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Original Article

Enhancing Productivity in Agricultural Packing Operations through TPM and Lean Manufacturing: A Case Study of Asparagus Processing in Peru

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Abstract *- This study investigates the integration of Total Productive Maintenance (TPM) and Lean methodologies within the Peruvian agricultural sector, focusing on asparagus packing operations. A model was developed to address critical challenges of low productivity, employing autonomous and preventive maintenance strategies to reduce unplanned downtime and the implementation of Standardized Work to eliminate inefficiencies. A pilot project was implemented using a sample of 72.98 kg of processed asparagus, using processing times from each activity as input data for the model's validation. The Kolmogorov-Smirnov and Chi-square statistical tests were applied to establish time distributions. The proposed model, validated through Arena software, demonstrated a 21% increase in packing productivity, a 36 kg/man-hour improvement in labor productivity, and a 26.35% enhancement in machinery availability. These findings provide a replicable framework for medium-sized agro-exporting companies, enhancing their operational efficiency and competitiveness within global markets. The research contributes to the limited literature on Lean and TPM applications in agricultural processes, highlighting their potential to bridge productivity gaps in developing countries.*

Keywords *- Agricultural Industry, Autonomous Maintenance, Planned Maintenance, Productivity, Standardized Work.*

1. Introduction

Agriculture is an important sector of Peru's economy and the primary livelihood for numerous families. Technological progress, implementation of better public policies, and the increasing global demand for agricultural products due to the growing population have contributed to its growth. Since 2011, the sector's GDP has grown by 70%, reaching an important export development that has positioned Peru as one of the world's leading exporters of asparagus [1]. Despite its growth, the technological barrier of the agricultural sector in Peru is high compared to other countries in the region. Although Peru's agricultural performance is relevant in the region, the lack of adoption of new agricultural technologies causes the country to remain behind. According to the Global Competitiveness Index, it is 49 points below the highest position in technological readiness [2]. One of the sector's main problems is the low labour productivity, one of the most essential but most costly and regulated factors [3]. The productivity of a Peruvian agricultural worker is about 3084.5 dollars per worker, below Chile, with a productivity indicator of 11 936.93 dollars per worker, and Argentina, with 2.76 million dollars per worker [4]. The high productivity levels in countries like Brazil can be attributed to their advanced technology. [5] proposed a Computer Vision System based on lean principles to reduce the classification time of asparagus, thereby increasing productivity from 5 to 10 kg/hour. However, due to the lack of machinery in the Peruvian agricultural sector, a solution relying on the human workforce has been implemented.

The purpose of this research is to increase the productivity of asparagus packing in Peru through a TPM and Work Standardization improvement model. The present case study has a labour productivity of 1.29 kg/usd, while other companies in the sector have a labour productivity of 1.73 kg/usd [5], with a gap of 0.44 kg/usd. This comparison is based on the initial conditions of the study, which emphasizes genetic improvements in asparagus to boost productivity, given the limited research focused on labor productivity enhancement. Regarding machinery productivity, agricultural companies in Brazil have an indicator of 342.47 kg/usd due to the implementation of automated systems and reduction in the use of labour [6]. While the case study has a machinery productivity of 40.44 kg/usd, calculating a gap of 302.03 kg/usd. The total technical productivity gap is 302.47 kg/usd, indicating that the company presents an opportunity to improve its productivity and, consequently, its competitiveness in the sector.

The following questions are formulated for the research: How is the TPM tool and the standardization of work applied to improve productivity in asparagus packing? How is the TPM tool applied to a fruit or vegetable packing line? What is the relationship between the application of Standardized work and the reduction of processing times in packing? To what extent did the implementation of TPM and Standardization of work improve the productivity of the companies that implemented it? The study's main objective is to increase the productivity of asparagus packing using TPM and Lean tools. The specific objectives are to reduce untimely line stoppages, reduce process downtime, and implement standard operating procedures.

A study developed a TPM-based scheme applied to the United Beverage Company in Kuwait (KSCC), a company with 11 production lines for filling bottles. After nine months of applying the scheme, glass line efficiency increased by 44%, line availability increased by 13%, and Overall Equipment Efficiency (OEE) increased by 62.6%. On the other hand, Ahuja and Kumar implemented TPM at Tata Steel Tubes Strategic Business Unit in India. They achieved a 78% improvement in productivity, a 59% improvement in OEE, and a 63% reduction in equipment breakdowns [7].

CVNS Industries implemented a standardized approach in parts manufacturing by identifying and eliminating non-value-added activities. This led to the proposal and adoption of a new work method. After training the personnel and implementing the new approach, the total process time decreased by 8%, from 537 minutes to 496 minutes, significantly boosting productivity by reducing manufacturing times. Similarly, Jolocar, a company based in Lima, applied the same standardization tool to its dispatch process. By identifying and eliminating unproductive times, the company achieved a 17.10% improvement in productivity. Other researchers have also emphasized the importance of eliminating unnecessary activities and optimizing the combination and sequence of tasks to streamline work processes.

This study addresses a critical gap in the existing literature regarding implementing lean manufacturing tools within the Peruvian agricultural sector. While significant improvements have been documented across various global industries, the application of these methodologies in Peru, particularly in agriculture, remains underexplored. This research offers a comprehensive empirical analysis of how autonomous and planned TPM tools, along with Standardized Work, can effectively tackle the issue of low productivity in asparagus packing in Peru. The findings demonstrate a notable enhancement in productivity, accompanied by significant reductions in processing time and production costs. Furthermore, the production model presented is replicable for medium-sized asparagus exporting companies operating under similar conditions. Ultimately, this contribution not only fills a crucial gap in the literature but also provides a practical framework for enhancing the competitiveness of agricultural enterprises, especially in developing countries.

2. Literature Review

2.1. Production Models to Improve Productivity in the Agro-Industrial Sector

Golroudbary and Zahraee highlight that organizations in the manufacturing industry commonly face challenges such as quality losses, production declines, and material waste, all of which negatively impact productivity [8]. To address these issues, various studies have implemented models to enhance productivity within the packaging industry. For instance, Lean practices have been employed to improve performance indicators in companies involved in plastic packaging manufacturing.

Lean concepts were implemented in the standardization of processes and routines and the reorganization of work processes to minimize manual tasks. These efforts resulted in significant improvements in injection processes and reductions in nonconforming products [9]. Six Sigma was used in an olive packaging line to reduce weight variation in the olives. The team noted that a lack of training of unskilled personnel could result in production failures, highlighting the importance of training not only line operators but all personnel. In addition, poor equipment maintenance resulted in out-of-specification jars, but the study did not use Total Productive Maintenance (TPM) as a corrective measure [10].

