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Implementing Lean Warehousing and WMS to Enhance Warehouse Efficiency: A Case Study in Peruvian Construction SMEs

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Abstract

The construction SME sector in Peru, critical for the country's infrastructure development, faces significant challenges, particularly in warehouse management. Inefficiencies such as extended lead times, low operational efficiency, and inadequate material handling impede the sector's ability to meet project demands. To address these issues, a Lean Warehousing model was proposed, integrating methodologies like 5S, ABC analysis, layout redesign, and a Warehouse Management System (WMS). The model aimed to streamline operations, reduce waste, and enhance the overall efficiency of warehouse processes. The study's findings demonstrated the model's effectiveness, with efficiency improving from 35.59% to 71.85%, lead time reduced by 87.89%, and inventory record accuracy increasing by 153.83%. These results indicate that the model significantly optimized warehouse management, contributing to the sector's competitiveness. The research underscores the importance of adopting systematic methodologies in construction SMEs, offering a practical framework for enhancing operational efficiency. This research contributes to the academic discourse on Lean Warehousing and its application in construction SMEs, highlighting its potential for broader application. Future studies should explore the scalability of this model across different industries, fostering continuous improvement and innovation in warehouse management practices.

Keywords
Lean Warehousing, WMS, Construction SMEs, Process Efficiency, ABC Classification.

1. Introduction
The importance of the small and medium-sized construction industry (SMEs) is undeniable at a global level, especially in Latin America and Peru. These enterprises not only represent a significant part of the business fabric but are also fundamental to the economic and social development of their respective regions. In Latin America, SMEs account for approximately 90% of the productive units, generating about 60% of employment and contributing to more than 50% of total production (Lingán et al. 2022). In Peru, this sector is crucial, as the construction SMEs are responsible for a considerable part of the country's infrastructure, which in turn impacts on the quality of life of the population (Vera 2023). In addition, it has been shown that sustainability and innovation in these companies are essential to improve their competitiveness and adaptability in a changing economic environment (Briñez & Penagos 2021). The ability of SMEs to generate employment and promote local development makes them a pillar of economic growth, which highlights the need to strengthen their management and operations (García 2014).

However, the SME construction sector faces multiple challenges that affect its efficiency and responsiveness to project requirements. One of the most significant problems is the lack of organization in meeting requirements, which often results in delays in project implementation (Pellicer et al. 2014). This inefficiency is exacerbated by inadequate distribution of materials in warehouses, which causes delays in delivery and an increase in operating costs (Quiroz-Flores 2023). Most processes in these companies are carried out manually, which not only increases the risk of errors but also limits the ability of the companies to adapt to market demands (Nevliudov et al. 2021). The implementation of systematic methodologies and management tools, such as Lean Warehousing, could address these problems by optimizing the distribution of materials and improving the organization of processes (Anđelković et al. 2016). The lack of systematization in project and resource management is therefore a critical obstacle that must be overcome to improve the competitiveness of SMEs in the construction sector.

Solving these problems is of vital importance for the SME sector in the metal-manufacturing industry, which also faces similar challenges. Efficient resource management and attention to project requirements are essential to ensure the sustainability and growth of these companies (Molina-Flores 2024). Implementing Lean Warehousing tools can be particularly beneficial as it reduces waste and improves operational efficiency (Abhishek & Pratap 2020). By adopting a systematic approach to inventory management and material distribution, the SMEs in metal engineering can improve their responsiveness and ultimately their competitiveness in the market (Ambrosio-Flores et al. 2022). Improving the attention to requirements not only impacts on customer satisfaction, but also contributes to economic growth in the region by promoting a more dynamic and efficient business environment (García et al. 2018).

Despite the relevance of these issues, there is a notable gap in the literature on the application of Lean Warehousing tools in the context of construction and metal-engineering SMEs. Current research has not addressed in an exhaustive way how these tools can be implemented to solve the specific problems faced by these companies (Morantes & Elena, 2010). Therefore, the present research aims to develop a production model that integrates Lean Warehousing tools, such as 5S, ABC analysis, layout redistribution and warehouse management systems (WMS) (Donoriyanto 2024). This model not only seeks to improve operational efficiency, but also contributes to the sustainable development of the sector by promoting practices that reduce waste and optimize the use of resources (Jiménez 2024). By addressing this gap in the literature, research will provide a valuable framework for construction and mechanical engineering SMEs to implement significant improvements in their management and operation.In conclusion, the importance of the SME sector in construction and metal engineering is undisputed, as are the challenges it faces in terms of organization and efficiency. The implementation of Lean Warehousing tools can provide effective solutions to improve the attention to project requirements and optimize resource management. However, it is essential to address the knowledge gap in the literature to provide a theoretical and practical framework that supports these enterprises on their path towards continuous improvement and sustainability.

