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Process Maturity as a Foundation for Digital Transformation: An Empirical Lean Six Sigma Study of Warehouse Operations

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Abstract

Warehouses play a critical role in supply chain performance, yet many continue to operate with persistent inefficiencies despite growing interest in digital transformation. While advanced technologies are often promoted as primary solutions, unresolved process deficiencies can significantly limit their effectiveness. This study adopts a process-first perspective and investigates how systematic process redesign can enhance warehouse performance and establish readiness for digital transformation. Using an empirical case study of a distribution warehouse operating in a predominantly manual environment, the research applies an integrated Lean Six Sigma framework structured around the DMAIC cycle. Value stream mapping, inventory classification, workflow visualization, and statistical analysis are employed to identify dominant sources of non-value-added activities and evaluate improvement outcomes. The results demonstrate substantial reductions in non-value-added time exceeding 55% in outbound operations and approaching 80% in selected inbound activities, accompanied by improved order throughput and reduced process variability, achieved without additional labor or automation. These findings provide empirical evidence that process maturity is a critical enabler of sustainable performance improvement and a necessary foundation for effective digital transformation in warehouse systems. The study contributes to operations management literature by empirically linking Lean Six Sigma–based process improvement to digital readiness and offers practical guidance for organizations seeking to modernize warehouse operations without reinforcing existing inefficiencies.

Keywords
Warehouse operations; Lean Six Sigma; Process maturity; Digital transformation readiness; Non-value-added activities.

1. Introduction
Warehouses constitute a central component of contemporary supply chains, supporting product availability, order fulfillment, and service reliability across a wide range of industries. As supply chains become increasingly exposed to

demand uncertainty, cost pressures, and shortened delivery expectations, the operational performance of warehouses has gained strategic importance. In response, many organizations have turned to digital transformation initiatives such as automation, warehouse management systems, and advanced analytics to enhance efficiency and responsiveness. Despite these investments, however, operational shortcomings remain common in practice, suggesting that technology adoption alone does not guarantee improved performance.

Evidence from both research and industry practice indicates that many warehouse inefficiencies originate from fundamental process-related issues rather than technological constraints. Activities such as excessive searching, unnecessary travel, waiting, and rehandling often account for a substantial share of operational time, yet they are frequently embedded in daily routines and therefore overlooked (Boysen et al. 2019). When such inefficiencies persist, the introduction of digital tools may inadvertently institutionalize waste instead of eliminating it. This observation underscores the importance of addressing process stability and standardization before pursuing advanced digital solutions.

Lean Six Sigma (LSS) provides a structured approach for improving operational performance through systematic waste reduction, variation control, and process discipline. Its effectiveness has been demonstrated across manufacturing, healthcare, and service sectors (Antony et al. 2017). Within warehouse and logistics operations, however, existing studies tend to apply LSS tools in a fragmented manner or focus on narrowly defined improvements, such as layout redesign or picking optimization. Moreover, much of the warehouse optimization literature relies on simulation-based or conceptual models, offering limited insight into how improvement initiatives unfold in real operational settings. As a result, empirical evidence linking process improvement to broader digital transformation readiness remains relatively scarce.

This study adopts a process-first perspective to investigate how structured process improvement can enhance warehouse performance and support digital transformation readiness. Specifically, the study aims to (1) identify dominant sources of inefficiency in warehouse operations, particularly those associated with non-value-added activities such as searching and travel; (2) apply a structured LSS improvement framework to redesign operational processes and reduce these inefficiencies; and (3) examine how process standardization and operational stabilization contribute to establishing a foundation for future digital transformation initiatives in warehouse environments.

The contributions of this paper are threefold. First, it provides empirical evidence that a large proportion of warehouse inefficiency is attributable to unstructured processes and lack of standardization, particularly in storage and order preparation activities. Second, it demonstrates the value of integrating LSS tools with statistical validation to support evidence-based decision-making in warehouse operations. Third, the study positions process maturity as a critical enabler of digital transformation, offering practical insights for organizations seeking to modernize warehouse systems without first reinforcing inefficient processes.

The remainder of the paper is organized as follows. Section 2 reviews the literature on warehouse operations, LSS applications, and digital transformation readiness. Section 3 presents the research methodology and analytical framework. Section 4 describes the data collection process. Section 5 presents the results and discussion. Section 6 concludes the paper and outlines directions for future research.

