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Original Article

Reliability-Centered Maintenance Model to Improve OEE in a Mass-Consumption Food Company: A Case Study from Peru

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Abstract - *A high rate of failures, frequent unplanned stoppages, and low equipment effectiveness characterized the production process of a medium-sized cookie manufacturer in Peru. Previous studies addressed similar challenges using Lean and TPM methodologies, but limited evidence existed on integrating Reliability-Centered Maintenance (RCM) in food manufacturing contexts. This study aimed to design and implement a maintenance management model based on RCM to enhance operational availability and reduce losses. The proposed model combined AMEF, criticality analysis, and a five-phase RCM strategy. Key actions included failure mode identification, task prioritization, and customized maintenance planning. After implementation, availability increased from 75.67% to 80%, unplanned stoppages dropped significantly, and overall maintenance costs decreased. These results validated the model's effectiveness and practical adaptability. The findings contribute to the academic discourse on RCM applications in food manufacturing SMEs and present socioeconomic benefits through improved productivity. Future research is encouraged to replicate the model in similar sectors and scale its integration.*

Keywords - *Reliability-Centered Maintenance, Overall Equipment Effectiveness, Production Downtime. Manufacturing Defects Reduction, Food Manufacturing Industry.*

1. Introduction

The mass-consumption food industry—which encompasses products such as cookies, snacks, and other highly demanded edibles—plays a fundamental role both globally and regionally. This sector is an economic pillar in many countries, as it provides essential goods to the population and drives significant industrial activity. In fact, the food industry is recognized as a key contributor to economic production in contemporary societies [1]. Over the past few years, food-processing firms throughout Latin America—most notably in Peru—have moved forward at a remarkable speed, modernizing their operations through greater automation and new technologies [1].

Businesses producing cookies and other everyday items now serve the tastes of millions while generating a sizeable share of regional industrial GDP and export earnings. Their significance extends beyond sheer output figures; these firms provide jobs, bolster local supply chains, and enforce strict quality and safety protocols to satisfy ever-higher consumer expectations. In short, producers of mass-market foods are dynamic actors whose influence stretches from the global arena to the heart of the Andean economy, forming a pillar of both Peru's industrial base and its food system.

However, food manufacturing companies face serious operational challenges, particularly related to the maintenance of their production lines. Among the most critical problems are high rates of unplanned stoppages due to machine failures, a high rate of waste and defective products, and low equipment performance reflected in poor Overall Equipment Effectiveness (OEE) at the plant level. Many facilities still operate under traditional maintenance schemes (routine preventive or reactive) that fail to ensure the expected availability and effectiveness of production assets [2]. This leads to increased failure frequency and unplanned downtime, which in turn causes both production losses (raw material waste, reprocessing) and extended idle times due to equipment stoppages [3][4]. Such process interruptions and deviations also result in defective products, reducing the percentage of compliant units and generating additional costs from reprocessing or discarding [3]. Collectively, these factors impair line performance: machine availability decreases, the actual production speed falls below the nominal due to frequent stoppages, and quality is compromised. Consequently, the OEE indicator is negatively affected, falling well below the desirable reference values. For example, it has been reported that in certain plants, the global OEE of key equipment barely reaches ~53% due to continuous failures and interruptions in operations [5]. A low OEE reflects significant losses in availability, performance, and quality, highlighting the broad margin for improvement in the operations of these factories. In short, frequent failures, high waste, and low OEE form a problematic cycle in food companies: they reduce productivity, raise unit costs, and may hinder the company's ability to meet market demand and standards.

Given this situation, effectively addressing maintenance problems is of vital importance to reverse losses and ensure competitiveness in the food sector. Numerous studies emphasize that robust maintenance management minimizes downtime and costs while maximizing production and operating profits [6]. In the food business, using new methods like Reliability-Centered Maintenance (RCM) and other ways to keep getting better can make a big difference in how well things work. There is evidence to back this up: for example, using RCM has made equipment available more than 85% of the time in a processing plant, which has greatly improved operational continuity [7]. In the same way, using Total Productive Maintenance (TPM) strategies heavily on a food packaging line raised OEE from a low starting point of about 48% to about 74%, almost doubling its operational efficiency [8]. These examples show that fixing the problems that cause failures and making maintenance routines more efficient leads to lines that are more productive, with less waste and less downtime. Also, by lowering breakdowns and making the process more stable, the quality of the product goes up, and the number of defects that lead to losses goes down. This is good for both customer satisfaction and business profits. In summary, resolving maintenance deficiencies is crucial: companies can significantly increase their efficiency, better leverage their installed capacity, and strengthen their competitive position in the mass-consumption food market by keeping their assets in optimal condition [6]. The benefits range from reducing operating costs and more reliable production schedule compliance to greater adherence to quality and safety standards, which are essential aspects in this industry.

