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Original Article

Digital Procurement Transformation through Kraljic Segmentation: Evidence from Construction Supply Chains

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Abstract *- Material procurement inefficiencies remain a persistent barrier to profitability in the construction industry, particularly among small and medium-sized enterprises in emerging economies where digital maturity is low, and supply chains are fragmented. While the Kraljic matrix and process digitization have individually demonstrated value in manufacturing and retail supply chains, their synergistic integration in construction procurement has received limited empirical attention. This study addresses this gap by proposing and validating an integrated model that combines Kraljic-based strategic supplier segmentation with end-to-end procurement process digitization. The model was applied in three construction projects in a construction company based in Peru, utilizing a pre-experimental design of pre-tests and post-tests. Five performance indicators were analyzed, with the Wilcoxon signed-rank test with Holm-Bonferroni adjustment, bootstrapping, and effect size used for statistical verification. The outcomes indicated that all the measured parameters improved significantly: enhanced compliance with purchase orders by 20.79%, decreased supplier delays by 53.55%, increased order tracking accuracy by 65.61%, enhanced inventory accuracy by 10.08%, and improved profit by 6.22% (p_adj = 0.0313, r = 0.88). Thus, the study confirms that using a combination of strategic purchasing framework with digital processing has enabled construction firms to maximize supply chain performance.*

Keywords *- Construction supply chain, Kraljic matrix, Process digitization, Procurement optimization, Project profitability, Supplier segmentation, Wilcoxon signed-rank test.*

1. Introduction

The construction industry is a critical engine of economic growth in developing nations. In Peru, the National Institute of Statistics and Informatics (INEI) reported GDP growth of 3.9% in the first quarter of 2025, driven largely by domestic demand from the construction sector [1]. The Peruvian Chamber of Construction (CAPECO) estimated year-on-year growth of 3.6% by May 2025 [2], while domestic cement consumption rose by 7.72% during the same period [3], confirming the sector's dynamism and its multiplier effect across supply industries.

Despite this macroeconomic vitality, construction projects continue to suffer from chronic procurement inefficiencies. Average supplier selection times in Peruvian public infrastructure projects range from 11 to 27 business days, with a median of 26 days [4]. These delays propagate throughout the project lifecycle, creating material shortages, necessitating schedule rework, generating unplanned cost overruns, and ultimately eroding contractor profitability [5]. At the root of these problems lies a combination of inadequate procurement planning, unsystematic supplier evaluation, limited order traceability, and precarious inventory control [6]. When supply is untimely, downstream production processes suffer from compounding delays and cost escalations across project milestones [7].

Two established approaches offer potential solutions to these procurement challenges. First, the Kraljic matrix [8] provides a strategic framework for classifying materials by their supply risk and profit impact, enabling differentiated sourcing strategies such as framework agreements, competitive bidding, contingency planning, and simplified procurement. While widely adopted in manufacturing and retail [9, 10], its application in construction remains limited, particularly among Small and Medium-Sized Enterprises

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(SMEs) in emerging economies. Second, process digitization—the conversion of manual workflows into structured, auditable digital systems-has demonstrated benefits in enhancing supply chain traceability, real-time visibility, and proactive risk management [11, 12]. However, systematic integration of digitization with strategic procurement frameworks in construction is underexplored.

A critical review of the literature reveals a significant research gap: while studies have examined the Kraljic matrix in manufacturing contexts [9, 13] and digitalization in construction management [11] and purchasing portfolio models in construction [14], few have investigated the synergistic integration of both approaches within a single procurement improvement model for construction SMEs. Moreover, empirical validations of such integrated models in emerging-economy construction firms are virtually absent. This gap is consequential because construction supply chains in these contexts face unique challenges—temporary project-based supplier relationships, geographical dispersion, low digital maturity, and limited institutional capacity—that demand tailored, evidence-based solutions rather than direct transfers from other industries.

In order to fill this gap, this paper suggests an integrated approach, which brings together the Kraljic portfolio model for strategic supplier segmentation and end-to-end digitization of procurement and inventory management processes. The model allows for: 1) strategic supplier segmentation by analyzing the importance of the material in terms of criticality and risk. 2) complete digitization of the procurement process from requisition to arrival in the warehouse, providing order monitoring and visibility of inventory in real time. 3) an ongoing monitoring process using five Key Performance Indicators (KPIs).

This model was tested using a pre-experimental study (pretest/posttest without a control group methodology) in relation to three different infrastructure projects implemented by a medium-sized construction company in Peru. Statistically, the Wilcoxon signed rank test with Holm-Bonferroni to control for multiple comparisons, bootstrap confidence intervals (95%, 10,000 replications), and a non-parametric effect size estimation ($r = Z/ n\sqrt{}$) was used. This provided strong evidence for validity despite the low number of subjects involved in the study.

The structure of the paper is as follows. First, Section 2 presents a detailed literature review on the Kraljic Matrix, digitization of processes, as well as optimizing supply chains in construction, and discusses the formulated research questions. Section 3 describes the methodology, including description of the model, the design of methods, performance indicators, as well as the statistical methods. In the next section, Section 4 results of the implementation of the model are described, including statistical analysis. Finally, Section 5 discusses the implications of the findings. Finally, suggestions for practice and future research are shown in Section 6.

2. Literature Review

2.1. The Kraljic Matrix: Origins, Evolution, and Applications

The Kraljic matrix refers to the concepts presented by Peter Kraljic [8] in a well-known article that asserts that buy-side companies need to move away from their operational purchasing department into strategic supply management. Kraljic suggested that purchased products fall within one of four quadrants-strategic (high risk/high impact), leverage (low risk/high impact), bottleneck (high risk/low impact), and routine (low risk/low impact). Each of the quadrants indicates a very specific sourcing approach to use on products based on their category.

Strategic products should be obtained through strategic alliances and framework agreements; leverage products should be acquired using competitive bidding and volume consolidation practices; bottleneck products should be purchased through contingency planning and secondary sourcing; and routine products should be bought via straightforward, standardized processes [9]. Earlier research studies improved on Kraljic's original logic. For example, Padhi et al. [9] put forth an approach to commodity positioning using a unit of analysis scoring method based on fuzzy multi-criteria analysis, which assisted in minimizing bias in subjective nature of earlier work. Mutual work by Montgomery et al. [10] included a complete quantitative analysis based on decision analysis functioning, improving objectivity and reproducibility of the study. Taghipour et al. [13] combined the use of the Best Worst Method with PROMETHEE and sustainable shared value-based supplier segmentation. The most recent use is the Circular Assessment of Suppliers (CAoS) tool [15], which employs the Kraljic matrix process to include sustainability factors in evaluating suppliers. In the context of construction, Pacheco and Clausen [16] applied the concepts of Kraljic thinking to arrive at a sustainable purchasing supply chain management framework within the context of a design science approach. Ferreira et al. [14] utilized the Kraljic process to develop a purchasing portfolio model. However, there has been limited research into implementation studies to assess the operational effect of using the matrix on the construction industry domain, which is particularly problematic in developing nations.

2.2. Process Digitization in Construction Supply Chains

Process digitization refers to the conversion of manual, paper-based workflows into structured digital systems that enable automated execution, real-time monitoring, and auditable record-keeping [17]. In supply chain management, digitization provides three fundamental capabilities: end-to-end traceability, real-time visibility, and proactive risk control through automated alerts and decision rules [18].

According to Nikmehr et al. [11], digitalization is seen as an effective strategic approach for achieving sustainable efficiencies in construction management. The primary finding of their review is that digital technology has the potential to allow access to fragmented information and coordinated manual efforts without being limited to time and space. In contrast, in their paper, Tetik et al. [19] focused on maturity levels defined for the adoption of methods related to industrial logistics in construction, presenting a detailed process of maturity that helps evaluate the current state of an organization regarding the adoption of digitalization and its development in small steps. Moreover, Li and Zhao [20] present empirical results that prove the efficiency of digital transformation in terms of improving the effectiveness of construction firms. In addition, Setiawan et al. [21] provided evidence regarding the positive effect of the integration of the two processes into the green supply chain by demonstrating that their implementation leads to high competition.

As for traceability, Celik et al. [22] showed that the application of Building Information Modeling (BIM) with blockchain solves issues with tracing and version control. Tortorella et al. [17] identified the factors facilitating and hindering the process of digitalization of traceability in the construction industry and discussed organizational culture, the leadership of the organization, and the digital competence of employees. Tiwari et al. [23], in their research, analyzed the application of blockchain in third-party logistics companies by demonstrating the ways to automate contract management and event reporting in organizations within the global system.

Ben Mahmoud et al. [24] analyzed the literature regarding the integration of material suppliers into the construction supply chain and classified various coordination mechanisms, including contracts, sharing of information, or performance evaluation for implementing collaboration. Their findings indicate that using the existing digital coordination mechanisms leads to improving material flows and minimizing rework through increased efficiency.