2. Literature Review

2.1 Application of Lean Warehousing in SMEs

The Lean Warehousing methodology has been studied in several studies that analyze its application in the storage management processes of small and medium-sized enterprises (SMEs) building. This methodology focuses on waste elimination and optimization of logistics processes, which is crucial for improving operational efficiency in the construction sector. According to and Amaya (2014), the implementation of Lean in SMEs allows not only to reduce costs but also to improve the quality of customer service, which is essential in a highly competitive sector such as construction (Jiménez & Amaya 2014). In addition, Morales (2023) highlights that the adoption of Lean tools has proven to be effective in improving work organization, which translates into increased productivity (Morales 2023). In a study carried out by (Atto et al. 2020), it was shown that SMEs that integrate Lean practices into their logistics operations achieve greater customer satisfaction, by meeting delivery deadlines and reducing errors in inventory management (Atto et al. 2020). Finally, the research highlights that the implementation of Lean Warehousing not only improves efficiency but also fosters a culture of continuous improvement within organizations, which is essential for their long-term sustainability (Muñoz-Arcentales et al. 2022).

2.2 Redesign of Layout in the SME Constructors

Layout redesign is another methodology that has been applied in construction SMEs to improve storage management. This approach aims to optimize the physical layout of resources in the workspace, which can result in a significant reduction in travel times and an improvement in operational efficiency. According to, a well-designed layout allows

for better circulation of materials and reduced lead times, which is crucial in construction projects where time is a determining factor (Rodríguez-Ugalde 2023). In a study by Briñez and Penagos (2021), it was found that the redesign of the layout in a construction company resulted in a 30% improvement in space use efficiency and a 25% reduction in material handling times (Briñez & Penagos 2021). In addition, research by Zambrano et al. (2018) suggests that the implementation of an optimized layout not only improves efficiency but also contributes to a safer and more ergonomic working environment for employees (Zambrano et al. 2018). Finally, the literature review by indicates that layout redesign is a practice that, although requiring initial investment, can generate significant long-term savings by reducing operating costs and improving productivity (Pinzón et al. 2018).

2.3 Implementation of 5S in SMEs Construction

The 5S methodology is a fundamental tool in storage management that seeks to improve organization and cleanliness in the workplace. This methodology has been successfully applied in several construction SMEs, where its implementation has been shown to lead to significant improvements in operational efficiency. According to research, the adoption of 5S in construction SMEs not only improves the organization of the workplace, but also fosters a culture of discipline and responsibility among employees (García et al. 2018). In addition, the research of Villa (2023) highlights that 5S methodology contributes to waste reduction and process optimization, which is essential in a sector where costs can escalate rapidly (Villa 2023). In a study by Félix and Aldana (2022), it was observed that companies implementing 5S achieved a 20% reduction in material search times, which resulted in an improvement in overall productivity (Félix & Aldana 2022). Finally, the literature review concludes that the implementation of 5S is a critical step towards the adoption of broader Lean practices in construction SMEs, as it lays the foundations for a culture of continuous improvement (Muñoz-Arcentales et al. 2022).

2.4 ABC analysis in SMEs Construction

ABC analysis is a stock management technique that classifies products according to importance and value. This methodology has been applied in construction SMEs to optimize storage management and improve resource efficiency. According to research by (Carreras et al. 2017), ABC analysis allows companies to identify which products are the most critical and thus focus their efforts on managing these elements (Carreras et al. 2017). In a study by, it was shown that SMEs implementing ABC analysis achieve a 15% reduction in inventory costs by avoiding overabundance of minor products (Jiménez 2024). In addition, research by Ruiz et al. (2017) suggests that ABC analysis not only improves efficiency in inventory management but also allows for better planning and control of resources, what is essential in construction projects where deadlines are critical (Ruiz et al., 2017). Finally, the literature review by Morales (2023) indicates that ABC analysis is a valuable tool for construction SMEs as it allows them to make informed decisions about the acquisition and management of materials Morales (2023).

2.5 Implementation of WMS in SMEs Construction

Warehouse management systems (WMS) are technological tools that have been adopted by construction SMEs to improve efficiency in storage management. The implementation of WMS allows for better visibility and control of inventories, which is crucial in a sector where material management is critical. According to research, the adoption of a WMS in construction SMEs can result in a 30% improvement in inventory accuracy and a 25% reduction in order preparation times (Ambrosio-Flores et al. 2022). In addition, the research of and Amaya (2014) highlights that WMS allows for better planning and scheduling of storage activities, resulting in greater operational efficiency (Jiménez & Amaya 2014). In a study conducted by (Valenzuela et al. 2021), it was found that companies implementing WMS achieve a significant improvement in customer satisfaction by reducing errors in order management (Valenzuela et al. 2021). Finally, the literature review by Félix and Aldana (2022) concludes that the implementation of WMS is a critical step for construction SMEs to remain competitive in an ever-changing market (Félix & Aldana 2022).

3. Methods

3.1 Basis of the Proposed Model

In Figure 1, the production model based on Lean Warehousing and the Warehouse Management System (WMS) is depicted, designed specifically for SMEs in the construction sector. The model integrated the principles of Lean Warehousing, which emphasize waste reduction, efficient space utilization, and streamlined processes, with the advanced functionalities of a WMS, which ensures real-time inventory management, accurate order fulfillment, and effective resource allocation. The objective of this model was to transition companies from a state of low efficiency to high efficiency by systematically addressing inefficiencies in warehouse operations. This was achieved through a series of structured steps, including the analysis of the current situation using Value Stream Mapping (VSM), the

application of the 5S methodology to enhance workplace organization, the implementation of ABC analysis for inventory classification, the redesign of the warehouse layout to optimize space utilization, and finally, the integration of a WMS to manage and monitor warehouse activities efficiently. The model aimed to create a lean, responsive, and highly efficient warehouse environment that supports the overall operational excellence of SMEs in the construction industry.

