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Original Article

Lean and RCM-Based Production Model to Improve Operational Efficiency in the Production Line of a Peruvian Dairy SME

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Abstract - *Many small dairy companies lose productivity over and over again because they have to switch equipment too often, and it breaks down too often. Earlier research looked at these problems separately using Lean or maintenance tools, but they rarely combined the two. This study tried to fill that gap by suggesting a model that combines SMED and Reliability-Centered Maintenance (RCM) to improve the packaging stage of a small business in Peru. The study dealt with urgent problems like long setup times and a lack of equipment. The model included structured changeover procedures, failure mode analysis, and maintenance routines that could be done on their own. Because of this, the setup time went down by 56%, the MTBF went up by 75%, and the packaging OEE went up by 17%. These results showed that the model could help operations run more smoothly and make them more responsive to what the market wants. The model was useful for more than just academics; it was also a cheap option for small and medium-sized businesses in developing countries. Researchers should use this integrated approach in other fields and keep testing it over time.*

Keywords - *Lean Manufacturing, Reliability-Centered Maintenance (RCM), Operational Efficiency, Production Line Performance, SMEs, Dairy Industry.*

1. Introduction

The dairy industry, especially making by-products like yogurt, is very important for the economies of Latin America, and especially for Peru. This sector not only meets the basic nutritional needs of the population, but it also helps the economy grow by creating jobs and adding value to local supply chains. The food industry, which includes dairy production, is very important to the Peruvian economy. It makes up a large part of the country's industrial GDP and is a major contributor to both domestic and foreign trade [1]. Also, most of the businesses in this industry are Small and Medium-Sized Enterprises (SMEs), which shows how fragmented and locally based they are. These small dairy businesses, which make things like yogurt, cheese, and fresh milk, help the economies of their regions by getting their raw materials from small farmers and selling traditional products to niche markets. Even though they are small, they all play a big role in providing food and boosting the national income. This shows how important it is to make them more productive and competitive.

However, small and medium-sized dairy farms have big problems with production that make it hard for them to run their businesses efficiently. Several studies have shown that their productivity is limited by problems like bad maintenance and not having standard procedures. On the one hand, machinery often breaks down because of poor or reactive maintenance, which causes production lines to stop unexpectedly. Most of the time, small-scale food processing plants have to stop working due to equipment problems. In one case study, almost 80% of the interruptions were caused by machinery problems and their effects on other things [4]. The fact that these assets are not reliable is because they do not receive the right preventive maintenance and are not properly staffed with specialized technical staff, which is common in small and medium-sized businesses that do not have a lot of money. On the other hand, it takes a long time to change or set up a product because there are no standardized procedures, and Lean practices are not used on the production floor. Many small and medium-sized food businesses do not manage their processes well, leading to long preparation and operation times and low performance levels [3]. For example, some plants have an average efficiency level of only about 60%, which is much lower than the industry standard of about 80% [2]. This mix of frequent breakdowns and slow changeovers makes production hours much less effective, raises operating costs, and makes it harder to fill orders on time. High variability in the quality of raw materials, limited staff training, and low levels of automation are also common causes that make the productivity problem even worse. These things all add up to explain why many small and medium-sized dairy businesses are not very competitive. They have a hard time meeting rising demand in a way that is both profitable and long-lasting.

Because of this, small and medium-sized businesses (SMEs) in the dairy industry must make the issues mentioned above a top priority. Making operations more efficient would not only help these businesses make more money, but it would also help them stay in business in a market that is getting more competitive. Several studies have shown that using tools and methods for continuous improvement can help small food businesses a lot. For instance, using Lean Manufacturing methods has led to big gains in productivity and order fulfillment. A case study of a small Peruvian food business found that after using Lean tools like SMED, Kanban, and standardized operations, the rate of order fulfillment went up a lot, from about 80% to 95.86% [3]. Cutting cycle times in the main process by about 19% and getting rid of unnecessary waiting in the workflow cut down on delays and stockouts.

Taking care of equipment before it breaks down also improves availability and keeps operations running smoothly. In fact, combining maintenance strategies with Lean practices has worked in small-scale manufacturing settings. For example, when applied to a Peruvian company, equipment availability increased by 11.8% and overall cycle time decreased by more than 20% [5]. Cross-sectional studies in developing countries also show that small and medium-sized food and beverage businesses that use Lean methods to cut down on waste and downtime see increases in output and efficiency [6]. The use of continuous improvement principles has even helped at the supply chain level. For example, Lean practices helped cut down on food waste and losses in Uganda's dairy supply chain [7]. These results show that there is a lot of room for improvement. Dairy SMEs can greatly boost their productivity, service quality, and competitiveness by cutting down on breakdowns and unproductive time. Also, a more efficient and reliable operation makes better use of raw materials and inputs, which lowers costs and losses. This is especially helpful in the yogurt and fresh dairy business, where delays or failures can lead to waste of products that go bad quickly. In short, fixing operational inefficiencies makes internal performance metrics better (like OEE, service level, or unit costs) and makes the company stronger in the market against bigger companies, making it more likely to last over time.