2.3. Barriers and Enablers of Digital Adoption

There are significant challenges associated with the implementation of digitalization in construction, even though there are known to be various benefits of its adoption. For instance, Omari et al. [25] undertook a survey of contractors, owners, and consultants, and concluded that the following issues stand out as some of the major challenges that prevent the realization of benefits associated with the digitalization of the construction industry: cultural barriers, fragmentation of systems, and financial issues. On the other hand, Bajpai and Misra [26] studied the success factors that promote the digitalization of the construction industry and found that leadership, taking the necessary steps in different phases of technology adoption, and training the workforce are major enablers of the successful adoption of digital processes in the construction industry.

In another study, Marzi et al. [27] found that, in the case of Small- and Medium-Sized Enterprises (SMEs), the barriers to the adoption of technology differ in comparison to larger companies. The barriers for these companies are based on perceived costs, organizational inertia, and limited ability to build networks. Further, Skrickij et al. [28] established that limited industry-academic collaboration, as well as limited volumes of quality data, are examples of persistent challenges that affect the implementation of advanced analytics in supply chain digitalization. Finally, de Almeida Vittori Ferreira et al. [29] studied the role that the actions of organizations and stakeholders play in fulfilling sustainability requirements in construction and found the attainment of consensus among multiple stakeholders to be a prerequisite for the success of both strategic and digital procurement initiatives. Hence, based on these studies, it is clear that models that are related to implementation in SMEs should be based on realistic adoption paths as well as a demonstrable rate of return on investment.

2.4. Supply Chain Optimization under Uncertainty in Construction

Construction supply chains function in a very uncertain environment due to fluctuations in demand, supplier interruptions, and external factors affecting supply chains. A two-stage stochastic model proposed by Budiman and Rau [30] accounts for the application of postponement and modularization techniques to handle uncertainty arising from changes in demand. Chen et al. [31] applied the concept of robust optimization with backup suppliers and inventory management policies so as to lower costs associated with demand and supply shocks. Koutsokosta and Katsavounis [32] introduced a stochastic mixed-integer linear programming model for the transition phases in construction supply chains while using chances. Abdolazimi et al. [33] offered a sustainable forward supply chain configuration for construction industry operations while addressing the dilemma of environmental sustainability versus supply risks.

In supplier selection under uncertainty, Chen et al. [34] considered a fuzzy scenario-based environment with features like price, initial capacity, and lead time where material purchase and supplier selection can take place. Dorfeshan et al. [35] introduced a multicriteria decision-making model for project-driven supply chains based on interval type-2 fuzzy sets. Sahu et al. [36] suggested a framework for decision-making that incorporates MCDM approaches in the lean-agile-resilient-green environment. Attajer and Mecheri [37] presented a multi-agent-based simulation framework to facilitate the management of construction supply chains.

Abas et al. [38] highlighted major risk factors concerning construction supply chains in Pakistan, stating that the breakdown in communication, incorrect allocation of roles and responsibilities, and poor performance on the suppliers' side played a major role. Kaur et al. [39] developed an

integrated model that enhances supplier selection and investments in cyber resilience in the field of digital supply chains.

2.5. Research Gap and Contribution

The literature review reveals that while both the Kraljic matrix and process digitization have been independently studied, their synergistic integration within a single procurement improvement model for construction has not been empirically validated. Specifically, three gaps emerge: (1) existing Kraljic matrix applications in construction remain largely theoretical or case-descriptive, lacking rigorous statistical validation of implementation outcomes; (2) digitization studies in construction focus predominantly on BIM and project management rather than procurement process optimization; and (3) no study has documented the combined implementation of strategic supplier segmentation with procurement process digitization in construction SMEs in emerging economies, where supply chain challenges are most severe.

The gap in the aforementioned literature is addressed in this paper through an integrated model that combines Kraljic-type supplier classification with end-to-end procurement digitization by implementing it on various projects of a Peruvian construction company and providing sufficient proof regarding its efficacy. The contribution made in this study is both methodological, i.e., it shows how to create synergies between strategic and digital tools, and empirical because it provides adequate quantitative evidence related to the effectiveness of the proposed model with proper statistical validation on five performance indicators.

3. Methodology

3.1. Research Design and Case Study Context

This study utilizes a pre-experimental design, incorporating a single group pre-test/post-test format within the framework of quantitative research. The analysis unit is the procurement process of a medium-sized construction company in Peru (henceforth referred to as Company A), which is involved in construction design and building of public sector construction projects mainly in the education field in difficult and rugged areas. The company, which began its operations in 2008, had already conducted many public construction projects at the time of this study. Company A was selected for this research as it had the same procurement problems that all other Small and Medium-Sized Enterprises (SMEs) experienced in Peru, such as unexpected costs arising from frequent failures to adhere to the purchasing schedule, inability to manage suppliers, inadequate traceability of orders placed with the suppliers, and lack of inventory information. Three projects were selected as the context for the implementation of this procedure. Baseline data (pre-test) was taken on milestones of the projects where the model of this study had not been applied. The post-test data was collected from the milestones at which the model was applied. As a result of the two comparisons for each milestone, six comparisons were conducted (two milestones for each of the three projects). The outcome of the comparisons was sufficient for the purpose of non-parametric analysis. The initial diagnostic results of Company A's performance in procurement performance are presented in Table 1.

Table 1. Initial diagnostic assessment of Company A's procurement performance

Performance Indicator	Baseline	Target
Projected Profit Fulfillment	90.00%	100.00%
Purchase Schedule Compliance	62.90%	90.00%
Lost Days Due to Suppliers	9.20%	5.00%
Order Traceability Rate	36.60%	80.00%
Inventory Accuracy	84.22%	95.00%

According to the assessment, major shortcomings have been identified: less than 65% of the corporate purchase schedules met compliance standards, about 10% of the project days were affected by problems related to supplier management, and less than 40% of the purchase orders were traced adequately.

These problems adversely affect the ability of the company to reach its targeted profits and proved the necessity to implement a structured procurement enhancement strategy.

3.2. Proposed Model Architecture

The proposed model consists of two interconnected components: first, the use of the Kraljic matrix in order to segment suppliers strategically as well as define relevant procurement strategies, and secondly, digitization of the procurement process and of the inventory process in order to provide better performance in areas like tracking, visibility and control. The general outline of the model is shown in Figure 1.This model takes as input elements such as the progress plan of a project, the material needs for the project, where inventory is located today, lead times of suppliers, and supplier selection proposal. As outputs of the model, a company is able to implement strategies upon selected suppliers, have their material delivered in time, make cost savings by optimizing their procurement process.

3.3. Detailed Operational View

This model is executed using a coordinated process consisting of four organizational functions: the procurement department, the warehouse, the construction troupe, and construction foreman. The flow of operation is shown in Figure 2.

The operational process is as follows:

1. The construction manager prepares a list of materials required for the project, gives the due dates of delivery, and provides the anticipated progress of the work per week.
2. The procurement department assesses material requirements according to the existing stock of materials and prepares a purchase plan taking into account the volume of the stock of materials and Kraljic classification of materials and lead times of suppliers to send the purchase order to the vendors at the appropriate time.
3. Purchase orders are prepared and sent electronically to the vendors while also notifying the warehouse with the arrival dates of the materials.
4. The procurement department tracks the delivery process using the electronic tracking system.
5. After the receipt of the materials, the warehouse conducts the quality test of the materials received, and in case the results are satisfactory, the warehouse modifies the electronic tracking system with the acceptance of the received materials.
6. An audit of the materials taken is conducted every time a milestone is accomplished and any excess materials are brought back to the warehouse.
7. The construction project manager has overall supervision using the dashboard and keeping an eye on the process.

3.4. Purchasing Planning Process

The purchasing planning process ensures that material procurement is strategically aligned with project progress. Figure 3 illustrates the complete purchasing planning workflow.