On the other hand, a previous study applied Lean Manufacturing concepts in agribusiness to optimize the flow of the pig slaughter line from reception to the packing area. This study developed a model utilizing Value Stream Mapping (VSM) methodology and line balancing to demonstrate the application of simulation in increasing productivity within a pig slaughterhouse. The focus was on balancing the workstations by optimizing the idle time of operators and comparing it with the cycle time of each task at the evaluated workstations. The simulation results indicated an 11.89% increase in plant productivity through labor optimization [11].

Another study explored using TPM and 5S as tools to enhance productivity in an automotive parts factory in South Africa. Chapman describes 5S as an effective tool for managing and organizing various operational activities within manufacturing. The study found a statistically significant relationship between machine downtime and productivity and concluded that productivity was not directly related to the implementation of 5S [8]. This confirms a gap in the literature and the opportunity to apply Total Productive Maintenance and Standardization of Work tools in the manufacturing industry to increase machine availability and improve labor performance.

The studies mentioned employ various Lean tools to enhance productivity in various manufacturing sectors. However, there is a notable gap in research that combines Total Productive Maintenance (TPM) with Lean methodologies to specifically address the low productivity of packaging lines. This project presents a production model integrating autonomous and planned TPM with Work Standardization in asparagus packing. It is important to emphasize the scarcity of studies applying Lean Manufacturing in the agricultural sector, particularly in developing countries, where the technological gap makes it difficult to meet the growing food demand.

2.2. Low Productivity of the Agricultural Sector in Developing Countries

The food sector worldwide, especially in developing countries, is currently not sustainable. The world population is growing steadily, and the demand for food production is increasing proportionally. Several authors highlight that several factors reduce crop productivity and lead to food shortages, such as climate change, continuous depletion of natural resources, and negative environmental effects caused by chemical fertilizers and pesticides [12]. There is a consensus that agriculture is the backbone of many developing countries' economies, and therefore, there is a need to develop sustainable and fast-growing agricultural systems.

Three significant causes for low productivity in a mango processing line in Peru were discovered: the amount of time lost throughout the production process, the lack of mango inputs due to high discard rates from sorting, and the high reprocessing rate [13]. Therefore, the researchers proposed to increase the line's productivity through a management model that promotes continuous improvement and includes implementing Lean tools such as Standardization of Work, 5S and Systematic Layout Planning (SLP).

However, the limited research on the application of Lean and TPM tools in the agricultural sector, particularly in the fruit and vegetable processing industry, is concerning. It is crucial to validate and promote the use of these methodologies to enhance the productivity of agricultural companies, thereby boosting the industry's competitiveness.

2.3. Total Productive Maintenance (TPM)

TPM is an integrated maintenance methodology aimed at maximizing equipment operational efficiency through preventive maintenance, continuous improvement, and employee participation. Its goal is to reduce production losses due to breakdowns, stoppages, defects, and accidents by involving all personnel, from operators to managers. The principles of TPM are organized into eight pillars. The second pillar, autonomous maintenance, involves training line operators to perform basic maintenance tasks, such as cleaning, lubricating, and inspecting equipment. The third pillar, planned maintenance, focuses on implementing a preventive and predictive maintenance plan based on failure analysis and equipment conditions [14]. In a fruit processing line, autonomous maintenance can be applied to routine inspection and cleaning tasks, preventing debris buildup on equipment that could lead to failures. A well-planned TPM strategy also minimizes conveyor belt downtime and ensures consistent operation of refrigeration equipment.

2.4. Autonomous Maintenance in the Agricultural and/or Similar Sectors

Autonomous maintenance is the second pillar of TPM. It includes training on basic maintenance tasks, such as inspection, cleaning and lubrication of equipment to keep it in optimal condition and prevent major failures. A Six Sigma model was applied in an olive packing line, where poor equipment maintenance resulted in nonconforming jars and production delays. However, the lack of a maintenance strategy, personnel and time to perform it generated products with the wrong specifications [10].

Mwanza and Mbohwa emphasize that for a TPM program to succeed, commitment is required from everyone in the company, from top management to shop floor personnel [7]. In a clutch and hydraulic controls company, developing new autonomous maintenance procedures, followed by preventive maintenance plans, was crucial. The implementation procedure and the commitment adopted by all the company's staff and management were the keys to success [15]. The authors agree that operators should be empowered to identify and report failures, with routine maintenance being the responsibility of all operators, not just the maintenance team.

In this context, the present project aims to apply autonomous TPM in asparagus packing to enhance current maintenance practices and ensure the reliable operation of the line's equipment. However, the scarcity of research on autonomous TPM in the agricultural sector is concerning. It is essential to promote the adoption of this tool so that companies in the industry can leverage its competitive advantages.

2.5. Planned Maintenance in the Agricultural and/or Similar Sector

Planned maintenance, the third pillar of TPM, involves teaching failure analysis techniques and scheduling preventive and predictive maintenance activities to prevent process disruptions. Developing TPM-based maintenance plans is crucial for the industrial manufacturing sector, where equipment is often prone to failure.

One study implemented a sequential TPM scheme that increased overall equipment efficiency by 62.6% over nine months, significantly improving equipment availability, operational efficiency, and product quality. The authors agree that implementing TPM improves productivity OEE and reduces equipment breakdowns and manufacturing costs [7].

A second study developed a planned maintenance strategy in a plastic bag manufacturing company. After implementing this TPM pillar, equipment availability increased by 13%, and critical equipment breakdowns decreased by 83%. According to Gupta, TPM reduces equipment breakdown losses, setup/setup losses, downtime losses, startup losses, and losses due to defects and rework [7].

In this project, planned TPM is employed to prevent unplanned stoppages in the asparagus production process, enhance machine availability, and thereby boost productivity. To achieve this, inspections are scheduled on a weekly, monthly, or annual basis. However, the limited research on planned TPM in the agricultural sector is concerning. It is crucial not to overlook maintenance programs in manufacturing and agricultural industries, as inadequate maintenance systems can significantly reduce company productivity.