2. Literature Review

2.1 Warehouse Operations and Sources of Inefficiency

Warehouses serve as critical nodes within supply chains, linking production, distribution, and customer demand. Their operational performance directly affects order fulfillment speed, cost efficiency, and service reliability. Core warehouse activities such as receiving, storage, order picking, and shipping are highly interdependent, and inefficiencies in any one function can propagate throughout the system (Gu et al. 2010). Among these activities, order picking and storage-related decisions are consistently identified as the most labor-intensive and cost-dominant components of warehouse operations (De Koster et al. 2007).

A recurring theme in the literature is the prevalence of non-value-added activities within warehouse processes. Excessive travel distance, searching for stock keeping units (SKUs), waiting for shared resources, and rehandling of items have been shown to consume a significant portion of operational time (Roodbergen and Vis 2009). These inefficiencies are often exacerbated by unstructured storage policies, reliance on worker experience rather than formal rules, and limited process standardization. While such practices may emerge organically in manual environments, they tend to reduce transparency and increase variability, making performance difficult to control or improve systematically.

Storage assignment strategies play a particularly influential role in warehouse efficiency. Studies comparing random, dedicated, and class-based storage consistently report that unstructured or poorly implemented storage policies lead to longer travel times and increased searching effort (Gu et al. 2010; Van den Berg 1999). Class-based storage, which allocates items according to demand or turnover characteristics, has been widely recognized as a practical compromise between flexibility and efficiency. However, empirical evidence from real operational settings remains limited, as many studies rely heavily on simulation-based analysis rather than observed warehouse data, restricting insight into how such strategies perform under real operational constraints. Recent reviews of smart warehouse operations further emphasize the need for empirical investigations that capture real-world process behavior beyond modeled environments (Zhen et al. 2022).

2.2 Lean Six Sigma in Warehouse and Logistics Operations

LSS integrates Lean principles focused on waste elimination with Six Sigma's emphasis on variation reduction and process control. The combined methodology has been successfully applied across manufacturing and service sectors to improve productivity, quality, and operational stability (Antony et al. 2017). In logistics and warehousing contexts, LSS is particularly relevant due to the labor-intensive and repetitive nature of operations, which makes inefficiencies both costly and persistent.

Previous studies applying LSS to warehouse operations have reported reductions in cycle time, travel distance, and error rates through tools such as value stream mapping (VSM), spaghetti diagrams, and standardized work procedures (Jaca et al. 2014; Tortorella et al. 2018). VSM has been widely used to visualize material and information flows, enabling the identification of non-value-added activities across inbound and outbound processes. Despite these reported benefits, many LSS-based warehouse studies focus on isolated improvements rather than adopting a comprehensive, end-to-end improvement framework that integrates multiple tools within a structured methodology.

Moreover, the methodological rigor of existing empirical studies varies considerably. While some contributions provide descriptive before-and-after comparisons, fewer studies incorporate statistical validation to support claims of performance improvement. This limitation weakens the generalizability of findings and reduces confidence in the robustness of reported gains. As a result, there remains a need for empirically grounded studies that combine LSS tools with quantitative analysis to substantiate improvement outcomes in warehouse environments.

2.3 Digital Transformation and Process Maturity in Warehousing

Digital transformation in warehousing has attracted significant academic and managerial attention in recent years. Technologies such as warehouse management systems, automation, robotics, and data analytics are frequently promoted as solutions to rising complexity and performance demands (Boysen et al. 2019). While these technologies offer substantial potential benefits, their successful implementation depends heavily on the underlying quality of operational processes.

Several scholars have argued that process maturity is a critical prerequisite for effective digitalization. Poorly designed or unstable processes, when automated, can result in the rapid propagation of inefficiencies and errors at scale. In warehousing contexts, the absence of standardized workflows, clear storage policies, and reliable performance metrics can undermine the expected benefits of digital investments. Consequently, digital transformation initiatives that overlook process readiness often fail to deliver anticipated returns.