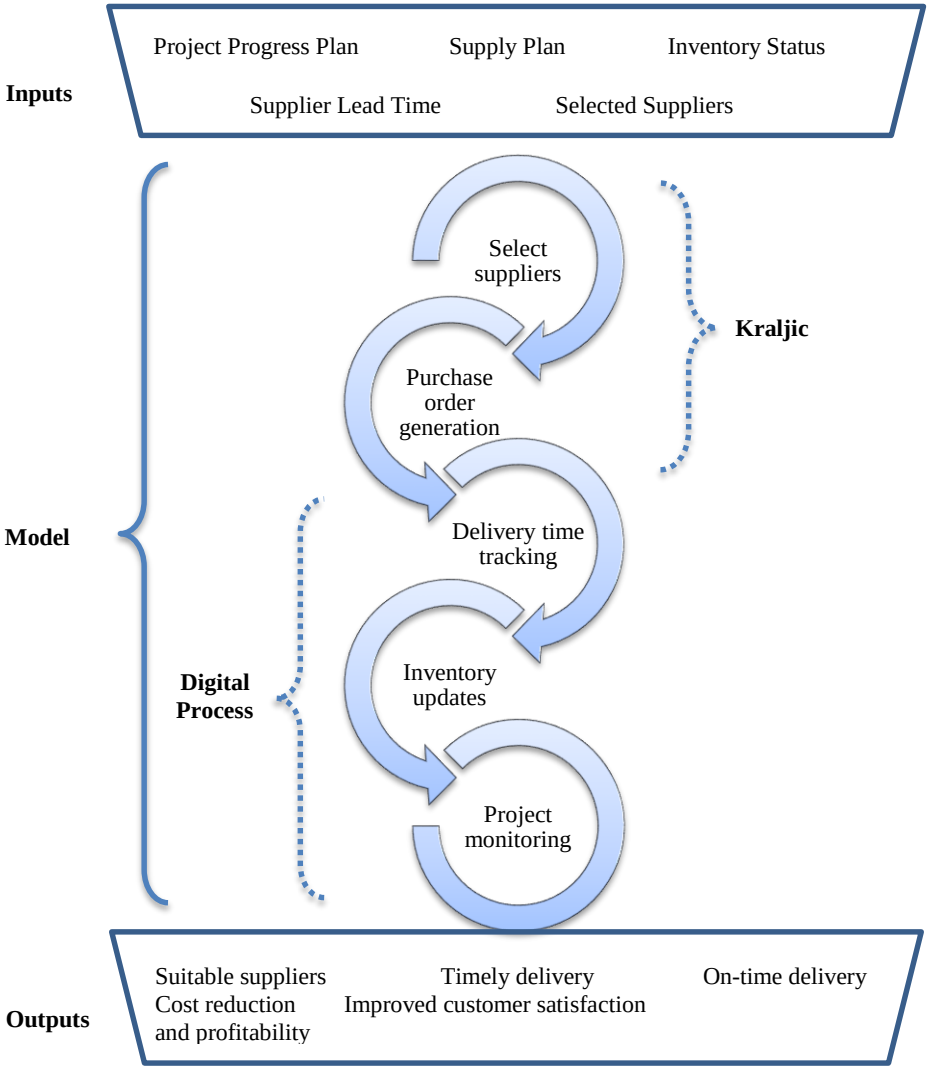

Fig. 1 Proposed model overview: Integration of the Kraljic matrix and process digitization

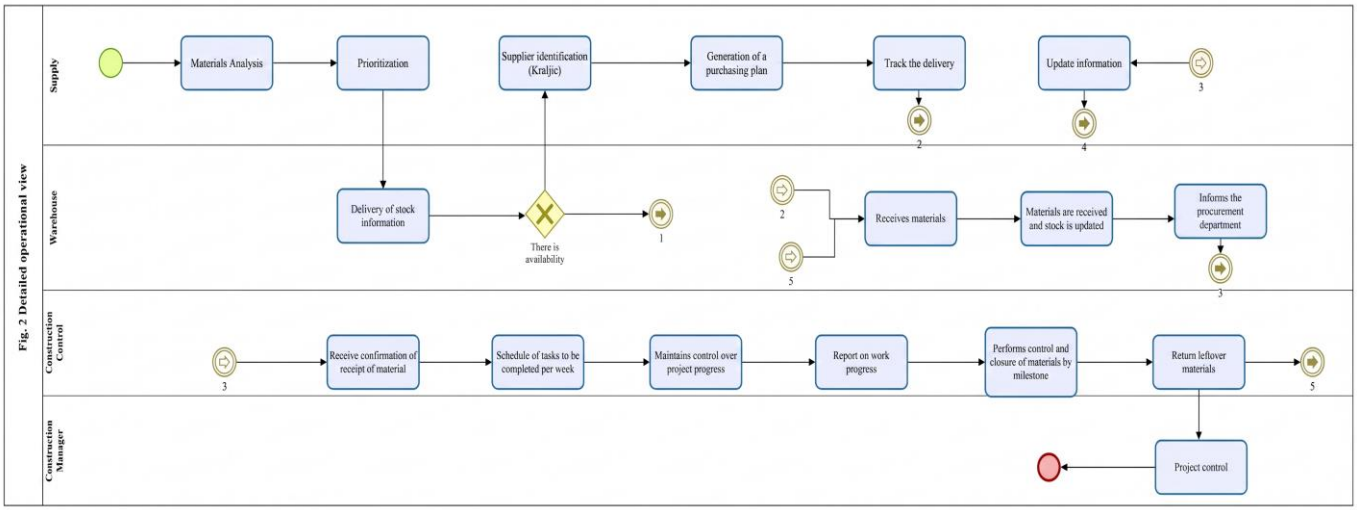

Fig. 2 Detailed operational view showing the workflow across procurement, warehouse, construction control, and management.

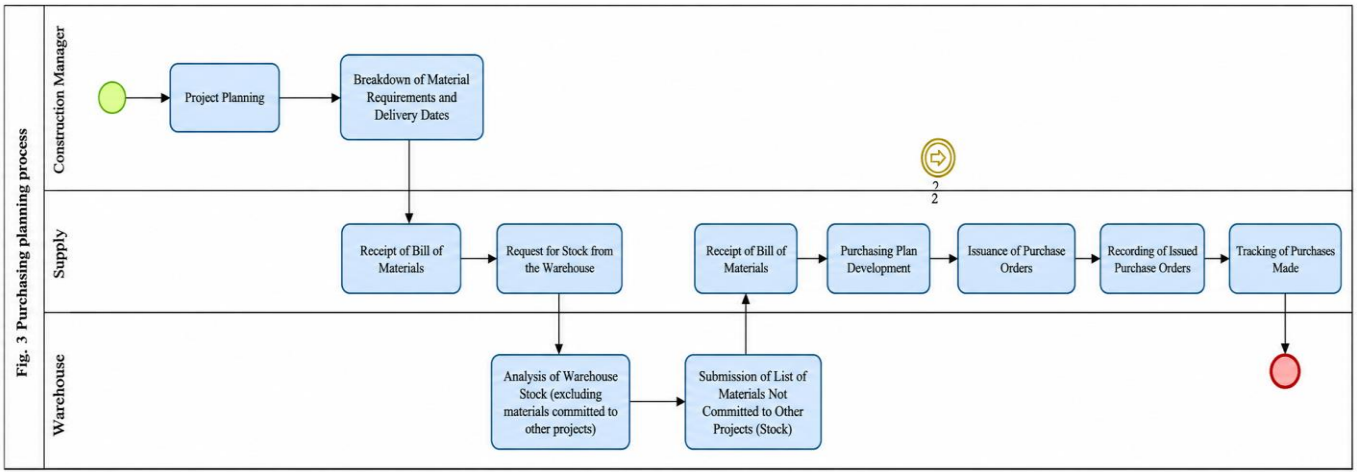

Fig. 3 Purchasing planning process: From project requirements through purchase order issuance and tracking

The process initiates through obtaining the material requirements of the project in alignment with construction schedules. A determination of actual needs is accomplished by the procurement department determining needs, based on the committed and available stock in inventory.

A purchasing plan is established, and the issuance of purchase orders is scheduled based on the historical lead time associated with each supplier. Each purchase order is tracked within digital documentation, allowing for structured processing of order status, order fulfillment dates and condition of materials received.

3.5. Supplier Selection using the Kraljic Matrix

The process for selecting suppliers uses the Kraljic matrix for strategic classification depending on the degree of importance and level of risk presented by the materials supplied. Figure 4 indicates the implementation of the Kraljic method, and Figure 5 outlines the supplier selection process.

Each type of material is reviewed in terms of two criteria: (1) supply risk (availability of suppliers, geographical location, substitutability, delivery reliability); and (2) profit impact (cost of units, amount consumed, time of delivery needed).

The outcome of this review allows the classification of each type of material-supplier combination into one of four categories based on the characteristics of each type of material: (1) the category of items requiring strategic partnerships (high risk, high profit impact); (2) bottleneck materials (high risk, low profit impact); (3) leverage materials (low risk, high profit impact); and (4) routine materials (low risk, low profit impact).

3.6. Traceability and Digital Workflow

The traceability process leverages digitization to provide end-to-end visibility of the procurement cycle. Figure 6 shows the complete digital traceability workflow.