2.6. Work Standardization

Work standardization is a key tool in Lean methodology, which focuses on establishing the best way to perform a task to ensure repeatability and reduce variability in work methods [16]. Effective implementation of this methodology requires a set of clear instructions and standardized work equipment [17]. In a fruit processing line, fruit handling and sorting can be standardized, as can all other procedures to define the best sequence of operations, cycle times and proper use of tools or equipment. Standard procedures can also be established to configure the machines according to the different types of fruit and packing formats.

2.7. Work Standardization in Agricultural and/or Similar Processes

Previous research shows that achieving work standardization in an organization requires investing both material and human resources to reduce quality failures, minimize variations, increase productivity and safety, and decrease material and time waste. CVNS Industries applied standardization to its manual production processes for part manufacturing. By identifying and eliminating non-value-added activities, they proposed a new work method. After training staff and implementing the new method, the total process time was reduced by 8%, from 537 minutes to 496 minutes. Additionally, Guerrero emphasizes the importance of optimizing the sequence of activities to simplify work and eliminate unproductive times.

In line with the above, another study demonstrated that reducing the number of workstations through standardization can maximize production rates [18]. Research consistently shows that standardizing work processes leads to time and resource savings, thereby enhancing overall productivity. For instance, standardizing the dispatch process at Jolocar, a company based in Lima, resulted in a 17.10% improvement in productivity.

This research aims to apply standardized work practices to the packing of asparagus, developing a consistent methodology for a section of the production line. Case studies have demonstrated significant improvements in productivity and reductions in total process time. However, the limited research on standardization within the agricultural sector is concerning. It is crucial to validate and advocate for the use of standardized work practices in fruit and vegetable processing lines, where operators engage in largely manual tasks. Implementing such practices could substantially enhance the productivity of agricultural companies.

3. Methodology

The literature review presented in the previous chapter revealed several thematic gaps in existing models. For each component listed in Table 1, we established the following criteria: literature review, engineering tool, case study, and metrics. We searched for models in the literature that applied specific techniques or tools to fruit or vegetable processing lines and measured indicators such as productivity, machine efficiency, and production times. By reviewing these models, we validated the tools used in the case studies. Due to the limited research on Lean Manufacturing and TPM in the agricultural sector, we used models from similar industries as references.

We found that most models met only 3 to 6 of the evaluated criteria, largely due to the different contexts in which the case studies were conducted. The proposed model addresses these gaps and incorporates successful elements from previous models. It includes performing a Failure Mode and Effect Analysis (FMEA), as this method has been used in earlier models to identify critical failures in packaging lines. Based on the FMEA, Total Productive Maintenance (TPM) was selected for implementation, given its proven effectiveness in enhancing the overall maintenance of machines and equipment in manufacturing settings. Additionally, Standardized Work has been adopted to eliminate unnecessary activities and reduce processing time. The models consulted employed tools such as SMED, Johnson's method, TPM in the plastics industry, and Six Sigma in olive packing. The initial diagnosis of the study concluded that implementing both autonomous and planned TPM, along with Standardized Work, would be most effective in improving productivity.

3.1. Proposed Model

A notable gap exists in the study of TPM and Work Standardization applications within the agricultural industry. While various tools have been employed in the manufacturing industry to enhance line effectiveness, few models have combined the proposed tools to improve productivity in specific case studies. This highlights a gap in applying Total Productive Maintenance (TPM) and Lean methodologies to increase machine availability and enhance labor performance in packaging lines. The proposed model addresses this gap in the literature and offers a practical framework to boost the competitiveness of agricultural enterprises, particularly in developing countries.

The primary goal of applying TPM is to reduce unexpected stoppages in the production line. The root causes identified for this issue include a lack of autonomous maintenance and inadequate preventive maintenance. To address the first issue, operators are trained in basic maintenance practices to ensure that machinery and the workplace are kept in optimal condition. Planned TPM then establishes periodic maintenance standards at each station. Through standardization, the model aims to reduce downtime and address long waiting times between operations. This tool creates a consistent methodology for the manual tasks performed by operators, establishing uniform procedures that reduce variability and errors. In doing so, it resolves the problem of inconsistent methods used in the process due to the absence of standardized procedures. The objective of the model is to increase productivity by reducing production times and increasing machine availability. As shown in Figure 1, the diagnosis of the current situation is performed by means of timing and the Modal Analysis of Effects and Failures. Then, solutions based on Autonomous TPM, Planned TPM and Work Standardization are implemented. Afterwards, the model validation is performed using a simulation.

3.2. Model Components

3.2.1. Component 0: Analysis of the Current Situation

The first component of the model focuses on identifying the current issues in the asparagus packing line. To do this, production indicators are evaluated to pinpoint technical gaps. Next, an Industrial Timing analysis is conducted to identify bottlenecks, and a Failure Mode and Effects Analysis (FMEA) is performed to highlight areas for improvement in maintenance. Using this information, a problem tree is developed, where priority issues are identified through a Ranking of Factors. Based on these findings, the tools needed to increase productivity are determined.

3.2.2. Component 1: Intervention

Component 1 focuses on implementing improvements to address the problems identified in the diagnosis. The first step is the implementation of Autonomous TPM, which begins with introducing TPM concepts to the operators and emphasizing its importance in the packaging line. All operators receive training in basic maintenance tasks, including cleaning, lubrication, and machine and equipment inspections. Following the training, a knowledge evaluation is conducted to ensure that operators correctly follow procedures for tasks such as inspecting table alignment, belt alignment, station cleaning, and bearing lubrication. Based on this, cleaning, lubrication, and inspection teams are established, and a schedule of routine activities for operators is put into practice.

The second tool is Planned TPM, which begins with measuring machinery availability. Operators then receive training on planning periodic interventions based on the incidence rates of each piece of machinery. A maintenance schedule is created to define the frequency of these interventions. After three months of implementing both autonomous and planned maintenance, the indicators are reevaluated to determine if there has been an improvement in the process. If improvements are not observed, additional training is conducted.

The third tool is work standardization, which begins with identifying and measuring the indicators on the line balance sheet. Following this, workstations are reorganized to optimize the flow of raw materials based on the process times identified earlier.

In this way, the stations that involve a short-term and whose entity is the same are placed in the same work block. This reorganization leads to the creating a standard work diagram, which serves as the foundation for subsequent training.

3.2.3. Component 2: Validation

Component 2 assesses the effectiveness of the implemented improvements by measuring the study indicators. This involves simulating both the current model and the model after the improvements have been applied. By reevaluating the times and indicators, the model determines whether there has been a productivity improvement, and the results are documented accordingly. Figure 2 outlines the implementation process of the proposed model.

