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Productivity Improvement in Portland Cement Production Using Lean Manufacturing and Six Sigma

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Abstract

The Peruvian cement industry faces notable productivity pressures: current Overall Equipment Effectiveness (OEE) averages around 65.6%, below the worldclass benchmark of 85%; national dispatches declined 1.3% in April 2025, with production falling 1.6% year on year (OEE, ASOCEM). Additionally, defect rates can reach 7.5% in bagging operations (Shesarina et al., 2022). To address these and reduce waste encompassing excess inventory, waiting, and defects the study applied Lean Manufacturing and Six Sigma in the packaging and dispatch stages of a Portland cement plant. Using Value Stream Mapping (VSM), key bottlenecks were identified. Interventions included Kanban for inventory control, SMED to reduce changeover time by 60%, and DMAIC to structure improvements. Implementation resulted in a 50.2% reduction in defective bags (from 4,666 to 2,324 per shift), a 167-minute decline in truck processing time, and dispatch capacity increased from 7 to 10 trucks per shift. Dispatch inventory dropped by over 40%, while OEE improved significantly. Economically, operational costs fell by 18%, achieving ROI in just 1.59 months. These findings demonstrate how integrated Lean Six Sigma tools can markedly boost operational efficiency, quality, and sustainability in the cement sector, closing the OEE gap and responding to declining sectoral performance.

Keywords
Lean Manufacturing, Six Sigma, Continuous Improvement, Cement Industry, Productivity Improvement.

1. Introduction
Portland cement production faces significant challenges that directly affect its operational efficiency and profitability. Recent studies have identified that areas such as packaging and dispatch present recurring issues, including weight measurement inaccuracies, logistical delays, and inventory accumulation, all of which generate additional costs and compromise product quality (Hossen Irfan et al., 2025). In the case of the studied cement plant, these inefficiencies were reflected in a pre-improvement production rate of 3,647 tons per hour, which limited throughput and increased variability.

In the case of the cement plant studied, these inefficiencies were reflected in a pre-improvement production rate of 3,647 tons per hour, limiting output and increasing variability. The COVID-19 pandemic also caused a significant reduction in cement demand, increasing pressure to optimize processes. Added to this is the generation of waste, with some cement plants reporting waste levels of up to 15% of total production, negatively impacting sustainability and profitability. (Masmali, 2021).

In response to this scenario, the application of Lean Manufacturing and Six Sigma methodologies has proven to be an effective strategy for improving productivity and reducing variability in critical processes. Tools such as Value Stream Mapping (VSM) help identify bottlenecks and non-value-adding activities in production stages, while the use of Kanban systems has effectively managed inventory and material flow, minimizing downtime and overproduction (Hossen Irfan et al., 2025).

Moreover, the DMAIC methodology, inherent to Six Sigma, has shown positive results by structuring continuous improvement projects that reduce defects, optimize resources, and improve operational stability (Sakib et al., 2025). In a recent case study from the Indian cement industry, the implementation of DMAIC led to a 7.7% increase in daily productivity. This resulted in a significant annual economic benefit (Jena et al., 2024). Likewise, another study conducted in a Brazilian cement plant applied DMAIC to improve internal logistics processes related to dispatch operations, successfully identifying out-of-control processes, standardizing loading and unloading flows through control charts, and implementing daily monitoring routines that stabilized logistics and enhanced operational efficiency (Bonetti et al., 2023).

In this context, the present research will focus on analyzing recurring issues in the packaging and dispatch area of a cement plant and applying Lean Six Sigma techniques, including VSM, DMAIC, SMED, and Kanban, with the goal of optimizing process management, reducing operational costs, and improving final product quality. While several studies have addressed process improvement in manufacturing, limited attention has been given to the integration of Lean Six Sigma tools in the specific context of packaging and dispatch operations within the cement industry. To address this gap, this study is guided by the following research question: **How can the integration of Lean Six Sigma tools optimize packaging and dispatch processes in the cement industry?** By answering this question, the study aims to contribute practical insights into how continuous improvement methodologies can be adapted to enhance performance in late-stage production logistics within the cement sector.

1.1 Objectives

The main objective of this project is to increase the productivity and efficiency of the Portland cement production process through the application of continuous improvement tools

Specific Objectives:

- Analyze the Portland cement production process and diagnose the existing issues within the production.
- Develop a proposal for improving the Portland cement production process.
- Evaluate the productivity level of the Portland cement manufacturing process.
- Reduce the percentage of waste by at least 2% in the Portland cement production process.
- Evaluate the economic feasibility and potential return on investment of implementing the proposed improvements within Company X.