Recent research has further formalized this relationship through the development of logistics and warehouse maturity models that assess digital readiness across dimensions such as process standardization, automation, and data integration (Zoubek and Simon 2021; Min 2023). These studies consistently emphasize that stable and well-defined processes constitute a necessary foundation for the effective deployment of Industry 4.0 technologies. Despite this recognition, the literature provides limited statistically validated, real-world evidence demonstrating how process improvement efforts contribute to digital readiness in warehouse operations. Most studies treat process improvement and digitalization as separate streams of research, with few explicitly linking Lean Six Sigma-based interventions to digital transformation capability. This gap is particularly evident in manual or semi-manual warehouse environments, where organizations may pursue automation without first addressing fundamental sources of waste.

Recent studies on digital transformation in logistics increasingly emphasize the importance of process maturity as a prerequisite for successful technology adoption. Digital technologies such as warehouse management systems, automation, and robotics rely on stable and well-defined operational processes to deliver their intended performance benefits. When underlying workflows remain unstructured, digitalization efforts may simply automate existing inefficiencies rather than eliminate them. Consequently, improving process stability and operational transparency is widely recognized as a critical step in preparing organizations for digital transformation initiatives.

In summary, prior research highlights the importance of efficient warehouse processes, the potential of Lean Six Sigma as an improvement methodology, and the growing role of digital transformation in logistics operations. However, three key gaps remain. First, empirical studies grounded in real warehouse operations remain relatively scarce, particularly those addressing storage and order preparation inefficiencies in manual environments. Second, many LSS-based warehouse studies lack statistical validation, limiting the robustness of their conclusions. Third, the relationship between process maturity and digital transformation readiness has not been sufficiently explored in the warehouse context using real operational data and organizational readiness perspectives (Ali et al. 2024).

This study addresses these gaps by empirically examining warehouse operations through an integrated LSS framework, supported by statistical analysis, and by explicitly framing process improvement as a foundation for digital transformation. Unlike much of the existing warehouse optimization literature that relies predominantly on simulation-based analysis, this study is grounded in observed operational data from an active warehouse environment. In doing so, it contributes to a more nuanced understanding of how operational excellence can be achieved and sustained prior to the adoption of advanced digital technologies.

3. Methods

3.1 Research Design

This study adopts an empirical case study research design to investigate operational inefficiencies and process improvement opportunities within a real warehouse environment. Case study approaches are widely used in operations management research when the objective is to examine complex operational phenomena within their practical context and to understand how structured improvement initiatives influence performance (Yin 2018). The selected case represents a warehouse operating predominantly through manual processes, making it an appropriate setting for examining the role of process maturity prior to the introduction of digital technologies.

The methodological approach is grounded in LSS and structured around the DMAIC (Define-Measure-Analyze-Improve-Control) improvement cycle. The DMAIC cycle provides a structured framework for identifying inefficiencies, implementing data-driven improvements, and sustaining operational performance gains., implementing data-driven improvements, and sustaining operational performance gains. Rather than relying on a single analytical tool, the study integrates multiple complementary techniques within the DMAIC framework to ensure methodological rigor and practical relevance for warehouse operations.

3.2 Lean Six Sigma Framework

The improvement initiative was implemented using the DMAIC framework, which structured the investigation and guided the development of process improvements within the warehouse environment.

The define phase focused on identifying the operational challenges affecting warehouse performance. Initial observations and discussions with warehouse personnel indicated that inbound receiving and outbound order preparation were characterized by excessive searching for items, inefficient movement within the storage area, and delays associated with storage allocation decisions. Based on these observations, the scope of the improvement project was defined to include inbound handling, storage allocation, and outbound picking processes. The primary performance objectives were to reduce non-value-added activities, improve workflow stability, and enhance overall operational efficiency.

During the measurement phase, baseline operational data were collected to quantify current process performance. Direct observations and structured time studies were conducted to record the duration of key activities within inbound and outbound operations. Additional operational records were analyzed to determine order volumes, item demand frequencies, and the utilization of shared handling equipment. The collected data were used to establish baseline performance indicators including process cycle time, non-value-added time, searching time during order preparation, and order throughput.

The analysis phase aimed to identify the root causes of the observed inefficiencies. VSM was used to visualize the sequence of operational activities and to distinguish between value-added and non-value-added tasks. Workflow visualization techniques were applied to examine movement patterns within the warehouse layout and identify excessive travel and backtracking. Inventory classification analysis was conducted to evaluate the relationship between item demand frequency and storage location assignment. In addition, statistical analysis using analysis of variance (ANOVA) was applied to examine the influence of storage conditions on order picking time and to validate the operational significance of observed performance differences.

