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ORIGINAL

Lean Manufacturing: effective tools to optimize dairy beverage production. Evidence based on a statistical analysis

Manufactura Esbelta: herramientas eficaces para optimizar la producción de bebidas lácteas. Evidencia basada en un análisis estadístico

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ABSTRACT

Lean Manufacturing is a set of tools with a production management approach that aims to maximize customer value by reducing waste and optimizing processes; in industries, it helps improve efficiency, reduce costs, and increase quality by eliminating non-value-added activities, thus promoting a culture of continuous improvement and flexibility in production. The objective of this research is aimed at the application of these tools to optimize the production line of dairy beverages. The research approach is quantitative, for which the inductive-deductive and analytical methods were applied. The current situation of the production process was analyzed to identify existing problems such as inefficient use of production time, lack of process standardization, absence of a production control plan, and untrained personnel. To mitigate these issues, optimal Lean tools such as VSM (Value Stream Mapping), 5S, Layout, and Kanban were applied, which allowed for a 5,34 % increase in productivity by eliminating activities that do not add value to the production process, with an improvement in the Value-Added Index (VAI) from 86,48 % to 92,75 %. Additionally, efficiency and effectiveness increased by 3 % and 2 %, respectively. The implementation of Kanban cards as management tools significantly influences the reduction of shift changeover time, decreasing the time variability from 19 % to 11 %, and the average value from 42,62 minutes to 12,43 minutes.

Keywords: Lean Manufacturing; Dairy Industry; Value Stream Mapping (VSM); Layout; Kanban.

RESUMEN

La Manufactura Esbelta es un conjunto de herramientas con un enfoque de gestión de la producción que busca maximizar el valor para el cliente reduciendo desperdicios y optimizando procesos; en las industrias permiten mejorar la eficiencia, reducir costos y aumentar la calidad al eliminar actividades que no agregan valor, promoviendo así una cultura de mejora continua y flexibilidad en la producción. El objetivo de esta investigación se orienta a la aplicación de estas herramientas para optimizar la línea de producción de bebidas lácteas. El enfoque de la investigación es de tipo cuantitativo para lo cual se aplicaron los métodos inductivo-deductivo y analítico, se analizó la situación actual del proceso productivo para la identificación de los problemas existentes tales como: uso ineficiente del tiempo de producción, falta de estandarización del proceso, carencia de un plan de control de producción y personal no capacitado. Para su mitigación se aplicaron herramientas Lean óptimas como: VSM (Mapeo del flujo de valor), 5S, Layout y Kanban, las cuales permitieron incrementar la productividad un 5,34 % al eliminar actividades que no agregan valor al proceso productivo, con una mejora del Índice de Valor Agregado (IVA) de 86,48 % a 92,75 %, además se incrementó la eficiencia del Índice de Valor Agregado (IVA) de 86,48 % a 92,75 %, además se incrementó la eficiencia y la eficacia en un 3 % y 2 % respectivamente. La implementación de las tarjetas Kanban como herramientas de gestión, influyen significativamente en la reducción del tiempo de cambio de turno, se disminuyó la variabilidad de tiempo del 19 % al 11 %, y el valor de la media de 42,62 minutos a 12,43 minutos.

Palabras clave: Manufactura Esbelta; Industria láctea; VSM; Layout; Kanban.

INTRODUCTION

Today, companies apply different techniques to keep up with increasing competition and changing consumer demands,[1] they aim to continuously optimize and improve processes through strategies that enable them to achieve high standards in product and service quality,[2] thereby sustaining their operations, productivity, and reliability.[3]

In 2021,[4] they stated that every manufacturing or service-based organization will survive and remain competitive by responding systematically to customer needs. Lean manufacturing, formerly the Toyota Production System,[5] is a practical management philosophy for improving businesses in a competitive market by eliminating waste and improving process operations.[6]

Lean manufacturing comprises a system of tools and activities for managing a manufacturing industry or service operation.[7] It also focuses on the rapid and accurate implementation of lean techniques,[8] which significantly transform the way companies operate[9] and make them highly competitive both regionally and internationally.[10]