2. Methods

The overall structure of the proposed model designed to achieve the objectives of this study is presented in Figure 1.

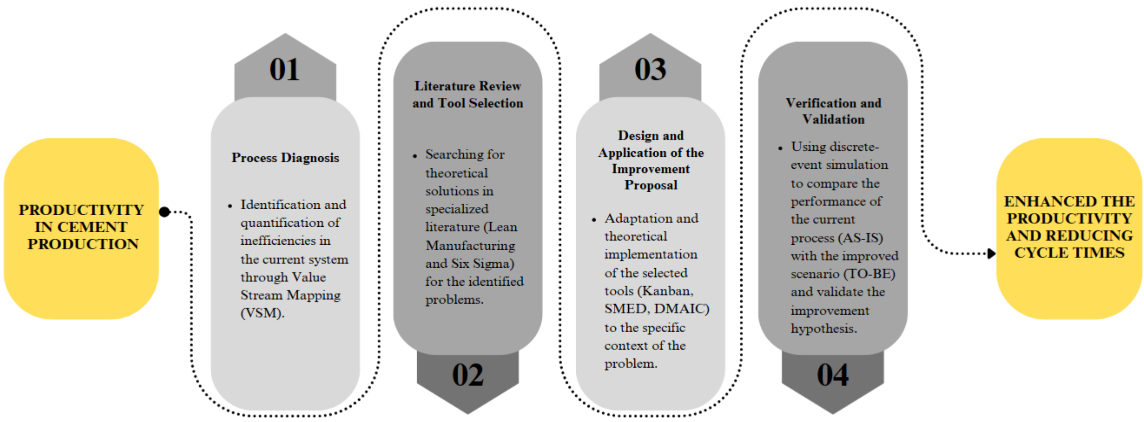

Figure 1. General Structure of the Proposed Model

To accomplish the established objectives, it is important to emphasize that the study adhered to the principles of the scientific method, beginning with the identification of the research problem and the formulation of a hypothesis, which was subsequently addressed through an experimental design and the systematic analysis of results. The research process was structured into four phases of well-defined stages, which are detailed in the following sections.

Phase I: Diagnosis

The problem tree is a structured analytical tool used to identify the root causes and effects of a central problem. In this study, it is applied to the production process of Portland cement Type I to reveal the underlying operational inefficiencies. This analysis serves as a basis for proposing improvement strategies grounded in Lean Manufacturing and Six Sigma methodologies (Figure 2 and Figure 3).