3.3. Model Indicators

- Machinery availability: Measures machinery utilization time over total production time. Several studies suggest that using TPM increases machinery availability by up to 17.69%.

$$Machinery\ Availability\ (\%) = \frac{Machinery\ Utilization\ Time}{Total\ Production\ Time} \quad (1)$$

- Average employee utilization: Measures the time an operator performs productive activities over the total production time. Multiple studies indicate that standardization of work can improve the original state of study by up to 27.66%.

$$Average\ Employee\ Utilization\ (\%) = \frac{Operator\ Active\ Time}{Total\ Production\ Time} \quad (2)$$

- Production time of each station to be standardized: Studies suggest that implementing work standardization can improve production time by up to 64.58%.

$$Production\ Time_{Station}(min/entity) = \sum_{Activity} Production\ Time \quad (3)$$

Table 1. Comparative table of the components of the proposal model vs literature review

	Optimization model to increase the efficiency of the flexible packaging production process by applying the **Johnson Method, SMED and TPM** in an SME in the Plastics Sector.		Application of **Six Sigma** methodology using DMAIC approach for a packaging olive production system: a case study		Relationship between **TPM** practices and operational performance in soft drinks manufacturing industry		Model based on **TPM** and **Standardization** for the maximization of efficiency in an SME in the plastics sector		A production service management model using **Lean tools** to increase productivity in an agro-export company		A sequential **TPM**-based scheme for improving production effectiveness presented with a case study		Increasing Productivity through **TPM** and **Standardized Work** in an Asparagus Packing: Case Study in Peru	
	Miranda – López, Y., Toledo – Loza, F., & Altamirano - Flores, E. (2022)		Tsarouhas, P. & Sidiropoulou, N. (2023)		Singh, A. & Fentaw, N. (2023)		Aguilar-Schlaefli, J., Campos-Levano, Z., Leon-Chavarri, C., & Saenz-Moron, M. (2022)		Ramos-Leon, H.; Montoya-Valdiviezo, G.; Castillo, J.; Cardenas, L. (2023)		Bataineh, O., Al-Hawari, T., & Dalalah, D. (2018)		Farah-Alva, M., Montaño-Vaez, S. & Quiroz-Flores J. (2024)	
Component 0: Problem Diagnosis • Literature review • Engineering tool: **FMEA** and **Industrial Timing** • Case study: Asparagus Agro-export company • Metrics: Productivity, production times, failures	Literature review	✓	Literature review	✗	Literature review	✓	Literature review	✓	Literature review	✓	Literature review	✗	Literature review	✓
	Engineering tool	✓	Engineering tool	✗	Engineering tool	✓	Engineering tool	✓	Engineering tool	✗	Engineering tool	✗	Engineering tool	✓
	Case study	✗	Case study	✗	Case study	✗	Case study	✗	Case study	✓	Case study	✗	Case study	✓
	Metrics	✓	Metrics	✓	Metrics	✗	Metrics	✗	Metrics	✓	Metrics	✗	Metrics	✓
Component 1: Implementation • Literature Review • Engineering Tool: **TPM** and **Standardization** • Case Study: Asparagus Agro-export Company • Metrics: Production times, availability of machinery	Literature review	✓	Literature review	✗	Literature review	✓	Literature review	✓	Literature review	✓	Literature review	✓	Literature review	✓
	Engineering tool	✓	Engineering tool	✗	Engineering tool	✓	Engineering tool	✓	Engineering tool	✓	Engineering tool	✓	Engineering tool	✓
	Case study	✗	Case study	✗	Case study	✗	Case study	✗	Case study	✗	Case study	✗	Case study	✓
	Metrics	✓	Metrics	✓	Metrics	✗	Metrics	✓	Metrics	✓	Metrics	✓	Metrics	✓
Component 2: Validation • Literature review • Engineering tool: **Simulation** • Case study: Asparagus agro-export company • Metrics: Production times, machinery availability, employee utilization	Literature review	✓	Literature review	✗	Literature review	✗	Literature review	✗	Literature review	✓	Literature review	✗	Literature review	✓
	Engineering tool	✓	Engineering tool	✗	Engineering tool	✗	Engineering tool	✗	Engineering tool	✓	Engineering tool	✗	Engineering tool	✓
	Case study	✗	Case study	✗	Case study	✗	Case study	✗	Case study	✗	Case study	✗	Case study	✓
	Metrics	✓	Metrics	✓	Metrics	✗	Metrics	✓	Metrics	✓	Metrics	✓	Metrics	✓
	Total	**9**	**Total**	**3**	**Total**	**4**	**Total**	**6**	**Total**	**9**	**Total**	**4**	**Total**	**12**