Several studies[11] define Lean Manufacturing tools as an optimal and reproducible management method.[12] Their application has immediate results, causing a tremendous visual impact and increasing process efficiency, which leads to customer satisfaction.[13] However, not all lean tools can be applied in any company; it depends on the type of production used to obtain the expected results.[14]

The 5S methodology is the basis of Lean Manufacturing[15] systems and establishes five stages: Seiri (Sort), Seiton (Set in order), Seisou (Shine), Seiketsu (Standardize), and Shitsuke (Sustain).[16] Its objective is to improve efficiency, productivity, and quality by making the workplace tidy, pleasant, and organized,[17] for which the stages above must be implemented. The support of available resources and adaptation to the company's culture are essential.[13]

The main objective of VSM (Value Stream Mapping) is the comprehensive optimization of the process,[18] reorganizing or eliminating all types of waste in the value stream.[19] In addition, this tool allows you to identify processes that can be improved,[20] as well as opportunities for various Lean techniques.[21] It is a lean manufacturing strategy that uses symbols, metrics, and arrows to visualize and improve inventory flow and necessary information.[22] It is a graphical representation of the process flow that identifies factors that can be enhanced in value-added and non-value-added activities.[23] These capabilities significantly distinguish VSM from tools such as process mapping or design diagrams.[24] However, when not applied correctly, VSM can complicate the identification of waste and evaluation errors and undermine the implementation of future improvements.[25]

The use of VSM in mass production has proven successful due to the product's predictable volume and repetitive nature.[26] In contrast, some adaptation of the VSM tool[27] is required in non-repetitive unit production. On the other hand, value stream mapping and work standardization are key tools used in lean manufacturing and transformation, resulting in increased productivity.[28]

Layout allows for proper plant distribution, contributing significantly to production processes,[29] reducing the time it takes to move raw materials from one workstation to another, and minimizing material handling costs.[30] Facility design involves the analysis, planning, and interrelationships between the physical layout of the facilities,[31] material movements, activities associated with personnel, and information flow. It also considers quantitative inputs such as distance and frequency of material movement.[32]

Kanban is a Japanese word meaning "visible record," and is a manufacturing strategy for lean production that allows for minimal inventory, reduced costs,[33] and control of inventory levels, production, and component supply,[34] providing optimal inventory levels, shorter product delivery times, and effective use of resources.[35] In a lean manufacturing system, reserve inventory levels can be controlled to regulate production using the Kanban tool,[36] which maintains that there are two types of customers in the supply chain: internal and external. The premise of Kanban is that material is not moved to the customer until there is a signal to do so.[33]

Finally, the commitment of senior management and employees is essential for the effective operation of Kanban,[37] as well as for organizing communication and the movement of materials between manufacturing cells.[38]

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METHOD

This research used the Lean Manufacturing methodology to solve problems that influence poor productivity.[39] It began with the collection of data, which was then statistically analyzed. A field study was conducted by gathering information directly through on-site visits to the plant to identify the factors that influence the production process. In addition, a documentary-descriptive investigation[40] was carried out using bibliographic material to understand the Lean Manufacturing tools in detail, and the proposal was described within the established context.

The research methods used were deductive-inductive and analytical for analyzing the production line, identifying in detail the process and the possible causes of the problems, and determining the key strategy to correct or mitigate them. Qualitative techniques such as interviews and document analysis were applied to determine factors influencing the process, as well as quantitative methods such as VSM and process diagrams to identify activities that do not add value to production. Descriptive statistics were applied to understand the behavior of the process in terms of statistical parameters that are considered benchmarks for comparing results.

DEVELOPMENT

The research began with direct observation, and the current situation of the oat milk beverage production process was determined. A production process diagram was drawn to understand it correctly, detailing the activities and operations carried out during the production cycle. The processes identified were: receipt of raw materials, quality control of raw materials received, storage of raw milk, pasteurization of milk, transport to the mixing tank, preparation of caramel, transport of ingredients, storage of caramel, transport to the mixing tank, transport to the cooking pot, final quality control, packaging, and refrigeration. It was observed that several of these processes have added value, and processes that, according to the Lean Manufacturing concept, do not generate value, such as excess movement, delays, and storage. Therefore, an initial VSM was used to analyze these activities.