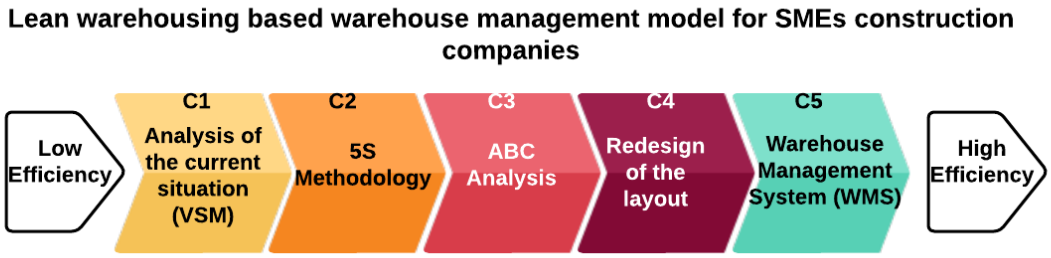

Figure 1. Proposed Model

3.2 Description of the model components

The proposed model based on Lean Warehousing and the Warehouse Management System (WMS), is essential to integrate the foundational philosophies and principles that underpin its development. The model presented in Figure 1 represents a significant contribution to the literature on warehouse management, especially for small and medium-sized enterprises (SMEs) in the construction sector. Lean storage is based on the Lean manufacturing philosophy, which aims to eliminate waste, optimize processes, and improve overall efficiency. WMS integration adds a layer of technological sophistication, allowing real-time data management, accurate inventory control, and simplified operations. The model is structured around five key components: current situation analysis, application of 5S methodology, ABC analysis for inventory classification, redesign of the warehouse design, and integration of the warehouse management system. Each component is designed to address specific inefficiencies within warehouse operations, ultimately leading to a more efficient and responsive warehouse environment.

Analysis of the Current Situation (VSM)

The first step in implementing the Lean Warehousing model involves conducting a thorough analysis of the current warehouse operations using Value Stream Mapping (VSM). VSM is a Lean tool that provides a visual representation of the flow of materials and information within a process. This stage is critical for identifying existing inefficiencies, such as bottlenecks, unnecessary movements, and delays, which hinder the overall efficiency of warehouse operations. By mapping the current state, the team can pinpoint areas that require immediate attention and prioritize them for improvement. The VSM process also helps in understanding the relationship between various activities within the warehouse, allowing for a more holistic approach to problem-solving. The insights gained from this analysis form the foundation for subsequent stages of the model. According to Rother and Shook (2003), VSM is an indispensable tool in Lean implementations as it highlights waste and identifies opportunities for process improvements. This stage sets the groundwork for the Lean transformation by providing a clear picture of the current operational inefficiencies.

Implementation of the 5S Methodology

Following the analysis of the current situation, the next step is the implementation of the 5S methodology, which is a cornerstone of Lean Warehousing. The 5S methodology—Sort, Set in order, Shine, Standardize, and Sustain—focuses on creating and maintaining a clean, organized, and efficient workspace. In the context of warehouse management, the 5S methodology was applied to improve the organization of storage areas, reduce the time spent searching for materials, and eliminate clutter. The process began with the "Sort" phase, where unnecessary items were removed from the warehouse, freeing up valuable space. The "Set in order" phase involved organizing the remaining items in a way that optimized space utilization and made them easily accessible. The "Shine" phase focused on cleaning the warehouse to create a more pleasant and safe working environment. "Standardize" involved creating standard procedures for maintaining the cleanliness and organization achieved in the previous steps, ensuring that these practices were consistently followed. Finally, the "Sustain" phase emphasized the importance of maintaining the improvements over time through regular audits and employee engagement. As noted by Hirano (1996), the 5S

methodology is essential for sustaining Lean initiatives as it creates the foundation for continuous improvement and operational excellence. The implementation of 5S in the warehouse led to significant improvements in workplace organization, reducing lead times and increasing overall efficiency.

ABC Analysis for Inventory Classification

The third component of the Lean Warehousing model is the application of ABC analysis for inventory classification. ABC analysis is a method of categorizing inventory items based on their importance, typically measured by their value or turnover rate. In this model, inventory items were classified into three categories: A, B, and C. Category A items represented the most valuable or frequently used items, which required the most attention and management. Category B items were of moderate value or usage, while Category C items were the least valuable or least frequently used. This classification allowed the warehouse management team to prioritize their efforts and resources on the most critical inventory items, ensuring that Category A items were always in stock and easily accessible. The ABC analysis also helped in optimizing storage space by allocating the most accessible locations to Category A items, thereby reducing the time and effort required to retrieve them. The application of ABC analysis is widely recognized in the literature as a powerful tool for improving inventory management and reducing costs. As stated by Ramanathan (2006), ABC analysis helps in aligning inventory management practices with the overall business strategy, ensuring that resources are allocated efficiently.

