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Enhancing Production Efficiency and Quality in the Carbonated Beverage Industry: A Lean Manufacturing Approach

Bianca Joyce Vargas-Romero
Bachelors in industrial engineering
Faculty of Engineering, Universidad de Lima, Peru
20153409@aloe.ulima.edu.pe

Borys Gastón Urbizagastegui-Jaramillo
Bachelors in industrial engineering
Faculty of Engineering, Universidad de Lima, Peru
20153397@aloe.ulima.edu.pe

Martín Fidel Collao-Díaz
Research Professor
Faculty of Engineering, Universidad de Lima, Peru
mcollao@ulima.edu.pe

Abstract

In the dynamic and competitive sector of carbonated beverages, manufacturers in Peru face significant challenges related to machine maintenance, process standardization, and defect management. These issues not only impair production efficiency but also impact public health and consumer satisfaction. This study introduces an integrated approach utilizing Lean Manufacturing methodologies—specifically 5S, Standardized Work, and Total Productive Maintenance (TPM)—to address these challenges. The proposed model systematically enhances the production processes by reducing waste, improving machine reliability, and standardizing operations to ensure consistent product quality. The implementation of this model in a Peruvian beverage manufacturing facility led to notable improvements: a reduction in the defect rate by 32%, an increase in Overall Equipment Effectiveness (OEE) from 61% to 81%, a decrease in downtime by 48%, and a significant reduction in waste. These results demonstrate the effectiveness of Lean Manufacturing tools in transforming production environments by enhancing operational efficiency and reducing losses, thereby fostering a sustainable and consumer-oriented production landscape.

Keywords
Lean Manufacturing, 5S, Standardized Work, TPM, carbonated beverages, production efficiency.

1. Introduction
The carbonated beverages sector plays a significant role worldwide, in Latin America and specifically in Peru. Carbonated beverages are widely consumed and represent an important part of the food and beverage industry. According to (Mialon et al., 2015), the corporate political activity of the food industry, including gasified beverages, can influence public health and the prevention of non-communicable diseases. In Latin America, the production and consumption of soft drinks have been subject to analysis, as noted by Mialon and Gomes (2019), who highlight the political activity of large transnational corporations in the region. In the Peruvian context, carbonated beverages are

an integral part of the diet and economy, reflecting the importance of understanding the impacts of their consumption on health and the economy, as discussed by Tahmassebi and Banihani (2019).

However, the carbonated beverage industry faces significant production challenges. Problems such as poor machine maintenance, lack of process standardization and the presence of defective products pose major obstacles. Viejo et al. (2019) highlight the importance of foam stability and consumer perception in carbonated beverages, underlining the need to control production processes to ensure the quality of the final product. Likewise, Bottani et al. (2012) analyze beverage carbonation systems, which demonstrates the relevance of technology in the production of carbonated beverages.

Solving production problems in the carbonated beverages sector is crucial. Improving machine maintenance, standardizing processes, and reducing the presence of defective products will not only guarantee the quality of drinks, but will also contribute to public health and consumer satisfaction. As mentioned Tahmassebi et al. (2006), carbonated beverages can have impacts on dental health, highlighting the importance of addressing production problems to mitigate possible negative effects on consumers' health. In this sense, it is essential to consider the sustainability and quality of products, as discussed (Wong et al., 2021), to ensure responsible and beneficial production practices for both industry and consumers.

2. Literature Review

In the beverage industry, the application of Lean Manufacturing has been a topic of interest. Research by Dora et al. (2013) highlighted the implementation of lean practices in small and medium-sized food enterprises, emphasizing productivity and business aspects. Lean manufacturing, known for its ability to enhance efficiency and effectiveness, has been recognized as a major approach to improving quality and productivity in manufacturing processes (Phan et al., 2023). By focusing on eliminating waste and optimizing processes, Lean Manufacturing can significantly impact the production process of carbonated beverages, leading to improved operational performance and cost reduction.

The method 5S, a fundamental tool in Lean Manufacturing, has also found relevance in the beverage industry. Studies on the implementation of 5S in manufacturing processes have shown its effectiveness in enhancing labor productivity (Ketoeva et al., 2019). By standardizing the design and manufacturing processes, minimizing waste, and ensuring a continuous flow, the 5S program can contribute to streamlining operations in the production of beverages, including carbonated drinks. This structured approach to workplace organization and cleanliness can lead to improved efficiency and quality in the manufacturing process.

Standardized Work is another essential aspect of Lean Manufacturing that has implications for the beverage industry. Ghobadian et al. (2020) discussed how lean manufacturing brings about incremental change through administrative, process, and routine levers, emphasizing the importance of standardized work procedures. By establishing standardized work instructions and procedures, beverage manufacturers can ensure consistency, quality, and efficiency in their production processes. This method can help in reducing variability, improving productivity, and maintaining quality standards in the production of carbonated beverages.