With the development of the Ishikawa Diagram, it was observed that the effect of poor productivity leads to unmet demand due to various problems in the process, such as downtime, repetitive transportation of raw materials, periods of insufficient raw materials, lack of process standardization, excessive cleaning times, non-existent production control methodology, lack of order and cleaning methodology, manual packaging, very long production times, outdated equipment and machinery, inefficient use of labor, lack of training, unbalanced production line, poor signage in work areas, very long activity times, insufficient ventilation, lack of productivity indicators, lack of quality indicators, and unmet demand. These issues will be corrected using Lean tools: VSM, 5S, Kanban, and Layout.

Application of Value Streaming Mapping (VSM)

To analyze the production process of oat milk beverages in detail, a diagnostic VSM (figure 1) is used to identify activities that do not generate value, seek alternatives for improvement, and eliminate waste.

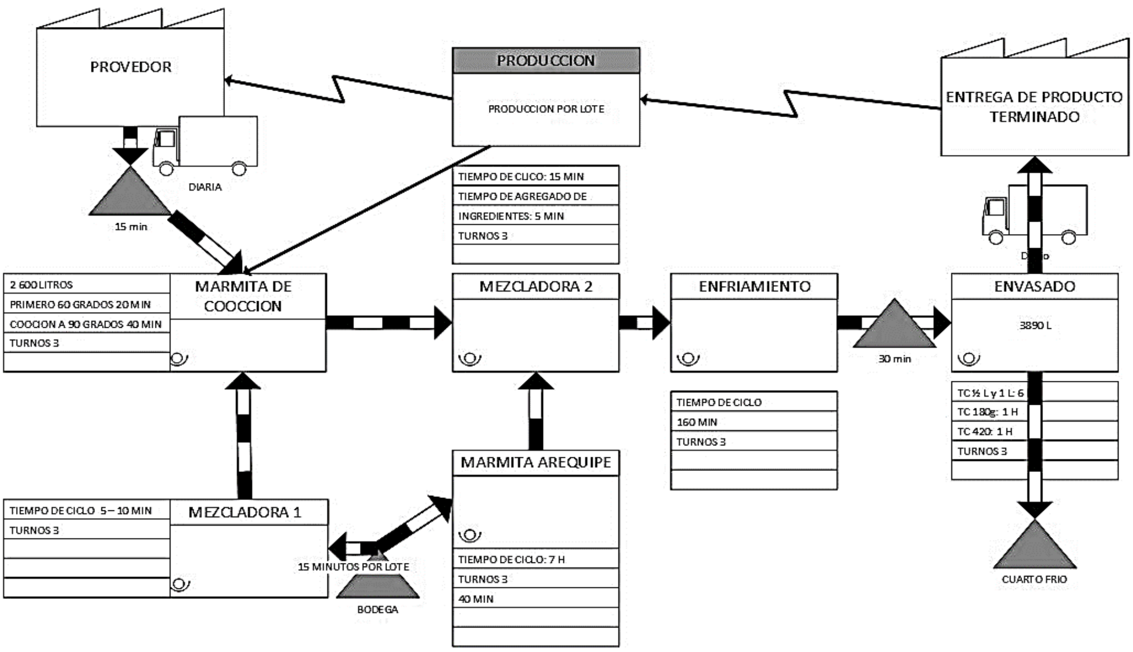

Figure 1. Initial VSM for the milk drink with oats

In addition, the times of activities that add and do not add value to the production process were identified, with a value of 100 minutes for those that do not add value, while those that add value are 640 minutes. The value of the Value Added Index (IVA) and the Value Added Analysis (AVA) were then calculated. For this purpose, the criterion was used to determine whether the value of the IVA is greater than or equal to 75 %; otherwise, the process is ineffective.

VAT Calculated

$$IVA = \frac{tiempo\ de\ valor\ agregado}{tiempo\ total\ requerido} * 100\% = \frac{640\ min}{740\ min} * 100\% = \mathbf{86,48}\%$$

As it is an Effective Process, the value that each stage adds to the final product is considered, minimizing waste generated by unnecessary activities.

VAT Calculated

$$AVA = \frac{\#\ de\ actividades\ de\ valor\ agregado}{\#\ total\ de\ actividades\ del\ proceso} * 100\% = \frac{5}{10} * 100\% = \mathbf{50}\ \%$$

The AVA obtained shows that all activities that add value to the product are 50 % efficient in relation to the total activities that are part of the production line.