Despite the evident advantages of improving maintenance management, a clear gap exists in the literature and current practices regarding specific strategies for mass-consumption food companies. Most previous research has addressed only partial aspects or different industrial contexts, leaving a relative void in the comprehensive analysis of this sector. For example, in the construction sector, maintenance models focused on reliability have been implemented to increase the availability of heavy machinery [9], and in the naval sector, RCM and TPM approaches have been combined to optimize maintenance times and costs in the management of nautical assets [10]. While these studies offer valuable references, none directly address the reality of mass-consumption food plants or the operational particularities of food SMEs in the region. In other words, a knowledge gap persists: the absence of a comprehensive and validated maintenance management model for manufacturers of high-demand food products (such as cookies and similar items), which integrates RCM tools with the specific needs of continuous production, waste control, and OEE improvement in this sector. This research seeks to fill that gap through the proposal of a reliability-centered maintenance management model, specifically designed for a mass-consumption cookie production line. This model integrates classic RCM tools (such as failure modes and effects analysis, criticality, and proactive maintenance plans) within a framework adapted to the conditions and limitations of a real plant. The novelty of the contribution lies in its practical application: the model is implemented and validated in the operational environment of a Peruvian company in the sector, demonstrating significant reductions in unplanned failures, defective product rates, and improvements in indicators such as OEE. Unlike previous studies, our approach holistically addresses maintenance issues (reliability, availability, performance, and quality) in a food company, presenting original results that compare favorably with those reported in other sectors. In conclusion, this work presents an innovative contribution to both the literature and the industry: a maintenance model based on RCM specifically aimed at mass-consumption food manufacturers, which fills the identified gap and provides a practical guide to improving efficiency and competitiveness in this important industrial sector.

2. Literature Review

2.1. RCM in Food Industries: Effective Applications and Empirical Evidence

The implementation of Reliability-Centered Maintenance (RCM) in mass food processing plants has demonstrated tangible results in operational efficiency and asset reliability. Tsarouhas applied RCM in a bakery line, showing a 15% increase in reliability and a significant reduction in unplanned stoppages [11]. Another study in the dairy industry revealed that by identifying critical failure modes and focusing maintenance efforts, the yogurt line's availability reached around 95% [12]. In ice cream production, Tsarouhas documented that RCM increased OEE by identifying bottlenecks [13]. Capcha-Huamali et al. combined RCM with Lean in a Peruvian bottling plant, achieving an 8.8% efficiency improvement [14]. Uzoigwe reviewed multiple food and beverage facilities, concluding that RCM significantly reduces unplanned outages and extends asset life [15]. These cases confirm that RCM is not only applicable but highly effective in mass-production food plants.

2.2. FMEA: A Key Tool within RCM for Food Plants

The Failure Modes and Effects Analysis (FMEA) is a core element of RCM in food production plants. Scipioni et al. demonstrated that integrating FMEA with HACCP in poultry processing improved quality and food safety by identifying and mitigating failure points [16]. Iswidibyo et al. applied FMEA-RCM in a beverage filling line, reducing failure rates from 11% to 4.2% [17]. Iswidibyo et al. optimized FMECA in a textile plant, showing that prioritizing critical components reduces maintenance costs and improves efficiency—principles transferable to food processing due to comparable continuous production dynamics. Geisbush and Ariaratnam assessed integrated use of RCM and FMEA, emphasizing their complementariness to design highly targeted preventive interventions [18]. This confirms FMEA's role as a structured diagnostic tool supporting efficient maintenance tailored to plant needs.

2.3. Operational Implications of RCM: Results and Transformation

Adopting RCM has profound operational implications for maintenance and overall plant performance. Supriyanto reported that RCM improves equipment availability and quality, reducing downtime and increasing operational satisfaction [19]. Suthep and Kullawong implemented RCM in a hard-chrome plating plant, integrating maintenance into production scheduling and achieving greater availability [20]. Kardas showed significant improvements in machine time efficiency after applying RCM-based maintenance practices [21]. Sahani documented positive ROI from RCM implementation in cement plants, validating the investment [22]. These studies also highlight cultural transformation: staff involvement, ongoing training, and a shift toward a reliability-first mindset. In food plants, these translate into cleaner, safer, and more efficient production lines.

2.4. Limitations and Challenges of RCM Implementation in Industrial Plants

Despite its benefits, RCM faces significant practical challenges during implementation. Bloom documented that over 60% of RCM initiatives fail due to poor planning and limited resources [23]. Lack of historical data and qualified staff complicates execution [23], [24]. Cultural resistance is another barrier: operators accustomed to reactive maintenance may resist change [17]. Sahani and others warned that initial cost and return periods may deter adoption if not planned with medium-term perspectives [22], [23]. Nabhan noted that without foundational systems—like CMMS, spare part management, and documentation—RCM can become unnecessarily burdensome [24]. To succeed, organizations should prioritize critical assets, secure management support, and foster a continuous improvement culture.