Total Productive Maintenance (TPM) is a methodology that focuses on maximizing the effectiveness of equipment and machinery in manufacturing processes. Research on TPM in the context of the beverage industry can provide insights into optimizing equipment performance and minimizing downtime. By integrating TPM practices, such as proactive maintenance and autonomous maintenance, beverage manufacturers can enhance equipment reliability, reduce defects, and improve overall equipment efficiency in the production of carbonated beverages. This approach aligns with the principles of Lean Manufacturing, aiming to create a culture of continuous improvement and operational excellence in the beverage manufacturing sector (Arevalo et al., 2019).

3. Methods

3.1 Basis of the Proposed Model

To solve the problem raised in this case study, a production model was developed with the aim of improving the operating conditions of the bottling plant. This model integrated Lean Manufacturing tools, such as the 5S, which served as a starting point for the incorporation of additional process improvement tools. This was reflected in **Figure 1**, which shows the innovative solution proposal. It was key to optimize the current workstations of the beverage line, reduce waste, eliminate risks and increase process productivity, thanks to the redesign of the workstations and the subsequent standardization of methods. Finally, the autonomous and planned maintenance pillars of the TPM solved the problems of breakdowns, defective products and quality problems, this being a key factor for this type of process with continuous online flow.

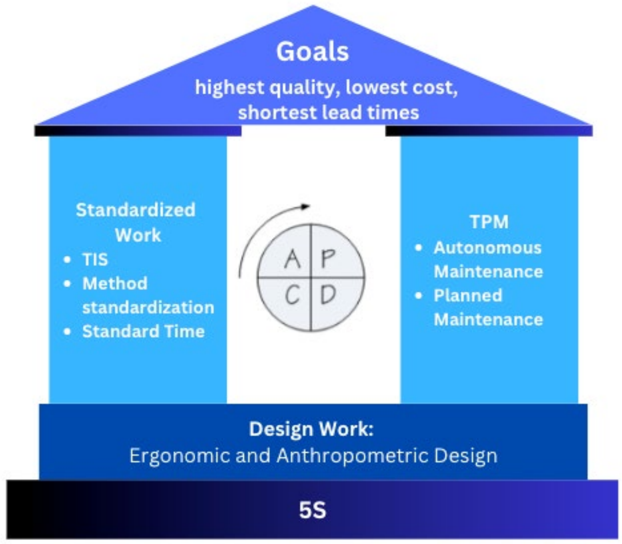

Figure 1. Proposed Model

3.2 Description of the model components

Phase 1: At this initial stage, the 5S methodology was implemented with the aim of improving working conditions at the workstations of the beverage line. The disorder was eliminated, a culture of order and cleanliness was incorporated, and the visual management of the process was improved, which allowed to lay the foundations for the redesign of the workstations and their subsequent standardization (Espinoza et al., 2021). Following staff training on this tool, the initial audit was conducted, obtaining an average result of 2.5 points on a standard of 5. This result confirmed the need and urgency to implement the tool to improve the basic working conditions in the filling stations. Thanks to the implementation of this tool, new habits of order and cleanliness were created and subsequently normalized in cleaning plans and calendars.

Phase 2: In the second stage, the redesign of the workstations was implemented. The aim of this phase was to increase the productivity, efficiency and effectiveness of the workforce. With the redesign, the conditions were optimized, adapting them to the requirements and needs of the workers so that they could meet the established production objectives. This optimization contributed to the reduction of ergonomic risks, thus increasing the safety and efficiency of all operators in charge of the improved workstations (Kawakami et al., 2022).

Phase 3: In the third phase, processes were standardized. During this stage, the current working methods of the stations involved were analyzed and the optimal method and conditions for the implementation of these new methods were subsequently established. This facilitated the measurement and determination of new cycle times, which would serve to control and verify the efficiency, effectiveness, and productivity of the workforce. The objective of work standardization was to eliminate activities that did not add value, in order to optimize time and improve the results of each season (Huamani et al., 2022).

Phase 4: In the last phase, the implementation of two fundamental pillars of Total Productive Maintenance (TPM) was established: autonomous maintenance and planned maintenance. These pillars were key to bringing machines to basic operating conditions (Caso et al., 2023). Approach strategies were developed for implementation, starting with machines with the highest failure rate. Once these machines were identified, an effect and failure mode analysis (FMEA) was applied to identify the systems with the highest severity, frequency and severity rates, and thus be able to determine the root causes of each failure and implement preventive actions that managed to reduce breakdowns. At the same time, personnel were trained in cleaning, lubrication and regulation activities so that operators incorporated these habits, thus increasing the time of use of their machines and reducing unplanned stoppages. The control indicators to evaluate these actions were the MTTR, MTTF and OEE, which evaluated and provided feedback to the team to verify the effectiveness of the actions implemented.