Based on the analytical findings, targeted process redesign interventions were implemented. A class-based storage policy was introduced to allocate high-frequency items to storage zones located closer to picking areas, thereby reducing travel distance and searching time during order preparation. Storage labeling and item grouping were also improved to facilitate faster identification of products. In addition, standardized picking procedures were introduced to establish consistent workflows for order preparation activities and reduce reliance on individual worker experience.

The control phase focused on sustaining the improvements achieved during the project. Standardized operating procedures were established for storage allocation and order picking activities, and performance indicators related to process time, order throughput, and non-value-added activities were defined for ongoing monitoring. These measures help maintain process stability and ensure that the improved operational structure provides a reliable foundation for future digital transformation initiatives within the warehouse.

4. Data Collection

4.1 Data Collection Process

Data were collected over an extended observation period to ensure representative coverage of warehouse operations. Both inbound and outbound processes were examined in detail, capturing activities from receipt through dispatch. Time-based measurements were obtained using structured time studies, while frequency and volume data were extracted from operational records.

4.2 Performance Measures

The primary performance measures used in the analysis included process cycle time for inbound and outbound operations, non-value-added (NVA) time expressed as a proportion of total operational time, searching and travel time associated with order picking, resource utilization particularly for shared handling equipment and order throughput measured as completed orders per operating period. These metrics were selected due to their relevance in assessing process efficiency, labor intensity, and operational stability in warehouse environments (De Koster et al. 2007).

4.3 Analytical Techniques

Several complementary analytical techniques were employed to ensure robust diagnosis and validation of improvement outcomes. VSM was used to visualize material and information flows, enabling the identification of bottlenecks and waste across processes. Inventory classification analysis supported the evaluation of storage strategies by grouping items according to operational relevance, thereby informing storage allocation decisions.

To enhance analytical rigor, statistical analysis was applied to assess whether observed differences in process performance were statistically significant. Analysis of variance (ANOVA) was used to examine the effect of operational factors on key performance metrics, such as order picking time. The use of statistical validation distinguishes this study from descriptive case reports and strengthens the credibility of the findings.

4.4 Validity and Reliability

Several measures were taken to enhance the validity and reliability of the study. Data were collected from multiple sources and cross-checked to reduce measurement bias. Observations were repeated across different operating periods to capture variability in daily operations. The structured DMAIC framework ensured methodological consistency, while the use of established analytical tools supports replicability in similar operational contexts.

While the case study design limits statistical generalization, the objective of the study is analytical generalization, demonstrating how a process-first improvement framework can be applied to warehouse systems facing similar challenges. This approach aligns with established practices in operations management research and supports the transferability of insights to comparable settings.

5. Results and Discussion

This section presents the empirical results obtained from applying the Lean Six Sigma–based improvement framework to warehouse operations and discusses their implications. The results are organized to establish baseline performance, identify dominant sources of inefficiency, validate process effects statistically, and evaluate post-improvement operational outcomes. Visual and quantitative evidence is used selectively to support key findings.

5.1 Baseline Performance and Sources of Inefficiency

Baseline analysis revealed that both inbound and outbound warehouse operations were characterized by a high proportion of non-value-added activities. VSM of the inbound process indicated that waiting, searching for storage locations, and delays related to shared resource availability substantially extended total cycle time. Although core handling activities were completed within a single shift, cumulative delays caused inbound processing to exceed nominal operating hours.

Outbound operations exhibited more severe inefficiencies. Order preparation activities were dominated by searching and travel, reflecting the absence of structured storage rules and standardized workflows. Workers frequently relied on personal experience to locate items, resulting in substantial variability in task completion times. As a consequence, non-value-added activities accounted for the majority of outbound processing time, exceeding the time spent on value-adding picking and packing tasks.

The structure and relative inefficiency of the baseline processes are illustrated in Figure 1, which compares the current-state and improved-state value stream maps and highlights the reduction in non-value-added activities following process redesign.

