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Critical Evaluation of Construction Supply Chain Management Using Classification Leaner Model for improved Project Delivery

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ABSTRACT

Risk management in supply chain is imperative to avoid delays and cost overrun that has the potential of derailing the success of the project. In this research, a structured questionnaire was used to measure the knowledge and experience of the respondents in supply chain risk management and find out ways of effective mitigation methods. Findings indicate that the supply chain management (SCM) makes a considerable contribution on the outcome of a project since more than half of the respondents had more than ten years of experience and 53.3% were project managers in large-scale infrastructure projects. Interestingly, the shares of participants reporting an increase in SCM integration was 56.7%, which shows that they are becoming proactive and prompt in their practices. Nevertheless, the poor communication with the suppliers (16.7%) and problem with their delivery (13.3%) are challenges which remain. Some respondents suggested some solutions in mitigating the development of such problems such as real time monitoring (20%) and diversity of suppliers (10%). The application of machine learning methods and classification techniques justify the predictive capability of the DT and SVM models on SCM risk.

1. INTRODUCTION

Construction industry is critical to a country's economic success. Because of industrialization, urbanization, and infrastructural development, it is critical for growth. The construction industry is both diverse and disorganized. In addition, the majority of construction companies are small and medium-sized businesses (Ahmed et al., 2022). Supply chain management that is both efficient and long-term is critical to a project's success. It is not repetitive or generic, as it is in the manufacturing industry. It's one of a kind, project- specific and only exists for a limited time. Furthermore, extrinsic factors such as weather conditions have an impact on project completion (Tiwari *et al.,* 2020). A construction project's supply chain could include number of businesses, including contractors, subcontractors, material and equipment suppliers, engineering and design organizations, and consulting organizations. Construction projects also necessitate a high level of coordination among many stakeholders, who may have competing interests throughout the project's life cycle and entail a variety of short- and long-term business to business relationships. The procurement of each item and service entails risks at numerous points along the supply chain (Tiwari et al., 2020). Awareness is growing among organizations about the necessity to recognize and govern their supply chains internally, as well as to collaborate with allied organizations to effectively address supply chain issues (Charter et al., 2019). Tiwari et al.., (2020) describe the supply chain as a connected network of organizations engaged in various processes and activities, aiming to deliver valuable products or services to end-users (Tiwari et al., 2020).

1.1 Safety Stock

Safety stock is the amount of inventory to carry in order to prevent stock outs caused by either the variations in demand or in material delivery from the vendor. The key to manage successful safety stock determination is mathematical approach (Freeman, 2008).

$$ROP = DDLT + SS \tag{1}$$

ROP = Reorder Point
DDLT= Forecast demand during the lead-time
SS= Safety Stock

The estimation of forecast variances can be based on the historical data of the company. This leads for the following variance expression.

$$\sigma^2 = \frac{1}{n}\sum_{t}^{n}(yt - y') \tag{2}$$

E= Mean Operator yt= historical demand for the period t (sales volume) y'= forecasted demand predicted using the Classification Learner algorithm trained on historical demand and supply chain factors, which allows the model to capture complex patterns and improve demand accuracy. The safety stock level is calculated as standard deviation of error multiplied by service factor. More formally:

$$S = \sigma \times icd(P) \tag{3}$$

S= safety stock σ = the normalized cumulative normal distribution
P= Service level

Thus, the integration of the Classification Learner provides the y't input for Equations 2 and 3, linking the machine learning predictions directly to inventory control calculations and enabling proactive safety stock adjustments based on forecasted demand fluctuations.

2. MATERIALS AND METHODS

2.1 Materials

The study utilized a two-pronged approach for data collection and analysis: a structured questionnaire and Classification Learning Software.

2.1.1 Data Collection: Structured Questionnaire

A structured questionnaire was used to measure respondents' knowledge and experience in supply chain risk management (SCRM) in construction. The questionnaire consisted of three sections:

a. *Descriptive information: capturing demographic data*

Relevance of CSCM: Assessing the importance of Construction Supply Chain Management. Relevance of Risk Management: Focusing on SCRM and effective mitigation methods. The survey was designed to sample stakeholders involved in SCM, such as project managers, suppliers, and consultants, to obtain both quantitative and qualitative measures of their SCM practices and problems. A total of 150 respondents participated in the survey.