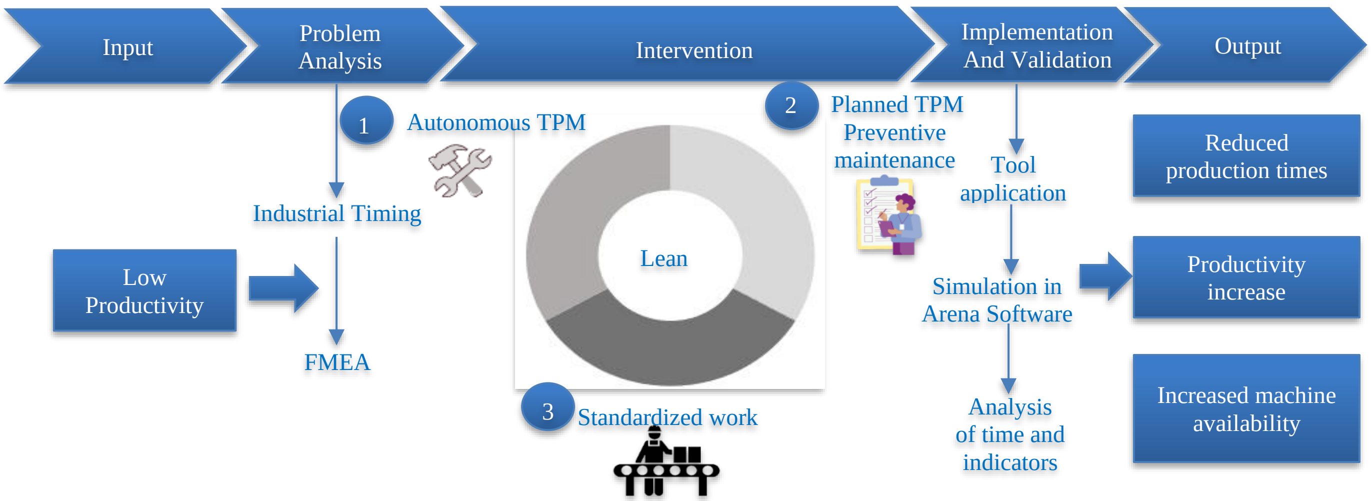


Fig. 1 Proposed model

4. Results

4.1. Scenario Description

The case study was developed in the asparagus packing area of an agricultural company, where the research was validated. This Peruvian company was founded in 1990 to cultivate and export fresh asparagus. Since 1993, it has expanded through land purchases and usufruct agreements, currently owning 284 hectares of land and 264 hectares under usufruct in Huarmey, along with an asparagus packing facility. Figure 3 shows the current process model, which is limited from the asparagus feeding to transport the asparagus boxes to the hydrocooler.

4.2. Initial Diagnosis

The asparagus packaging recorded a low total productivity of 41.73 kg/$ due to low partial labor productivity of 1.29 kg/$ and machinery productivity of 40.44 kg/$. The root causes included unplanned shutdowns, excessive downtime, and a lack of standardized procedures across the production line. The absence of autonomous and adequate preventive maintenance led to unplanned interruptions. Additionally, significant downtime was observed due to idle periods between workstations. The absence of standard procedures resulted in inconsistent methodologies being applied to the same operations. Under the current process model, maintenance-related downtime results in a loss equivalent to 24.5 days per year, translating to an annual financial impact of S/84,754.69. The proposed model aims to reduce the occurrence of critical maintenance issues, which involve the loss of a productive day, by 27%. Figure 4 presents the initial diagnosis of the asparagus packing plant and the tools employed to address the low productivity problem.

4.3. Design and Validation Results

4.3.1. Validation Method

To evaluate the effectiveness of the proposed solution, a pilot was conducted in the asparagus packing process three months after the introduction and implementation of Lean and TPM methodologies.

Following the pilot, the model was validated through a simulation using Arena software version 16.2. Timing measurements were taken before and after the implementation of the improvement model to determine the normal and triangular distributions of each process, validating the results with the Kolmogorov-Smirnov and Chi-square statistical tests.

The proposed model involved implementing a new work methodology, encompassing the entire process from cutting to labeling, packaging, and weight verification. Through applying TPM and Work Standardization, the aim is to reduce the average time that a 5 kg box remains in the system and maximize the utilization of the line operators, eliminating idle times.

4.3.2. Model simulation in Arena Software

The sample size used was 72.98 kg of asparagus, considering a confidence level (Z) of 95% and a total production size (N) of 878,158.8 kg. For its determination, the following formula was used, establishing a confidence level (P) of 95% and a maximum tolerable margin of error (E) of 5%. The Input Analyzer tool was used to determine the time distribution, as shown in Table 2.

$$n = \frac{N \times Z^2 \times p \times (1-p)}{(N-1) * e^2 + Z^2 \times p \times (1-p)} \qquad (4)$$

The Failure module in the simulator was used to model the frequency of line failures (percentage of failures), acknowledging that current failures account for 27% of total operational time, equivalent to 29.5 days of lost productivity per year. Ten replication cycles were conducted for the simulation. The Arena model is illustrated in Figure 5 and Figure 6.