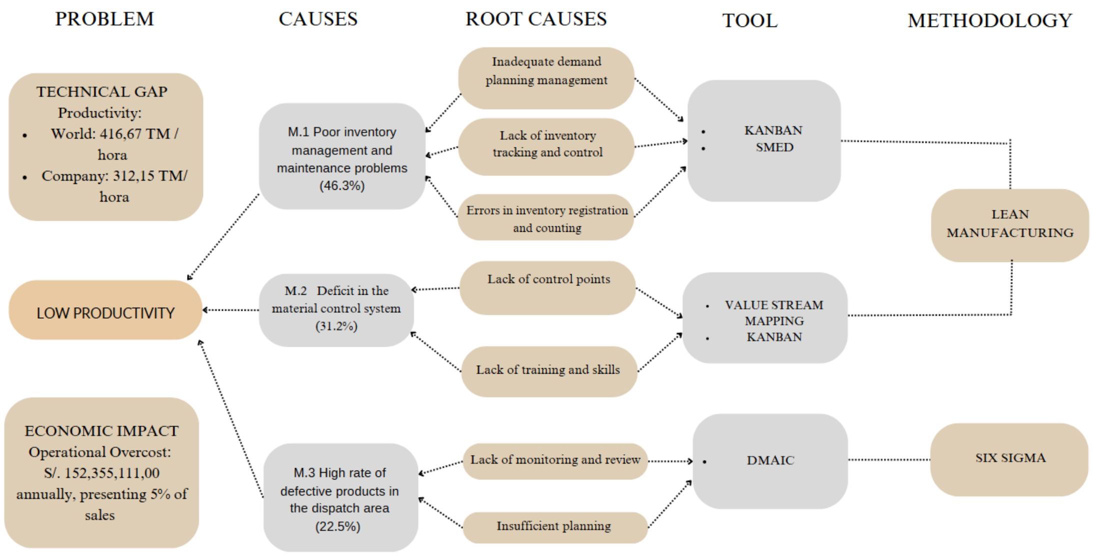

Figure 2. Problem Tree

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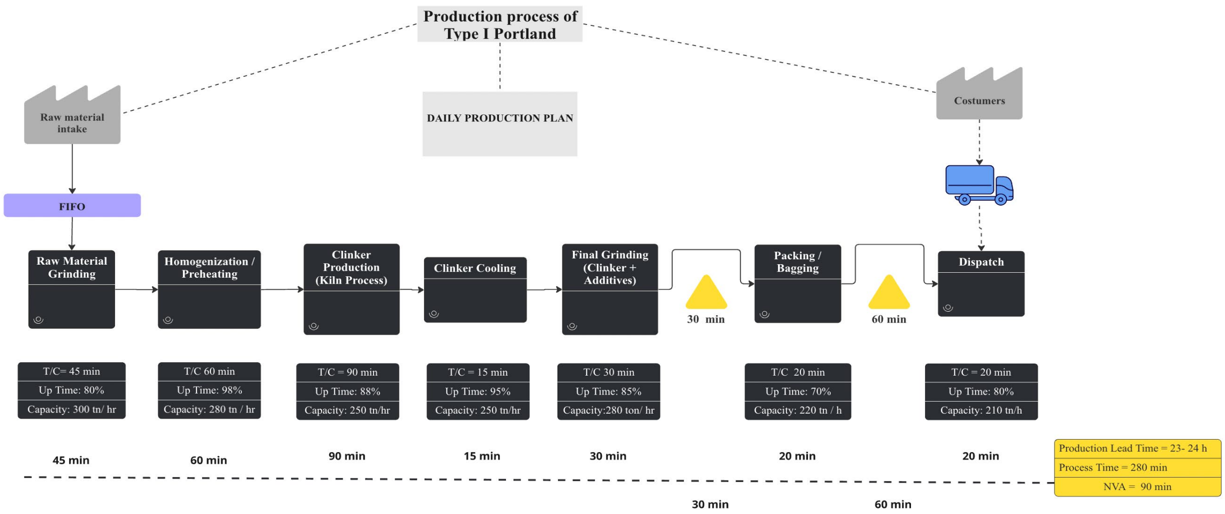

Figure 3. Current Value Stream Mapping

The Value Stream Mapping (VSM) analysis revealed that the most significant inefficiencies in the production process occur in the final stages, specifically between packaging and dispatch. A 90-minute delay was identified in these areas, caused by manual handling operations, inefficient product transfer, and delays in correcting bag weights exceeding the 42.5 kg specification. Additionally, extended waiting times in the finished product warehouse, due to limited dispatch coordination, contribute to inventory accumulation and increased operational costs. The analysis confirmed that these issues represent the primary bottlenecks in the system, directly affecting process flow, lead time, and overall productivity.

Phases II and III: Selection and Application of Improvement Techniques

Based on the VSM findings, the most appropriate techniques were selected. For each technique, its theoretical foundation according to the literature is described first, followed by its specific application in this study. In addition, discrete-event simulation was employed to compare the current state and proposed future state scenarios. Control and comparison criteria included key performance indicators (KPIs) such as average waiting time, setup time, defect rate, and inventory levels. These indicators were used both to validate improvements and to monitor process sustainability during the Control phase.

2.2.1 Kanban for Flow and Inventory Management

- **Literature Foundation:** The Kanban tool is a visual production control system based on signals that authorize the production or movement of material in a "pull" system. Its objective is to limit work in process (WIP), prevent overproduction, and synchronize consecutive stages of a process, thereby reducing waiting times and inventory costs (Masmali, 2021). Studies have shown its effectiveness in inventory management and material flow to minimize downtime. (Hossen Irfan et al., 2025).

- **Application in the Case Study:** To address the 60-minute wait and inventory accumulation between bagging and dispatch identified by VSM, a visual Kanban system was designed. This system regulates the flow of cement pallets to the dispatch area, ensuring that a product only moves when there is a signal of actual demand (a truck ready to load). This aims to eliminate unnecessary inventory and synchronize operations, directly attacking the identified bottleneck.