Redesign of the Warehouse Layout

The fourth component of the model involves the redesign of the warehouse layout to optimize space utilization and improve workflow efficiency. Based on the insights gained from the VSM and ABC analysis, the warehouse layout was restructured to minimize unnecessary movements and reduce the distance between related activities. The redesign focused on creating a logical flow of materials from receiving to storage, picking, packing, and shipping. High-priority items, identified through the ABC analysis, were placed in easily accessible locations near the shipping area to reduce picking time. The redesign also included the implementation of cross-docking areas for items that needed minimal handling before being shipped out, further streamlining the process. The warehouse layout was also adjusted to accommodate the implementation of the WMS, ensuring that the system's capabilities were fully leveraged. The redesign of the warehouse layout is crucial in Lean Warehousing as it directly impacts the efficiency of material handling and storage operations. According to Tompkins et al. (2010), a well-designed warehouse layout is essential for maximizing space utilization, reducing operational costs, and improving overall productivity.

Integration of the Warehouse Management System (WMS)

The final component of the Lean Warehousing model is the integration of a Warehouse Management System (WMS). The WMS is a software solution that provides real-time visibility and control over warehouse operations, including inventory management, order processing, and shipping. The integration of WMS in the model was aimed at automating routine tasks, reducing manual errors, and enhancing decision-making through data-driven insights. The WMS enabled the warehouse to track inventory levels in real-time, optimize picking routes, and generate automated replenishment orders, ensuring that inventory levels were always aligned with demand. The system also provided detailed analytics on warehouse performance, allowing for continuous monitoring and improvement. The implementation of WMS is particularly important in Lean Warehousing as it supports the principles of waste reduction and process optimization by providing the tools needed to manage complex operations efficiently. As noted by Frazelle (2002), the integration of WMS into warehouse operations significantly enhances the ability to manage inventory, reduce lead times, and improve customer service levels.

In conclusion, the Lean Warehousing model developed for SMEs in the construction industry integrates the foundational principles of Lean Manufacturing with the technological capabilities of a Warehouse Management System (WMS). Each component of the model—Analysis of the Current Situation, Implementation of the 5S Methodology, ABC Analysis for Inventory Classification, Redesign of the Warehouse Layout, and Integration of the WMS—plays a critical role in addressing the inefficiencies in warehouse operations. The model's systematic approach ensures that SMEs can transition from a state of low efficiency to high efficiency, ultimately improving their competitiveness in the market. The implementation of this model not only contributes to the existing literature on warehouse management but also provides a practical framework that can be adapted to other industries facing similar challenges.

3.3 Model Indicators

To evaluate the impact of the warehouse management model based on Lean Warehousing and WMS for construction SMEs, specialized metrics were developed. These metrics were designed to monitor and assess performance throughout the case study, providing a robust foundation for analyzing critical aspects of warehouse management within an SME environment. This systematic approach facilitated a thorough investigation of key performance indicators, including efficiency, lead time, accuracy of inventory records (ERI), and the utilization rate of the warehouse area. This comprehensive evaluation ensured the effective monitoring and continuous improvement of production processes.

Efficiency Rate: Measures the ratio of actual output to the potential output, indicating the effectiveness of the production process.

$$\text{Efficiency Rate}(\%) = \left(\frac{\text{Actual Output}}{\text{Potential Output}}\right) \times 100 \quad (1)$$

Lead Time: Represents the total time taken from the initiation of a process to its completion, reflecting the speed of the process.

$$\text{Lead Time (minutes)} = \text{Completion Time} - \text{Start Time} \quad (2)$$

Accuracy of Inventory Records: Indicates the percentage of inventory records that match the physical count, showing the reliability of inventory management.

$$\text{Accuracy of Inventory Records}(\%) = \left(\frac{\text{Accurate Records}}{\text{Total Records}}\right) \times \mathbf{100} \quad (3)$$

Storage Space Utilization Rate: Measures the percentage of warehouse space that is effectively utilized for storage, indicating space efficiency.

$$\text{Storage Space Utilization Rate}(\%) = \left(\frac{\text{Space Used for Storage}}{\text{Total Storage Space Available}}\right) \times \mathbf{100} \quad (4)$$

Audit 5S: Indicates the percentage score obtained in a 5S audit, reflecting the level of workplace organization and adherence to the 5S methodology.

$$\text{Audit 5S}(\%) = \left(\frac{\text{5S Score Obtained}}{\text{Total Possible 5S Score}}\right) \times 100 \quad (5)$$

4. Validation

4.1 Initial Diagnosis

In Figure 2, the problem tree illustrates the summary of the diagnostic analysis conducted in the case study to identify the causes and root causes that generate the research problem. The central issue identified was the low efficiency in handling dispatch vouchers, with an efficiency rate of 35.59%, significantly lower than the industry standard of 63.98%. This efficiency gap resulted in an economic impact estimated at 73,382 USD annually, representing 48.12% of the company's annual revenue. The analysis revealed that 85.09% of the problem was due to delays in voucher handling, primarily caused by unproductive times in searching for codes and entering them into physical vouchers (46.6%), inadequate distribution of storage areas and materials (23.8%), and delays in physical stock verification (11.7%). Additionally, 14.01% of the issue was attributed to delays in the issuance of vouchers, with significant contributions from unproductive times in searching for technical names of materials (13.6%) and delays in manual PEP search and compliance visas (1.3%). This structured diagnostic approach provided a comprehensive understanding of the underlying issues, guiding the formulation of targeted interventions for improving the voucher handling process in the company.

