the benefits of a correct tool application, how to detect faults in the machines, which cleaning methods will be used, and what type of formats will be used to classify elements that require maintenance. Likewise, through this training, the company's operators will understand how to implement an optimal autonomous maintenance plan, including its gradual implementation in TPM meetings, activity boards and essential maintenance skills development.

Phase 2-General Inspection and Application of Standards

In the previous step, the operators who work with the packaging machine were involved in promoting proper cleaning and disinfection of the machine. This step seeks to develop practical solutions to the previously identified problems for the staff and the head of the area. The objective of this step is to improve the availability of the machine (Life cycle) by carrying out general inspections to prevent forced deterioration in each of the parts of the machine: nuts and bolts, control systems, etc.

As well as understanding the equipment's structure, functions, and principles through training in mechanics, hydraulics, lubrication, and electricity training. In other words, this step seeks to inspect the machinery through training, allowing operators to meet the company's objectives and good practices in developing the project. Likewise, the application of the 5S is carried out since the objective is for the company to operate with the resources it needs, preserve the collaborators, always be orderly, and maintain high productivity.

Table 6. 5S Adequate workspaces

Denomination	Concept	Objective
Classification	Separate the necessary	Delete the workspace is useless
Order	Necessary situation	Organize the workspace effectively
Clearing	Remove dirt	Improve the level of cleanliness of the places
Standardization	Signal anomalies	Prevent the appearance of dirt and clutter
Maintain discipline	Further improve	Encourage efforts in this regard

Table 7. Theoretical vs. accurate preventive maintenance of the pilot test

Pilot Test			
Months	**Hours of preventive maintenance**	**Hours of factual preventive maintenance**	**Extra hours**
Month 1	14.00	25.00	11.00
Month 2	12.00	20.00	8.00

Phase 3-Systematized Maintenance

It seeks to develop and extend the knowledge of the operators so that they can decide and act in the face of any breakdown that occurs in the machinery. Likewise, in this way, the workers will be able to find the root cause of the problem through general inspections of the equipment and, in turn, formulate procedures to correct the anomalies that emerge in the equipment. In the same way, in this last step, additional developments of policies and goals are sought, regularly increasing improvement activities. In addition, it seeks to actively achieve all the previous steps to comply effectively with the implementation of autonomous maintenance and provide results conducive to the investigation.

4.4. Validation Indicators

4.4.1. RCM and MP Results

According to what was implemented, after two months of application, a new analysis of why the tool plans to reduce production delays was carried out. Given the recurrence of failures after maintenance, the same machines where the improvement was applied were evaluated, and the most critical failures within each were evaluated. Despite the short time of the pilot test, some failures appeared to be 100% improvements due to their absence in the observation.

Table 8. Comparison of the configuration time between the year 2021 and the pilot test

	2021	**Pilot test (2 months)**		**Improvement**
	Average Monthly installation time	**Time setting**	**Average**	
Month 1	31.17	22	18.5	41%
Month 2		15		

Table 9. Pilot test on the leading causes of unplanned shutdowns

Pilot test		
Unplanned stops	**Improvement in the number of average stops (%)**	**Average stop time improvement (%)**
Breakdowns in the Machinery	12.20%	39.25%
Breakdowns due to human errors in calibration or operation	8.47%	38.38%

This way, the following data is determined, showing an improvement of around 60% in lost time. On the other hand, improvements related to the preventive maintenance schedule are observed and how these have developed throughout the trial. The scheduled times and the actual times taken to complete them are determined. It was ruled out that, in the same way, it took more time than it should have since it was the first time that the new methodology was carried out. As a result of applying RCM and PM, significant improvements are observed in each addressed issue because the proper implementation of preventive maintenance saves time on each occasion and reduces the number of interventions, allowing more time for average production on the line.

4.4.2. SMED Results

After applying the SMED tool, the times of each activity of the productive process are carried out. The delay in replenishing spare parts and materials for the machines was addressed with the optimisation of activities, and the setup for changing products within the confectionery line was improved. The data obtained after the pilot test created a small analysis table where averages were placed to better understand if improvements were found within the process. For this reason, there is approximately a 30% improvement in the number of stops and the average time of each stop. On the other hand, the installation time was measured again within the entire production process to see if some of the changes continued. The lost setup times were tracked over the two months; from them, the following average data was obtained to see if there was improvement. With this, the decrease in the average monthly installation time is observed by approximately 41%. There is a notable improvement during the test, which must be checked throughout the year to ensure the values.