Productivity Analysis

Once each activity involved in the production process had been determined, data was collected on the machines' available time and operating time, and the number of batches to be produced compared to the number of batches produced. This made it possible to obtain the daily efficiency, effectiveness, and productivity per shift, with productivity values of 85 % for the morning shift, 91 % for the afternoon shift, and 89 % for the night shift, giving an overall average of 88,33 %, in addition to an efficiency of 94,33 % and an effectiveness of 93,67 %. These data can be interpreted as: Efficiency = 94,33 % (correct use of the resources available to the company), Effectiveness = 93,67 % (percentage of compliance with the company's production), Productivity = 88,33 % (correct execution of each process on the production line).

Initial evaluation of the 5S tool

Using a checklist, an initial assessment of the 5S was carried out in the production area, which was aimed at operators to evaluate their workplaces based on each component of the 5S (sorting, setting in order, shining, standardizing, and sustaining). The checklist was developed based on NTE INEN ISO/TS 22002-1: 2014 and NTE INEN standards. 9:2015. The evaluation was carried out together with the plant manager, obtaining the following compliance results: Seiri 40 %, Seiton 41 %, Seiso 52 %, Seiketsu 45 %, Shitsuke 54 %, giving an average value of 46 %; therefore, improvement in the 5S's order and cleanliness of the production line is necessary.

Application of the Kanban tool

A proposal for implementing a Kanban production board has been designed to reduce production time, optimize the connection between processes, improve control over simultaneous activities, prevent downtime, and establish a schedule that shows the status of production. To do this, it is necessary to know everything required of the product from the moment the order is placed until delivery, then understand the flow of all the company's processes and make the necessary improvements and adjustments.

The flow diagram can be applied according to the production plant layout. To apply this tool, a plant diagram detailing the production area with the equipment available for the process was drawn up, in addition to the flow diagram, which allows the operator's activities at each workstation to be identified. Solutions that optimize the production line's performance are needed for those that generate idle time for the operator or the machine, repetitive or unnecessary movements when transporting raw materials.

RESULTS AND DISCUSSION

VSM Improved

In the improved VSM design (figure 2), there is a reduction in the time spent on activities that do not add value to the final product. This was achieved by eliminating the transport of dry ingredients and relocating the raw material storage area.

Table 1 shows the individual and total times for each VSM activity, before and after the improvement.