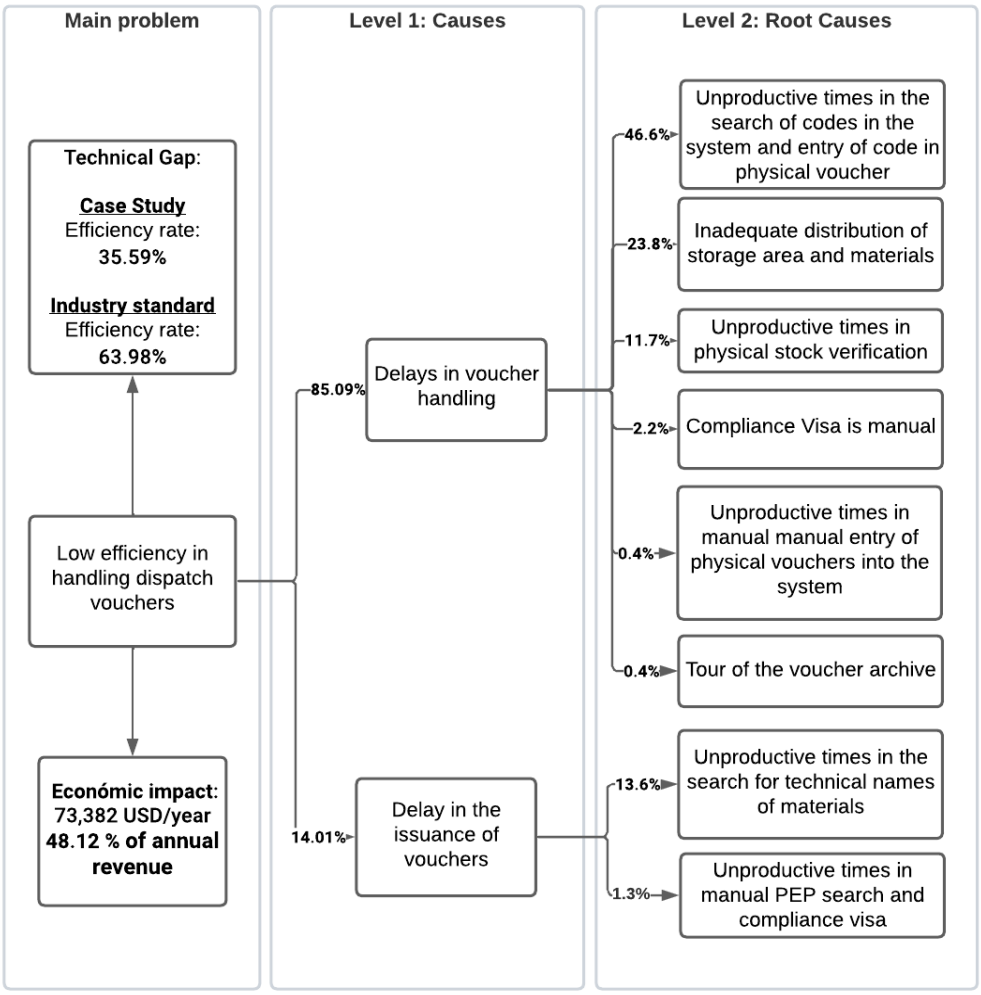

Figure 2. Problem Tree

4.2 Implementation of the model in the case study

The proposed model focused on improving warehouse management processes within a construction SME by applying a lean storage model. The main objective was to address identified weaknesses in the current system, particularly long lead times and low operational efficiency. The initial analysis, conducted using Value Flow Mapping (VSM), revealed a delivery time of 37 minutes per proof of shipment and an operational efficiency of only 35.59%. These metrics underscore the need for a comprehensive review of the warehouse management process.

Figure 3 illustrates the current Value Stream Mapping (VSM) for the application and handling of dispatch vouchers. The diagram maps out the flow of processes starting from the reception of orders to the dispatch of materials, highlighting both value-added and non-value-added activities within the workflow. Each step in the process, such as order verification, picking, and packing, is depicted along with its respective lead time and process efficiency. The summary of results at the bottom of the figure indicates that the current process handles a monthly demand of 3,500 vouchers, with an efficiency rate of 35.59%. The total value-added time is recorded as 32,025 minutes, while the non-value-added time amounts to 98,575 minutes. This stark contrast between value-added and non-value-added time emphasizes the significant inefficiencies present in the current system, highlighting the need for process improvement.

