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Productivity Improvement Through the Application of Lean Six Sigma Tools in a Non-Alcoholic Beverage Company

Stefanía Carolina Huerta Sánchez
Industrial Engineering Department
Universidad de Lima
Lima, Perú
20211305@aloe.ulima.edu.pe

Cesar David Mesia Perez
Industrial Engineering Department
Universidad de Lima
Lima, Perú
20211715@aloe.ulima.edu.pe

Rafael Mauricio Villanueva Flores
Associate Professor
Industrial Engineering Department
Universidad de Lima
Lima, Perú
rvillan@ulima.edu.pe

Jorge Alfredo Montoya Barragán
Associate Professor
Industrial Engineering Department
Universidad de Lima
Lima, Perú
jamonto@ulima.edu.pe

Abstract

This research presents an engineering-based intervention aimed at optimizing productivity in a water bottling company through the integrated application of Lean Six Sigma methodologies, specifically 5S, SMED, preventive maintenance, DMAIC, and process standardization. A diagnostic assessment identified an operational productivity level of 12.53 L/sol, representing a 34.7% deviation below the sector benchmark of 19.2 L/sol and an estimated annual economic loss of S/ 83,191.82. Following validation through a pilot implementation and discrete-event simulation, the proposed improvement framework is projected to increase productivity by 39.5%, recover 17,239 non-productive minutes per year, and enhance Overall Equipment Effectiveness (OEE) from 62% to 83%. Specifically, applying 5S would reduce tool search time by 30.7% (16.93 minutes per shift), while SMED would decrease setup time by 67.01% (from 56.55 to 18.67 minutes). Likewise, preventive maintenance would reduce downtimes due to mechanical failures by 83.15%

(from 73.83 to 12.44 minutes per shift), and DMAIC would help reduce defective products by 40%, equivalent to over 17,000 annually recovered units. The results confirm the technical feasibility, operational impact, and economic relevance of the proposed methodology, demonstrating its scalability potential and applicability to similar industrial environments in the beverage manufacturing sector. The findings reveal that the strategic integration of Lean Six Sigma tools represents a high-impact solution for low-automation settings with limited resources, highlighting its industrial relevance and contribution to the scientific knowledge base on continuous improvement methodologies.

Keywords
5S, SMED, DMAIC, Standard Work, Preventive Maintenance, Bottling Industry.

1. Introduction
Over recent years, the non-alcoholic beverage industry has experienced sustained growth driven by factors such as urbanization, shifting consumption habits, and rising demand for healthy products. In Peru, bottled water represents 28% of the sector's total production and is projected to grow at an annual rate of 4.7% between 2025 and 2034. Despite this favorable outlook, companies in the industry continue to face operational challenges such as low productivity, high levels of non-productive time, variability in quality, and dependence on manual activities. Recent studies demonstrate that integrating Lean and Six Sigma methodologies enhances efficiency indicators in similar food and beverage industries. However, empirical evidence remains limited regarding their application in water bottling plants operating under technological constraints.

The relevance of this study lies in the fact that the company under analysis exhibits a productivity level of 12.53 L/sol, which is 34.7% below the sector benchmark of 19.2 L/sol. This performance gap generates an estimated annual economic loss of S/ 83,191.82. The technical diagnostic identified key causes, including 16,800 minutes/year lost to changeover times (setup), 1,120 minutes/year due to mechanical failures, 42,336 defective units/year, and 17,472 minutes/year spent searching for tools. These findings confirm the need for a comprehensive intervention. In this context, methodologies such as 5S, SMED, preventive maintenance, DMAIC, and process standardization emerge as viable strategies for enhancing operational efficiency without relying on advanced technology.

Nevertheless, the systematic literature review revealed a significant research gap. While previous studies evaluate the individual application of Lean or Six Sigma tools, no evidence was found addressing their integrated and sequential implementation within water bottling companies that operate under similar conditions—specifically environments characterized by low digitalization and limited resources. Thus, this research aims to provide scientific evidence demonstrating that the combined implementation of these methodologies can improve productivity sustainably and, in a manner, suitable for replication.

Accordingly, the general objective of this study is to increase productivity in a non-alcoholic beverage company through the integrated application of Lean Six Sigma tools. The research question posed is: To what extent does the sequential implementation of 5S, SMED, preventive maintenance, DMAIC, and process standardization methodologies increase productivity and reduce non-productive time in a water bottling company?
Unlike previous studies that analyze these tools individually, the present research empirically demonstrates that their integrated and sequential implementation leads to higher levels of operational efficiency without requiring significant technological investment.