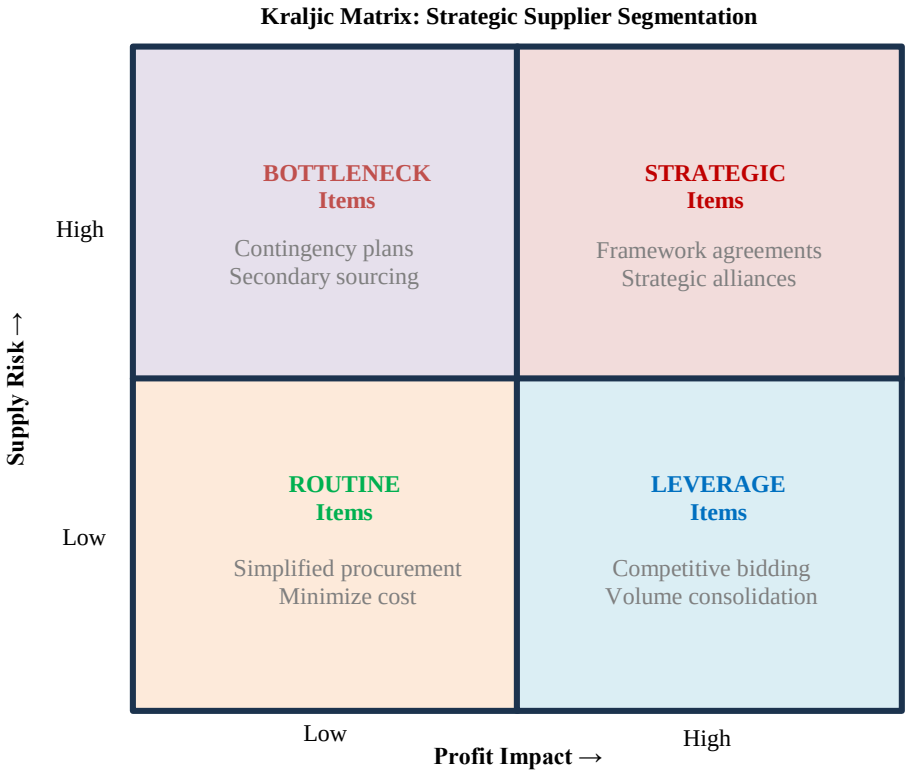

Fig. 4 Kraljic matrix framework applied to construction material classification

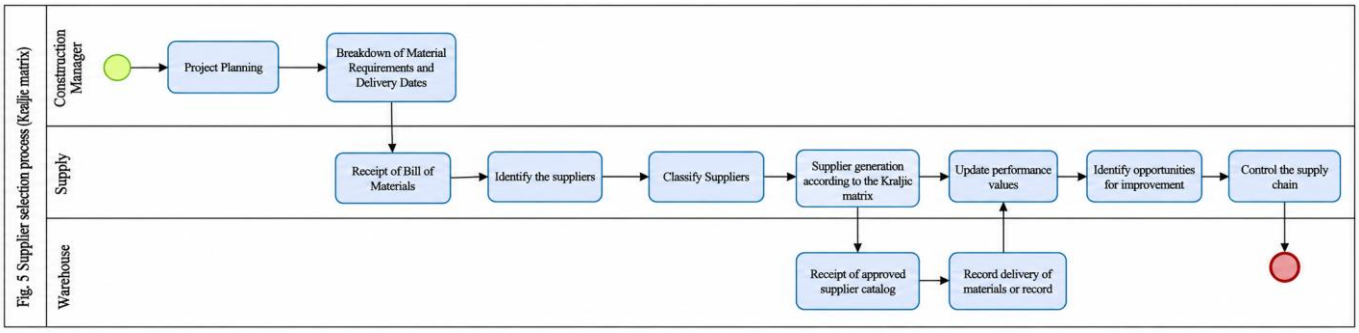

Fig. 5 Supplier selection process flow based on Kraljic matrix classification

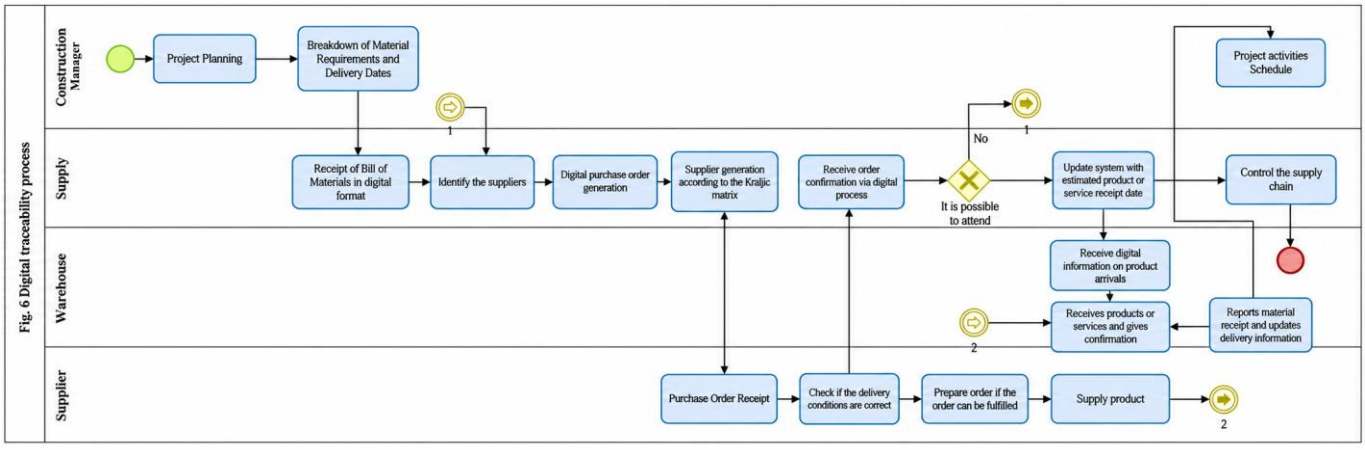

Fig. 6 Digital traceability process: End-to-End order tracking from requisition through delivery confirmation

The project manager prepares the needed materials in a digital format, accompanied by the deadlines. The procurement department then places orders through this digital system, providing further instructions regarding deadlines, amounts, standards for quality, acceptance criteria, etc. The suppliers will always have to confirm whether the goods will be delivered on time; if a supplier fails to do so, the system informs the question concerning the alternative supplier based on the Kraljic matrix. When the goods arrive, the warehouse manager checks if the conditions of the order are met according to the digital checklist before the materials are accepted into the inventory.

3.7. Supply Chain Audit and Control

The final process component involves structured weekly coordination meetings among warehouse, procurement, finance, and project management representatives. Figure 7 illustrates the audit and control cycle.

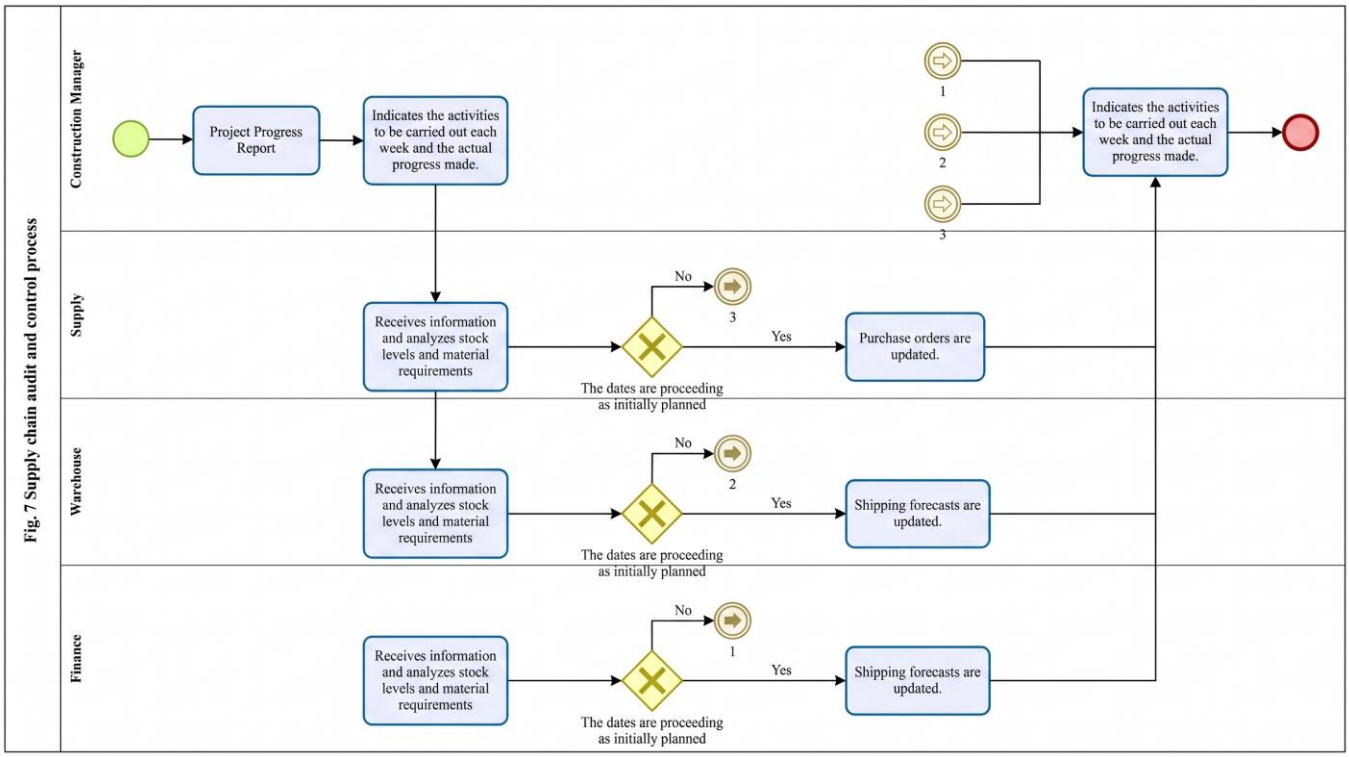

Fig. 7 Supply chain audit and control process with weekly cross-functional review cycles

At these meetings, the team will review the status of each project against plan, assess procurement key performance indicators from the dashboard, and decide what adjustments need to be made to the schedule. Use of this system will allow for a proactive approach to supply chain management: moving forward or deferring, or holding steady with agreements based on current project requirements and inventories.