4.4.3. TPM Results

The results of applying the first pillar of the TPM, Autonomous maintenance, are based on the analysis of the two leading causes of unplanned stops since this tool focuses on improving the response plan to unexpected breakdowns within the production process.Evidently, the average number of stops for both types of causes has decreased slightly. However, the duration of these stops has improved significantly, with a reduction exceeding 35%. This, along with the reduction in production delay times, enhances the availability of the machines under study and, consequently, improves the efficiency of the confectionery line.

5. Discussion

It is pertinent to highlight that a previous article conducted an initial diagnosis and an in-depth analysis of the problem and introduced an innovative proposal for this model. The current article elaborates on the model in detail and focuses on its validation. Comparatively with the initial diagnosis in the previous study of this work, it is observed that the OEE indicator has increased by approximately 13.01%. In this sense, this affects the rest of the KPIs presented. For example, availability increases by 12.10%; initially, this parameter presented a percentage of 79.06%, and after the implementation, a value equal to 89.37% was obtained. Likewise, the scheduled maintenance index reflects an improvement of 64.72% thanks to the RCM tool and planned maintenance implementation.

In the same way, an improvement of 22.81% in the process time is demonstrated due to the effectiveness of the SMED methodology. Finally, with the application of Autonomous Maintenance, it is possible to increase the value of MTBF and MTTR. In this case, at 16.34% and 11.47%, respectively, directly impacting the availability of machinery. In this sense, Loza et al. [7] specified that the reduction in the preparation time of the machines through SMED contributed to the increase in the capacity production of the company by 14% since part of the time required by the installation was available for production [26], which is also reflected in the present investigation because of the application of the methodology mentioned above, which demonstrates its effectiveness.

In the same way, another study indicates that the reduction of stops was 23.4%, and the number of breakdowns with the application of RCM and TPM decreased by 38.1%. Likewise, there was a 37.3% reduction in machine downtime and 16.7% in breakdowns. On the other hand, when analyzing their results regarding OEE, MTTR and MTBF, the data showed a very positive evolution, reaffirming the feasibility and good results of applying the methodologies above.

Similarly, another study indicates a 35.2% reduction in stoppages, and the number of breakdowns decreased by 27.8% with the application of RCM and TPM. Additionally, there was a 21.3% reduction in machine downtime and a 15.7% decrease in breakdowns. Finally, compared to the initial diagnosis by Lozano et al. [18], it is observed that the OEE indicator has increased by approximately 7.52%. Additionally, availability has improved; this parameter, which initially had a percentage of 76.39%, reached 85.22% after implementation. Furthermore, the scheduled maintenance index shows a 61.27% improvement due to the implementation of the RCM tool.

6. Conclusion

The primary indicator for measuring the company's current situation is the OEE, which presents a deficiency in the availability components and a value of 13.17% below expectations. This generates losses of more than USD 99,400, a value that is expected to be fully part of the cash flow within two years and remains there thanks to the application of tools of this model, which attack 93% of the current causes contributing to the greater competitiveness of the company. Integrating the RCM and MP tools has enhanced the production schedule through a comprehensive analysis of failures.

This involved identifying their common causes and evaluating the technical sheets for the two primary machines in the line under study. As a result, an optimal maintenance strategy for each machine was established, along with the appropriate timing for maintenance interventions. This approach led to a 72% reduction in the monthly average number of failures per machine and a 55% decrease in total corrective maintenance time.The time lost in the production line due to changes and machine setup improvements was significantly reduced through the analysis and implementation of corrective measures targeting areas with opportunities for enhancement.

Internal activities were redefined as external ones, non-value-added activities eliminated, tasks consolidated, and bottleneck times minimized. These improvements were achieved using the SMED tool, which, along with optimized production scheduling, reduced manufacturing waiting time by 23%, thereby recovering time for increased production efficiency. The number of stops due to machinery breakdowns and human errors was reduced, resulting in the optimization of the values of the MTBF MTTR indicators from 29.23 to 34.94 and from 7.72 to 8.72, respectively, with the application of the first pillar of TPM (Autonomous Maintenance).

With this, a systematized corrective maintenance system was carried out based on organization and order, involving all line workers since they are the ones who see the process day by day; likewise, the application of the 5S components is an essential foundation for the application to be successful.

With the application of the third pillar of TPM, he presented improvements within maintenance planning, managing to reduce Preventive Maintenance times by 65% of the initial value with the analysis of the current schedule, the operation of the line and finding the bottleneck within order to attend to maintenance for each without wasting time or stopping the entire production flow.

The RCM tool contributed to the improvement by focusing on the need for maintenance by evaluating the specifications of the machines to determine the appropriate time interval so that unexpected stops are not foreseen.

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