The article is structured as follows: Section 2 presents the literature review; Section 3 describes the research methodology; Section 4 summarizes the obtained results; Section 5 discusses the findings in comparison with scientific literature; and Sections 6 and 7 provide the conclusions and recommendations.

1.1 Objectives
- Reducing non-productive time associated with format changeovers (Set Up) through the application of the SMED methodology.
- Decreasing stoppage time caused by technical failures by implementing a structured preventive maintenance plan.
- Minimizing the proportion of defective products through the application of the DMAIC methodology focused on quality control.
- Optimizing tool and material search time through the implementation of the 5S methodology.

- Standardizing operational activities by developing and applying Standard Operating Procedures (SOPs).
- Evaluating the economic, social and environmental sustainability of the proposed improvement framework.

2. Literature Review

In recent years, several studies have demonstrated that the implementation of Lean and Six Sigma tools constitutes an effective strategy for improving efficiency and productivity within the food and beverage industry. Achibat et al. (2023) and Wang et al. (2020) indicate that competitive pressure in manufacturing environments has fostered the adoption of continuous improvement methodologies aimed at reducing waste, stabilizing processes, and increasing production capacity. In the specific case of the non-alcoholic beverage sector, Huarcaya and Platero (2023) report an average productivity reference value of 19.2 kg/sol, while Phukapak et al. (2024) show that OEE in juice production lines may reach approximately 79.65%, with potential optimization up to 80.72% through the application of Lean techniques. These studies concur that low productivity is typically associated with high non-productive time, operational variability, and a strong dependence on manual intervention.

Regarding product quality, Khwaja et al. (2021) demonstrated that the application of Six Sigma can reduce the proportion of defective items from 18% to 9%, whereas Núñez et al. (2023) report reductions close to 40% following the standardization of critical inspections in food processes. Similarly, Fan (2024) validates the use of the DMAIC cycle as a central tool for statistical process control, while Widiwati et al. (2024) and Chero-Yenque et al. (2022) suggest that the combined application of Lean and Six Sigma approaches yields more robust results than their isolated use, as it simultaneously addresses variability, rework, and defects. From a broader productivity perspective, studies by Castro and Pérez (2024) and Mendes et al. (2023) reveal that the integration of structured preventive maintenance can generate increases of up to 21.25% in OEE and improvements above 140% in productivity, mainly through reductions in unplanned stoppages and increased effective operating time.

In relation to time management, Flores et al. (2023) and Huarcaya-Meléndez and Platero-Mamani (2023) demonstrate that the implementation of the 5S methodology can reduce tool and material search times by up to 51.2%, improving operational time utilization and workplace organization. Conversely, Braglia et al. (2023), Sá et al. (2024), and Pawlak (2024) agree that SMED is among the most effective techniques for reducing setup time, with Pawlak (2024) reporting a 50.5% reduction. Moreover, Pérez-Canchanya et al. (2023) show that the structured implementation of SMED in Peruvian food manufacturing companies not only reduces changeover times but also improves delivery performance and reduces delay-related penalties. Complementarily, Rathia et al. (2023) and Mendes et al. (2023) point out that preventive maintenance focused on monitoring mean time between failures (MTBF) and mean time to repair (MTTR) can reduce the latter by around 30% and increase the former by approximately 40%, contributing to more stable and reliable production systems.

From a methodological integration perspective, Ortiz-Porras et al. (2023), Antosz et al. (2023), Cabrera et al. (2020), and Cuggia-Jiménez et al. (2020) demonstrate that combining Lean tools (such as 5S, SMED, and Kanban) with Six Sigma leads to significant improvements in waste reduction, cycle time, and defect minimization in the food industry. However, most of these studies apply the tools sequentially but not necessarily under a fully integrated and systematic model, executing them instead as isolated improvement projects. Additionally, Shahin et al. (2023) explore the concept of 5S+1 by incorporating computer vision to reinforce occupational safety, while Trebejo-Zelaya et al. (2022) expand the approach to 9S by integrating cultural and behavioral dimensions. These contributions indicate a trend toward greater technical and technological sophistication in Lean tools; nevertheless, many of these solutions are designed for environments with higher automation levels.