2.5. Research Gap Identified: Toward an RCM Model for SMEs in Food Manufacturing

Although RCM and FMEA have been applied effectively in baking, dairy, and beverage industries, there is a notable gap regarding their use in medium-sized cookie manufacturing plants. While large corporations are well documented, smaller and mid-sized firms (as in Peru) face resource, technology, and expertise constraints [25], [17], [26]. This research proposes a reliability-centered maintenance management model customized for cookie production lines, bridging the gap. Its contributions include a validated methodology, empirical improvements in OEE, defect reduction, and stoppage time, and a replicable framework for smaller-scale food enterprises. Thus, the proposed model is an original and necessary contribution to both academic literature and industrial practice.

3. Contribution

3.1. Proposed Model

Figure 1 presents the proposed maintenance management model, developed based on Reliability-Centered Maintenance (RCM) principles and implemented in an industrial facility dedicated to the mass production of cookies. This methodological approach aimed to enhance the operational reliability of critical assets through a structured framework designed to reduce recurrent failures and improve process continuity. The model began with the formation of a specialized RCM working team responsible for leading the technical and operational analysis. Following this, key assets and systems were identified, considering their impact on product quality and production efficiency.

A Failure Modes and Effects Analysis (FMEA) was then conducted to assess the operational risks associated with each component and to prioritize maintenance interventions. In the subsequent phase, tasks and activities were determined to address the identified failure modes, incorporating both preventive and corrective actions based on technical and process requirements. The final stage involved a post-implementation analysis, where outcomes were reviewed and strategies were refined to ensure continuous improvement of the maintenance system. This RCM-based model sought to align maintenance practices with the operational goals of the organization, contributing to greater equipment reliability and system performance within the production environment.

3.2. Model Components

The proposed maintenance management model, illustrated in Figure 1, emerges as a strategic response to the persistent operational challenges faced by manufacturing systems, particularly those dedicated to mass consumption products such as cookies. In highly competitive and quality-sensitive industries, interruptions caused by equipment failures and system inefficiencies can significantly hinder productivity and product integrity. This model contributes to the body of knowledge in industrial maintenance by integrating the principles of Reliability-Centered Maintenance (RCM) into a coherent and systematic framework that facilitates decision-making and promotes continuous operational improvement.

The methodological foundation of this model is rooted in the proactive identification and management of failure modes, focusing on preserving system functionality and optimizing asset utilization.

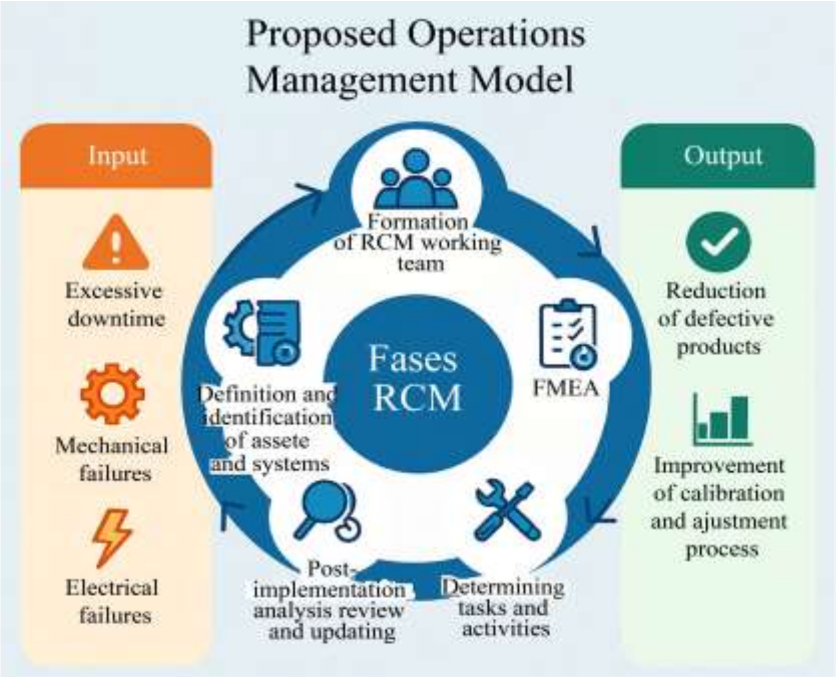

Fig. 1 Proposed model

By structuring the maintenance process into five interdependent phases, the model provides a clear roadmap that guides organizations from diagnosis to sustained improvement. Each phase is designed to ensure the alignment of technical efforts with the strategic objectives of production continuity and product quality.

3.2.1. Phase 1: Building the Foundation with a Multidisciplinary RCM Team

The initial phase of the model centres on the formation of a specialized RCM working team, which serves as the cornerstone of the entire implementation process. This team is composed of professionals with expertise in maintenance, operations, quality control, and safety. The rationale behind this interdisciplinary composition lies in the need to capture diverse perspectives and ensure that the analysis encompasses the full scope of operational variables.