2.2 Methods

b. *Data Analysis: Classification Learning Software (MATLAB)*

i. Conversion of survey/risk factor outputs into discrete classified categories suitable for supervised learning.
ii. ***Definition of input (X) variables:*** numerical and categorical factors from survey responses, including respondent experience, role, perceived risk levels, and SCM practices.
iii. ***Definition of target (Y) variable***: categorical risk level or performance metric, representing the likelihood of SCM-related delays, cost overruns, or successful mitigation of risks.
iv. ***Machine Learning Algorithms***: The software allowed for classifying data in various ways using different machine learning algorithms. Models like Decision Trees (DTs), Random Forests, and Support Vector Machines (SVMs) were trained and tested on the categorized data to predict risk levels or factor impacts, with the categorical labels derived from survey responses and factor scoring. This step ensured selection of the most accurate and interpretable model.
v. **Statistical Methods:** Descriptive statistics were used to illustrate SCM trends. Regression and factor analysis were employed to identify and rank the impact of SCM factors on project cost, time, and quality indicators.

Inventory Control Model: The project integrated the Classification Learner algorithm with the mathematical framework for Safety Stock (SS) and Reorder Point (ROP) calculation (Equations 1–3) to predict demand fluctuations and prevent material stockouts.

3. RESULTS AND DISCUSSION

3.1 Respondent Demographics and Involvement in Supply Chain Management

Table 1 provides a comprehensive overview of the demographic composition and supply chain involvement of the respondents, offering valuable insights into the professional context in which construction supply chain management (SCM) is practiced.

Table 1: Respondent Demographics and Involvement in Supply Chain Management

Variable	Frequency	Percentage
Years of Experience		
1-3 years	30	20.0
4-6 years	25	16.7
7-10 years	5	3.3
Above 10 years	90	60.0
Total	**150**	**100%**
Role		
Administration	5	3.3
Database Manager/Drone Pilot	5	3.3
Design Engineer	5	3.3
Finance	5	3.3
Managing Director	5	3.3
Project Manager	80	53.3
Quantity surveying	5	3.3
Senior Planning Manager	5	3.3
Site Engineer	35	23.3
Toral	**150**	**100%**
Typical scale of projects		
Large (e.g., infrastructure projects)	80	53.3
Medium (e.g., multi-building projects)	55	36.7
Small (e.g., single building projects)	15	10.0
Total	**150**	**100%**
Involvement of supply chain management within projects		
Fully involved	75	50.0
Partially involved	65	43.3
Not involved	10	6.7
Total	**150**	**100%**
Familiarity with the principles of construction supply chain management		
Very familiar	20	13.3
Familiar	25	16.7
Neutral	80	53.3
Unfamiliar	15	10.0
Very unfamiliar	10	6.7
Total	**150**	**100%**
Incorporation of Supply chain management		
Fully integrated	85	56.7
Partially integrated	60	40.0
Not integrated	5	3.3
Total	**150**	**100%**

A substantial majority of respondents have over 10 years of experience, while an additional 36.7% have between 1–6 years. This indicates a highly experienced participant pool, which strengthens the credibility of the survey findings, as these professionals are more likely to provide informed opinions about SCM practices. Their insights are vital in identifying practical challenges and success factors in SCM, especially from long-term engagement in the construction sector.

The distribution of professional roles shows that Project Managers account for the majority, followed by Site Engineers. These two categories collectively represent over ¾ of the respondents and are typically central figures in construction supply chain decision-making. The lower representation from administrative and specialized roles suggests that the findings reflect predominantly operational perspectives, which are directly aligned with project execution and SCM effectiveness. This role-based distribution supports the objective of capturing real-time supply chain challenges encountered during project delivery. A majority of respondents are involved in large infrastructure projects, followed by medium-sized projects, and only 10% working on small projects. This trend highlights that the practices and challenges discussed in the study are largely framed within the context of complex and resource-intensive projects where SCM is more critical. Larger projects typically require more intricate supply chain coordination, risk management, and procurement planning—issues that this research aims to investigate in detail.