Even though the benefits have been shown, there are still gaps in knowledge and application in literature and industry practice, especially for small and medium-sized dairy businesses. On the one hand, systematic reviews show that many small food businesses still do not fully use Lean tools, either because they do not know about them or because they can not use them [8]. This shows that there is a big chance for Latin American Small and Medium-sized Enterprises (SMEs) to modernize using proven methods for continuous improvement that they have not used much yet. On the other hand, a specific research gap has been found: most studies look at how to make production more efficient (through Lean Manufacturing or other methods) and how to make equipment more reliable (through maintenance strategies) separately. No studies in the Peruvian dairy SME sector have fully combined both approaches. For instance, some projects have focused on sustainable Lean Manufacturing to cut down on waste in a dairy plant. These projects have cut waste by more than 4% and increased efficiency by almost 14% [9]. However, these projects mostly focused on getting rid of process waste and visual management, and did not fully address the problem of recurring mechanical failures. In addition, other writers have suggested Reliability-Centered Maintenance (RCM) policies for the dairy industry that are based on the fact that small-scale plants run continuous processes [10]. These maintenance plans stressed the importance of making sure that important equipment is always available and showed how better maintenance planning can stop problems that lower the quality of the final product [10]. However, these plans usually do not include lean tools to fix time problems on the floor. This leaves a gap: no single model combines Lean techniques (like SMED to cut down on setup times) with reliability-centered maintenance methods to solve both of the main problems that were found: too much unproductive time and too many breakdowns. To meet this need, the current study suggests a new production model that combines Lean Manufacturing tools like standardized operations and systematic SMED implementation with a maintenance plan based on RCM that has been tailored to the needs of small and medium-sized dairy businesses. In the context of this study, this integrated approach is new because our model tries to improve both product changeover speed and machine reliability at the same time, unlike previous work that only looked at one aspect. So, it should make the yogurt production process as a whole work better in a more stable way. The proposed contribution is different from other research because it combines two previously separate paths to improvement: standalone Lean implementations have been able to cut down on some types of operational waste [9], and independent RCM initiatives have made assets more available [10]. The integrated solution presented here aims to do even better by addressing the root causes of inefficiency. By doing this, the study not only fills the gap in the literature but also gives small and medium-sized dairy businesses a practical way to improve their productivity and competitiveness by using Lean Manufacturing and RCM together. This will help the sector grow in a sustainable way in Latin America.

2. Literature Review

2.1. Lean Manufacturing: Increasing Efficiency with Concrete Evidence

The Lean method is all about getting rid of waste, making processes better, and encouraging ongoing improvement.

When it comes to small and medium-sized businesses in the dairy industry, tangible results show how important it is.

In a small food business in Peru, Huarcaya-Meléndez and Platero-Mamani came up with a model that combined 5S, Poka-Yoke, and Systematic Layout Planning (SLP). They cut the standard time per unit by 3.19%, waste by 54.17%, and improved labor productivity by 40.6% (from 17.8 to 25.02 kg/day) after using a 5S pilot and layout simulations [1].

Silva Carrijo and Batalha looked at a number of cases in the agricultural and food industry and found that tools like VSM and 5S cut down on waste and boost profits. This proves that Lean can work in processes that involve perishable materials and changing flows [11]. Verma and Sharma showed a real case in an Indian small business where they used Lean modeling and VSM to cut lead time by 83%, inventory levels by 89%, and operator productivity by 43% [12].

Choudhary et al. also did a study on a small business in the UK that looked at "green" Lean by adding sustainability criteria. They were able to make things better by combining Lean and Green Manufacturing. They used less energy, made less waste, and had better operational indicators [13].

2.2. SMED: Agility in Line Changes for Dairy SMEs

In dairy manufacturing, where changing product formats is routine, the Single-Minute Exchange of Die (SMED) method becomes indispensable. By shifting certain tasks usually done with the machine off to times when it is still running, SMED dramatically trims overall changeover duration [14].

Lozano and colleagues validated a tailored SMED process in the food sector and recorded sizable gains in Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR), and Overall Equipment Effectiveness (OEE), showing that dairy-like plants can benefit in the same way [14].