A systematic literature review using the PRISMA model allowed the initial screening of 71,189 articles, which was narrowed down to a final sample of 40 relevant studies sourced from Scopus and Web of Science. These were analyzed according to three typologies: Problem-Scenario (PxE), Technique–Cause (CxT), and Problem-Technique-Scenario (PxTxE). From this analysis, it is concluded that although studies by Huarcaya-Meléndez and Platero-Mamani (2023), Hernández et al. (2023), Khwaja et al. (2021), Tsai et al. (2022), Wang et al. (2020), Braglia et al. (2023), Sá et al. (2024), Pawlak (2024), Fan (2024), Widiwati et al. (2024), Chero-Yenque et al. (2022), Ortiz-Porras et al. (2023), Achibat et al. (2023), Antosz et al. (2023), Cabrera et al. (2020), Shahin et al. (2023), Trebejo-Zelaya et al. (2022), Castro and Pérez (2024), Mendes et al. (2023), Rathia et al. (2023), Pérez-Canchanya et al. (2023), Flores et al. (2023), Flores Hidalgo et al. (2024), and Phukapak et al. (2024) provide empirical evidence demonstrating the positive impact of these methodologies, none of them assess the combined and sequential application of 5S, SMED, preventive maintenance, DMAIC, and standard work in water bottling plants characterized by low digitalization and high reliance on manual operations. This constitutes the main scientific gap upon which the present research is founded.

3. System Design and Architecture

The proposed methodology begins with the identification of the technical performance gap in terms of productivity, quantified at 12.53 L/sol, which represents a 34.7% deviation below the reference industry standard. This finding justified the need for an operational intervention. Accordingly, a sequential improvement model was designed based on the integration of 5S, SMED, preventive maintenance, DMAIC, and process standardization. The model was structured using operational flowcharts for each tool to ensure methodological consistency throughout implementation.

Validation of the proposed model was conducted using both technical and economic performance indicators, highlighting a projected 39.5% increase in productivity, recovery of 17,239 non-productive minutes per year, and an improvement of Overall Equipment Effectiveness (OEE) from 62% to 83% (Figure 1).

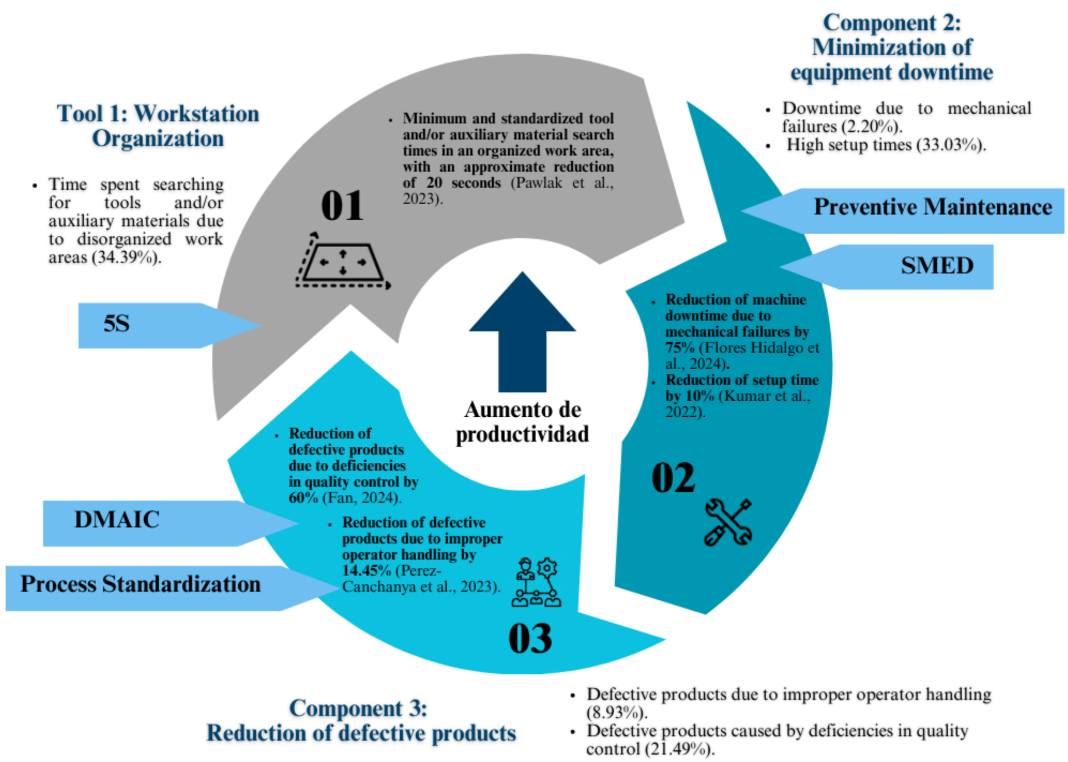

Figure 1. Conceptual model of a solution proposal

4. Methods

A sequential improvement framework was designed based on the integration of the 5S, SMED, preventive maintenance, DMAIC and process standardization methodologies. Each tool was validated through an in-plant pilot test and subsequently assessed using discrete-event simulation, enabling a quantitative comparison between the current (As-Is) and improved (To-Be) scenarios.