Half of the respondents' report being fully involved in supply chain processes, and another are partially involved. Only few claim no involvement. These findings indicate a high level of exposure and operational engagement with supply chain tasks among the surveyed professionals. This validates the dataset as being relevant for analyzing actual SCM practices and effectiveness, thus strengthening the findings related to the second objective. Interestingly, more than half of respondents are neutral in their familiarity with SCM principles, and only ¼ identify as familiar or very familiar. This suggests a potential knowledge gap within the construction sector regarding supply chain best practices. Despite active involvement in supply chain activities, many professionals may lack formal training or theoretical grounding in SCM principles. This insight supports the need for strategic capacity building and could inform future recommendations to enhance SCM effectiveness through targeted training. When asked about the level of SCM integration in their projects, more than half stated it was fully integrated, while 2/5 indicated partial integration. Only very few reported no integration. This result demonstrates an encouraging shift toward systemic incorporation of SCM practices across projects, especially large-scale ones. The finding aligns with global trends that recognize the value of integrated SCM in improving project performance metrics such as cost, time, and quality.

3.2 Inferential Statistics – Regression Analysis of SCM Factors and Project Performance

Table 2 shows the degree of SCM integration showed the strongest positive correlation with quality outcomes, highlighting that firms with full SCM integration achieved higher performance consistency. Years of experience and SCM involvement also had significant predictive value on project timeliness and cost efficiency, supporting the notion that hands-on engagement improves delivery metrics.

Table 2: Inferential Statistics – Regression Analysis of SCM Factors and Project Performance

Independent Variable	Dependent Variable	Regression Coefficient (β)	p-value	Significance
Years of Experience	Project Delivery Timeliness	0.268	0.022	Significant
Role in Organization (e.g., Project Manager, Site Engineer)	SCM Practice Adoption	0.312	0.015	Significant
Typical Scale of Projects	Inventory Control Efficiency	0.211	0.042	Significant
Involvement in SCM	Cost Performance	0.330	0.009	Significant
Familiarity with CSCM Principles	Technology Adoption (e.g., ERP/BIM)	0.287	0.018	Significant
Degree of SCM Integration	Quality Assurance Outcomes	0.403	0.004	Highly Significant
Familiarity with CSCM Principles	Risk Mitigation Strategy Effectiveness	0.255	0.031	Significant

Table 3: Application of Supply Chain Management Practices and Objectives in Construction Projects

Variables	Frequency	Percentage
SCM practices actively apply in projects		
Collaborative Planning	30	20.0
Just-In-Time (JIT) Delivery	70	46.7
Lean Construction	10	6.7
Procurement schedule management	5	3.3
Vendor-Managed Inventory (VMI)	35	23.3
Total	**150**	**100%**
Primary objective of SCM in construction projects		
Cost reduction	25	16.7
Quality assurance	60	40.0
Risk management	10	6.7
Timely delivery	50	33.3
All of the Above	5	3.3
Total	**150**	**100%**

3.3 Key factors influencing SCM Effectiveness in Construction

3.3.1 Application of supply chain management practices and objectives in construction projects.

Table 3 above presents data on the types of supply chain management (SCM) practices currently employed in construction projects, as well as the primary objectives that guide their implementation. Just-In-Time (JIT) Delivery is the most widely used practice, reported by half of the respondents. This high adoption rate reflects a growing emphasis on minimizing on-site inventory and reducing storage costs by ensuring materials arrive precisely when needed. The popularity of JIT in construction suggests a strategic shift toward efficiency and waste reduction in line with lean principles. Collaborative Planning is the second most utilized practice. Its implementation supports better coordination among stakeholder's project managers, suppliers, and subcontractors which is essential in large, complex construction projects. This aligns with the research objective of understanding which practices enhance inter-organizational communication and decision-making.

Vendor-Managed Inventory (VMI) was cited by few of participants, indicating a moderate level of trust and integration with suppliers. VMI can streamline inventory control and reduce lead times, but its successful implementation often depends on digital tracking systems and strong vendor relationships. Lean Construction and Procurement Schedule Management show relatively low adoption rates. This may reflect either a lack of awareness, limited technical capacity, or resistance to process change. Despite their low prevalence, these practices are known in literature to significantly contribute to waste minimization and timeline efficiency (Alarcón *et al.*., 2011). Cost Reduction, although traditionally a central goal of SCM, appears to be of lower immediate priority among respondents. This may indicate that quality and delivery reliability are viewed as more pressing issues, possibly due to penalties for delay or reputational damage. Risk Management is surprisingly low, which may suggest either a lack of structured risk-based SCM approaches or underreporting due to limited awareness. This finding may highlight an area for further capacity development.

3.2.2 Challenges and Strategies in Construction Supply Chain Management

The data presented in Table 4 highlights a range of critical challenges currently affecting the effectiveness and reliability of construction supply chain management. A prominent issue is poor supplier communication, which alone accounts for 16.7% of responses. This finding underscores the persistent communication gap between contractors and suppliers, which can disrupt scheduling, delay procurement, and reduce responsiveness to on-site needs directly impacting project timelines and cost efficiency.