The establishment of the team involves defining clear roles and responsibilities, as well as fostering a collaborative environment that encourages knowledge sharing and joint problem-solving. This phase also includes training sessions aimed at aligning the team’s understanding of RCM principles and tools, thereby ensuring methodological consistency throughout the implementation. As a result, the team becomes capable not only of identifying technical failures but also of contextualizing them within broader production dynamics.

3.2.2. Phase 2: Identifying Critical Assets and Systems

Following the team formation, the second phase focuses on the definition and identification of the assets and systems that are critical to the production process. In a mass-production cookie manufacturing facility, where process continuity is paramount, identifying equipment whose failure would significantly disrupt operations is essential.

This stage entails a systematic review of the production line, mapping all relevant assets, and evaluating their functional importance. The evaluation criteria include the frequency and severity of past failures, the complexity of repair, the impact on product quality, and the interdependencies among systems. The outcome is a prioritized list of assets that require detailed analysis, forming the basis for subsequent stages. The process of identification is both technical and strategic, incorporating not only equipment performance data but also operational insights provided by the RCM team. This dual perspective enhances the relevance of the selection and ensures that maintenance efforts are concentrated where they yield the highest return in terms of system reliability and production stability.

3.2.3. Phase 3: Analysing Risks with FMEA Methodology

After the organisation has identified its most mission-critical assets, the natural progression is to carry out a Failure Modes and Effects Analysis, commonly abbreviated as FMEA. This structured approach assembles specialists from different functions to break each asset down into every potential way it might fail, assess what those failures could mean for the overall operation, and trace the root causes that might give rise to them. The analysis leans heavily on observations made on the shop floor or in the field, ensuring that the discussion is anchored in practical experience rather than purely theoretical scenarios.

Once the team has catalogued the possible failure modes, each one is rated along three key axes: how likely it is to happen, how serious the impact would be if it did, and how easily it could be detected before it causes harm. Scores on these axes are multiplied together to produce a single Risk Priority Number. This number serves as a straightforward yardstick for prioritising responses, steering the conversation away from opinion and towards evidence when deciding where maintenance efforts and budget should be concentrated first.

FMEA, of course, contributes more than a set of numbers and scores. As cross-functional team members work through each failure mode together, they gradually build a shared, concrete picture of how the plant behaves day to day. Patterns that escape one-off risk reviews—those nagging bottlenecks that resurface or the same weaknesses in different equipment—come into sharper focus. Armed with this better visibility, engineers and supervisors can draft rooted reliability plans and adjust daily operations accordingly.

3.2.4. Phase 4: Defining Maintenance Tasks and Activities

Having ranked the most serious failure modes, the team can now pivot from what might go wrong to what will be done about it. In this step, the analysis meets the work floor, turning strategic insights into schedules and checklists that operators will follow.

Therefore, selecting the right maintenance action for each failure picture is crucial. When parts wear out steadily over time, regular swap-outs, documented in a preventive calendar, usually make the most sense. On the other hand, when malfunctions strike at random, condition-based tactics backed by vibration monitors or infrared cameras often pay bigger dividends. Every choice is measured not just by cost but also by how little it disrupts production.

Beyond the selection of maintenance strategies, any effective framework must also spell out exactly how that strategy is to be executed. For every planned job, there should be a clear set of procedural steps, a list of required tools, and an outline of the technical skills necessary to carry out the work safely and efficiently. By gathering all this information on a single, accessible platform, the organization makes it easier for maintenance crews to coordinate their tasks with production schedules, reduces the likelihood of last-minute breakdowns, and clarifies who is responsible for what across different teams.

3.2.5. Phase 5: Ensuring Sustainability Through Post-Implementation Review

The concluding phase highlights the importance of perpetual appraisal by setting forth a formal post-implementation review. This step concentrates on assessing the true effects of the most recent maintenance activities, spotting any gaps between actual performance and original targets, and fine-tuning the broader strategy in response.

To support a culture of ongoing improvement, the process incorporates several feedback channels that track key performance metrics, such as equipment uptime rates, frequency of breakdowns, and adherence to the published maintenance timetable. These figures serve as the centrepiece of regular review sessions, giving leaders the evidence required to modify tactics in line with changing conditions on the shop floor. At the same time, insights gained from these reflections are circulated across all relevant departments, helping to build a repository of shared experience that ultimately strengthens the entire enterprise.

The practice of contemporary maintenance is increasingly viewed as an adaptive rather than a fixed activity, a perspective strongly supported by the principles of Reliability-Centered Maintenance. By committing to regular recalibration of procedures, organisations ensure that their maintenance programmes grow in step with changing operational priorities, cultivating a long-lasting culture of resilience and ongoing improvement.