In Europe, Y. Malek Maalouf and M. Zaduminska paired Value-Stream Mapping (VSM) with SMED on a product line and cut changeover time by 34 percent while increasing capacity by 11 percent, underlining the power of these tools when used together [15]. Ribeiro and co-authors reported a 58-percent drop in changeover duration at a Brazilian agribusiness and a 50-percent reduction in operator movement, leading to a 14-percent gain in productive output, allowing additional workers [16].

Stapelbroek and his team, studying a non-dairy European food producer, identified nine technical and organizational elements critical for curbing downtime at line exchanges, reiterating that expert insight and cross-disciplinary teamwork are often decisive drivers of improvement [17].

The examples show that small- and medium-sized dairy firms can adopt SMED to cut changeover times, support small-batch runs, and streamline logistics, and when SMED is paired with 5S, TPM, and VSM, the gains are considerable yet do not demand large capital outlays.

2.3. RCM (Maintenance Centered on Reliability): Maximizing Uptime in Dairy SMEs

Reliability-Centered Maintenance (RCM) prioritizes the maintenance of assets whose failure may severely disrupt production or endanger personnel. In the dairy sector, for example, the unscheduled shutdown of a homogenizer or a dryer can ruin an entire batch; thus, RCM becomes essential for protecting both quality and operational flow.

In Stockholm Dairy, part of the Arla Foods group, researchers adopted RCM in 2017 alongside Value-Stream Mapping (VSM) and Analytic Hierarchy Process (AHP) to cut downtime on the 1.5-liter milk-packaging line. By tracing the root causes of stops and tailoring maintenance actions, the team boosted line availability and improved delivery accuracy[18].

Yavuz et al. (2019) piloted RCM at a Turkish food factory and reported Overall Equipment Effectiveness (OEE) gains for the packaging machines studied. Their work illustrated the shift from calendar-driven tasks to a regime anchored in each unit's actual functions[19].

Another project called Implementation of RCM and DOFR in milk powder drying unit combined RCM with Design Out for Reliability (DOFR) on the plant's critical components and dryer. Analysts noted a 12-15 percent longer operating time and a sharp drop in failure-related downtime[20].

A recent review on ResearchGate (2023) concludes that Reliability-Centered Maintenance in dairy beverage plants cuts unplanned downtime, reduces expenses, and improves safety and food quality [21].

3. Contribution

3.1. Proposed Model

Figure 1 shows a production model for a Small or Medium-sized Enterprise (SME) that makes dairy products. The goal is to make the packaging process more efficient by applying Lean Manufacturing principles and Reliability-Centered Maintenance (RCM) strategies in tandem. The model had three parts that were all connected to each other. The first component was based on the SMED methodology and focused on reducing changeover time in the packaging machine. To do this, a special team was put together, and practices like sorting tasks into internal and external ones and turning internal operations into external ones were put in place. All of this was done with the goal of continuous improvement and getting rid of waste. The second part was making a preventive maintenance plan based on RCM. This helped find critical functions, failure modes, and root causes so that preventive actions could be set up that were in line with how important the equipment was. Lastly, the third part was a verification process meant to make sure that the improvements made were permanent. This all-encompassing strategy made it possible to align technical and human resources with an operational philosophy centered on dependability. This helped ensure that the improvements made would last in a competitive setting.

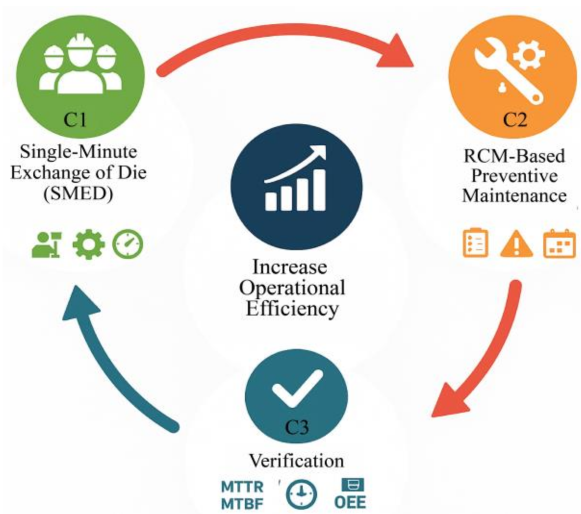

Fig. 1 Proposed model

3.2. Model Components

For Small and Medium-sized Enterprises (SMEs), implementing improvement models within the dairy sector serves as a strategic lever for enhancing competitiveness, particularly in the packaging process. The schematic model in Figure 1 was developed to address the operational constraints typical of such organizations. It combines the principles of Lean Manufacturing and the systematic procedures of Reliability-Centered Maintenance (RCM). The model is built around three components interlinked by a common aim: to reduce downtime and the packaging line non-productive changeover time, and to diminish machine failure incidences and their associated time losses. Each component of the model approaches the process, tackling different angles, focusing on productivity optimization and maintenance work stream efficiency. This blend of approaches makes the model unique in the context of SMEs– integrating tools for continuous improvement into the framework of reliability analysis methodologies merges with field work in a real operational setting.