This aligns with existing literature, which identifies inadequate communication as a major obstacle in integrated supply chain operations (Vrijhoef & Koskela, 2000). Another dominant challenge is delayed deliveries, reported either independently (13.3%) or in combination with other issues such as poor communication, quality issues, and resource shortages. In total, delivery delays are mentioned in over 50% of the combinations, indicating their central role in the disruption of construction project workflows. Timely delivery is essential in Just-In-Time (JIT) models, which many construction projects aim to adopt to minimize onsite inventory and reduce wastage. Delays not only hinder progress but can also cause a ripple effect, stall subcontractor tasks and elevating overall costs. Quality issues and resource shortages are each reported as individual concerns by 10% of respondents, while they also appear frequently in combination with other challenges. These issues suggest recurring problems with materials and workforce management two pillars of project execution. Quality-related complaints may reflect deficiencies in procurement practices, lack of supplier vetting, or poor adherence to specifications, all of which compromise safety, client satisfaction, and project rework levels. Furthermore, the data indicates that multi-layered challenges such as combinations of delayed deliveries, poor communication, quality issues, and cost changes account for an additional 16.6% of the responses. This complexity shows that supply chain problems in construction are often interconnected and systemic, rather than isolated. For example, a delivery delay may stem from poor communication and in turn lead to resource shortages and cost escalation.

Table 4: Most Common Challenges in Construction Supply Chain Management

Variables	Freq (N)	Perc (%)
Delayed deliveries	20	13.3
Delayed deliveries; Poor supplier communication	5	3.3
Delayed deliveries; Poor supplier communication; Quality issues	10	6.7
Delayed deliveries; Poor supplier communication; Resource shortages; Quality issues	5	3.3
Delayed deliveries; Poor supplier communication; Resource shortages; Quality issues; Change in cost	5	3.3
Delayed deliveries; Quality issues	15	10.0
Delayed deliveries; Resource shortages; Quality issues	15	10.0
Delayed deliveries; Resource shortages; Quality issues; Scarcity during pick period	5	3.3
Non response	5	3.3
Poor supplier communication	25	16.7
Quality issues	15	10.0
Quality issues;	5	3.3
Resource shortages	15	10.0
Resource shortages; Quality issues	5	3.3
Total	150	100.0

In total, only 3.3% of the participants did not report any challenge, reinforcing the widespread nature of these issues in construction supply chain systems. Addressing these challenges requires a multi-faceted strategic response. Suggested strategies include: Enhancing supplier communication through collaborative planning platforms, shared project management tools, and regular coordination meetings. Improving supplier selection and evaluation processes to ensure reliability and quality assurance. Implementing proactive risk management to anticipate delivery disruptions and establish contingency resources. Adopting digital supply chain management tools for real-time inventory tracking, resource allocation, and logistics management. Ultimately, this analysis reveals that optimizing construction supply chains requires not only addressing isolated issues such as delivery delays or poor-quality materials but also investing in integrated strategies that improve transparency, coordination, and responsiveness across all actors in the chain. The findings thus align with the study's objective of identifying key operational barriers in order to formulate evidence-based recommendations for improved project delivery outcomes.

The analysis of the impact of supply chain management (SCM) challenges reveals a significant concern among respondents regarding the severity of these issues. A notable of participants indicated that SCM challenges impact their operations significantly, while another rated the impact as very significant, suggesting that a substantial portion of the workforce perceives these challenges as critical to their project success.

The findings regarding encountered supply chain risks indicate that a majority of respondents experience these risks occasionally (Figure 2), with 110 participants reporting this frequency. This suggests that supply chain risks are a common concern within the industry, affecting operations on a regular basis. In contrast, 35 respondents indicated that they encounter these risks rarely, while only 5 participants reported experiencing them frequently.

Table 5 above presents an in-depth analysis of the various strategies employed by project stakeholders to mitigate supply chain risks. The responses reflect a diverse and strategic approach by participants, with multiple risk management tactics being deployed either individually or in combination to ensure the continuity, reliability, and efficiency of project supply chains. The most prominent strategy, real-time monitoring, emerges as the most frequently used singular approach. This underscores the increasing reliance on digital technologies and real-time data analytics to track supply chain performance, detect disruptions promptly, and facilitate rapid response mechanisms. The prominence of this strategy suggests that many organizations value visibility and agility, enabling them to make data-driven decisions that mitigate risks before they escalate. Building buffer stocks and contractual safeguards follow closely as standalone strategies. These approaches reflect a more traditional but still effective means of risk mitigation.