3.8. Key Performance Indicators

Five key performance indicators have been identified to comprehensively measure the effectiveness of the model: (1) purchase schedule compliance index indicates the percentage of purchase orders that are completed on schedule. (2) lost days index due to supplier management indicates the percentage of project days that are lost due to material shortages that happen as a result of supplier failures. (3) Order traceability index indicates the percentage of purchase orders that have enough validated digital tracking available. (4) Inventory accuracy index indicates the degree of accuracy of inventory levels that are recorded in a system compared to actual stock levels. (5) Project Profit after Model Implementation (PPAMI) shows the relationship between actual profit obtained and profit that was anticipated.

3.9. Statistical Validation Design

Due to the small sample size (n = 6 pairs), non-parametric statistics were used. The main test was the Wilcoxon signed-rank test (one-tailed, H1: improvement > 0). As a second validation method, the sign test was used.

Two primary variables (time reduction and increase in profit) could be tested concurrently, thus requiring the use of the Holm-Bonferroni sequential procedure for control of the chance of a Type I error by multiplicity. The effect sizes were calculated using the rank-biserial correlation (r = Z). Confidence intervals were calculated using the bootstrap method (BCa, 95%, 10,000 samples for both mean and median improvements).

4. Results

4.1. Implementation Timeline

The model was executed in a period of 16 weeks on the three infrastructure projects in four stages: (1) Diagnostic and baseline measurement (weeks 1–3). (2) Deployment of the Kraljic matrix and creation of supplier catalogues (weeks 4–6). (3) Process digitization, tool configuration, and training of personnel (weeks 5–10). (4) Monitoring the operation of the process and post-measurement (weeks 11–16).

4.2. Time Lost and Profitability: Paired Observations

Table 2 presents the paired pre-test and post-test observations for time lost and project profit achievement across all three projects. Figures 8 and 9 visualize the before-after comparison.

Table 2. Time lost and profitability: Pre-Test vs. Post-Test paired observations

Obs.	TL Pre (%)	TL Post (%)	ΔT (pp)	Profit Pre (%)	Profit Post (%)	ΔU (pp)
P1-M1	9.20	4.10	5.10	90.00	95.30	5.30
P1-M2	9.78	4.60	5.18	89.80	95.25	5.45
P2-M1	9.34	5.15	4.19	89.00	94.00	5.00
P2-M2	10.05	5.01	5.04	87.00	94.58	7.58
P3-M1	9.10	3.65	5.45	91.00	96.60	5.60
P3-M2	9.70	4.05	5.65	91.00	95.50	4.50
Mean	**9.53**	**4.43**	**5.10**	**89.63**	**95.21**	**5.57**

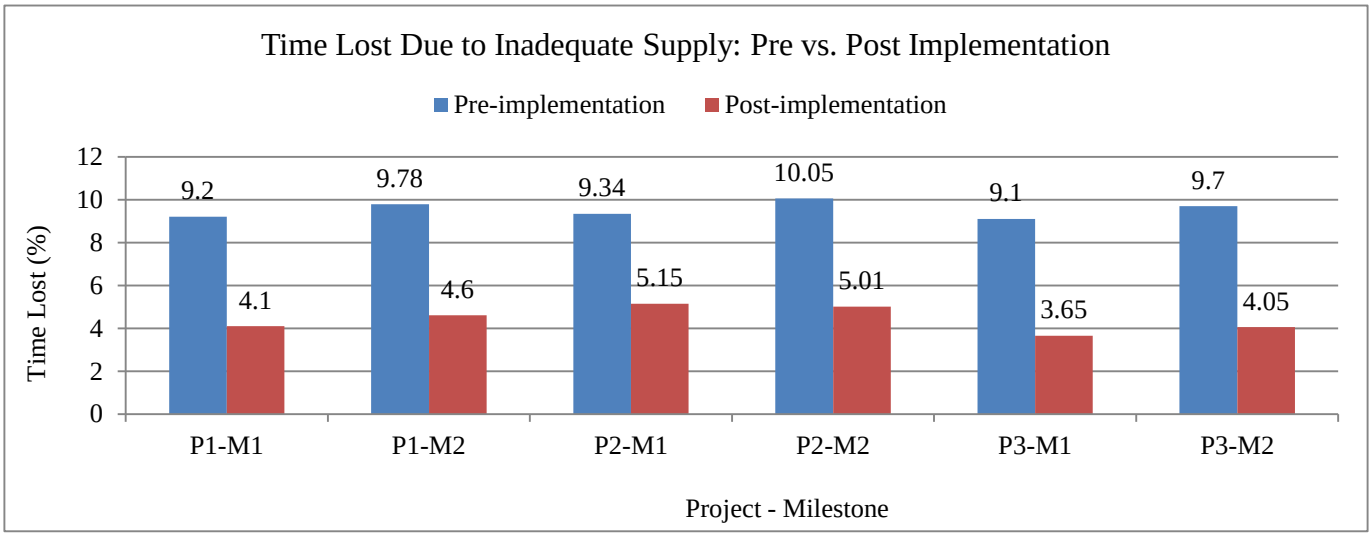

Fig. 8 Time lost due to inadequate supply: Pre- vs. post-implementation comparison

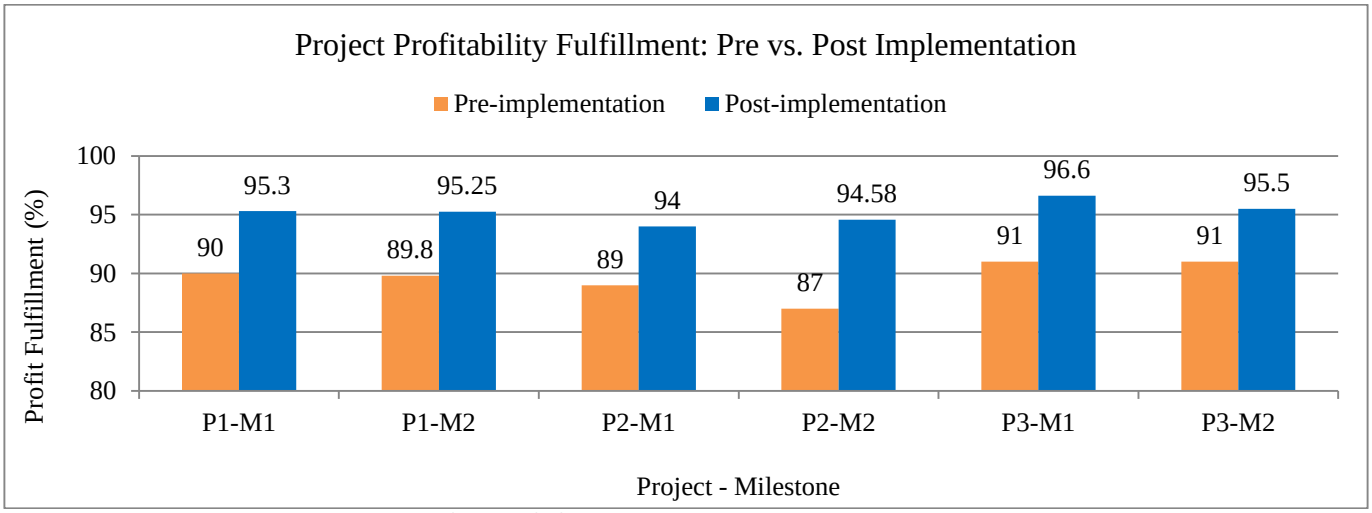

Fig. 9 Profitability fulfillment: Pre- vs. post-implementation comparison

There was an improvement in both measures in all six pairs of observations. The average time lost changed from 9.53% to 4.43%, a difference of 5.10 pp. On the other hand, the average profitability increased from 89.63% to 95.21% or an improvement in 5.57 pp from one measurement to the other.

4.3. Statistical Validation Results

Table 3. Statistical validation results

Statistical Measure	Time Lost (ΔT)	Profitability (ΔU)
Wilcoxon W statistic	21.0	21.0
p-value (one-tailed)	0.0156	0.0156
Holm–Bonferroni adj. p	0.0313	0.0313
Effect size ($r = Z/\sqrt{n}$)	0.88	0.88
Sign test (6/6 positive)	p = 0.0156	p = 0.0156

Both improvements have been shown to be statistically significant at the alpha threshold of 0.05 when considered under the Holm-Bonferroni correction (adjusted p = 0.0313). The W statistic is equal to 21.0, which is the highest value obtainable for a sample size of 6; this means that all calculated ranks were positive and favored improvements. The calculated effect size is equal to 0.88, which is much higher than the minimum required for a large effect size (0.5).