2.2.2 SMED (Single-Minute Exchange of Die) for Time Reduction

- **Literature Foundation:** The SMED methodology focuses on drastically reducing machine changeover or setup times. Its principle is to analyze setup tasks, classify them as "internal" (machine stopped) and "external" (machine running), and convert as many internal tasks as possible to external ones. The goal is to minimize machine downtime, increasing its availability and flexibility, which is a key component of a responsive Lean production system.
- **Application in the Case Study:** The SMED approach was applied to the adjustment process in the packaging line, which caused stoppages and variability. Weight adjustment and format change operations were analyzed, standardizing tools and reorganizing tasks so they could be performed in parallel or in advance. The goal was to reduce changeover time by 60% to 85%, which in turn would decrease process variability and, consequently, the defective product rate (from 5% to 2.5%).

2.2.3 DMAIC as a Structured Improvement Framework

- **Literature Foundation:** DMAIC (Define, Measure, Analyze, Improve, Control) is the structured framework of the Six Sigma methodology. It provides a systematic, data-driven approach to problem-solving and process optimization. It ensures that solutions are not only implemented but also sustained over time, which has shown positive results in defect reduction and operational stability improvement. (Sakib et al., 2025).

- **Application in the Case Study:** The DMAIC framework was used to guide the entire project. The "Improve" phase consisted of implementing the Kanban and SMED proposals. In addition, sensor technology was incorporated for real-time monitoring of bag weight. Finally, the "Control" phase was designed to establish monitoring mechanisms to ensure the sustainability of improvements, validating that the process remains stable and under control.

Although Lean and Six Sigma have been widely applied in manufacturing, most studies focus on early-stage processes such as production or quality control. In contrast, there is limited research on end-stage operations—particularly packaging and dispatch—which involve specific challenges like bulk material handling, synchronization, and safety requirements. Additionally, existing literature often addresses tools like Kanban or SMED in isolation, overlooking the benefits of their integrated use to resolve operational bottlenecks.

Furthermore, the study adds value by establishing explicit control criteria to ensure the long-term operational sustainability of the implemented improvements.

Phase IV: Verification Through Simulation

The validation method selected to evaluate the effectiveness of the proposed improvement plan was discrete-event simulation, one of the most applied methodologies in industrial process analysis. Simulation allows anticipating system behavior, validating proposed changes, and identifying optimal configurations before real-world implementation. For this study, Arena simulation software was used to model the cement packaging and dispatch process in its current and improved state, allowing for a comparative analysis between AS IS and TO BE scenarios. Consistent with the scientific method, this approach sought to test the hypothesis that continuous improvement methodologies can optimize process productivity.

Simulation Objectives:

- Quantify the reduction in truck waiting times.
- Measure changes in defect rates after SMED implementation.
- Evaluate improvements in inventory turnover and dispatch synchronization through Kanban application.
- Assess system stability and process variability control through DMAIC-monitored scenarios.

To ensure statistically reliable results and account for inherent system variability, 120 independent simulation replications were performed, each representing a full 12-hour operational shift. Random variability in truck arrivals, packaging rates, defect occurrences, and dispatch times was introduced using probability distributions derived from historical plant data. The accumulated waiting and processing times reported correspond to the aggregated performance of all trucks handled in each replication, providing robust performance estimates for both baseline and improved scenarios. Figure 4 below presents the Arena simulation after the application of Lean Manufacturing and Six Sigma.