Conclusion: Advancing Maintenance Management in Mass Production Contexts

The structured RCM methodology laid out here provides a thorough, step-by-step guide to asset stewardship that fits especially well in environments where output runs at full throttle. Organised into five linked phases, the framework allows engineering teams to identify operational hazards, weigh their consequences, and formulate effective responses accurately and clearly.

A recent pilot project at a high-capacity biscuit plant illustrates the model's practical benefits. It brought critical lines—namely the conveyor and baking systems—into a more stable operating state while also producing a marked increase in product consistency and a reduction in the complexity of everyday servicing. Key to this success was the active collaboration of personnel from production, quality, and maintenance, whose combined insights refined the method and pulled it closer to the plant's overall strategic goals.

In short, the framework promises mechanical dependability but delivers much more. It instils a deeper sense of accountability, sharpens competitive positioning, and helps push the field of maintenance forward in the fast-moving world of mass production.

4. Validation

4.1. Validation Scenario

The validation scenario unfolded within a case study of a medium-sized food manufacturer operating in Lima and several peri-urban regions of Peru. This firm, which concentrates on producing mass-market goods, especially cookies, manages industrial workflows of notable complexity owing to the volume it handles. Its market-oriented business model demands that the company maintain exceptionally high levels of efficiency and product quality throughout every step of the production sequence. Although it possesses a well-defined organisational framework and relatively sophisticated technical tools, the firm struggles with maintenance-management bottlenecks that frequently interrupt operations and degrade process performance. These persistent challenges have made it evident that the organisation requires targeted interventions to enhance equipment robustness and trim episodes of unplanned downtime across its plant infrastructure.

4.2. Initial Diagnosis

The diagnosis conducted in the case study identified the central problem as a low Overall Equipment Effectiveness (OEE) in the filled cookie production line, with an initial level of only 57.93%, revealing a technical gap in relation to the target of 80%. This condition resulted in an estimated annual financial loss of PEN 1,708,781. The analysis revealed three main reasons contributing to this issue: production line stoppages accounted for 49.2% of the problem, followed by low operational performance with a contribution of 46.5%, and a smaller share of 4.3% attributed to defective products. These reasons were linked to specific root causes: mechanical and electrical failures explained 30.2% of the stoppages, while instrumentation faults represented 19%.

Additionally, 46.5% of the low performance was due to improper adjustment of the sealing system, and the presence of defective products was associated with wear on the magazine chain of the primary packaging machine, accounting for 4.3%. These findings highlighted the urgency of improving the maintenance system to reduce unplanned downtimes, enhance performance, and ensure operational continuity.

4.3. Validation Design

A four-month pilot study was conducted to validate a Reliability-Centered Maintenance (RCM)-based maintenance management system in a medium-sized biscuit factory. The project started because of ongoing problems that had a big impact on the Overall Equipment Effectiveness (OEE) of several key production lines. The deployment followed a planned and structured path. It started with figuring out which assets had the biggest impact on production throughput, then moved on to registering and analysing potential failure mechanisms related to those assets.

Finally, it ended with designing maintenance activities that were specific to the plant's daily operations. The team was able to quickly see the technical feasibility and measurable benefits of the new maintenance model by continuously tracking and evaluating performance indicators.

4.3.1. Strategic Implementation of an RCM-Based Maintenance Model

The project described in this case study was a planned effort to fix long-lasting problems with the way things were done in a medium-sized cookie factory. Based on the principles of Reliability-Centered Maintenance, the strategy aimed to improve OEE by fixing machines that often stopped working, speeding up production, and lowering the number of rejections due to quality issues. There were five clear steps to the execution. It started with putting together a cross-functional group of people with skills in production, engineering, and quality assurance. The next step for this team was to make a map of the most important equipment and operations, putting them in order of how important they were. After that, the team did a detailed FMEA, which helped them find the root causes of the problems. After that, personalized maintenance plans were put in place. Finally, a full performance review was done after the system was put in place. All decisions made during the rollout were based on real-time data, which made sure that each action met the plant's specific needs and operational profile.

4.3.2. Formation and Engagement of the RCM Work Team

The first step was to put together a team that included maintenance technicians, production engineers, quality analysts, and operational supervisors from different fields. The group oversaw the implementation effort. They looked over technical documents, did field assessments, and wrote improvement proposals that followed established reliability principles.

Members met every two weeks to keep track of progress and share ideas. This created a regular place for sharing information, making decisions as a group, and updating each other on their status. This model of working together made it easier for departments to talk to each other and made everyone more committed to maintaining the quality of the maintenance.