3.2.1. First Component: Standardization and Agility through SMED in Dairy Operations

The first aspect of the model relates to adopting the SMED (Single-Minute Exchange of Die), which aims to dramatically cut the setup and packaging equipment change times. This phase is based on the principles of micro-scheduling and the rearrangement of social, internal, and external systems during changeovers in an attempt to create uninterrupted production flow continuity.

In this case, the model commences with assembling a specialized work unit comprising operators, technicians, and a production supervisor. Such a multidisciplinary work unit requires training on basic and advanced concepts of the SMED methodology so that it can be successfully implemented on the packaging line. In this case, the participation of the personnel on the shop floor is very important as their hands-on knowledge of the equipment enables them to pinpoint operational improvement opportunities.

Afterwards, a thorough investigation on the processes involved in scope changes is done, identifying which processes can be performed when the machine is running (external tasks) and which processes require machine shutdown (internal tasks). This classification is aimed at redesigning the changeover system with the objective of minimizing effective downtime.

As soon as tasks that can be externalized are recognized, the operation sequence undergoes changes to integrate additional steps like tools and materials pre-set preparation and machine calibration. At the same time, the model encourages the application of Lean tools such as 2S and Andon, which provide real-time problem visualization, thus enhancing workplace order. These methods improve organizational order and enable proactive correction of early variances, which allows for the standardization of changeover processes.

The change from internal to external processes involves more than just moving tasks to another location. It is a definite attempt to redesign workflows by removing, combining, and restructuring repetitive steps. This effort sustainably reduces the time taken to switch products on the packaging line, improving equipment's operational availability and the optimal scheduling of batches. The changes made enhance efficiency while minimizing the cost of idle time and unnecessary labor stemming from frequent changeovers.

3.2.2. Second Component: Operational Reliability through Preventive Maintenance based on RCM

After resolving inefficiencies associated with setup times, the model's second component shifts attention towards unplanned stoppages due to mechanical failures.

This goal is accomplished through the application of a preventive maintenance strategy based on RCM models, which organizes maintenance tasks according to the criticality of equipment and focuses on the most impactful operational assets.

This component outlines a systematic inventory of the system components and their roles and functions in the packaging process. This information outlines the critical functional prerequisites and the system constraints that are likely to frustrate their accomplishment. On the basis of such an analysis, potential failures are diagnosed along with their possible operational triggers and technical reasons that could cause the failures.

A critical part of this component is the definition of failure mode, which enables the decomposition of each potential issue to its root causes and defines its impacts at different operational levels. This is followed by a severity and criticality evaluation, which defines both the impact and the occurrence probability of the failure for each defined mode. This analysis justifies the rational approach towards sequencing maintenance actions and establishes the technical criteria for preventive measures.

The model identifies the most appropriate maintenance actions pertaining to each component as suggested by criticality. These may include, but are not limited to, regular inspections, replacement of specific parts, routine servicing of the system, and enhancements to lubrication. Maintenance actions can be stratified by impact and overall frequency of their occurrence, aligning the strategic plan with the SME's operational limits and resource availabilities.

3.2.3. Third Component: Comprehensive Verification and Sustainability of Results

The final aspects of the model involve cross-validation of the results and evaluation of their longevity. This verification step serves both purposes: measuring the results against the targets accomplishes one part of the model's two-way dynamics, while simultaneously establishing the basis for enduring enhancement, which achieves the other.

At this point, a systematic review of the processes and outcomes from earlier parts is referenced. Validation consists of quantitative measures like time and number of failures, as well as the qualitative evaluation of meeting the new compliance benchmarks, operational standards scrutiny, and employees' recalcitrance towards the model. This human dimension is crucial in SMEs because the determination and responsiveness of the team greatly influence the success of any improvement initiative.

Moreover, the gaps or discrepancies outlined with already defined metrics are revisited. This review is enhanced through feedback workshops with the staff concerned, which expose some operational angles that were perhaps too subtle to be noticed in the earlier phases. Procedures are modified as appropriate based on these reflections, integrating the empirical evidence and the recommendations that enhance the accuracy of the model.

This part stands out because it emphasizes operational sustainability. Verification, instead of being treated as a last step, is treated as a recurring practice that supports a cycle of continuous improvement. Therefore, the model fosters an organizational and cultural shift focused on routine reflection, collective learning, and consistent enhancement of processes and systems. This approach helps the SME gain immediate operational advantages while simultaneously enhancing its internal competencies for future difficult situations.