4.4. Bootstrap Confidence Intervals

Table 4. Bootstrap confidence intervals (95%, 10,000 Resamples)

Measure	Time Lost Red. (pp)	Profit Increase (pp)
Mean [95% CI]	5.10 [4.70, 5.42]	5.57 [4.93, 6.44]
Median [95% CI]	5.14 [4.62, 5.55]	5.38 [4.75, 6.59]
Avg. relative Δ	53.6% reduction	6.23% increase

The bootstrap CIs are narrow and entirely above zero for both metrics, confirming the robustness of the observed improvements.

4.5. Consolidated KPI Results across Projects

Table 5 presents the comprehensive results across all five KPIs, disaggregated by project. Figures 10–12 visualize the KPI comparisons.

Table 5. Consolidated performance indicators by project

Indicator / Project	Initial	Final	Improv.
Profit Fulfillment			
Project 1	89.90%	95.28%	+5.98%
Project 2	88.00%	94.29%	+7.15%
Project 3	91.00%	96.05%	+5.55%
Average	89.63%	95.20%	+6.22%
Schedule Compliance			
Project 1	62.50%	79.50%	+27.20%
Project 2	59.55%	72.65%	+22.00%
Project 3	65.50%	74.40%	+13.59%
Average	62.52%	75.52%	+20.79%
Lost Days (Suppliers)			
Project 1	9.49%	4.35%	−54.16%
Project 2	9.70%	5.08%	−47.60%
Project 3	9.40%	3.85%	−59.04%
Average	9.53%	4.43%	−53.55%
Order Traceability			
Project 1	36.60%	60.70%	+65.85%
Project 2	35.50%	58.80%	+65.63%
Project 3	37.80%	62.50%	+65.34%
Average	36.63%	60.67%	+65.61%
Inventory Accuracy			
Project 1	84.22%	92.65%	+10.01%
Project 2	82.70%	91.10%	+10.16%
Project 3	85.75%	94.40%	+10.08%
Average	84.22%	92.72%	+10.08%

Note: The initial company-wide assessment administered according to Table 1 yielded a baseline reading of 62.90 percent. Table 5 provides the mean score of 62.52 percent from the averages of measurements across the three projects examined in this research project (the measurements were taken, in part, at the same time but under different conditions). The slight difference in scores was produced as a result of the different context of the assessment for each project.