The technical performance indicators used in the study, productivity, non-productive time, Overall Equipment Effectiveness (OEE), and defect rate, were defined in accordance with international operational efficiency standards. Furthermore, they were validated jointly with plant specialists using technical-economic criteria to ensure consistency and reliability throughout the comparative analysis.

4.1 5S
During the diagnostic phase, 17,472 annual minutes were identified as being associated with tool search activities, equivalent to 10.87% of total working time. The implementation of 5S was carried out as a pilot intervention at the labelling station, where standardized signage, color-coded zoning and tool classification were applied. This resulted in a reduction of search time by 30.7%, equivalent to 16.93 minutes per shift. This improvement demonstrated significant enhancement in resource accessibility and established the foundation for the subsequent implementation of the remaining methodologies.

4.2 SMED
A total of 16,800 minutes per year associated with format changeover (Set Up) were identified, equivalent to 10.45% of productive time. Following process analysis, the application of the SMED methodology optimized the changeover cycle, reducing the setup time from 56.55 to 18.67 minutes, representing an improvement of 67.01%. This optimization directly contributes to the reduction of non-productive time and enhances process agility during format transitions.

4.3 Preventive Maintenance
This methodology was the only tool validated exclusively through process simulation using Arena software. Two scenarios (As-Is and To-Be) were modelled using the reverse osmosis system, identified as a critical component, as the unit of analysis. Mechanical failure downtime improved from 15.38% (73.83 min/shift) to 2.59% (12.44 min/shift) following implementation. Simulation enabled performance comparison without interrupting real plant operations.

4.4 DMAIC
The DMAIC approach was applied to support root cause analysis and process variability control. Indicators specified in the diagnostic phase, such as productivity (12.53 L/sol), non-productive time and defect rate (9.62%), were used to substantiate quantitatively the need for intervention. This methodology provided evidence-based justification for the simulation and the comparative analysis between the current and improved scenarios.

4.5 Process Standardization
Finally, optimized procedures were documented through Standard Operating Procedures (SOPs), with semi-annual review established to ensure sustainability of the improvements implemented. This stage served as the final phase of the model, with the purpose of guaranteeing replicability of results and facilitating future audits.

5. Testing and Results
The initial analysis revealed that the production line recorded a productivity level of 12.53 L/sol, representing a 34.7% deviation below the industry benchmark of 19.2 L/sol, thereby confirming a significant performance gap relative to expected operational standards. Following the sequential implementation of the Lean Six Sigma tools, the discrete-event simulation projected a 39.5% increase in productivity, indicating an upward trend toward the reference benchmark.

Additionally, the model estimated a total recovery of 17,239 non-productive minutes per year, mainly attributable to the reduction of time associated with tool search, format changeover and mechanical failures.

In relation to quality, the initial non-conformance rate was 9.62%, with a projected reduction of approximately 40% through the combined application of DMAIC and process standardization. Complementarily, tool search time (10.87%) and setup time (10.45%) were projected to be reduced by approximately 30.7% and 67.01%, respectively, while structured implementation of preventive maintenance would lead to an 83.15% decrease in downtime generated by mechanical failures, strengthening operational stability.

To support quantitative performance comparison, Table 1 presents key indicators under the As-Is (current) and To-Be (projected) scenarios, while Table 2 summarizes the relationship between the tools implemented and their operational impact.

Table 1. Performance Comparison Before and After Implementation

Indicator	Current Situation (As-Is)	Projected Scenario (To-Be)	Estimated Improvement
Productivity (L/sol)	12.53	17.50 – 19.20	+ 39.5 %
Defect rate (%)	9.62%	5.80 – 6.00 %	– 40 %
Tool search time (%)	10.87%	≈ 7.50 %	– 30.70 %
Changeover time (%)	10.45%	≈ 3.45 %	– 67.01%
Mechanical failure downtime (%)	15.38%	≈ 2.59 %	– 83.15 %
Non-productive time (min/year)	17, 239 min	~ 0 min	Full recovery

As observed in Table 1, the 39.5% projected increase in productivity narrows the performance gap toward the industry benchmark, reinforcing the effectiveness of the proposed framework.