5.2.4. Conclusion: Methodological synergy and real-world applicability in SMEs

In conclusion, the proposed model describes three methodological parts that focus on different but related aspects of the production process in a small dairy business. The model is a full intervention that uses Lean Manufacturing tools and RCM principles to deal with both losses that happen during changeovers and unplanned downtime caused by equipment failures.

Its sequential structure makes it easier to use in real-world situations because each part builds on the results of the one before it, creating a methodological synergy that makes the overall impact stronger. Figure 1 shows how this integration works by showing how technical and human resources are strategically aligned to make the packaging process more efficient.

This model offers a strong methodological option for Small and Medium-sized Enterprises (SMEs) that want to boost their productivity and operational reliability in a very competitive market but have limited resources. Based on solid principles and organized around a logic of continuous improvement, it can be used in other production environments with similar process characteristics, not just a yogurt packaging line. The implementation experience described here is therefore a valuable addition to both the field of industrial engineering and the field of business.

3.3. Model Indicators

Assessment of the production model incorporating Lean techniques alongside RCM strategy emphasized tracking vital metrics pertaining to quality in the Small and Medium Enterprises (SMEs) in the dairy production sector. An explicit definitional scheme reflecting intervention success was developed to capture the impact across particular defined stages holistically. These indicators facilitated a systematic analysis of production processes, allowing for immediate corrective actions and trend identification associated with the decrease in defects.

This methodological approach captured a foundational reference for process variability assessment, promoting sustained evaluation and establishing a continuous improvement framework focused on quality within the dynamic framework of small dairy producers.

3.3.1. Setup Time

Setup time refers to the duration required to prepare equipment or a production line for the next batch. Reducing it helps minimize downtime and boost productivity.

$$\text{Setup Time} = \text{End of Setup} - \text{Start of Setup}$$

3.3.2. MTBF (Mean Time Between Failures)

MTBF indicates the average operating time between two consecutive equipment failures. A higher value suggests greater reliability of the production system $\frac{\text{Total Operating Time}}{\text{Number of Failures}}$.

3.3.3. MTTR (Mean Time To Repair)

MTTR represents the average time it takes to repair equipment after a failure. It reflects the maintainability of machinery and directly impacts availability, MTTR, and

3.3.4. Availability

Availability measures the percentage of time that equipment is ready and functioning when needed, considering both operational and repair times.

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \times 100$$

3.3.5. OEE (Packaging Subprocess)

OEE in the packaging subprocess assesses overall efficiency by combining availability, performance, and quality, offering a comprehensive view of equipment effectiveness.

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality}$$

OEE (Production Process Overall)

This indicator evaluates the total productive efficiency of the manufacturing process, reflecting the system's ability to deliver expected output without delays or defects.

$$\text{OEE}_{\text{Overall}} = \frac{\text{Good Products} \times \text{Ideal Cycle Time}}{\text{Planned Production Time}} \times 100$$

4. Validation

4.1. Validation Scenario

The validation scenario was based on a case study of a small to medium-sized business (SME) in Peru that made and sold dairy products. The company ran a factory that made and packaged drinkable yogurt in a variety of ways. The company had been in business for a long time and had a good position in the market, but it still had problems with its operations that made it less productive, especially when it came to quality and efficiency. More specifically, the company had trouble meeting production goals while also having to do more rework and losing more products. These things hurt profitability, operational and long-term productivity, so a thorough systematic study was needed to find out what was causing the problem. This study looked at the shop floor, which is where the company's most important production processes took place.

4.2. Initial Diagnosis

The study's diagnosis showed that the process of making 1.9 kg of drinkable yogurt was not very efficient. This had a big economic effect, costing the company 1,388,307.8 soles a year, which is 7.3% of its total annual revenue. This result showed that the average efficiency level over the past twelve months was 67.7%, which is lower than the industry standard. The analysis found two main reasons for this inefficiency: unproductive time during the packaging process, which made up 63% of the problem, and product losses during the filling process, which made up the other 37%. The first reason had a lot of problems that caused the filling machine to break down often (55.8% of the problems) and setup time delays (44.2% of the inefficiencies). The second main cause was that the machine's calibration was lost because it was old and worn out, which resulted in more defective output. These results made the operational problem very clear and set the stage for future actions to improve performance in the process being studied.

4.3. Validation Design

The frameworks for production management based on Lean methodologies and Reliability-Centered Maintenance (RCM) were validated in a systematic, field-based implementation. This study was conducted over a four-month period dedicated to the operational optimization of yogurt production. The validation plan was formulated based on the opportunistic principles that guided the approach during the diagnostic phase and implemented through a series of lean techniques such as task assignment, time-efficient maintenance scheduling, and preventive maintenance. Model effectiveness was measured based on changes observed during ongoing daily operations, thereby allowing the assessment of impact and practical integration in the production workflow.