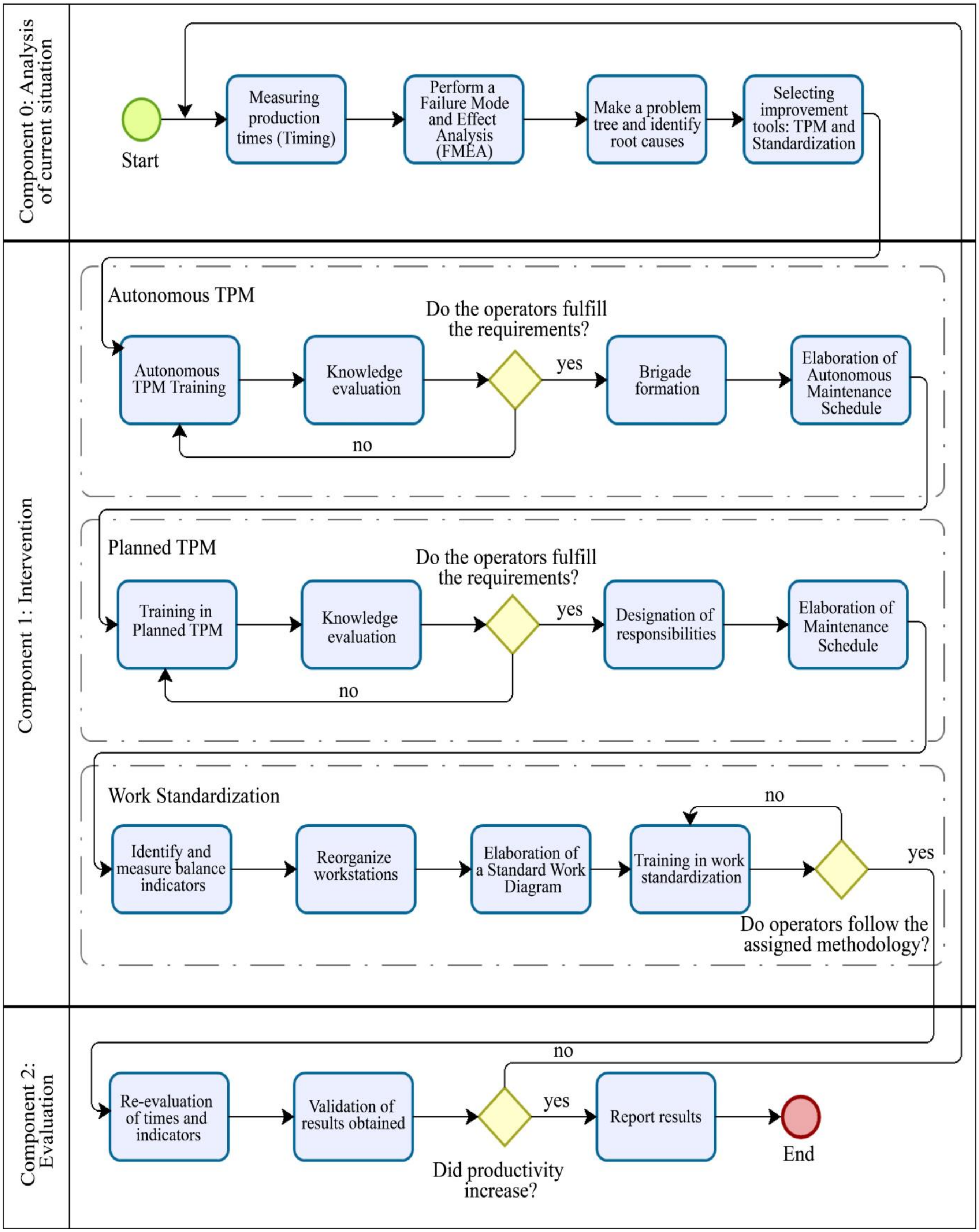


Fig. 2 Proposed method flow

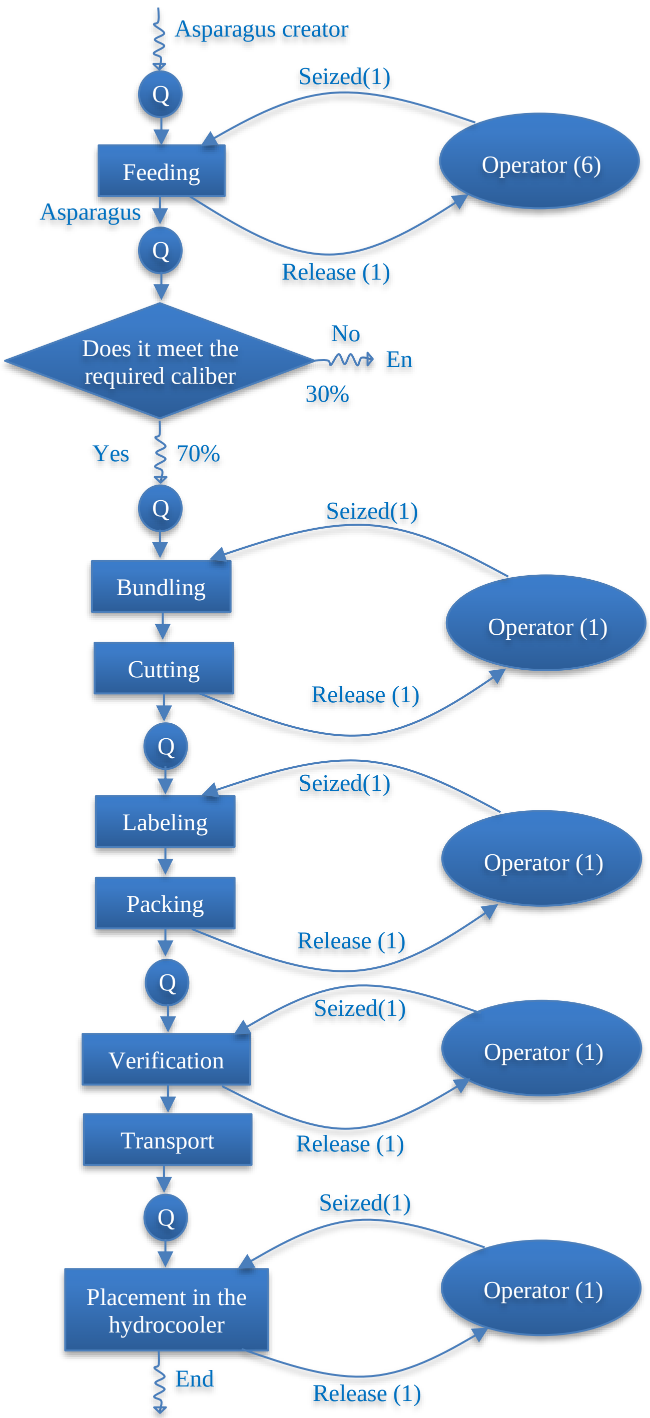


Fig. 3 Representation of current model

4.3.3. Simulation Results

Table 3 presents the initial system indicators alongside the values observed after implementing the proposed improvements. Following the application of the model's tools, there was a notable increase in productivity, machine availability, and average employee utilization, as well as a reduction in production time between blocks.

The proposed model effectively addresses the issue of low productivity, resulting in a 21% increase in the total productivity rate. Labor productivity improved significantly, rising from 34.83 kg/H-H to 71.05 kg/H-H, marking a 104.01% increase. Additionally, machinery availability improved by 26.35%, and average employee utilization increased by 0.42%.

The block of stations responsible for bundling, cutting, and labeling saw a remarkable reduction in processing time, decreasing by 71.81% from 5.93 minutes per bunch to 1.67 minutes per bunch. Furthermore, the block of stations from packing to verification achieved a 21.87% improvement in production time.

4.3.4. Economic Validation

A 12-month financial cash flow projection was developed, considering the costs associated with implementing the improvement model tools, with an initial investment amounting to S/. 29,712. The project yielded a Net Present Value (NPV) of S/ 75,553, confirming its viability, and an Internal Rate of Return (IRR) of 32%, which exceeds the Cost of Capital (COK) of 1.08%, indicating profitability.

Additionally, the Discounted Payback Period (DPP) is 3 months, meaning the project will start generating profits within this period and is expected to deliver annual savings of S/ 112,652. The economic indicators obtained are detailed in Table 4.

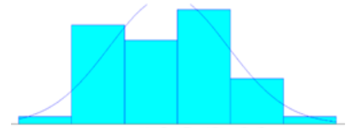
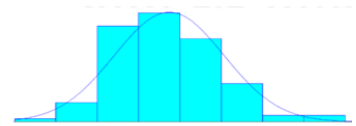
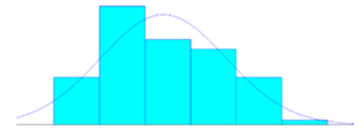
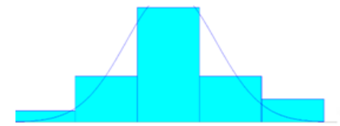
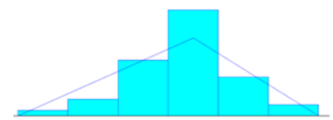
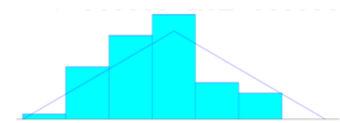
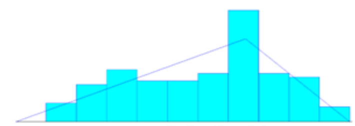
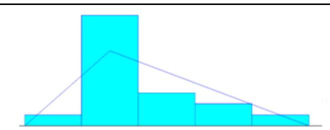
5. Discussion

The simulation validated the effectiveness of the proposed model in enhancing asparagus packing productivity, showing a 21% increase following the implementation of standardization and TPM.