Table 2. Implemented Changes and Operational Impact

Methodology Applied	Corrected Gap	Expected Quantitative Impact
5S	Operational disorder and non-productive time	–30.70% in tool search time
SMED	Extended format changeover duration	–67.01% in setup time
Preventive Maintenance	Recurring mechanical failures	–83.15% in downtime
DMAIC	Process variability and defects	–40% in non-conforming products
Process Standardization	Operational dependency	Increased process repeatability

Table 2 highlights the alignment between each implemented tool and the corrected gap, evidencing the sequential integration as a key driver for operational improvement.

6. Conclusion

The results obtained demonstrate that the sequential integration of the 5S, SMED, preventive maintenance, DMAIC and process standardization methodologies represents a technically efficient strategy for addressing the main operational gaps identified in non-alcoholic beverage manufacturing companies. The structured application of these tools enabled optimization of productive time, reinforcement of system reliability and reduction of process variability, confirming the suitability of the proposed model in industrial contexts characterized by low automation levels and limited technological resources.

The methodological approach proved not only technically feasible but also cost-effective, as it achieved significant operational improvements without requiring additional technological investment. From a scientific standpoint, this research contributes empirical evidence validating the effectiveness of an integrated methodological approach, contrary to most of the existing literature that assesses these tools individually. The study enriches the Lean Six Sigma knowledge base by demonstrating that coordinated implementation generates higher levels of operational efficiency and sustainability compared with isolated applications.

These results are consistent with Flores Hidalgo et al. (2024), who reported comparable improvements in productivity recovery through preventive maintenance in semi-automated systems. However, unlike previous studies, this research validates the integrated and sequential application of multiple Lean Six Sigma tools in low-digitalization environments, reinforcing the scientific robustness of the proposed model.

In practical terms, the study provides a replicable intervention model for manufacturing environments with similar characteristics, offering a valuable reference for continuous improvement strategies, data-driven decision-making and productivity-oriented operational planning. It further reinforces the methodological value of sequential integration as a strategic alternative to improve industrial productivity under digitalization constraints. The applied model can be replicated in manufacturing companies with similar operational conditions, particularly those with high manual dependence and low automation, representing a methodological foundation for future research and industrial applications.

Consequently, it can be concluded that the proposed methodology not only constitutes a viable alternative to improve productive performance in the water bottling industry, but also contributes to future research by demonstrating the potential of Lean Six Sigma tools when implemented under a cohesive, sequential and context-based approach adapted to real operational conditions.

7. Future Work

Although the proposed model has proven technically feasible and appropriate for the intended scope, the following lines of research are suggested to enhance its applicability, strengthen sustainability and broaden its future implementation.

I) **Incorporating digital tools for production monitoring:** Current indicator measurement was performed through manual recording and discrete-event simulation. The implementation of digital data capture systems (e.g., IoT sensors, industrial dashboards or real-time monitoring software) would improve control accuracy, shorten reaction times to failures and strengthen data-driven decision-making.

II) **Partially automating inspection and quality control processes:** Quality control is currently dependent on manual intervention. The integration of automated detection sensors, machine vision systems or intelligent inspection technologies would help reduce process variability, increase traceability and improve final product consistency.

III) **Extending the model to other product lines or industrial plants:** The study was conducted on a specific bottling line. It is recommended to validate the model in operational settings with greater complexity, multiple formats or different automation levels to assess its scalability and methodological robustness.

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Biographies

Stefanía Carolina Huerta Sánchez is a final-year Industrial Engineering student at Universidad de Lima. She has experience in the wholesale retail sector and the energy industry, where she has worked in the procurement and supply area, as well as in the People and Organization department. Her academic interests include supply chain management, organizational development and continuous improvement.

Cesar David Mesia Perez is a final-year Industrial Engineering student at Universidad de Lima. He has experience working in the product and commercial area within the machinery industry. His academic interests include operations management, strategic planning and industrial process optimization

Ms. Rafael Mauricio Villanueva Flores is an Industrial Engineer from Universidad de Lima and holds a Master of Science from Kansas State University. He currently serves as Operations Manager at Anita Food and is a professor at the Faculty of Engineering and Architecture of Universidad de Lima. He is an executive with extensive experience in managing industrial operations and has authored multiple publications related to the food industry.

Mr. Jorge Antonio Montoya Barragán is a professional in Logistics and Supply Chain Management with more than 14 years of experience in materials management, supply chain optimization, and sales planning within the pharmaceutical and retail sectors. He currently serves as a faculty member at the School of Engineering of Universidad de Lima. His professional profile is characterized by solid expertise in industrial operations management and strategic planning applied to the manufacturing and distribution industries.