4.3.1. Component 1: Optimization of Setup Time through SMED Implementation

The first part of the suggested model uses the SMED method to try to cut down on the time it takes to set up equipment for making yogurt. During the diagnostic phase, it was found that 63% of production downtime was caused by long setup times, especially on the filling machine. The average setup time alone was 37.5 minutes, which made things much less efficient and cut down on effective working time. By carefully watching and doing time studies, we were able to sort tasks during changeover into internal and external ones. This classification made it easier to plan the external activity parts so that they could be done more quickly or with less waiting time. A new standard procedure was made that involved putting the necessary materials in place ahead of time, automating some parts of the changeover process, and getting rid of verbal instructions. The average setup time went down to 18.75 minutes, which is half of what it used to be. There was more uptime for machines, less work to do during shift changes, and better throughput. Operators were able to actively and willingly follow the defined optimized steps thanks to visual work instructions and operator training. This helped keep the process gains. This part helped build a culture of lean thinking among the production staff, in addition to providing short-term benefits.

Figure 2 shows a comparison of the setup time before and after the SMED was put in place. The first setup took 37.3 minutes, but after using the method, it only took 16.3 minutes. Changing internal tasks to external ones cut down on costs and greatly improved the efficiency of the yogurt production process.

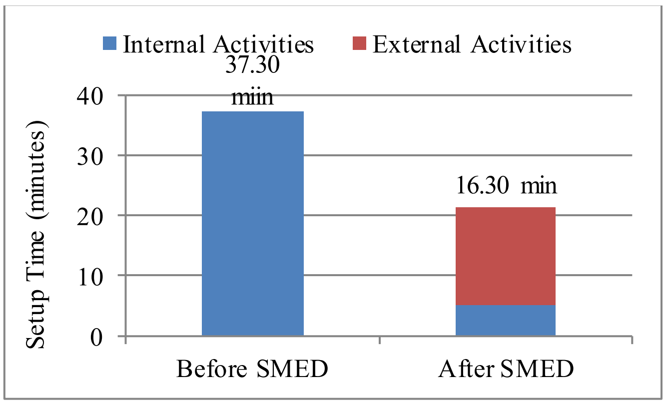

Fig. 2 Setup Time Comparison before and after SMED implementation

4.3.2. Component 2: Reliability Enhancement through Preventive Maintenance Based on RCM

This part is about using a structured RCM-based preventive maintenance strategy to make the equipment more reliable. The system's Mean Time Between Failures (MTBF) was 3.57 hours, and the Mean Time to Repair (MTTR) was 1.53 hours before it was used. These numbers showed that the system broke down a lot and took a long time to recover, which meant it was only available 69.9% of the time. On the other hand, a functional analysis of the yogurt-filling machine was done. This involved mapping out each subsystem, finding out how they could fail, and figuring out how bad, how often, and how easily faults could be found. This analysis helped us find the most important parts and come up with a plan for preventive maintenance that included daily lubrication, weekly mechanical inspections, and monthly checks of the control panel. After the new plan was put into place, MTBF went up by 63.6% to 5.84 hours, and MTTR went up by 49.6% to 0.77 hours. Because of this, system availability went up to 80.6%. These things, along with less downtime in production, made the manufacturing flow much more stable. We changed the shift schedules to include the preventive tasks and made the maintenance logs digital to make it easier to keep track of them.

Also, the staff got more involved by attending failure analysis meetings and helping create a culture of proactive maintenance. This part made it much less necessary to take reactive measures and improved the continuity of operations.

Figure 3 presents the Failure Mode and Effect Analysis (FMEA), which identifies critical failure modes and prioritizes them based on their Risk Priority Number (RPN). Preventive measures were established for each failure to reduce recurrence. The analysis guided the design of a structured maintenance plan to improve equipment reliability and performance.

4.3.3. Component 3: Monitoring and Control to Ensure Model Sustainability

The third part makes a control system that will keep an eye on the improvements and make sure they keep working over time. After using the SMED method and the RCM-based maintenance strategy together, it was important to find out if these changes led to long-term operational improvements. We set up a dashboard of key performance indicators and looked at PEMX metrics like downtime, failure frequency, and production volume in real time every week.