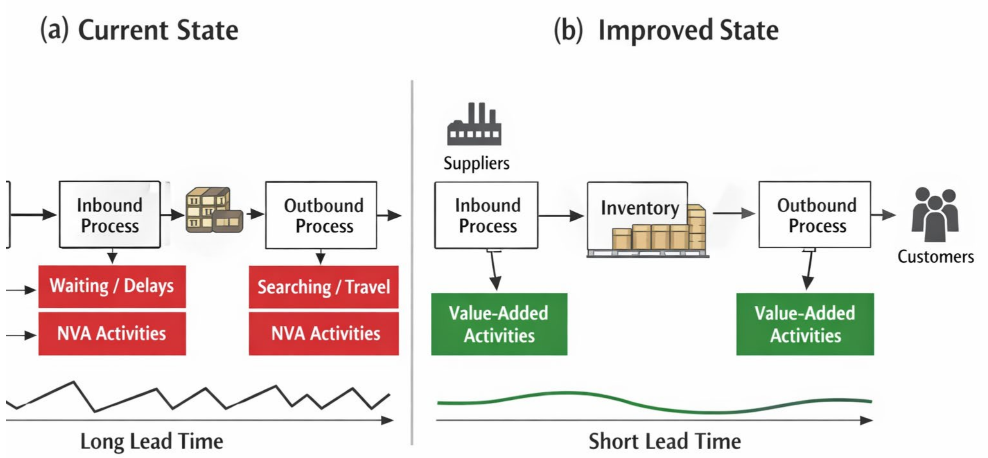

Figure 1. **Value Stream Comparison**

Simplified comparison of current-state and improved-state value stream maps for warehouse operations. The figure illustrates the relative distribution of value-added (VA) and non-value-added (NVA) activities before and after the Lean Six Sigma intervention. The improved-state process demonstrates a significant reduction in waiting, searching, and unnecessary movement activities.

Detailed process analysis further identified searching and travel time as the dominant contributors to inefficiency, particularly in outbound operations. Workflow visualization revealed fragmented movement patterns and frequent backtracking, indicating ineffective spatial organization and uncoordinated item placement. In inbound operations, temporary congestion and delayed put-away decisions contributed to idle time and blocked material flow.

Inventory classification analysis revealed a clear misalignment between item demand characteristics and storage locations. High-frequency items were not consistently assigned to easily accessible storage zones, increasing dependence on handling equipment and contributing to congestion and waiting. These findings confirmed that inefficiencies were primarily rooted in process design and storage policy rather than labor availability or capacity constraints.

5.2 Statistical Validation of Process Effects

To validate the observed performance differences, statistical analysis was conducted using operational data collected during the measurement phase. The dataset consisted of structured time-study observations of order picking activities under different storage conditions, capturing variations in retrieval time associated with item accessibility and handling requirements. These observations provided a basis for comparing the efficiency of alternative storage configurations within the warehouse environment.

Analysis of variance (ANOVA) was applied to examine whether differences in order picking time across storage conditions were statistically significant. The analysis compared average retrieval times between items stored in readily accessible locations and items requiring additional handling steps or longer travel distances. This approach made it possible to assess whether the observed variability in picking performance could be attributed to storage configuration rather than random operational fluctuation.

The results indicated a statistically significant effect of storage location and handling requirements on order picking time. Items requiring additional handling steps exhibited substantially longer retrieval times than items stored in more accessible locations. The magnitude of this difference was also operationally meaningful, with retrieval times for certain storage configurations exceeding those of more accessible locations by several multiples.

This statistical evidence confirms that unstructured storage allocation was a major driver of performance variability and provides quantitative support for prioritizing storage redesign during the improvement phase. In this regard, the ANOVA results complement the findings from value stream mapping and workflow visualization by demonstrating that the identified inefficiencies were not only operationally visible but also statistically substantiated.

5.3 Post-Improvement Operational Outcomes

The improvement phase focused on redesigning operational processes to eliminate the dominant sources of non-value-added activities identified during the analysis stage. One of the primary interventions involved the implementation of a class-based storage policy, in which high-frequency items were relocated to easily accessible storage zones closer to the primary picking areas. This reorganization reduced the need for extensive searching and minimized travel distance during order preparation.

In addition to the storage redesign, standardized picking procedures were introduced to establish consistent workflows for order preparation activities. These procedures defined clear steps for locating, retrieving, and preparing items for shipment. Improved storage identification and systematic grouping of frequently co-picked items were also implemented to reduce variability in locating products and to improve operational consistency. Together, these changes reduced reliance on individual worker experience and created a more structured and predictable picking process.