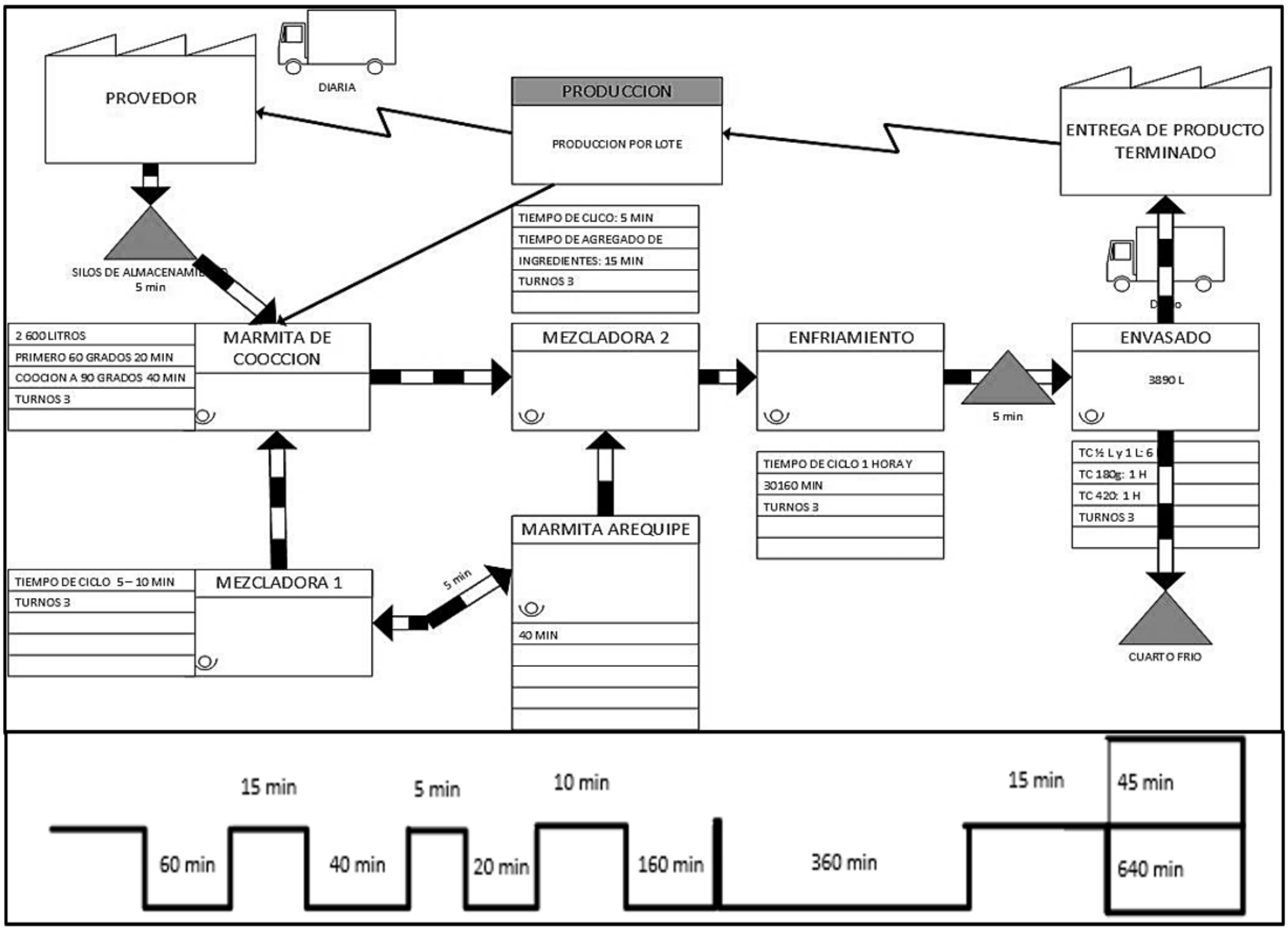

Figure 2. Improved Value Stream Map

Table 1. Time spent on VSM activities before and after improvement

Before the improvement		Time (min)	Activities that do not add value	Time (min)
	Value-adding activities	60		25
	Cooking the oats	20	Milk transport	15
	Mixing liquids	40	Ingredient transport	15
	Mixing dry ingredients	160	Arequipe transport	25
	Cooling	360	Liquid transport	20
	Packaging	640	Additional transport	100
After improvement	Total	Time (min)	Total	Time (min)
	Value-adding activities	60	Activities that do not add value	15
	Cooking the oats	20	Milk transport	5
	Mixing liquids	40	Ingredient transport	10
	Mixing dry ingredients	160	Arequipe transport	
	Cooling	360	Additional transport	15
	Packaging	640	Total	45

Value Streaming Mapping established a reduction to 45 minutes in the total time spent on activities that do not add value to the final product, while activities that add value to the final product remained at 640 minutes; this means that approximately 6 % of the time is spent transporting product inputs.

The evaluation of efficiency in a production process is based on the value that each phase adds to the final product, seeking to minimise waste generated by unnecessary activities or steps. To do this, the Value Added Index and Value Added Analysis are determined..

Value Added Index

$$IVA = \frac{tiempo\ de\ valor\ agregado}{tiempo\ total\ requerido} * 100\% \ = \frac{640\ min}{685\ min} * 100\% = \mathbf{93,43\%}$$

With 93,43 % of VAT collected, the process is deemed highly effective, and it is concluded that the overall efficiency of the entire production line ensures its efficiency and the added value of the final product.

Value Added Analysis

$$AVA = \frac{\#\ de\ actividades\ de\ valor\ agregado}{\#\ total\ de\ actividades\ del\ proceso} * 100\% = \frac{5}{9} * 100\% = \mathbf{55,56}\ \%$$

The 55,55 % AVA establishes the level of efficiency of activities that add value to the product compared to the total activities within the production line.