N°	Components	Functions	Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)	Occurrence	Current Controls	Detection	RPN	Measures	Frequency	Recommended Action(s)	Estimated Time to Perform Activities (min)	Responsible and Completion Date	Actions Taken Since	SEV	OCC	DET	RPN	N° times per month	Maintenance Minutes/ Month
3	Piston Dosing Pumps	Allow dosing of yogurt to the filling cylinders	Pressure drop in dosing pump	Does not dose yogurt correctly to filling cylinders	7	Leaks in filling pistons	7	Pressure, vibration, power check	6	294	Inspection	Every 7 days	Check for yogurt leaks in filling pistons, change damaged O-rings, clean machine, adjust pneumatic/electronic system, change hoses and electrical connectors	55	Maintenance Manager 26/05/2024	15/04/24	5	2	3	30	4	220
10	Positioning Motor	Move conveyor belt	Yogurt spill	Delays in bottle transport	6	Misalignment of bottle to fill	4	Motor power control	6	144	Inspection	Every 7 days	Check mechanical and electrical system. Implement system adjustments and bottle positioning. Replace worn belts.	40	Maintenance Manager 26/05/2024	15/04/24	5	2	4	40	2	40
			Insufficient belt drive force	Low fluid motion on belt	5	Belt misadjustment	2	Motor power control	5	50	Inspection	Every 7 days	Check belt alignment and tension. Apply tensioning measures if out of adjustment.	20	Maintenance Manager 26/05/2024	15/04/24	3	2	4	24	2	40
14	Capping Head	Adjust cap to bottle	Capping head misalignment	Reprocessing product	5	Head misadjustment	5	Part condition control	6	150	Inspection	Every 7 days	Inspect capping head. Replace part if necessary.	30	Maintenance Manager 26/05/2024	15/04/24	3	3	4	36	4	120
18	Sealing Valve	Allow vertical and rotary movement of capping head	Pressure miscalibration	Bottles poorly sealed with yogurt	6	Head center and sensor failure	4	Motor power control	5	120	Inspection	Every 7 days	Check push buttons and photoelectric sensors. Align sensors and confirm correct detection of bottles.	60	Maintenance Manager 26/05/2024	15/04/24	5	2	3	30	2	60

Fig. 3 Failure Mode and Effect Analysis (FMEA) and Determination of Preventive Measures

It was confirmed that system availability went up by 10.7 percentage points, the OEE of the filling subprocess went up from 60.4% to 70.6%, and the overall production OEE went up to 72.8%, which is an eight-percentage-point increase. In this step of verification, it was possible to find some minor inefficiencies that were fixed with small changes. Process control and progress charts were also used to help the mentored peer teams become more aware of how to work together to solve problems. Regularly scheduled review meetings made people think more deeply and made operators and supervisors more responsible. After the first good results were maintained, this closed-loop system became very important for scaling the model to other parts of the company.

4.4. Results

The effects captured from the validation of the production management model utilizing Lean Manufacturing tools and Reliability-Centered Maintenance (RCM) in the yogurt processing industry are presented in Table 1. The findings demonstrate an operational reliability improvement by a marked 56% reduction in setup time and a 75% increase in MTBF.

A slight decrease in MTTR of 2% and a rise in system availability by 15 percentage points brought it to 80.6%. Furthermore, the OEE of the packaging subprocess was enhanced by 17%, and the total production process OEE improved by 8%, indicating overall better performance.

The results achieved corroborated the rationality of the designed model in the effectiveness of performance resource optimization, operational waste reduction, production system stabilization, and integrated multi-factor control strategy enhancement.

Table 1. Results of the pilot

Indicator	Unit	As-Is	To-Be	Results	Variation (%)
Setup Time	**minutes**	37.5	18.75	**16.39**	-56%
MTBF	**hour**	3.57	5.84	**6.23**	75%
MTTR	**hour**	1.53	0.77	**1.5**	-2%
Availability	**%**	69.90%	80%	**80.60%**	15%
OEE (Packaging Subprocess)	**%**	60.40%	70%	**70.60%**	17%
OEE (Production Process Overall)	**%**	67.70%	72.70%	**72.80%**	8%