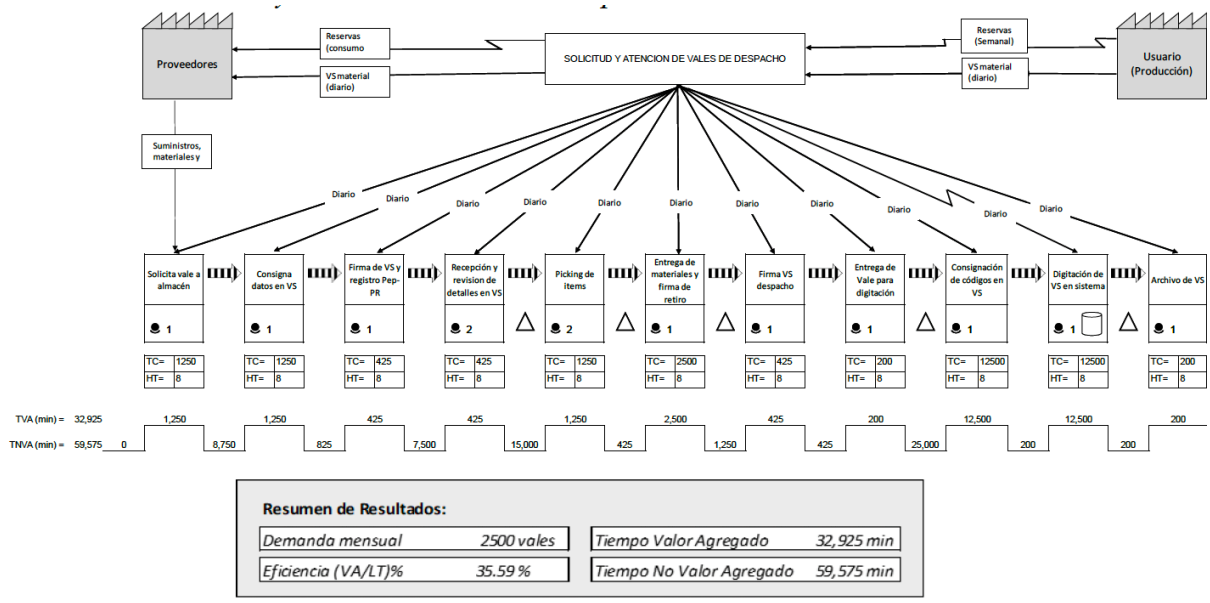

Figure 3. VSM current application and handling of dispatch vouchers

Application of Lean Warehousing Principles

The proposed solution was structured around the implementation of key Lean Warehousing tools, which included the 5S methodology, ABC analysis, layout redesign, and the integration of a Warehouse Management System (WMS). The systematic approach began with the application of the 5S methodology, which aimed to streamline operations by eliminating unnecessary items and improving workplace organization. This was crucial in reducing the non-value-added time, which constituted a significant portion of the total process time.

The 5S methodology was implemented in two phases: planning and execution, followed by continuous monitoring and improvement. The initial phase focused on sorting and setting in order, which involved the reorganization of the storage areas based on the frequency of material usage. This reorganization reduced the time spent searching for materials, which had previously accounted for 35.48% of the non-value-added time. By standardizing these processes, the company achieved significant improvements in workplace efficiency and organization.

ABC Analysis and Layout Redesign

Following the 5S implementation, an ABC analysis was conducted to classify materials based on their rotation frequency and importance. The analysis revealed that 20% of the materials generated 80% of the transactions, highlighting the need for a strategic placement of high-turnover items within the warehouse. The subsequent layout redesign aimed to optimize the flow of materials and reduce unnecessary movements. This redesign was crucial in decreasing picking times and improving overall efficiency, with a significant reduction in the distance workers needed to travel within the warehouse.

The new layout, informed by the ABC analysis, was implemented with the goal of maximizing space utilization while ensuring easy access to frequently used items. The redesign process included the identification and reorganization of critical areas within the warehouse, such as the reception, dispatch, and storage zones. The results of this redesign were evident in the improved efficiency of material handling processes and the reduction of time wasted on unnecessary movements.

Figure 4 showcases the transformation achieved through the implementation of the 5S methodology, ABC analysis, and the redesign of the warehouse layout. The "Before" images at the top display a cluttered and disorganized storage area, with materials and documents scattered randomly, making it difficult to locate items efficiently. The "After" images at the bottom reveal a significantly improved workspace, where items are systematically organized on shelves according to the frequency of use, as determined by the ABC analysis. The materials are neatly stored, labeled, and easily accessible, reflecting the impact of the 5S implementation in creating a more efficient and orderly environment.

The redesign of the layout has optimized space utilization, reduced retrieval times, and enhanced the overall efficiency of the warehouse operations. This visual comparison highlights the effectiveness of the applied Lean tools in transforming the warehouse into a more productive and manageable space.

Figure 4. Implementation of 5s, ABC analysis and redesign of Layout

Integration of Warehouse Management System (WMS)

To further enhance the efficiency of warehouse operations, a WMS was integrated into the existing system. The WMS played a pivotal role in automating the dispatch voucher process, which had previously been a manual and time-consuming task. The system allowed for real-time tracking of inventory and streamlined the dispatch process, reducing the lead time from 37 minutes to 4.48 minutes per voucher. The accuracy of inventory records also saw a dramatic improvement, increasing from 33.33% to 84.6%, which was critical in ensuring the reliability of the warehouse management process.