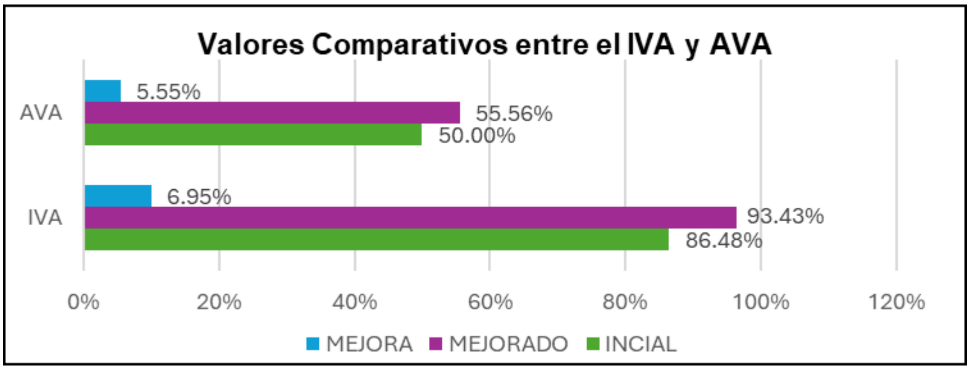

Figure 3. Comparative values of VAT and AVA

Figure 3 shows a 6,95 % improvement in VAT, while AVA improved by 5,56 %, demonstrating that eliminating one of the transport stages for inputs in the final product optimises the production line.

Results of implementing the 5Ss

Figure 4 shows the percentage before and after the application of the 5S tools, demonstrating that their implementation significantly improves organisation, order, cleanliness, and the working environment and atmosphere, with improvements ranging from 29 % to 47 %

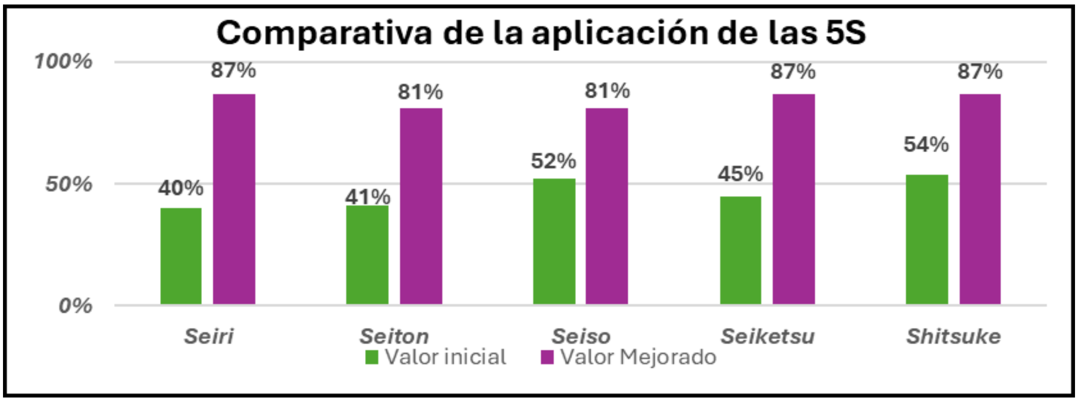

Figure 4. Comparison of results before and after applying the 5 S tools

Results of Kanban card implementation

Statistically, there is a reduction in the average and variability of shift change times with the use of Kanban cards (figure 5). The coefficient of variability was used as the appropriate statistic to compare variability before and after the improvement actions with the application of Kanban in the production process.