In comparison, a frozen mango processing plant that used a model incorporating Lean tools such as Standardized Work and the 5S methodology achieved a 23% improvement in productivity from its initial value [13], which demonstrates that the result of the model is consistent with the percentage improvement found by other researchers.

Significant improvements in production time were observed in the first block of stations, which included binding, cutting, and labeling. The implementation of work standardization led to a 71.81% reduction in production time, demonstrating that standardization effectively eliminates non-value-added activities and standardizes methodologies within the same station. Additionally, this tool improved efficiency by 20.63% in the block from packaging to weight verification, reducing production time from 0.32 minutes per box to 0.25 minutes per box. This result aligns with a previous study where standardization in a printing plant reduced standard time at a workstation by 18.44% per assembled box [19].

Table 2. Time distribution per process

Process	Distribution Type	Interval	Unit	Kolmogorov-Smirnov test	Chi-square test	Accepted / No accepted	Graph
Feeding	Normal Distribution	(0.32, 0.0317)	min/crate	> 0.15	0.104	Yes	
Selection	Normal Distribution	(0.201, 0.0677)	min/bunch	> 0.15	0.0859	Yes	
Bundling & Cutting	Normal Distribution	(0.154, 0.0258)	min/bunch	> 0.15	0.152	Yes	
Labeling	Normal Distribution	(0.167, 0.0277)	min/bunch	> 0.15	0.159	Yes	
Packing	Triangular Distribution	(0.13, 0.287, 0.40)	min/box	> 0.15	0.0616	Yes	
Verification	Triangular Distribution	(0.01, 0.0528, 0.08)	min/box	> 0.15	0.0528	Yes	
Transport	Triangular Distribution	(1.12, 1.29, 1.37)	min/box	> 0.15	0.106	Yes	
Placement	Triangular Distribution	(0.01, 0.024, 0.08)	min/box	> 0.15	0.076	Yes	

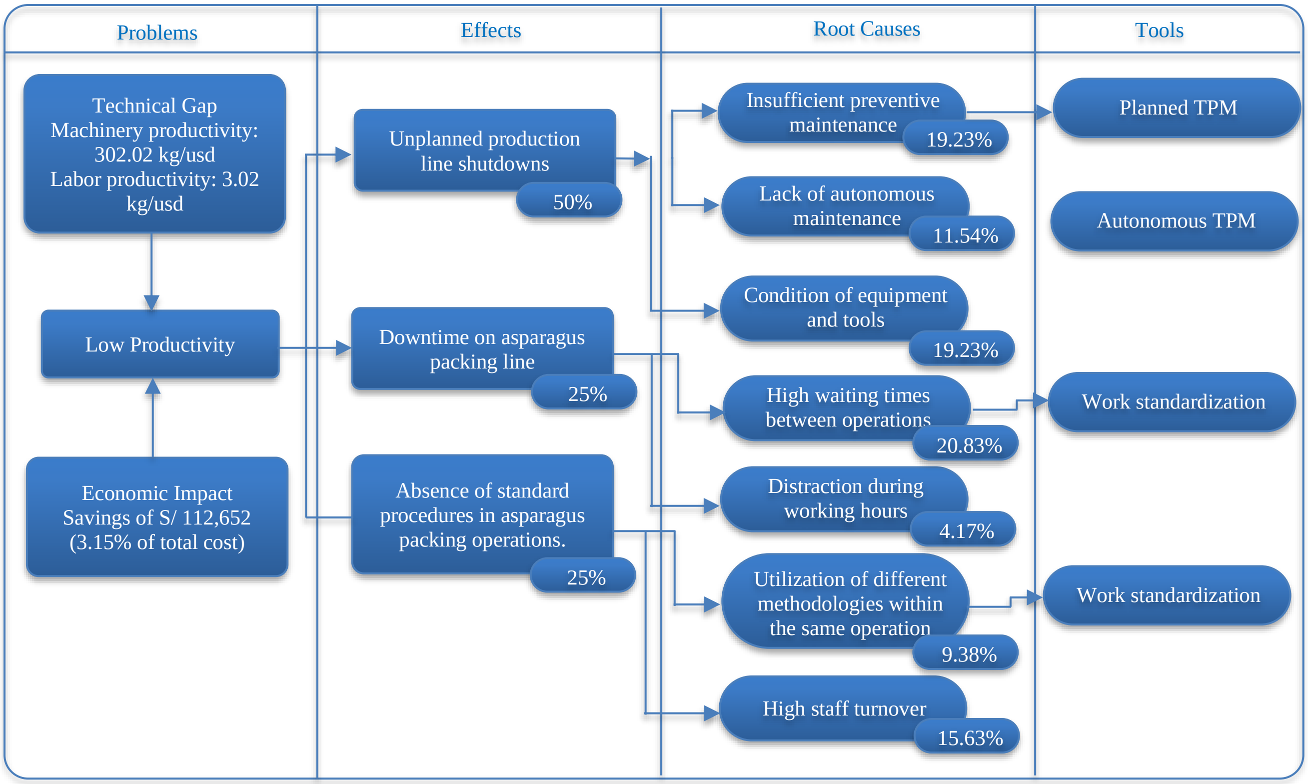


Fig. 4 Problem tree

Table 3. Validation process results

Description	Indicator	Original Model	Proposed Model	Improvement	Tool / Model
Total productivity	Productivity (kg/usd)	41.73	50.64	21%	Production model
Labor productivity	Productivity rate (kg/H-H)	34.83	71.045	104.01%	Work standardization
Unplanned production line downtime	Machinery availability	75.11%	94.90%	26.35%	Planned TPM
Downtime on the asparagus line	Average employee utilization	96.85%	97.26%	0.42%	Work standardization
Use of different methodologies within the same operation	Production time from bundling to labelling (min/bunch)	5.93	1.67	71.81%	Work standardization
	Production time from packing to verification (min/box)	0.32	0.25	20.63%	Work standardization