Table 1. RCM Team

Company Personnel	RCM Team Role	Required Work Experience
Maintenance Planner	RCM Facilitator	2 years
Maintenance Manager	RCM Member	4 years
Maintenance and Reliability Manager	RCM Member	2 years
Instrumentation Technician	RCM Member	3 years
Mechanical Technician	RCM Member	3 years
Electrical Technician	RCM Member	3 years
Production Manager	RCM Member	4 years

Table 2. List of equipment and actual cost

Item	Equipment	Quantity	Total Cost (PEN)
1	Dosing Scale	1	2,112,500.00
2	Mixer	1	1,625,000.00
3	Laminator	1	1,300,000.00
4	Oven	1	650,000.00
5	Belts	6	390,000.00
6	Metal Detector	2	195,000.00
7	Primary Packaging Machine	4	1,137,500.00
8	Secondary Packaging Machine	2	1,820,000.00
9	Boxing Machine	1	1,625,000.00
10	Palletizer	1	1,950,000.00
Total Line			**12,805,000.00**

Table 1 presents the composition of the RCM team formed for the case study, specifying each member's roles and required experience. It includes personnel from maintenance, reliability, instrumentation, and production, with experience requirements ranging from 2 to 4 years, ensuring technical expertise and cross-functional collaboration throughout the implementation process.

4.3.3. Definition and Identification of Assets and Systems

In this phase, the team conducted a detailed mapping of the production line to identify critical equipment and systems. This effort was supported by a diagnostic analysis of historical maintenance records and real-time performance data. The baseline OEE was recorded at 57.93%, with unplanned stoppages representing 49.2% of inefficiencies, low performance accounting for 46.5%, and defective products contributing 4.3%. Key systems such as the sealing module and primary packaging conveyors were prioritized due to their high failure frequency and impact on production flow. The use of Pareto analysis and failure classification matrices allowed the team to focus on the most influential components.

Table 2 presents the equipment inventory for a cookie production line, detailing the quantity and total cost in Peruvian soles (PEN). Ten pieces of equipment are listed, with the dosing scale and palletizer being the most expensive. The total cost of the entire production line amounts to PEN 12,805,000.00.

4.3.4. Comprehensive Failure Modes and Effects Analysis (FMEA)

Once the essential assets were clearly mapped out, the team undertook a Failure Modes and Effects Analysis, or FMEA, to explore how each component could fail. By applying the familiar criteria of severity, occurrence, and detection, they generated Risk Priority Numbers—RPNs—that ultimately steered later design and maintenance choices. The analysis highlighted the sealing module as a particular concern; its high RPN stemmed chiefly from erratic heating cycles and early signs of mechanical fatigue. At the same time, problems persisted on the main conveyor lines, where chain-drive issues repeatedly emerged. This level of detail allowed the group to outline precise intervention points, log root causes and possible outcomes, and suggest repair activities along the way. Furthermore, the insights gained from the FMEA became a foundational element for developing maintenance schedules that were both more targeted and more effective than previous plans.

Figure 2 displays the results of the Failure Modes and Effects Analysis (FMEA) conducted on the line that produces filled cookies. The analysis identified a total of eighteen separate failure modes, among which four were classified as high risk because their Risk Priority Numbers (RPNs) surpassed the arbitrary cutoff of six hundred. The heightened risk associated with these particular modes stems chiefly from issues affecting the sealing apparatus and certain electrical faults within the production setup.

System	Equipment	Part	Function	Functional Failure (Loss of Function)	Failure Mode (Cause of Failure)	Potential Effects of Failure	G = Severity	O = Occurrence	D = Detection	RPN = Risk Priority Number	Risk Description
Primary Packaging Machine	Servo motor	Bearings	Allow rotation	Does not start	MF01 Damaged	Line stop	8	10	8	640	🔴 High failure risk
	Sensors	Connectors	Transmit electrical power	Poor sealing	MF02 Damaged sensor	Scrap	10	10	8	800	🔴 High failure risk
	PLC		Synchronize movements	Poor sealing	MF03 Damaged PLC	Scrap	10	10	6	600	🔴 High failure risk
	Cream filler	Pump	Transfer the cream	Does not start	MF04 Damaged	Line stop	8	10	8	640	🔴 High failure risk
	Stencil	Tubes	Distribute the cream	Poor distribution	MF05 Damaged	Scrap	10	6	6	360	🔴 High failure risk
		Nozzles	Dose the cream	Does not dose	MF06 Damaged	Scrap	10	6	6	360	🟠 Medium failure risk
	Magazine	Chain	Transfer cookies	Does not transfer	MF07 Chain breakage	Line stop	8	6	8	384	🟠 Medium failure risk
				Breaks cookies	MF08 Wear	Scrap	10	8	6	480	🟠 Medium failure risk
		Spindles	Transfer cookies	Does not transfer	MF09 Spindle breakage	Line stop	8	6	8	384	🟠 Medium failure risk
				Breaks cookies	MF10 Wear	Scrap	10	8	6	480	🟠 Medium failure risk
	Motor	Windings	Generate movement	Does not start	MF11 Wear	Line stop	8	7	8	448	🟠 Medium failure risk
		Bearing	Allow rotation	Does not rotate	MF12 Lack of maintenance	Line stop	8	6	8	384	🟠 Medium failure risk
				High vibration	MF13 Wear	Scrap	5	4	5	100	🟢 Low failure risk
				Overheating	MF14 Poor assembly	Scrap	6	2	8	96	🟢 Low failure risk
	Reducer	Crown	Transmit motion	Does not rotate	MF15 Lack of maintenance	Line stop	7	3	5	105	🟢 Low failure risk
		Bearing	Allow rotation	Does not rotate	MF16 Lack of maintenance	Line stop	7	4	4	112	🟢 Low failure risk
				High vibration	MF17 Wear	Scrap	6	4	4	96	🟢 Low failure risk
				Overheating	MF18 Poor assembly	Scrap	6	2	4	48	🟢 Low failure risk