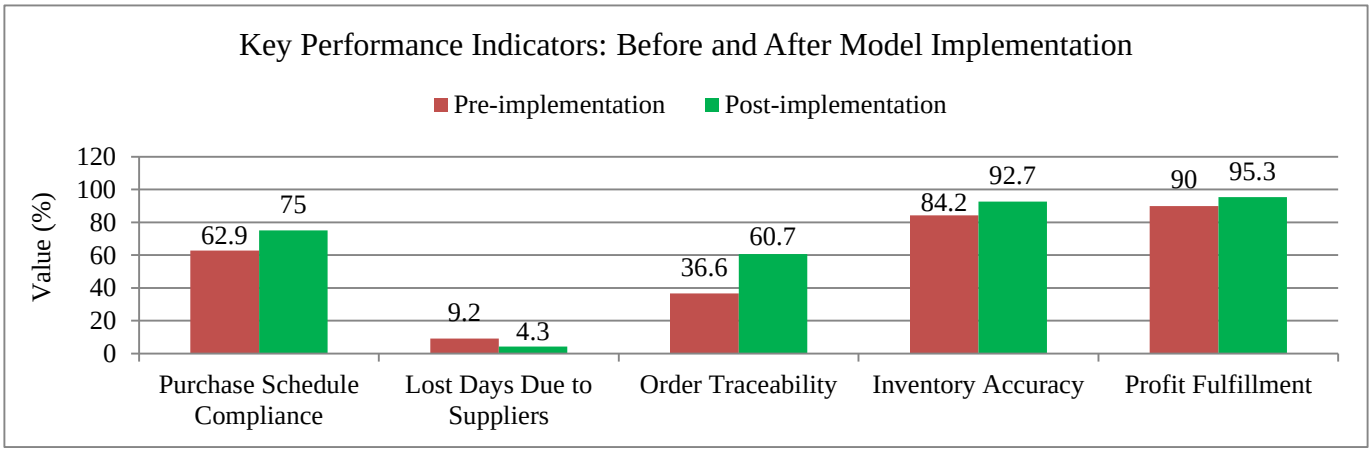

Fig. 10 Summary of all five KPIs before and after model implementation

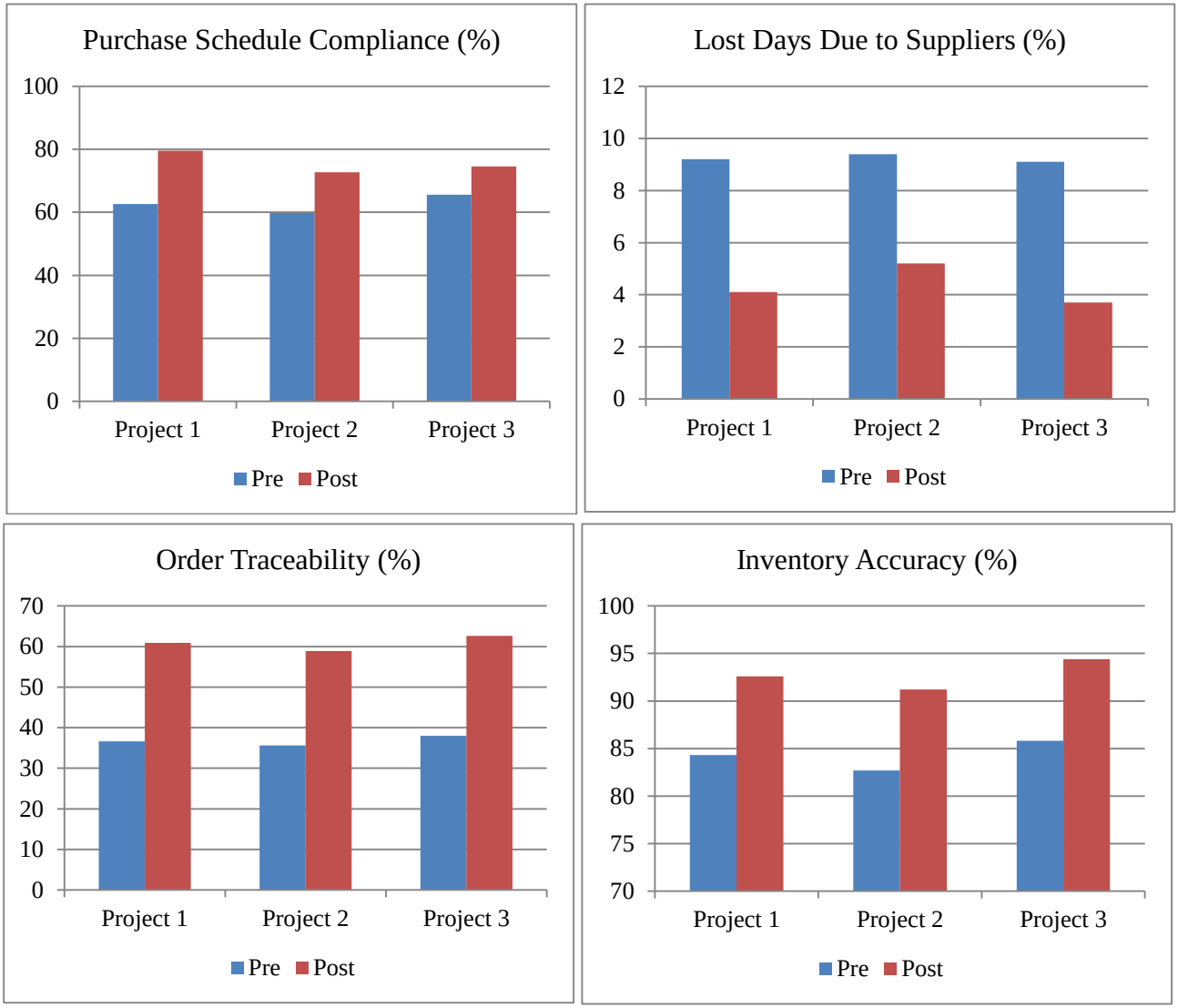

Fig. 11 Per-Project KPI comparison across four operational indicators

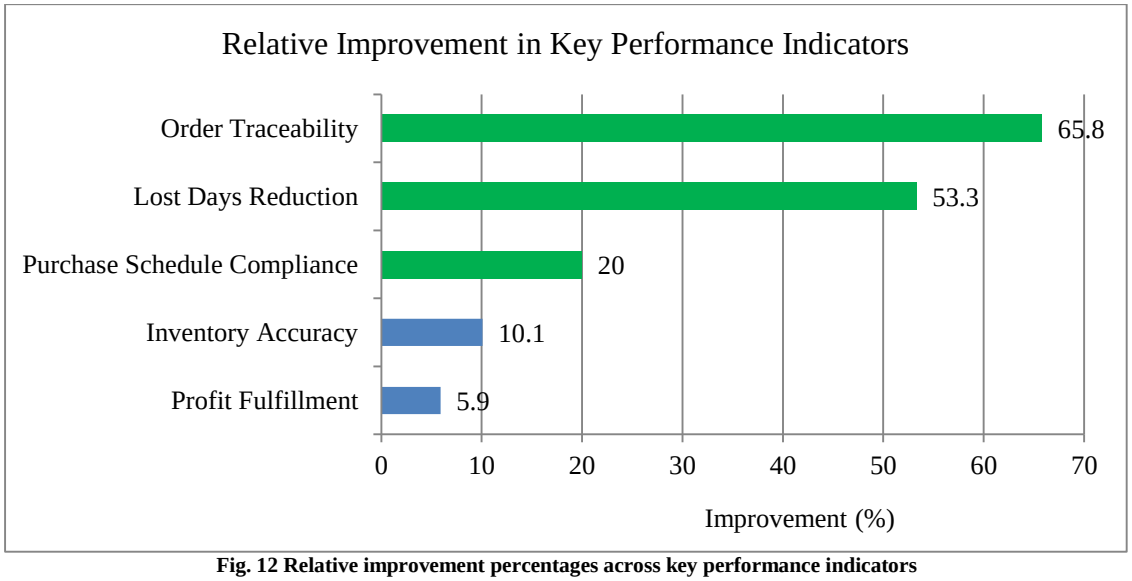

Fig. 12 Relative improvement percentages across key performance indicators

The analysis reveals a consistent enhancement in all projects and all parameters. Order traceability presented the highest increase at +65.61%, due to the substitution of traditional paperwork with electronic tracking systems. Lost days declined by 53.55%, due to successful implementation of Kraljic supplier segmentation. In terms of purchase schedule compliance, this indicator grew by 20.79%, while inventory accuracy improved by 10.08%, and overall profit margin grew by 6.22%.

5. Discussion

5.1. Synergistic Mechanisms and Causal Explanations

The findings of this research indicate that the adoption of Kraljic-based supplier classification alongside complete procurement digitization has yielded results greater than applying each intervention independently. Gaining insight into the causal processes responsible for achieving improvement in any KPI is vital for progressing theory and practice.

The change of 53.55% in the number of lost days caused by supplier failures can be explained by two closely connected processes working at the same time. Firstly, the usage of Kraljic classification allowed the procurement team to distinguish strategic and bottleneck commodities which needed proactive management and enforcing pre-negotiated framework agreements with trustworthy suppliers, as well as establishing backup sources for the supply of dangerous products. The classification thus changed the procurement method from the previous homogeneous and reactive way of buying all types of products through ad hoc negotiations to proactive procurement using appropriate procurement strategies according to the criticality of materials.

Secondly, the process of digital tracking provided the procurement team in the organization with real-time information about order status, allowing them to detect early delivery problems and intervene in a proactive manner. The evidence of digitalization of the procuring took place now, allowing the Kraljic classification to classify suppliers requiring strict oversight whilst enabling the digital system to take care of the implementation of it in operation.

The change of 20.79% in compliance with the purchase schedule demonstrates the transition from an informal experience-based planning strategy to a structured, data-driven procurement process. The integrated model organized all this information so that the Kraljic classification laid down rules regarding which procurement orders should be prioritized, and the digital planning tool automated the scheduling of purchasing orders based on milestones on the construction schedule and vendor lead times. Doing so reduced variability in manual scheduling while keeping the needed flexibility for construction's dynamic work environment.

The improving traceability by 65.61%, the highest relative gain, can chiefly be attributed to the technology component of digitization, which changed the practice from a fragmented and paper-based record-keeping system to a fully centralized electronic data platform. At the same time, it is important to understand the significance of this level of achievement: traceability was at 60% based on a baseline of 80%, which represents an accomplishment that possesses limited success. This data follows the technology adoption literature showing S-curve patterns in digitization maturity [17, 25].

The early times of digitization typically allow for the rapid identification of inefficiencies that were once performed manually but lead to slower, later developments of deeper organizational behaviors such as entry of information into the system in a disciplined and consistent manner and the use of systematic checklists, among others [26]. Tortorella et al. [17] described similar patterns of use in their research on the Australian construction supply chain, finding that organizational cultural issues and workforce digital literacy enable the need for continual investment that goes beyond the early period of introducing new technology.

Thus, the implementation period of 16 weeks, while sufficient to show a trial that demonstrates the applicability of the newly-developed digital traceability system, may not have allowed enough time to show cultural and behavioral changes required for broader system acceptance.

An improvement in inventory accuracy by 10.08% arose from two mechanisms that contributed to the achievement involved. One element was through the digital recording of materials received and consumed, which prevented errors caused by the earlier manual counting processes and then well-planned procurement processes that were based on the Kraljic strategy. The relatively low level of change in inventory accuracy as compared with the dramatic improvements in digital traceability shows that the newer technology must rely on appropriate physical handling of materials used in the warehouse rather than exclusively on the technological capabilities of the new digitized records.

An increase in profitability of 6.22% was the financial result due to the operational achievements identified prior to this point in the study. This change occurred for a variety of reasons that involved the combination of the reduction in lost days, which eliminated unnecessary labor costs and idle equipment costs, as well as the reduction of economic losses that resulted from improving compliance to the construction schedule. As there has been consistency between all three projects in terms of profit levels affiliated with each type of project in light of the various eligible criteria information, it can be concluded that profit mechanisms are consistent across these projects regardless of their particulars.

5.2. Theoretical Implications and Research Gap Contributions

The current study makes three important contributions to the existing body of knowledge concerning the Kraljic procurement process, as outlined in Section 2.5.

First, this study addresses the statistical validation of the Kraljic matrix in the construction industry (sub-gap 1) by providing an empirical validation of the Kraljic procurement process within a construction Small and Medium-sized Enterprizes (SME) utilizing rigorous non-parametric statistical techniques.

Prior research employing the Kraljic model in the construction industry did not utilize any statistical validation of the findings (i.e., Ferreira et al. [14], Pacheco and Clausen [16]), as these studies used qualitative case study and/or descriptive techniques to arrive at their conclusions.

Padhi et al. [9] and Montgomery et al. [10] have created a quantitative Kraljic matrix but applied its use within manufacturing.

This study provides validity to the Kraljic model in the construction industry;

Second, concerning the digitization focus rather than procurement (sub-gap 2), the current study demonstrates that significant improvements within procurement can occur through the digitization of process-oriented information without the use of Building Information Model (BIM) or other advanced technology relating to construction. The aforementioned research conducted by Nikmehr et al. [11] and Celik et al. [22] focuses on the areas of BIM-based solutions, blockchain-enabled traceability, and enterprise solutions only. The benefit of having such solutions is outweighed by the difficulties regarding their use/implementation for SMEs in developing countries, as it calls for high costs, longer learning periods, and the necessity to implement them throughout the entire ecosystem [25, 27]. The research shows that this gap could be filled with some digital solutions that are not sophisticated but nevertheless capable of providing good traces (cloud computing spreadsheets, digital dashboards, tracking templates) with a very low level of investment. The data reveal that the change has certainly demonstrated that there is no absolute need to use advanced technologies to achieve significant results when it comes to digitization.

Additionally, with respect to the lack of integrated approaches for SMEs in the developing world (Sub-gap 3), this research experience provides the first-ever successful integration of strategic purchasing classification and process digitization concerning efforts undertaken in a construction SME in the developing economy. The significance of this integration is not only methodological, as it brings practical benefits that can also be applied within the framework of construction however, unlike the sector of manufacturing, which was tested before [20, 21] since the context of construction is much more challenging because it is characterized by temporary nature of project-oriented relations, remoteness of different locations involved, the level of digital literacy, etc. [38]. The specific situation in Peru when public procurement is limited to having 11-27 business days [4] and fragmentation of the supply chain can be a real indicator of further applicability of the proposed model. [5]

In a theoretical sense, these results contribute into the process of discussing whether strategic purchasing classification can be transferred for use among various industries. If it was developed by Kraljic [8] for use in manufacturing only, and thus since Kraljic series of enhancements [9, 10, 13, 15] confirmed potential use of Kraljic matrix in manufacturing field, this research shows how one can transfer the ideas of the concept into construction sphere, and this is due to having a proper operational structure to support such an implementation.

5.3. Comparison with Prior Research: Convergences and Divergences

The study reports a 20.79% improvement in schedule adherence consistent with Asadujjaman et al.'s [40] findings that show efficient resource planning greatly enhances construction project schedules. The current research takes an important step forward by demonstrating that the combination of supplier classification with digital processes improves schedule adherence even further than what can be achieved through resource planning alone. Asadujjaman et al. were concerned with computational optimization in regard to resource allocation, while the current study's approach implements strategic differentiation in the planning area itself, suggesting that the quality of procurement decisions is just as important as their computational effectiveness.