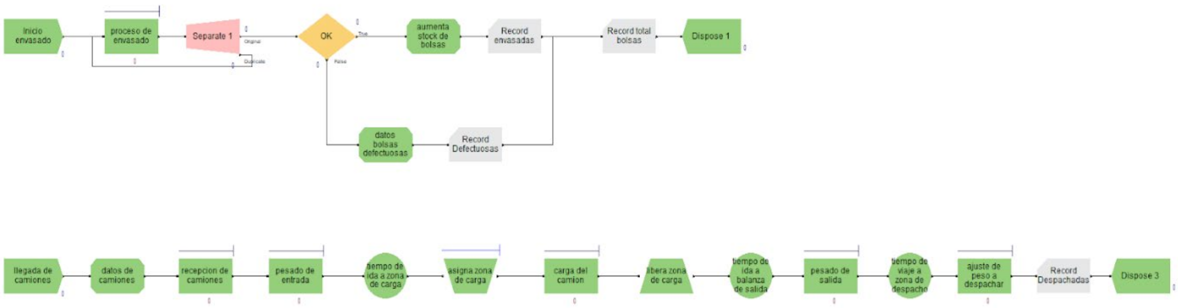

Figure 4. Arena Simulation

Sensitivity and Risk Analysis

To complement the simulation model, a sensitivity and risk analysis was conducted using RISK software to evaluate variations in key parameters such as cost, performance, and time impact financial outcomes. The results of this analysis are illustrated in Figure 5. Three economic scenarios were analyzed. In the optimistic scenario, improved throughput and defect reduction resulted in an IRR of 99.45%; the most likely scenario yielded an IRR of 71.73%, while the pessimistic scenario, assuming limited defect reduction, produced an IRR of 52.61%. The IRR simulation showed a 90% confidence interval of ±0.485%, confirming the robustness and economic feasibility of the Lean Six Sigma implementation under different operational conditions.

	TIR
Cell	Model!C29
Minimum	52.164%
Maximum	99.454%
Mean	71.728%
CI: 90%	0.485%
Mode	66.300%
Median	70.575%
Std Dev.	9.312%
Skewness	52.850%
Kurtosis	2.838%

Figure 5. IRR Simulation Statistics

Data Collection

Through a systematic data collection process, a comprehensive database was developed, comprising specialized articles addressing challenges within the cement industry and the implementation of improvement methodologies in case study contexts.

In addition to the literature review, valuable information was obtained through semi-structured interviews with production managers and guided plant tours, which provided direct insights and reliable data from real-world Portland cement manufacturing environments. This combination of documentary analysis and field research ensured a robust and contextualized understanding of current operational issues and improvement opportunities within the industry.

Furthermore, the data presented in the following Table 1 was gathered during plant visits and technical meetings with operational personnel. These figures represent key operational indicators and will serve as a foundation for the application of the proposed improvement model and the development of the simulation scenarios aimed at optimizing production and logistics performance.

Table 1. Operational Indicators for Portland Cement Type I Production

Indicator	Value
% of Defective Products	5%
Cycle Time per-Ton	20 – 25 seg
Clinker Production Capacity	14,000 ton/day
Cost per Ton of Clinker	$ 100 ton de clinker
Portland Cement Inventory	4,000 – 6,000 bags
Raw Material Safety Stock	21,000 ton per day

To effectively evaluate and simulate the operational performance of the cement production system, it is essential to gather accurate data related to the packaging and dispatch areas. Tables 2 and 3 summarize the key resources, capacities, and time-related metrics.

Table 2. Required Data for the Packaging Area

Resource	Quantity
Number of Packaging Machines	2 manual machines
Production Capacity	2,300 bags/hour
Operators	2 operators per machine (1 shift)
Weight Limits	42.5 kg ± 0.1

Table 3. Required Data for the Dispatch Area

Resource	Quantity
Number of Trucks	190 trucks/day
Truck Capacity	700 bags/truck
Operators	13 operators

3. Results

The simulation assumed a total production output aligned with current daily averages, identifying that 5% of the manufactured cement bags were classified as defective. This proportion equated to approximately 4,666 bags in 12 hours, representing a significant source of material loss, increased operational costs, and added strain on dispatch logistics.

Additionally, the simulation recorded cumulative truck waiting times reaching 1,523 minutes per day, primarily caused by delays in packaging corrections and product transfer between operational areas. These inefficiencies generated inventory accumulation in the dispatch zone and negatively affected turnover rates.

The baseline simulation scenario served as a critical input for the design of targeted Lean Manufacturing and Six Sigma interventions, with subsequent simulated adjustments projecting notable improvements in defect rates, equipment downtime, and dispatch lead times.

Figure. 6. Improvement in waiting times in the dispatch area.

As depicted in Figure 6, the implementation of the proposed improvements led to a notable reduction in both trucks waiting time and total truck processing time. In comparison to the real system, the truck waiting time was reduced by 278 minutes, while the total truck time decreased by 167 minutes. These findings underscore the effectiveness of Kanban in enhancing dispatch performance, synchronizing operations, and improving overall logistics flow efficiency (Table 4).