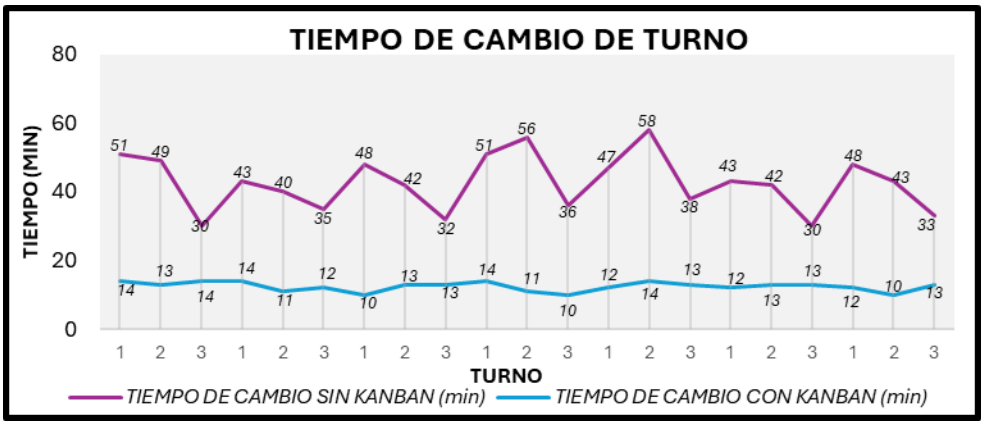

Figure 5. Comparison of shift change times

Table 2. Change time statistics			
	Average	**Standard deviation**	**Coefficient of variability**
Changeover time without KANBAN (min)	42,62	8,15	19 %
Changeover time with KANBAN (min))	12,43	1,36	11 %

Table 2 shows that implementing Kanban cards as a management tool in production significantly reduces shift change times. This makes Kanban a key source of information for production and transport, making workers dependent on its use to perform their tasks. In addition, the balance of the production system becomes very important, as it avoids speculation about the future need for materials in the next process and also prevents a later process from requesting that the production of a new batch be brought forward to the previous process.

Layout for route reduction

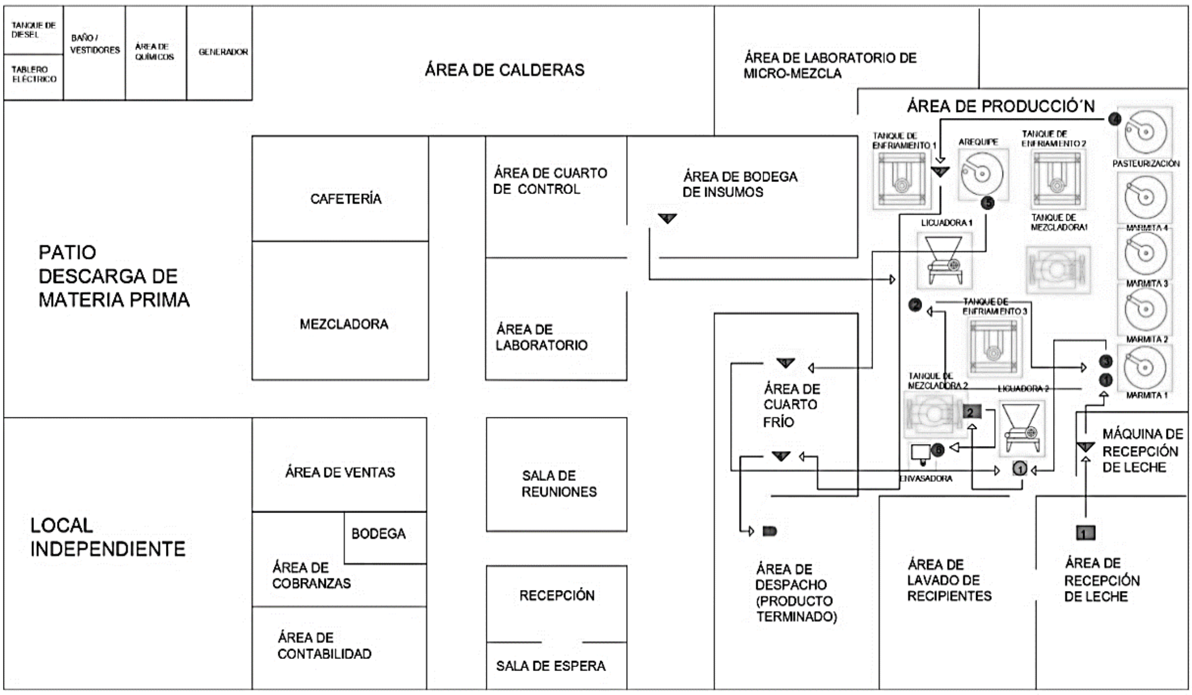

Figure 6. Layout for route reduction

The layout was designed using a flow diagram to optimise the plant's distribution, reduce raw material transport times, and eliminate unnecessary movements between the different workstations. This helps minimise the time and physical effort required by workers while maintaining adequate order and efficient space distribution between the machines within the production area.