3.3 Model Indicators

Once the components are implemented, indicators will be assigned to oversee the progress of the project.

Efficiency refers to the correlation between the outcome obtained and the resources expended. Resources are limited.

$$Efficiency = \frac{Useful\ Time}{Total\ time} \quad (1)$$

5S Audit: It is the average score obtained in the verification of compliance of each of the 5S in the work area.

$$5S\ Audit = \frac{\sum(Score\ Obtained\ \ in\ each\ "S")}{Total\ Score} \quad (2)$$

Defective Products: This indication will be utilized to ascertain the quantity of noncompliant products that will be disposed of.

$$defective\ Products = \frac{Bottles\ with\ dents}{month} \quad (3)$$

Wasted bags: This formula allows you to have a clear view of the number of bags that are being wasted in the process, helping to identify areas of improvement to reduce waste and optimize the use of resources.

$$Wasted\ bags\ (units) = Bags\ damaged\ during\ the\ process + Bags\ incorrectly\ used + Bags\ not\ compliant \quad (4)$$

Downtime machines: It is the total time in minutes during which a machine is out of service and is not able to produce.

$$Downtime\ machines = \sum(stop\ time\ of\ \ each\ incident) \quad (5)$$

Overall Equipment Effectiveness (OEE) is a crucial metric that reflects the true production capacities without defects, the actual performance rates of the process, and the availability rates of the equipment in percentage.

$$OEE = Availability\ \times\ Quality\ \times\ Performance \quad (6)$$

4. Validation

The validation of the proposed model was developed through pilot plans that lasted six months. These pilots implemented the necessary lean tools to increase the efficiency of the beverage line. The problem with the case study was the lack of standardization of the beverage line processes. In addition, the cost-effective working station conditions and the lack of proper maintenance of the line machines resulted in low production efficiency, quality problems and waste.

4.1 5S Tool

During the initial phase, products that were in acceptable condition were carefully selected, while others were discarded or recycled. Subsequent analysis revealed that 67 per cent of items deemed unnecessary were eliminated. Following this process, signals were installed to instruct staff to relocate all used materials to their respective locations. However, lack of space prevented reaching the desired order, resulting in a rating of 2.2. The workers worked continuously to maintain cleanliness in their working environment. The introduction of a shelf at each workstation was an effective measure, eliminating the need to move to the central warehouse located at the main entrance.

4.2 Design Work

To carry out the pilot project to redesign the working environment, the old tables were replaced by better quality ones, from the dining room and the warehouse. This change was mainly applied in the spraying area. The adoption of these new surfaces resulted in a noticeable decrease in the number of bottles falling. Workers also adopted more efficient operating techniques. During the six months of application, the rate of non-compliant products in the spraying area decreased. After making these adjustments, the average number of damaged bottles decreased to 28%.
The pilot showed a reduction in the risk of dis-ergonomic from 3 to 1 according to the postural risk assessment tool OWAS, achieving ergonomic working conditions that protect the body and the health of the operators.

4.3 Standardized Work

This tool was implemented in four different stages of the production process: grouping, labeling, filling and atomization. During the grouping stage, a method was established in which operators would dry the bottles meticulously for an extended time before grouping them. After consultation with the team, it was decided to try a new method where freshly cleaned bottles were placed in a trolley to dry naturally in the air for an hour at room temperature. This modification allowed the bottles to dry after the set time, thus facilitating the continuity of the process and reducing the operating time by at least 16%.

As far as labelling is concerned, this process was relocated at the beginning of the production chain, allowing the bottles to be labeled before being filled. This change significantly improved labelling efficiency and decreased the likelihood of label release, thanks to the lower friction generated. This resulted in a more than 50% reduction in label waste, optimizing operators' resources and time and minimizing the need for reprocessing.

In the filling process, it was identified that the previous method generated unnecessary liquid waste. The introduction of funnels substantially improved the efficiency of this process, reducing waste by 65% and increasing production to 128 bottles per month since the initial implementation.

Finally, in the atomization stage, tests were carried out with carts and standard boxes, pending approval to purchase customized boxes that would facilitate the handling of the bottles. Information posters were placed and operators were trained on standardized methods for handling guns with the aim of reducing movement by protecting the operator from fatigue and injury to his musculoskeletal system. These initiatives reduced the duration of the atomization process by 12%, and more experienced operators achieved a further reduction of 21%. In addition, the adoption of these techniques and proper guidance helped to prevent problems arising from excess heat, which was reflected in a 34% decrease in the discarding of bags in the following months.