Table 4. Comparative Indicators Between AS-IS and TO-BE Scenarios

Indicator	(AS-IS)	Kanban Ap (TO-BE)
Total, truck time (Avarege)	1,588 min	1,421 min
Truck waiting time (Avarage)	1,523 min	1,361 min
N° trucks dispatched	7 trucks	10 trucks
Average Inventory in Dispatch	>3,000 bags	1,500- 1,700 bags

After applying SMED-based improvements including externalizing preparatory activities, standardizing tool setups, pre-positioning materials, and training operators in rapid changeover techniques. The average changeover time was reduced to 12 minutes, representing a 60% improvement. As a direct consequence, production stability during transitions increased, reducing defective cement bags from 4,666 to 2,324 per shift, as evidenced in the simulation outcomes.

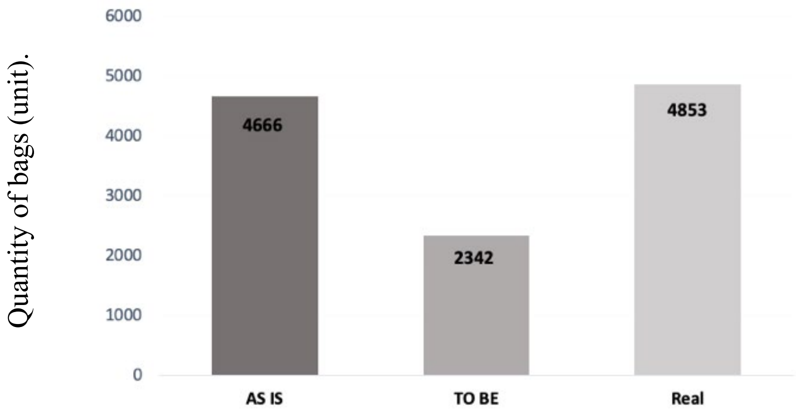

Figure 7. Result of the optimization of the percentage of defective bags.

Figure 7 illustrates an improvement of approximately 50.2% after the impact of initiatives on reducing the number of defective cement bags. This significant decrease of 2,324 defective bags highlights the decisive role of SMED in stabilizing operational parameters during packaging transitions and minimizing variability. Additionally, the DMAIC methodology provided a structured framework for monitoring, validating, and sustaining these improvements over time, ensuring that defect levels remain consistently below the established benchmarks while supporting continuous process optimization.

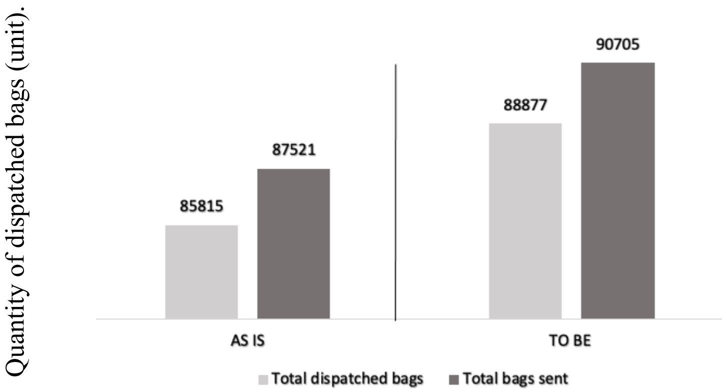

Figure 8. Result of the optimization of bags packaged and dispatched.

Figure 8 reveals a substantial improvement in the coordination between packaging and dispatch operations following the implementation of the Kanban system. The total number of dispatched bags increased from 85,815 in the current state (AS IS) to 88,877 in the improved scenario (TO BE), while the total number of bags sent rose from 87,521 to 90,705. These results indicate a more consistent and efficient synchronization of processes, reducing bottlenecks and ensuring a smoother flow of materials through the dispatch area.

Furthermore, an economic evaluation of the project was conducted, the results of which are presented in Table 5.

Table 5. Economic evaluation

Indicators	Results
Economic NPV	S/ 301,079.40
Economic IRR	70.79%
Benefit/Cost	1.81
Recovery period	1.59 months

The results of the economic evaluation confirm the viability of implementing Lean and Six Sigma methodologies in the cement production process. The anticipated benefits not only surpass the costs incurred but also lead to a rapid return on investment, estimated at 1.59 months, highlighting the efficiency and financial soundness of the proposed improvements.

4. Discussion

After the compilation and analysis of specialized articles, it was considered that the present research should surpass the limitations and contributions presented in other studies, as many of the investigations were qualitative in nature. Regarding the results, the efficiency achieved by the company is 58%. According to Adeodu et al. (2023), implementing this tool in the cement packaging station resulted in a process cycle efficiency improvement of up to 70%. It is worth noting that results may vary as they depend on the context and measurement methodologies used. This indicates that while the improvement percentage in this research was optimal compared to previous articles, there is still potential for further enhancement. In terms of economic evaluation, the application of Kanban generates a 10% reduction in inventory and storage costs. In the present study, an 18% monthly cost reduction was achieved, considering energy costs for the use of conveyor belts connecting the dispatch and packaging areas.