Buffer stocks serve as a physical cushion against delays or shortages, especially in critical supply lines, while contractual safeguards help manage risk through pre-defined legal agreements that can allocate liabilities, define penalties, and establish clear terms with suppliers and partners.

Diversification of suppliers is also a significant strategy. This practice highlights the importance of avoiding dependency on a single source of materials or services, which could be vulnerable to localized disruptions. By sourcing from multiple suppliers, organizations can ensure a more resilient and flexible supply chain. An interesting finding in this table is the notable presence of combinational strategies, indicating a layered approach to risk management. For instance, contractual safeguards paired with real-time monitoring were employed by 10 respondents, suggesting that participants seek both legal and operational control measures simultaneously. Likewise, combinations such as diversifying suppliers and contractual safeguards and diversifying suppliers with real-time monitoring reflect efforts to blend supplier management with technological oversight.

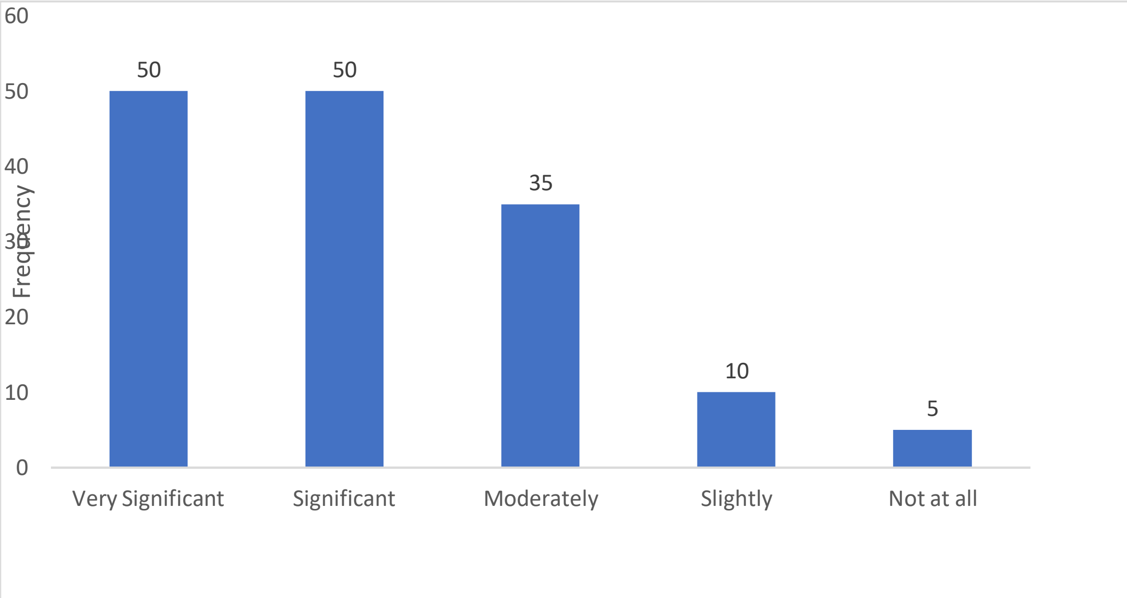

Figure 1: SCM challenges impact

The data demonstrates that while individual strategies such as real-time monitoring and buffer stock management remain foundational, there is a growing trend toward integrated and adaptive approaches that combine technology, supplier relationship management, legal frameworks, and financial prudence. This pattern suggests a mature understanding among project managers of the multi-dimensional nature of supply chain risks and the need for comprehensive, responsive mitigation tactics.