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The layout design took into account the arrangement of the plant elements, such as machines, work areas, storage areas, corridors, and common areas within the production line. A layout based on the product or assembly line was also implemented, as this approach follows a specific sequence of operations to manufacture high-volume, low-variety products.

The following factors were considered for the plant layout:

- Machinery: identification of the type of production process.
- Materials/Raw materials: availability of key information on weight, volume, and shape, as well as the sequence in which they must be incorporated into the process.
- Labour: determination of the number of employees required in each work area.
- Industrial safety: creating a safe working environment and ensuring compliance with safety standards to protect workers.
- Buildings and facilities: evaluation of both internal and external infrastructure.
- Movement or route: management of the efficient flow of labour and materials throughout the production process.

Production indicators

After applying the Lean Manufacturing Tools, their results are evaluated using the following indicators: efficiency, effectiveness, and productivity. The average values across the three work shifts showed a noticeable increase of 3 % in efficiency, 2 % in effectiveness, and 5,34 % in productivity.

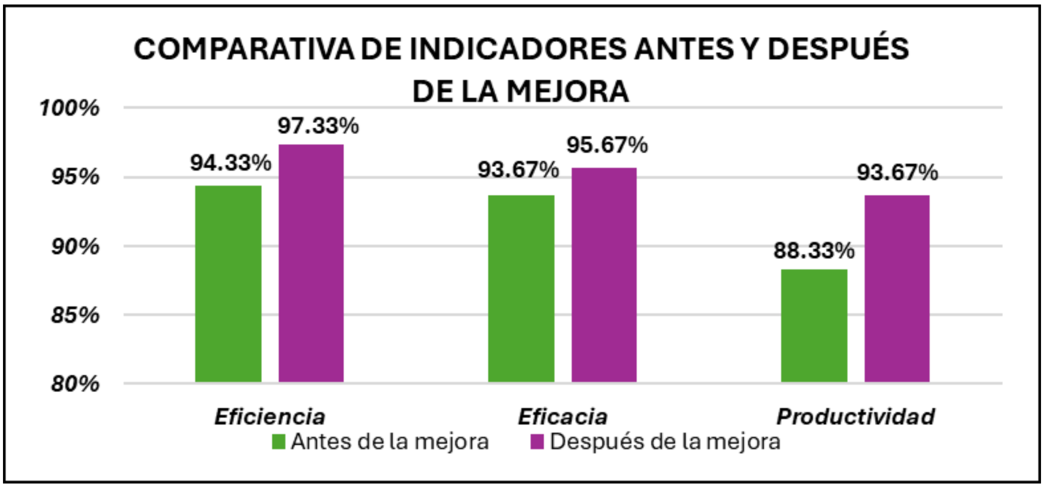

Figure 7. Comparison of indicators before and after the improvement

Figure 7 shows the values before and after implementing Lean Manufacturing Tools. Although acceptable values were obtained in the initial assessment, the improvement shows a considerable increase.

CONCLUSIONS

The Value Stream Mapping tool allowed for the identification of existing problems in the production process and the elimination of activities that did not add value, reducing costs and total time.

The 5S serve as a basis for implementing other Lean tools, allowing for the organization and cleaning of each workstation. In addition, these should be followed up with a culture of zero defects, cost reduction, and other improvement activities.

The correct implementation of Kanban cards allowed for the optimization of resources and a reduction in the time spent on shift changes, reducing the variability coefficient from 19 % to 11 %.

The layout design facilitated a reduction in raw material transport times, eliminated unnecessary movements between different workstations, and reduced workers' physical effort while ensuring proper order and efficient space distribution between machines in the production area.

Implementing appropriate Lean tools in the production process of milk drinks with oats improved productivity by 5,34 %, while efficiency and effectiveness increased by 2 % and 3 %, respectively.

Lean Manufacturing tools enabled the elimination or mitigation of problems identified as: rework, repetitive and unnecessary movements, process delays, activities that do not add value, and work areas lacking order and cleanliness, positively influencing the production process and, therefore, customer satisfaction.

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