Fig. 2 AMEF Results

4.3.5. Determination and Standardization of Maintenance Tasks

Based on the FMEA results, specific maintenance tasks were categorized and scheduled according to their nature. Preventive tasks included lubrication, tension adjustments, and alignment checks, while predictive tasks involved the use of vibration analysis and thermal inspection to anticipate potential breakdowns. Corrective actions were revised to include quick-response protocols and scheduled part replacements. Maintenance manuals and work instructions were developed to ensure task standardization, incorporating visual aids and checklists for ease of implementation. Operators received training in autonomous maintenance to enhance their ability to detect anomalies and reduce dependency on specialized technicians.

Table 3 outlines the maintenance plan for the packaging machine, detailing eleven specific tasks assigned to instrumentation, mechanical, and electrical technicians, as well as external services. Each activity includes its estimated duration in hours and execution frequency, covering replacements, inspections, and technical analyses aimed at ensuring equipment reliability and operational continuity.

Table 3. Packaging machine maintenance plan

Task	Responsible	Duration (hours)
Servo Replacement (every 4 years)	Instrumentation Tech	8
Sensor Replacement (every 3 years)	Instrumentation Tech	8
PLC Replacement (every 8 years)	Instrumentation Tech	16
Bearing Replacement for Cream Pump	Mechanical Technician	8
Inspection of Distributor Tubes	Mechanical Technician	2
Inspection of Dosing Nozzles	Mechanical Technician	2
Chain Replacement for Peg Transport	Mechanical Technician	12
Peg Inspection	Mechanical Technician	8
Chain Motor Winding Inspection	Electrical Technician	4
Chain Motor Bearing Replacement	Electrical Technician	4
Vibration Analysis of Chain Motor	External Service	2

4.3.6. Post-Implementation Analysis and Performance Review

The final phase assessed the impact of the model through a four-month monitoring period. The OEE improved significantly from 57.93% to 75.67%, marking a 30.62% increase in productive efficiency. Downtime from equipment failures decreased from 23.53% to 13.86%, reflecting better system availability. The performance rate rose from 77.74% to 86.14%, and the defect rate dropped from 2.04% to 1.21%, confirming the model's effectiveness in enhancing process stability and product quality. These outcomes demonstrated the success of the structured RCM-based approach and its potential for long-term adoption in similar industrial contexts.

4.3.7. Conclusion: Consolidating Maintenance Reliability in Industrial Operations

The implementation of the RCM model not only yielded measurable improvements in operational indicators but also contributed to institutional learning and cultural change. Maintenance personnel acquired new competencies in failure analysis, while operators became more proactive in identifying early warning signs. The integration of feedback loops and continuous monitoring ensured that improvements were sustained over time. This experience confirmed the value of a structured and participatory approach to maintenance management, particularly in medium-sized companies seeking to enhance reliability, reduce costs, and increase overall efficiency in mass production environments.

4.4. Results

Table 4 presents the performance results obtained after validating the maintenance management model based on the Reliability-Centered Maintenance (RCM) philosophy in a large-scale cookie manufacturing facility. The Overall Equipment Effectiveness (OEE) metric improved from 57.93% to 75.67%, translating to a net gain of 30.62 percentage points in systemic efficiency. Parallel to this, the Defective Product Rate fell from 2.04% to 1.21%, a reduction of 40.69% that underscores enhanced product quality.

The Failure Downtime Rate also witnessed a decline, decreasing from 23.53% to 13.86%, or 41.10%, thus indicating better management of unplanned outages. Furthermore, the Production Line Performance Rate increased from 77.74% to 86.14%, yielding a rise of 10.81% that reflects marked operational improvement. Collectively, these metrics validate the proposed model's effectiveness in boosting equipment reliability, stabilizing processes, and sustaining production continuity.