In the specific context of implementing SMED in the company, particularly in the packaging area, reduce the average setup time from 30 minutes to 12 minutes, a 60% improvement. This improvement minimized operational variability during product transitions, directly contributing to a 50.2% reduction in defective cement bags, lowering them from 4,666 to 2,324 per shift. Such results reaffirm the importance of standardized changeover procedures and proactive workforce training in achieving consistent quality outcomes.

According to Aswin et al. (2022) it is crucial to test the impact of digital tools based on the five principles of Lean Manufacturing in the supply chains of manufacturing companies. Therefore, it is confirmed that the application of this project is viable and will bring benefits to the company. Additionally, the initially set objective of reducing waste by at least 2.5% is achieved. The impact of this reduction includes cost savings in waste, improved production efficiency by optimizing downtime, and enhanced product quality, thereby reducing costs associated with defective or rejected products.

Similarly, notable improvements in efficiency have been achieved in the dispatch area. Before the implementation of the tool, waiting times in the loading area reached 1,639 minutes. However, thanks to the implementation, these times have been reduced to 1,458 minutes. This achievement not only helps minimize downtime but also generates significant savings in operational costs. These results align with the findings Jiang et al. (2023), who applied the Six Sigma methodology in a construction sector company to reduce process times, achieving a reduction in the average process cycle from 788.49 minutes to 616.08 minutes. Regarding the previously set objective of reducing waiting times by 10%, in this case, it was reduced by 11%.

As for the limitations encountered in this work, it focused on the manual packaging line, limiting the quantity of specialized articles and, consequently, the comparative data. Additionally, for economic evaluation, most articles involved acquiring new machinery, resulting in higher investments with a minimum 5-year lifespan. Therefore, this work reflects that it is a project with significant profitability potential and a recovery period in months. Based on the results of this research and findings from other studies, the project's viability is confirmed, offering broader quantitative information for future investigations interested in applying improvement techniques in the cement industry.

5. Conclusions

The implementation of Lean - Six Sigma tools in the production process of Portland cement demonstrates a substantial improvement in productivity. Pre-implementation diagnostics revealed a production rate of 3,647 tn/hour, which increased to 3,800 tn/hour post-implementation with the incorporation of Kanban and SMED tools. Furthermore, the chosen continuous improvement techniques not only enhance operational efficiency but also lead to cost reduction, improved product quality, and increased customer satisfaction, as the company strives for on-time deliveries. Results indicate the achievement of initial objectives, showcasing increased profitability and a reduction in defects by over 2%.

Moreover, the economic evaluation reinforces the strategic value of the intervention. With an additional monthly value generated of S/. 449,279.40, the company significantly exceeds its direct production costs, and a positive Return on Investment (ROI) achieved within the first six months signals a strong trend toward profitability. These financial results indicate not only the achievement of the project's objectives but also the potential for long-term, scalable improvements.

While the primary contribution of this study lies in its practical application within the cement industry, it also offers academic value by providing empirical evidence of how the integration of Lean and Six Sigma tools can be effectively adapted to end-stage logistical processes. Although no new theoretical model is developed, the study presents a replicable methodological approach supported by statistical validation and simulation, which may serve as a foundation for future comparative research or multi-criteria studies in the field of industrial engineering.

To ensure the sustainability of improvements, it is recommended to invest in operational staff training and to strengthen collaboration among production, logistics, and quality departments. Additionally, industry stakeholders should promote policies that encourage standardization and digitalization through the adoption of Lean technologies. Finally, given the positive return on investment observed, this methodology should be replicated across other cement plants as part of a corporate continuous improvement strategy.

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Biographies

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Macarena Crespo Egúsquiza graduated with a bachelor's degree in industrial engineering from the University of Lima, Perú in 2024. She currently works at Unicon Professionals in Concrete, a company within the UNACEM Group in Peru. She is part of the Marketing Department, where she leads projects focused on enhancing customer experience and optimizing the customer journey across different stages. Her professional interests include process optimization, customer experience management, digital transformation, data-driven marketing, and service design.

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