5. Discussion

This study achieves a 56 percent reduction in setup time, a 75 percent increase in Mean Time Between Failures (MTBF), and a 17 percent improvement in packaging subprocess Overall Equipment Effectiveness (OEE), highlighting the value of combining Single-Minute Exchange of die (SMED) with Reliability-Centered Maintenance (RCM) in one framework. These results align with earlier investigations that underscore the advantages Lean and maintenance tools offer Small and Medium-sized Enterprises (SMEs) in the food sector. For example, Pérez-Canchanya et al. recorded a jump in order-fulfillment 8rates fromto 95.86 percent to 95.86 percent in SME after introducing SMED and standardized work procedures [3]. Similarly, Lozano et al. validated a SMED protocol in that same industry and observed marked improvements in OEE and repair times [14]. With respect to reliability, Yavuz et al. raised packaging machines' OEE by implementing RCM in a Turkish food plant [19], and Haneda-Miyashiro, along with Navarro-Hoyos, combined Lean, Total Productive Maintenance (TPM), and RCM in a Peruvian metalworking SME to boost equipment availability by 11.8 percent [5]. Additionally, Aguirre-Cueva et al.
Lean Manufacturing tools have been shown to enhance production efficiency in small-and medium-sized enterprises within the food sector, enabling these firms to work around many structural constraints [2]. Building on that foundation, the current study focuses on an unexamined issue: the failure to link Lean practices with Reliability-Centered Maintenance. Although Chaparín Japa et al. employed a sustainable Lean framework to cut waste at a dairy plant in Peru, their model overlooked persistent mechanical faults [9]. In contrast, the present research combines Lean and RCM techniques so that losses from slow setups and sudden breakdowns can be tackled together, yielding gains in productivity, equipment dependability, and long-term sustainability.

5.1. Study Limitations

While the proposed model demonstrated strong performance in a Peruvian SME that produces yogurt, generalizing its benefits to other dairy items or entirely different industries warrants caution. Testing occurred within a well-supervised, actively supportive setting that may not mirror the varied circumstances found in many factories.

The four-month research period offered a useful snapshot of immediate metrics like OEE and MTBF, yet it fell short of capturing the long-term persistence of cultural shifts and stable adherence to maintenance routines. Moreover, critical actions such as workforce training and process redesign depended heavily on local enthusiasm and leadership maturity, factors that could prove elusive in organizations with greater resistance to change or weaker managerial structures.

5.2. Practical Implications

The study provides evidence that a joint Lean Manufacturing and Reliability-Centred Maintenance framework is workable and beneficial for small and medium-sized enterprises that routinely confront tight budgets and skeletal staffing. Notably shorter changeover times allow managers to schedule more frequent short runs, boost overall equipment effectiveness, and respond more swiftly to the rapid demand swings typical in markets for easily spoiled goods such as yogurt. In parallel, gains in machine dependability smooth the workflow, trim the costs associated with emergency repairs, and build a sturdier operational base. Equally important, the approach cultivates a forward-looking attitude among shop-floor staff and encourages cross-functional teamwork, characteristics that usually prove rare and most needed in capital-constrained firms. For other SMEs considering the model, the key enablers remain committed leadership and a carefully steered change initiative.

5.3. Future Works

Building on the work reported here, subsequent investigations could broaden the proposed simulation framework to the upstream operations-pasteurization, fermentation, and even internal logistics- in order to clarify how these stages, once linked quantitatively, affect the overall performance of the yoghurt production line. In parallel, comparative assessments across other dairy items and, where practical, small-to-medium-sized food-processing enterprises from outside the dairy sector will reveal whether the model retains predictive power and managerial utility in more varied production contexts.

A third avenue of inquiry examines the potential benefits of coupling the simulation with Industry 4.0 tools, such as IoT-based predictive maintenance alerts and configurable real-time dashboards, so that operators gain more timely visibility into bottlenecks and can therefore make faster, data-enriched decisions. Finally, researchers are encouraged to undertake longitudinal studies that track key performance indicators over several production cycles, thereby showing whether the original gains persist and whether accompanying shifts in organizational behavior, financial health, and a culture of continuous improvement follow in Latin American SMEs.

6. Conclusion

The study confirms that an integrated approach bringing together Single-Minute Exchange of Dies (SMED) and Reliability-Centered Maintenance (RCM) can significantly enhance critical performance indicators in the packaging line of a Small-to-Medium-sized Enterprise (SME). By following standardized changeover steps and directing maintenance attention toward identified failure modes, the firm reduces setup times, boosts equipment reliability, and lifts overall operational efficiency. These gains demonstrate that combining Lean practices with targeted maintenance actions can simultaneously tackle the operational delays and mechanical failures that typically diminish productivity in resource-limited settings.

The significance of the work emerges from its attention to the day-to-day hurdles small and medium food producers confront, especially in emerging markets where expensive automation remains out of reach. By offering a workable, low-cost intervention that smaller firms can copy, the research shows that systematic process improvements need not demand heavy capital outlays but depend instead on staff buy-in and disciplined application of proven methods. Such findings underline the necessity of customizing continuous improvement frameworks to fit the real world of low- and mid-volume production operations.

From an academic standpoint, this study presents a step-by-step framework that meshes Lean thinking with Reliability-Centered Maintenance, backing its arguments with real-data examples that show joint use lifts measures like mean time between failures, overall equipment effectiveness, and changeover duration. Doing so fills a noticeable hole in current literature where similar integrations have rarely been explored systematically.

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