Table 4. Results of the pilot

Indicator	Unit	As-Is	To-Be	Results	Variation (%)
OEE	%	57.93%	80%	75.67%	30.62%
Defective Product Rate	%	2.04%	1%	1.21%	-40.69%
Failure Downtime Rate	%	23.53%	12%	13.86%	-41.10%
Production Line Performance Rate	%	77.74%	90%	86.14%	10.81%

5. Discussion

The results of this study show that the Overall Equipment Effectiveness (OEE) of the production line improved significantly after using the Reliability-Centered Maintenance (RCM) framework. It went from 57.93% to 75.67%. This result agrees with what Yavuz et al. [2] found: using RCM in food production makes equipment more available by reducing the number of times it breaks down. Muñoz Cevallos and Cantos Macías [7] also saw big drops in both downtime and maintenance costs after using RCM on tuna processing lines. This shows that this method can be used in many different food sectors. The results also match what Tsarouhas [13] said: better process flow and stability are linked to higher OEE.

Capcha-Huamali et al. [14] showed that RCM works well with Lean practices by showing that it improved both the quantity and quality of production on beverage bottling lines. This effect was also seen in this case. Ihueze and U-Dominic [8] came to similar conclusions, saying that structured maintenance models made food manufacturing more available and improved quality. The current study shows that RCM can be used more widely to make production more reliable by reducing unplanned stoppages and enforcing standardized tasks.

5.1. Study Limitations

Even though the results are promising, there are some limitations that need to be recognized. The study only looked at one line in a medium-sized food facility, so the results cannot be applied to other industries with different levels of complexity. Also, the four-month time frame might not show all of the long-term effects or hidden problems that could come up after a long period of operation. The first FMEA is also limited because it is based on interviews with operators and historical breakdown records. These sources may be helpful, but they could also be biased or miss problems that have not been documented. Scipioni et al. [16] say that the accuracy of any FMEA depends a lot on how consistent and knowledgeable the people who contribute are. Finally, the lack of real-time IoT-based monitoring limited predictive capabilities, which could have helped find failures sooner and made interventions even better.

5.2. Practical Implications

This study has clear benefits for both the strategic planning and the day-to-day running of food production systems. By targeting potential failures before they get worse, a structured RCM implementation lets manufacturers proactively fix performance gaps. This creates a culture of continuous reliability. Calderón Osco et al. [5] stressed how combining RCM with tools like TPM and SMED can have synergistic effects, especially when it comes to making things more consistent and getting workers more involved. For facilities with limited resources, using standardized checklists and self-directed maintenance routines is a cost-effective way to keep improvements going.

Prioritizing tasks based on how important they are to the company's assets makes sure that maintenance resources are used wisely. Afsharnia and Rohani [6] showed that well-planned maintenance improves safety, ensures quality standards are met, and lowers variability. Tsarouhas and Arvanitoyannis [12] also said that reliability assessments in dairy operations cut down on the need for reprocessing and keep the quality of the products consistent. These results are similar to what was found in this study.

5.3. Future Works

More research should look into how the proposed RCM model can be used in more lines of business and food processing categories, such as dairy, candy, and meat products. This wider use would allow for comparisons that look at how the model's effectiveness changes with the complexity of the machinery and the variability of production. Longer monitoring periods are also suggested to see how long improvements last and to find patterns of failure that develop over time. Combining RCM with Industry 4.0 technologies like sensors, real-time data analytics, and machine learning could also improve maintenance planning by giving predictive insights. According to da Silva et al. [23], combining RCM with digital platforms makes systems more resilient and speeds up the process of making decisions. Finally, learning about human factors like operator training, team coordination, and motivation can help find new ways to make high-reliability practices a part of changing manufacturing settings.

6. Conclusion

This study evaluated the effects of a maintenance strategy rooted in Reliability-Centered Maintenance (RCM) principles within a medium-sized cookie manufacturing facility. The implementation yielded meaningful operational gains, including a 20.7% reduction in production line downtime and a notable improvement in OEE from 45.6% to 65.5%. These advances point to improved asset availability and performance regularity. Additionally, using FMEA allowed for the systematic identification and prioritization of failure modes, sharpening preventive and corrective maintenance activities. As a result, the maintenance process became more focused, reducing unnecessary labor and spare part consumption while also lowering the volume of defective products. The framework not only improved performance metrics but also established a sustainable foundation for long-term maintenance excellence.

These outcomes carry particular significance for the mass-consumption food industry, an arena where tight market schedules compel manufacturers to sustain exceptional levels of uptime, efficiency, and product quality.

The study proves that even in resource-constrained environments like medium-sized enterprises, substantial improvements in maintenance management are achievable through structured methodologies focused on reliability.

The contributions of this research to the field of industrial engineering are manifold. First, it provides practical validation of the RCM approach in a specific and underdocumented industry such as cookie manufacturing. Second, it offers a systematic approach for failure identification, prioritization of interventions, and resource management, which can be replicated in other industries with similar characteristics.

As a final observation, future research should delve into the integration of digital tools to automate maintenance planning and failure prediction. Additionally, it would be valuable to explore the model's impact on other key performance indicators such as product quality and customer satisfaction.

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