4.4 TPM

After finalizing the maintenance plan and compiling the necessary inventory of spare parts, the plant technician took over the responsibility of training operators in charge of the bottling process during the absence of the specialized technician. Training sessions focused on explaining the most common causes of failures in filling machines and instructing on how to change key spare parts such as valves, pistons and external tubes. These sessions were organized after establishing certain regulations.
In addition, a decrease in the number of machine stops was observed, as evidenced by the table of validation results shown in the next section. This change resulted in an overall reduction of 48% in machine interruptions and a 34% decrease in interruptions caused by technical problems, which are those that generate higher costs for the organization.

5. Results

After completing the validation of the project, the improvements implemented during the six-month duration of the pilots achieved the results reflected in **Table 1**, where it is observed that the Global Efficiency of the Teams (OEE) of the company increased from 61% initial to 81% after the application of the proposed model.

Table 1. Validation results

Tool/Objective	Indicator	As Is	To Be	Variation (%)
Central Problem	Efficiency (%)	75.20%	84.40%	**12.23%**
5S Tool	Audit 5S	2.8	4.0	**42.86%**
Design Work	OWAS Rate	3	1	-66.67%
	Defective bottles (unit)	172	61	-64.53%
Standardized Work	Bags wasted (units)	83	56	**-32.53%**
	Wasted labels (labels/month)	780	330	**-57.69%**
	Lotting cycle time (min)	21.2	18.4	**-13.21%**
	Sprying cicle time (min)	6.5	3.9	**-40.00%**
TPM	OEE (%)	61%	81%	**32.79%**
	Downtime machines (min)	185	95	-48.65%
	Number of machines stops	32	21	-34.38%

Based on the evaluation carried out, it was observed that the OWAS instrument used to assess physical workloads, decreased its score from 3 to 1. The implementation of process standardization tools will lead to a reduction in waste and cycle time. A particularly significant decrease, up to 40%, in line bottling was highlighted.

6. Conclusions

This study has successfully addressed the production challenges in the gasified beverage industry, highlighting improvements in machine maintainability, standardization of processes and reduction of defective products as a means of ensuring the quality of drinks and their impact on public health and consumer satisfaction. The findings reveal that the implementation of lean methodologies, such as 5S, Standardized Work and Total Productive Maintenance (TPM), contributes significantly to improving operational efficiency and reducing costs. These interventions have been shown to be effective in optimizing equipment performance, minimizing downtime, and reducing defects, reflecting a notable improvement in overall equipment effectiveness (OEE).

The relevance of this research lies in its contribution to a deeper understanding of how lean manufacturing practices can be adapted and applied in the beverage sector to address specific production and sustainability challenges. In a context where efficiency and sustainability are increasingly crucial to the long-term viability of industries, This study highlights the importance of advanced operations management techniques to improve quality and efficiency standards without compromising public health needs.

From an academic and practical point of view, this research contributes to the field of industrial engineering by providing a validated framework for the integration of lean tools in the management of production operations. The proposed model and its validation offer a replicable and scalable path for other companies in the sector, thus facilitating the adoption of continuous improvement practices that are essential for competitiveness and innovation in modern industry.

In conclusion, the results of this study are not only promising for the gasified beverage industry, but also offer prospects for future research in the application of lean methodologies beyond traditional production environments. It is suggested to explore the applicability of these methods in other production areas with similar challenges, and to study the long-term impact of these interventions on environmental sustainability and corporate social responsibility. In addition, future studies could investigate the interaction between different Lean tools and their combined impact on operational efficiency and waste reduction.

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Biographies

Bianca Joyce Vargas-Romero Recently graduated in Industrial Engineering, expert in business development with multi-sector experience. Strategic decision maker focused on information and construction of processes that allow the sustainable growth of the business in charge. Great capacity for analysis and results orientation..

Borys Gastón Urbizagastegui-Jaramillo Borys Gaston Urbizagastegui-Jaramillo holds a bachelor's degree in industrial engineering with expertise in the retail sector and the sales and maintenance service sector of industrial machinery. He is currently working as a Junior in Project Management in a leading Peruvian company specializing in standardized maintenance and operations control services in Peru, Ecuador, and Bolivia with a focus on efficiency, quality, and customer satisfaction.

Martín Fidel Collao-Díaz at ESAN University and Industrial Engineer from the University of Lima specialized in supply. chain management and operations. Leader with more than 25 years in local and international experience in national and multinational companies at industrial, hydrocarbon and mass consumption sectors. Broad experience in supply chain management (purchasing, inventory, suppliers and supply sources management, logistics: transport, distribution and warehouse management), operations (planning and control of production and maintenance) and integrated system management (ISO 9001, ISO 14001 and OHSAS 18001). Business alignment based on sales and operations planning (S&OP). Besides, continuous search for improvements in profitability based on process optimization and saving projects using tools such as Six Sigma methodology among others, focused to be a High-performance Organization (HPO). Development of high-performance team. Member of IEEE and CIP (College of Engineers of Peru).