The WMS also facilitated the digitalization of inventory management, reducing the reliance on manual data entry and minimizing the risk of errors. This digital transformation was supported by the integration of the WMS with the company's existing ERP system, further enhancing the overall efficiency and accuracy of warehouse operations. The implementation of the WMS was a key component of the solution, providing the technological backbone necessary to support the Lean Warehousing model.

Figure 5 illustrates a model for the implementation of digital vouchers within a warehouse management process. The model is divided into three main stages: Inputs, Process, and Outputs. The Inputs section details the necessary resources for the correct loading of digital vouchers, which include SAP codes, material lists, and authorization signatures, all managed digitally. The Process stage is split into two sub-processes: manual and digital. The manual process involves the user's signature for material requests and the final signing on a tablet by personnel collecting the materials. The digital process includes data entry, filling out forms, and the automatic generation of material requisition based on the input needs. The Outputs section results in the generation of databases and digital attachments that can be directly uploaded into the SAP system for further processing. This figure effectively outlines the workflow transition from manual to digital processes, enhancing the efficiency and accuracy of managing material requests and approvals within the warehouse environment.

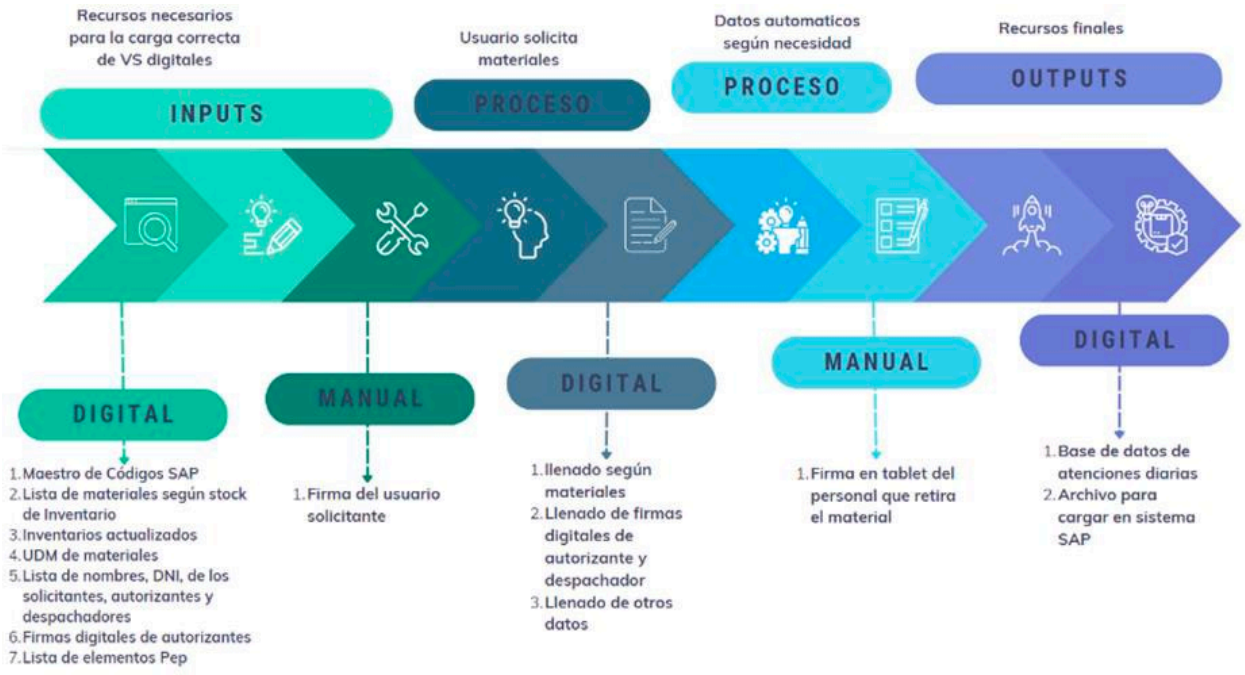

Figure 5. Model for the implementation of digital vouchers

Figure 6 shows the impact of implementing a Warehouse Management System (WMS) by comparing the "Before" and "After" states of document handling within the warehouse. The "Before" image on the left illustrates a manual, paper-based system where documents are filled out by hand, prone to errors, and requiring physical signatures. This method is time-consuming and inefficient, leading to potential delays in processing and inaccuracies in record-keeping. The "After" image on the right displays a digitalized system implemented through the WMS, where documents are electronically generated, clearly formatted, and include digital signatures. This transition has streamlined the process, significantly improving accuracy, reducing processing time, and enhancing overall operational efficiency within the warehouse. The figure effectively highlights the benefits of moving from a manual to a digital system in warehouse management.