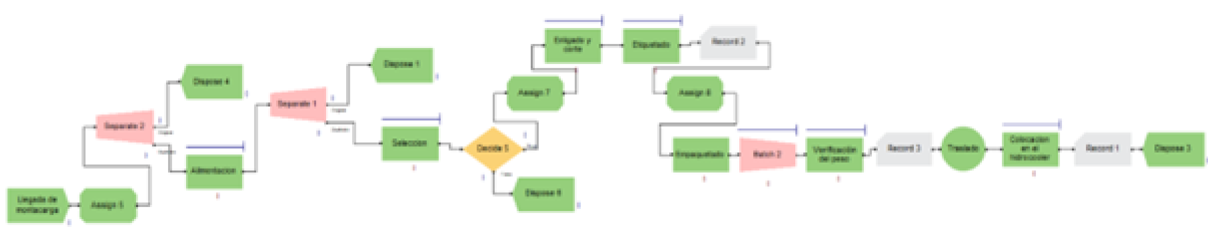


Fig. 5 Original Model in Arena 16.2 Software

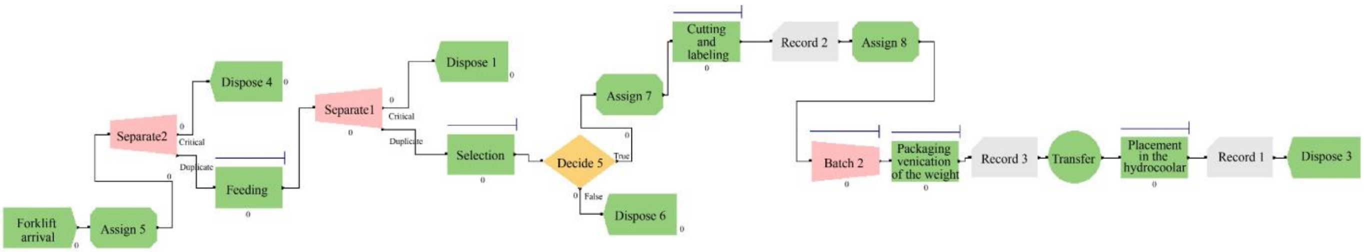


Fig. 6 Proposed model in arena 16.2 software

Table 4. Economic indicators

Indicator	Value
Net Present Value (NPV)	75 553
Internal Rate of Return (IRR)	32%
B/C	3.54
Payback (months)	3

Additionally, average employee utilization improved by 0.42%, increasing labor productivity. The application of standardized work controls processes and helps minimize costs and maximize employee utilization. Machine availability saw a notable improvement of 26.35%, increasing from 75.11% to 94.9%. This enhancement reflects the effectiveness of implementing autonomous and planned TPM in reducing unplanned stoppages on the production line. A previous study that applied similar TPM pillars in a bag production plant achieved a 13% increase in sealing equipment availability. The percentage difference is explained by the fact that, before TPM implementation, sealing equipment availability was already relatively high at 83% and improved to 96% post-implementation, aligning closely with the results obtained from the improvement model. This demonstrates that machine downtime, and consequently machine availability, has a statistically significant impact on productivity.

In this way, it is proved that the proposed model maximises the total productivity rate, the availability of machinery and the average utilization of employees. Similarly, it minimizes the processing times of the stations to which the standardization was applied.

It is recommended that future research incorporate Kanban to represent the workflow in standardization processes. For autonomous and planned maintenance, implementing temporary loops for designing inspection, cleaning, lubrication, and general maintenance routines should be explored. Additionally, the model addresses only 60.98% of the issues identified in the initial diagnosis, leaving secondary problems unresolved.

Additionally, the next improvement cycle could focus on integrating digital technologies into the asparagus packing line to enable real-time monitoring of the entire process. Industry 4.0 technologies, such as artificial intelligence, the Internet of Things, and big data, could enhance decision-making and operational efficiency. Future research could also explore strategies to address equipment and parts deterioration to prevent stoppages and tackle the challenge of high personnel turnover, which complicates the implementation of a consistent work methodology. Finally, it would be interesting to validate the model in more than one scenario, such as in different asparagus plants or packing lines of other fruits or vegetables.

6. Conclusion

The research results indicate that the solution model based on TPM and Standardized Work significantly enhances machinery availability by 26.35% and increases labor productivity by 36.22 kg/HH in an asparagus packing plant, leading to a 21% improvement in overall process productivity. Additionally, implementing autonomous and planned TPM reduces unplanned line stoppages by 21.9%. Standardized Work further decreases downtime, with production times reduced by 71.81% from bundling to labeling and 20.63% from packaging to weight verification. The application of standard procedures also improves employee utilization by 0.42%. These findings demonstrate that a robust maintenance strategy can substantially boost productivity and minimize downtime while Standardized Work effectively compensates for the absence of advanced manufacturing technologies in the processes.

The main challenges and limitations of implementing TPM and Lean methodologies in the agricultural sector are discussed below. Both methodologies demand an investment of economic resources and time, making it advisable to begin a pilot project in a single unit. Implementing TPM involves investments in training, documentation, and new technologies for monitoring and analysis. Introducing cost-effective technological solutions for equipment monitoring, such as basic sensors and data analysis applications, is recommended to minimize initial costs and assess feasibility. Additionally, most companies lack a preventive maintenance culture, with corrective maintenance being predominant. Shifting this culture requires a mindset change. Management must strongly commit to TPM principles, actively promoting and rewarding improvement initiatives. Implementing incentive systems to recognize personnel who adhere to preventive maintenance practices is recommended to encourage sustained engagement.

On the other hand, there is resistance to change among workers regarding the proposed methodology. Workers often rely on work practices and habits developed over the years in agriculture. Altering these routines means pushing them out of their comfort zones, which can lead to resistance. The diffusion of methodologies is challenging, as processes are often performed empirically or passed down orally, with limited formalization or documentation of consistent standards, a situation further complicated by high personnel turnover. To address this, involving experienced workers in creating and validating new standards is recommended, along with developing thorough process documentation.

This research contributes to the literature by presenting a novel application of TPM and Standardized Work in an asparagus packaging line, an area previously unexplored. It highlights the importance of proper maintenance and work standardization for reducing processing times, minimizing indirect manufacturing costs, and enhancing overall productivity and competitiveness. As this is a case study located in Peru, the model's effectiveness cannot be generalized to all asparagus agro-exporting companies. However, the model can be replicated in medium-sized companies with predominantly manual processes and limited manufacturing technology.

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