These interventions directly targeted the dominant inefficiencies identified during the analysis phase, particularly excessive searching and travel time associated with unstructured storage and informal work practices. By improving spatial organization and establishing clearer operational rules, the redesigned processes facilitated smoother material flow between storage locations and order preparation areas.

Following the implementation of these improvements, measurable gains were observed across both inbound and outbound operations. Revised VSM demonstrated a pronounced reduction in non-value-added activities, particularly waiting, searching, and unnecessary movement. Inbound operations experienced improved flow stability, while outbound operations benefited from clearer storage rules and standardized picking procedures.

The proportion of non-value-added time in outbound operations was reduced by more than half, primarily due to reductions in searching and travel time. As a result, order throughput increased without additional labor or equipment resources. These outcomes indicate that disciplined process redesign can unlock substantial latent capacity in warehouse systems operating in predominantly manual environments.

Key performance changes are summarized quantitatively in Table 1, which compares baseline and post-improvement metrics.

Table 1. Summary of key warehouse performance metrics before and after process improvement. NVA = Non-Value-Added activities. Improvements reflect the impact of Lean Six Sigma process redesign on inbound and outbound warehouse operations.

Performance Metric	Baseline	Post-Improvement	Change
Inbound NVA time (%)	High	Significantly reduced	−79%
Outbound NVA time (%)	Very high	Reduced	−55%
Average order picking time	Long and variable	Shorter and stable	↓
Order throughput	Low	Increased	↑
Process variability	High	Reduced	↓

5.4 Interpretation and Synthesis of Results

Overall, the results demonstrate that systematic process redesign led to substantial improvements in warehouse efficiency, productivity, and operational stability. Importantly, these gains were achieved without the introduction of automation or advanced digital technologies. The findings provide empirical evidence that process maturity, achieved through a structured LSS intervention, can significantly enhance warehouse performance and establish a stable operational baseline suitable for subsequent digital transformation initiatives.

The magnitude of improvement observed supports the argument that warehouse inefficiencies are often primarily process-driven rather than technology-driven. In many operational environments, inefficiencies arise from unstructured workflows, inconsistent storage policies, and reliance on informal practices rather than standardized procedures. Addressing these fundamental sources of waste through structured process redesign is therefore a necessary step before pursuing technology-intensive solutions. In this regard, the results reinforce the role of LSS not only as an operational improvement methodology but also as a mechanism for building the organizational and operational foundations required for digital readiness.

Beyond the immediate operational improvements, the findings highlight the importance of process maturity as a prerequisite for successful digital transformation in warehouse environments. The interventions implemented in this study including standardized workflows, class-based storage policies, and improved operational visibility created a more stable and predictable process environment. Such stability is essential for the effective implementation of digital technologies such as warehouse management systems (WMS), automated storage and retrieval systems, and robotics. These technologies rely on consistent process structures, reliable operational data, and clearly defined workflows to function effectively. By reducing process variability and establishing clearer operational rules, the improvements achieved through LSS create a foundation upon which digital technologies can be introduced without reinforcing existing inefficiencies.

Finally, the results also underline the importance of human and organizational factors in sustaining process improvements. Employee participation during process observation and improvement discussions contributed to identifying operational inefficiencies and validating proposed workflow changes. Involving warehouse operators in the improvement process facilitated the adoption of standardized procedures and helped ensure the practical feasibility of the redesigned workflows. This highlights the role of employee engagement and change management in supporting long-term process stability and sustaining the operational maturity required for future digital transformation initiatives.

6. Conclusion

This study examined whether meaningful improvements in warehouse performance can be achieved through systematic process redesign prior to the adoption of advanced digital technologies. Using an empirical case study and an integrated LSS framework, the findings demonstrate that a substantial share of warehouse inefficiency originates from process-related issues rather than technological limitations. By reducing non-value-added activities, particularly those associated with searching, travel, and waiting the study shows that operational performance can be significantly improved even in predominantly manual warehouse environments.

The results confirm that structured application of the DMAIC cycle enables not only effective waste identification but also sustained process stabilization. Reductions in non-value-added time exceeding half of baseline levels, alongside improved throughput achieved without additional resources, provide strong empirical evidence that process discipline can unlock latent operational capacity. These findings reinforce the argument that technology should not be viewed as a substitute for process improvement, but rather as a complementary step that builds upon a stable and standardized operational foundation.