The findings reveal a 53.55% decrease in lost days, corroborating the results found by Dixit [41], demonstrating that strategic sourcing greatly lessens supply disruptions. Furthermore, Awaad et al. [42] show the significance of material supply chain management in terms of productivity in construction work. In addition, the reduction seen in the current research is much higher than that found by the above studies when considered separately, indicating a synergistic amplification effect of strategically sourcing materials used in conjunction with digital monitoring processes. This finding is supported by Li and Zhao [20], indicating that digital development improves supply chain performance relative to information flow and decision quality.

The traceability results also diverge from the literature in an educative way. Celik et al. [22] and Tiwari et al. [23] showed that nearly complete traceability could be attained using the BIM/blockchain integration and DLT, respectively, while the current paper demonstrated a 60.67% traceability

through much simpler digital systems. The divergence in the findings is likely due to three contextual variables: (a) gaps in the sophistication of the technologies used, (b) the low level of digital maturity represented by the company studied, and (c) cultural and behavioral barriers to digitalization previously cited by Omari et al. [25] and Bajpai and Misra [26]. The divergence, instead of undermining our findings, demonstrates an important practical consideration: construction SMEs in developing countries operate within a different segment of the digital maturity curve as compared to organizations situated in developed nations, necessitating some adjustments in the intervention model. Moreover, the sizable relative improvement attained (+65.61%) despite the use of simpler tools points out that the benefits of basic digital tools are relatively higher in lower maturity contexts, even when the absolute performance values do not match those reported in more advanced digital contexts.

The 6.22% improvement in profitability correlates with McKinsey's [43] analysis of procurement optimization as it relates to construction and with Ghoroqi et al.'s [44] findings of cost savings through integrated management and scheduling. The study reported by Thunberg and Fredriksson [45] also shows that improvements in terms of logistics yield credible financial benefits. In addition, Liu and Zheng [46] found evidence of financial ties through the application of supply chain finance methods, which improve supplier stability according to corporate risk-taking mediation. Overall, the correspondence of the current results with these varied studies indicates that the pathways to profitability stemming from procurement optimization are stable across settings and methodological approaches.

5.4. Managerial Implications

The results of the research lead to five concrete and implementable recommendations for managers of construction Small and Medium-Sized Enterprises (SMEs) that desire to improve their procurement function.

First, companies must initiate their procurement improvement program by using Kraljic's purchasing matrix to categorize the value and risk of each item before spending money on IT systems for procurement management. This categorization can be done easily without the use of an elaborate system; it simply requires defining the risk level of supply for each item based on supplier availability, distance to supply base, availability of substitutes if a supplier fails, and supply reliability before calculating the profit impact based on unit price, volume required, and the importance of delivery timing considerations. During the initial weeks of the study, all the classifications were easily completed in a matter of three weeks.

Second, SMEs must implement the digitization process gradually and without the use of an enterprise-wide IT solution. The previous study was able to show success by using the current cloud-based worksheet form an organized method of organizing all of the necessary inputs and outputs instead of using some type of IT system. Implementing alternative systems reduces the resistance to adoption outlined by Marzi el al. [27], where SMEs resist adopting both because of the perceived costs of implementation and the complexity of the IT system. It is the approach of ensuring that the process becomes standardized and recorded digitally that is important.

Third, companies must allow for at least six months for the complete digital adoption and implementation, instead of the 16 weeks used in this study, especially for traceability processes where behavioral change is required. The failure to implement the desired level of traceability illustrated in the study (60.67% instead of the 80% goal) indicates that once the technology is put in place, a time period of coaching and follow-up will be necessary before there is the cultural shift required for the changes to occur. Bajpai and Misra [26] provide support of this recommendation by finding that phased implementation and training is an essential component to provide a higher probability of success.

Fourth, the importance of weekly coordination meetings includes these meetings as a requirement, rather than simply an optional addition to the further improved process. Those meetings were critical to the success of moving forward with significantly improving procurement efforts because it was the principal vehicle to move from digital data to practicing making decisions based on what the data demonstrated. Ben Mahmoud et al. [24] supported the need for structured coordination efforts as a primary enabler of enhancing the construction supply chain.

Fifth, if companies are operating in a situation similar to that which exists in Peru, where the process and timing of government procurement can be extended, and suppliers experience issues with national and global supply chains, they must be able to utilize the Kraljic matrix. A major achievement of the study was due to the adoption of a proactive strategy in order to limit problems by being able to develop a strategy to have backup logistics capabilities.

5.5. Boundary Conditions, Limitations, and Future Research

There are a few boundary conditions that will influence the generalizability of the results. The model is likely to produce benefits only in construction SMEs that fulfill the following conditions: (a) its pre-intervention procurement process is largely undifferentiated and manual, resulting in a high starting point for improvement; (b) its material portfolio is sufficiently varied, making it possible for strategic differentiation to take effect (excluding those firms that only procure standardized materials); (c) there is a commitment from management to follow through with implementation (including willingness to invest in training and change processes); and (d) the supplier market is competitive enough

to allow for the strategic differentiation shown in the Kraljic quadrants (in fact, in the case of monopolistic supply markets, strategic classification has limited application).

On the other hand, one might expect lesser results where the following conditions apply: (a) there are already moderate to high levels of digital maturity, meaning any added benefits from digitization will be minimal; (b) there is only a short timeframe for construction projects, meaning the model will have little opportunity to accrue benefits; (c) regulatory constraints dictate how procurement is to be managed; or (d) suppliers' engagements are governed through commitments rather than project-specific negotiations. These boundary conditions will serve to define a future research agenda across different contexts.

Using a pre-experimental design with no control group may limit causal attribution because other factors that influence the outcomes—seasonal changes in material availability, macroeconomic changes, or simultaneous improvements in organizational practices—could cause the improvements that were observed in the study. Although the stability of the results obtained in all three projects, in conjunction with the large effect sizes ($r = 0.88$) indicates that the model was the main cause behind the results, using a quasi-experimental design with a matched control group would provide more validity to the causal claims made in this study. The number of projects (three), while adequate for non-parametric analysis, limits the statistical power and generalizability of the results. Wilcoxon signed-rank testing is suitable for the sample size, but it is essential to be cautious with confidence intervals due to the small number of independent projects.

This study was performed within a single company that operated within the segment of public education in the Peruvian construction industry, which limits the generalizability of findings to other sectors of construction, company sizes, or geographic contexts. The possibility that the personnel may be aware of being studied and were improving their performance also needs to be considered. Although the study lasted 16 weeks, which is enough time to show short-term results, it does not show how long the gains would continue after the intensity of monitoring is reduced.

Future research endeavors should overcome these shortcomings by using quasi-experimental designs with control groups and larger sample sizes of companies in different segments. Replication studies throughout developing countries would add external validity to the study, especially in regions like Sub-Saharan Africa and Southeast Asia where construction SMEs face similar procurement problems. Furthermore, utilizing machine learning for demand forecasting and supplier risk assessment in this study holds great promise and could lead to the development of maturity models for strategic-digital procurement based on Tetik's framework [19].

Moreover, studying the impact of organizational culture and readiness for change on the relationship would also be beneficial to practitioners implementing similar models.

6. Conclusion

This paper outlines an integrated model developed, tested, and implemented to incorporate the Kraljic Matrix for strategic supplier segmentation and end-to-end digitization of the procurement process. Using the model on three infrastructure projects in a small to medium-sized construction firm in Peru allowed the authors to carry out their analysis of the proposed model using a statistical procedure centered on five Key Performance Indicators (KPIs).

The results showed significant results in all dimensions. Most notably, there was a 20.79% increase in purchase schedule compliance, 53.55% in reduced lost days, 65.61% in improved order trackability, 10.08% in increased inventory accuracy, and 6.22% in increased profitability, with all of the major metrics being statistically significant after Holm-Bonferroni adjustment ($p_{adj}=0.0313$) with large effect sizes ($r=0.88$).

The present research contributes to three areas: (1) empirical proof of synergy between the Kraljic matrix and digitization of processes; (2) proof that the SMEs in the construction industry within emerging countries can gain improved procurement results using the simple tools available; and (3) the rigorous statistical validation processes used.

Future studies will continue to use this model via quasi-experimental procedures using larger samples, more diverse populations, and expanding upon the technology utilized through implementation of AI for supply risk prediction, demand forecasting, and procurement. Comparative studies across industries can help gauge if the synergistic benefits provided in this study transfer to other industries/project management areas. It would also be important to examine how organizational culture and readiness for change would moderate the interventions carried out. Additionally, work on developing a maturity model for integrating strategic and digital procurement use based on the framework developed by Tetik et al. [19] would be another avenue worth exploring.

Conflicts of Interest

The authors declare no conflicts of interest.

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Author Contributions

M.A.G.M. and O.G.A.S. collected and analyzed the data. M.A.G.M. and O.G.A.S. prepared the first draft of the manuscript. J.A.R.G. supervised the research process and contributed to the methodology design and data collection.

J.C.Q.F. supervised the overall research process, reviewed and approved the methodology and model, and contributed to the writing, revision, and final approval of the manuscript. S.N. provided methodological support and guidance in model validation. All authors reviewed and approved the final manuscript.

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