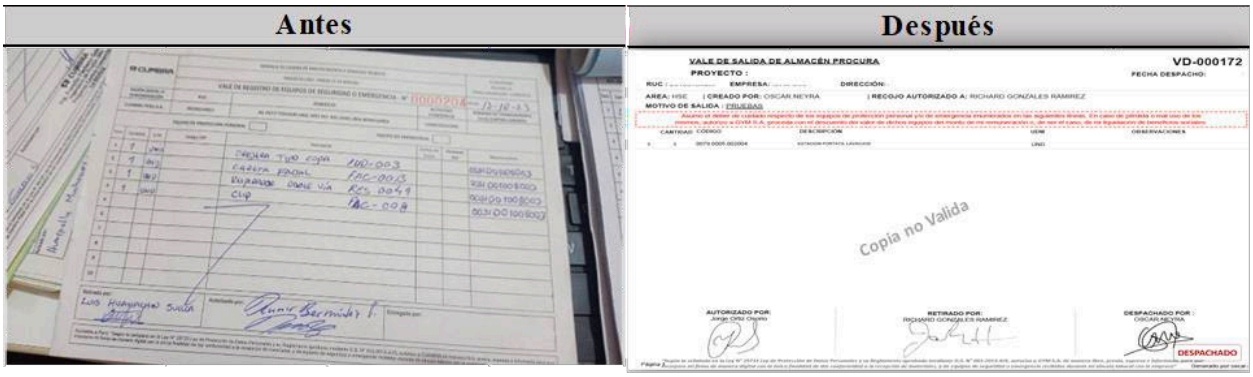

Figure 6. Implementation of a warehouse management system

Quantitative Impact of the Solution

The implementation of the proposed Lean Warehousing model yielded significant improvements in key performance indicators. The efficiency of the warehouse management process increased from 35.59% to 71.85%, while the lead time for processing dispatch vouchers was reduced by 87.89%. Additionally, the accuracy of inventory records improved by 153.83%, and the space utilization rate was optimized, reflecting a 45.30% reduction in space usage. The 5S audit score also showed a marked improvement, rising to 91.67%, which represented a 323.08% increase in compliance.

The financial analysis of the solution demonstrated its viability, with a cost-benefit ratio of 1.38, indicating a strong return on investment. This analysis, combined with the significant operational improvements achieved, underscored the effectiveness of the Lean Warehousing model in addressing the inefficiencies identified in the initial VSM analysis. The solution not only improved the operational performance of the warehouse but also provided a scalable model that could be applied to other areas of the organization.

5. Results

In Table 1, the results of the validation of the warehouse management model based on Lean Warehousing are presented, as applied in the case study with the objective of addressing the research problem. The model successfully increased the efficiency rate by 101.88%, reduced lead time by 87.89%, and improved the accuracy of inventory records by 153.83%. Additionally, the 5S audit achieved a 91.67% compliance rate, representing a significant increase of 323.08%. These results demonstrate the effectiveness of the proposed model in optimizing warehouse processes within the studied context.

Table 1. Results of the validation of the proposed model

Indicator	Unit	As-Is	To-Be	Results	Variation (%)
Efficiency Rate	%	35.59%	63.98%	71.85%	101.88%
Lead time	minute	37	5.7	4.48	-87.89%
Accuracy of inventory records	%	33.33%	95%	84.60%	153.83%
Storage space utilization rate	%	49.78%	25%	27.23%	-45.30%
5S Audit	%	21.67%	100%	91.67%	323.08%

6. Conclusions.

The findings of this study revealed significant improvements in the efficiency and effectiveness of warehouse management processes in a construction SME. The implementation of Lean Warehousing principles, such as 5S methodology, ABC analysis, and the integration of a Warehouse Management System (WMS), resulted in a remarkable increase in the efficiency rate from 35.59% to 71.85%. Additionally, the lead time for processing dispatch vouchers was drastically reduced from 37 minutes to 4.48 minutes, representing an 87.89% improvement. The accuracy of inventory records improved from 33.33% to 84.60%, demonstrating a substantial enhancement in the reliability of inventory management. The space utilization rate in the warehouse also saw a significant reduction in

wasted space, with a 45.30% decrease in the space used. The 5S audit score increased from 21.67% to 91.67%, indicating a 323.08% improvement in workplace organization and cleanliness.

The importance of this research lies in its ability to address critical inefficiencies in warehouse management within the construction SME sector. By applying a structured approach based on Lean principles, the study not only improved operational efficiency but also provided a framework that other SMEs can adopt to enhance their warehouse management practices. The research highlights the potential for Lean Warehousing to drive significant improvements in key performance indicators, which is crucial for the competitiveness of SMEs in the construction industry. This study also contributes to the growing body of literature on Lean Warehousing, particularly in the context of construction SMEs, where such research is currently limited.

The contributions of this study extend beyond the immediate context of warehouse management in construction SMEs. The integration of Lean Warehousing with modern technologies like WMS provides a scalable model that can be adapted to various industries facing similar challenges. The study offers practical insights into how SMEs can leverage Lean principles to optimize their operations, reduce waste, and improve overall efficiency. By providing a detailed account of the implementation process and the resulting improvements, this research serves as a valuable reference for academics and practitioners alike, contributing to the ongoing discourse on operational efficiency and Lean management in SMEs.

In conclusion, the study demonstrates the effectiveness of combining Lean Warehousing principles with technology to achieve significant improvements in warehouse management. The findings suggest that SMEs in the construction industry, and potentially other sectors, can greatly benefit from adopting similar approaches. However, further research is necessary to explore the scalability of this model across different industries and regions. Future studies should also consider the long-term sustainability of the improvements achieved through Lean Warehousing and WMS integration, as well as the potential for continuous improvement in warehouse management practices. This research provides a solid foundation for future investigations and encourages a broader application of Lean principles in various operational contexts.

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