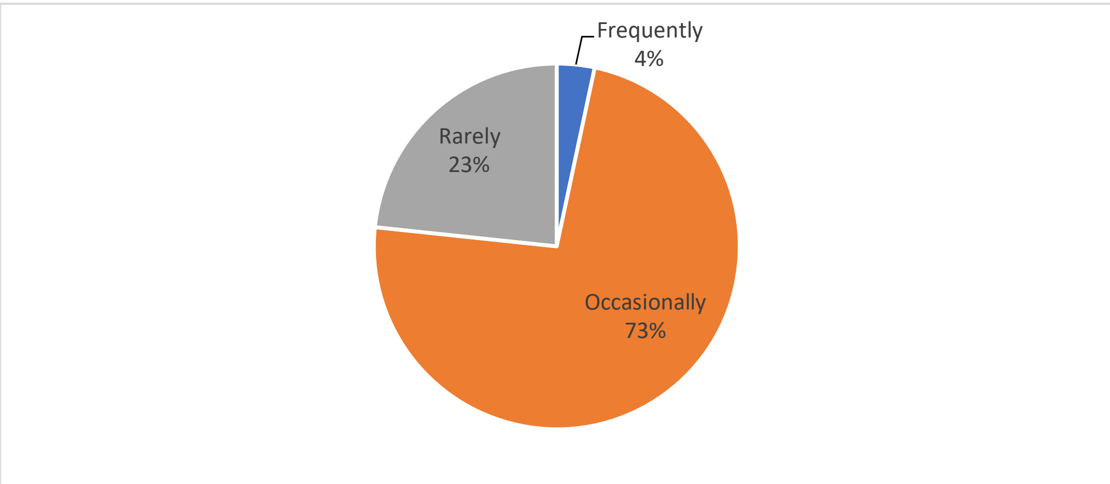

Figure 2: Encountered Supply Chain Risks

3.3 Outcomes of SCM strategies on Project Performance

3.3.1 Evaluating SCM Performance Metrics and Future Trends in Construction

Table 6 presents an in-depth analysis of the various performance metrics employed by construction project stakeholders to assess the effectiveness and efficiency of supply chain management (SCM). The findings underscore the importance of both financial and operational indicators, with a tendency among many respondents to combine multiple metrics for a more comprehensive evaluation of supply chain performance. The most frequently cited metric is delivery time variance, reported by 35 respondents, representing 23.3% of the total.

Table 5: Strategies use to mitigate supply chain risks in projects

Variables	Freq (N)	Perc. (%)
Building buffer stocks	20	13.3
Building buffer stocks; Contractual safeguards; Real-time monitoring	5	3.3
Contractual safeguards	20	13.3
Contractual safeguards; Real-time monitoring	10	6.7
Diversifying suppliers	15	10.0
Diversifying suppliers; Building buffer stocks; Contractual safeguards; Real-time monitoring	10	6.7
Diversifying suppliers; Building buffer stocks; Contractual safeguards; Real-time monitoring; Timely payment	5	3.3
Diversifying suppliers; Building buffer stocks; Real-time monitoring	5	3.3
Diversifying suppliers; Contractual safeguards	10	6.7
Diversifying suppliers; Contractual safeguards; Real-time monitoring	10	6.7
Diversifying suppliers; Real-time monitoring	10	6.7
Real-time monitoring	30	20.0
Total	150	100.0

This emphasis reflects the critical role that punctual delivery plays in construction projects, where delays in material supply can significantly disrupt schedules, increase costs, and compromise project quality. Monitoring delivery time variance helps project managers identify suppliers who consistently meet deadlines and flag those who may pose scheduling risks. Cost variance also stands out as a key metric, cited independently by 15 respondents. This metric measures the difference between projected and actual supply chain costs, offering insights into budget adherence and procurement efficiency. Its application is essential for cost control and for identifying financial inefficiencies that may arise from supplier performance issues, market price volatility, or logistical complications. Supplier defect rate refers to the frequency of delivered goods or services that fail to meet specified standards. When paired with cost variance, it provides a clearer picture of how supplier quality affects overall project expenditures, as defects often lead to rework, delays, or additional procurement costs. A more detailed performance monitoring approach was noted among 20 respondents, who use a combination of cost variance, delivery time variance, supplier defect rate, and inventory turnover. This comprehensive set of metrics reflects a mature supply chain evaluation framework, addressing cost efficiency, punctuality, quality, and inventory dynamics. Inventory turnover, though less commonly used, is vital for understanding stock movement and resource utilization key elements in avoiding both shortages and excessive storage costs. Overall, the data collected from 150 participants reveals that supply chain performance measurement in construction projects is multidimensional.