From a theoretical perspective, the study contributes to operations management and logistics literature by explicitly linking process maturity to digital transformation readiness. While digitalization is often discussed as a technology-driven endeavor, this research supports a process-based view in which operational excellence precedes and enables effective technology adoption. By empirically demonstrating this relationship in a warehouse context, the study extends existing work on LSS applications and digital transformation beyond conceptual discussions.

From a practical standpoint, the findings offer clear guidance for managers. Organizations seeking to modernize warehouse operations should prioritize process assessment, standardization, and waste elimination before investing in automation or digital systems. Doing so not only yields immediate performance gains but also reduces the risk of embedding inefficiencies into future digital solutions. The study further highlights the value of data-driven decision-making and statistical validation in supporting improvement initiatives and building organizational confidence in change efforts.

This research is subject to certain limitations. The findings are based on a single case study, which constrains statistical generalization. Additionally, the warehouse examined operated in a largely manual environment, and the study did not evaluate the performance impact of specific digital technologies following process improvement. These limitations point to several avenues for future research. Comparative studies across multiple warehouses, as well as longitudinal analyses examining performance before and after digital technology implementation, would further enrich understanding of the interaction between process maturity and digital transformation.

In conclusion, this study demonstrates that process-first improvement is not only feasible but essential for achieving sustainable warehouse performance and digital readiness. By establishing a disciplined operational baseline through Lean Six Sigma, organizations can position themselves to realize the full benefits of digital transformation rather than merely automating existing inefficiencies.

References

Ali, S. S., Garza-Reyes, J. A., Kumar, V. and Mishra, N., A decision-making framework for determinants of an organization's readiness for smart warehouse, *Production Planning and Control*, vol. 35, no. 14, pp. 1887–1908, 2024.

Antony, J., Snee, R. and Hoerl, R., Lean Six Sigma: Yesterday, today and tomorrow, *International Journal of Quality and Reliability Management,* vol. 34, no. 7, pp. 1073–1093, 2017.

Boysen, N., de Koster, R. and Weidinger, F., Warehousing in the e-commerce era: A survey, *European Journal of Operational Research*, vol. 277, no. 2, pp. 396–411, 2019.

De Koster, R., Le-Duc, T. and Roodbergen, K. J., Design and control of warehouse order picking: A literature review, *European Journal of Operational Research*, vol. 182, no. 2, pp. 481–501, 2007.

Gu, J., Goetschalckx, M. and McGinnis, L. F., Research on warehouse design and performance evaluation: A comprehensive review, *European Journal of Operational Research*, vol. 203, no. 3, pp. 539–549, 2010.

Jaca, C., Viles, E., Jurburg, D. and Tanco, M., Do companies with greater deployment of Lean Six Sigma perform better? An empirical study, *International Journal of Production Research*, vol. 52, no. 18, pp. 5322–5340, 2014.

Min, H., Smart warehousing as a wave of the future, *Logistics*, vol. 7, no. 2, pp. 1–15, 2023.

Roodbergen, K. J. and Vis, I. F. A., A survey of literature on automated storage and retrieval systems, European *Journal of Operational Research*, vol. 194, no. 2, pp. 343–362, 2009.

Tortorella, G. L., Miorando, R., Caiado, R. G. G., Nascimento, D. L. M. and Staudacher, A. P., The mediating effect of employees' involvement on the relationship between Lean manufacturing and operational performance, *International Journal of Production Economics,* vol. 201, pp. 135–145, 2018.

Van den Berg, J. P., A literature survey on planning and control of warehousing systems, *IIE Transactions*, vol. 31, no. 8, pp. 751–762, 1999.

Yin, R. K., Case study research and applications: Design and methods, *Sage Publications*, 2018.

Zhen, L., Li, Z. and Zhao, Y., A literature review of smart warehouse operations management, *Frontiers of Engineering Management*, vol. 9, no. 2, pp. 227–246, 2022.

Zoubek, M. and Simon, P., A framework for a logistics 4.0 maturity model with a specification for internal logistics, *MM Science Journal*, vol. 2021, no. 1, pp. 4092–4100, 2021.

Biographies

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