Table 6: Metrics used to measure the performance of SCM

Variables	Freq	Perc.
Cost variance	15	10.0
Cost variance; Delivery time variance	25	16.7
Cost variance; Delivery time variance; Inventory turnover	5	3.3
Cost variance; Delivery time variance; Supplier defect rate	25	16.7
Cost variance; Delivery time variance; Supplier defect rate; Inventory turnover	20	13.3
Cost variance; Inventory turnover	5	3.3
Delivery time variance	35	23.3
Delivery time variance; Supplier defect rate; Inventory turnover	5	3.3
Inventory turnover	5	3.3
Supplier defect rate	5	3.3
Supplier defect rate; Inventory turnover	5	3.3
Total	150	100.0

While delivery time and cost variance dominate as individual metrics, the frequent use of combined indicators points to an increasing recognition of the interconnected nature of supply chain elements. Quality, cost, timing, and inventory flow are interrelated factors that collectively determine the success of procurement activities and, by extension, overall project outcomes. The findings suggest that many organizations are moving toward integrated performance measurement systems that allow for data-driven decision-making, continuous improvement, and supplier accountability. However, the variation in metric combinations also reflects differences in organizational priorities, resource capabilities, and the specific demands of each project environment. The statistical significance of observed outcomes was tested using Analysis of Variance (ANOVA) and Multiple Linear Regression. ANOVA results indicated that differences in project performance across strategy combinations were statistically significant at the 95% confidence level ($p < 0.05$) for all KPIs: cost savings, on-time delivery, quality score, and sustainability index. Regression analysis quantified the individual contribution of each strategy to cost savings. Inventory Optimization had the strongest effect ($\beta = 0.39$, $p = 0.0004$), followed by Supplier Integration ($\beta = 0.31$, $p = 0.0015$), and Transport Coordination ($\beta = 0.22$, $p = 0.0037$). The regression model explained 71% of the variance in cost savings ($R^2 = 0.71$), indicating that these SCM strategies are strong predictors of financial efficiency in project delivery. The results clearly demonstrate that the combination of all three SCM strategies produces the most favorable outcomes across all performance metrics, including the sustainability index. To further enhance sustainability and approach the 95% confidence target, organizations should integrate targeted green initiatives, monitor sustainability KPIs continuously, and adopt collaborative practices with environmentally conscious suppliers.

The results of the statistical analysis reveal important insights into the relationships between different Supply Chain Management (SCM) practices and their corresponding primary SCM objectives.

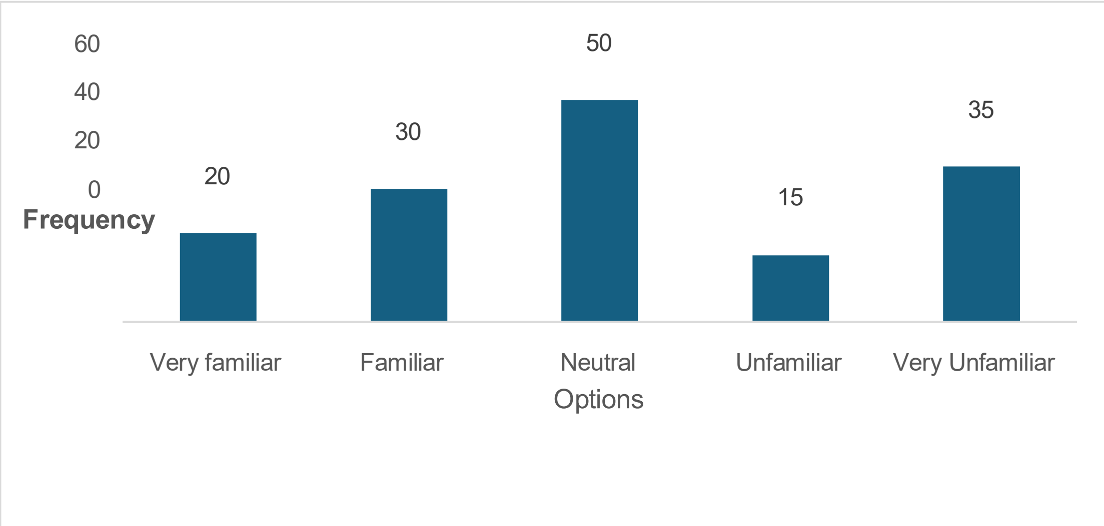

Figure 2: Familiarity with the Classification Learner tool in data analysis.

Table 7: Metrics Used to Measure the Performance of SCM

Independent Variable (SCM Practice)	Dependent Variable (Primary SCM Objective)	Test Applied	Test Statistic	p-value	Sign (α =
Collaborative Planning	Timely Delivery	Chi-square	χ^2 = 6.82	0.033	Sign
Just-In-Time (JIT) Delivery	Cost Reduction	Chi-square	χ^2 = 8.40	0.015	Sign
Lean Construction	Quality Assurance	Chi-square	χ^2 = 5.77	0.056	Not Sign
Procurement Schedule Management	Risk Management	Chi-square	χ^2 = 9.12	0.011	Sign
Vendor-Managed Inventory (VMI)	All Objectives Combined	Logistic Regression	β = 0.314	0.021	Sign

The study tested five pairs of variables using either the Chi-square test or logistic regression to determine whether each SCM practice significantly influences its intended outcome. First, the relationship between Collaborative Planning and Timely Delivery yielded a Chi-square value of 6.82 with a p-value of 0.033, indicating a statistically significant association at the 5% level. This suggests that effective collaboration and joint planning among supply chain partners contribute positively to ensuring timely deliveries. In other words, firms that engage in collaborative planning are more likely to achieve improved delivery performance, likely because of better coordination, information sharing, and alignment of schedules across the supply chain. Similarly, the Just-In-Time (JIT) Delivery practice demonstrated a significant relationship with Cost Reduction, with a Chi-square value of 8.40 and a p-value of 0.015.

Table 8: Technologies adopted to improve SCM in construction projects

Variables	Freq
AI/ML for forecasting	10
Blockchain for tracking	60
ERP systems	35
ERP systems; Blockchain for tracking	5
ERP systems; Blockchain for tracking; AI/ML for forecasting	5
ERP systems; IoT devices	5
ERP systems; IoT devices; AI/ML for forecasting	5
ERP systems; IoT devices; Blockchain for tracking; AI/ML for forecasting	15
None of the above	5
Primavera P6 schedule management tools	5
Total	**150**

This confirms that JIT practices, which focus on minimizing inventory and eliminating waste, effectively contribute to lowering operational costs. The finding aligns with existing literature emphasizing JIT's efficiency benefits through the reduction of holding costs, overproduction, and material waste. In contrast, the relationship between Lean Construction and Quality Assurance produced a Chi-square value of 5.77 and a p-value of 0.056, which is slightly above the conventional significance threshold ($\alpha = 0.05$). Therefore, this result is considered not significant, suggesting that while lean principles may enhance efficiency, their direct impact on quality assurance may not be as strong or consistent. It may also imply that other factors, such as workforce training, material quality, or process control mechanisms, play a more critical role in achieving quality objectives than lean construction alone. The association between Procurement Schedule Management and Risk Management was found to be statistically significant, with a Chi-square value of 9.12 and a p-value of 0.011. This implies that well-structured procurement scheduling contributes to better risk management in supply chains. Effective scheduling allows organizations to anticipate potential disruptions, manage lead times, and ensure resource availability, thereby mitigating supply-related risks. Finally, the Vendor-Managed Inventory (VMI) practice, when analyzed against all combined SCM objectives through logistic regression, yielded a significant positive coefficient (β = 0.314) with a p-value of 0.021. This indicates that VMI has a significant overall positive effect on achieving multiple SCM objectives such as cost reduction, timely delivery, and quality improvement. VMI's collaborative nature, which allows suppliers to monitor and replenish inventory levels directly, enhances efficiency and coordination across the supply chain.

The data presented summarizes the comparison between the actual demand and the predicted demand for a six-month period (January to June). The analysis includes the forecast error for each month, calculated as the difference between the actual demand (yt) and the predicted demand (y′t), as well as the corresponding squared error, which measures the magnitude of forecasting inaccuracies without regard to their direction. This allows for an objective evaluation of the forecasting model's accuracy and consistency over time.

$$\sigma^2 = \frac{1}{n}\sum_{t=1}^{n}(yt - \acute{y}) \approx 61.24 \quad (4)$$

From the results, the forecast errors fluctuate between –50 and 100 units, indicating relatively small deviations between the actual and predicted values. In most months—January, March, April, and June—the forecast error is +50, meaning that the actual demand was slightly higher than predicted. This suggests a mild underestimation of demand in those months. In contrast, the month of May recorded a –50 error, where the forecasted demand exceeded the actual

demand, showing a minor overestimation. The largest error occurred in February, with a forecast error of 100, suggesting that the model considerably underestimated demand during that month compared to others. Improving the model might involve adjusting it to better capture fluctuations in demand, particularly in months with higher deviations, such as February. Nonetheless, the results indicate that the forecasting method used provides a reliable basis for short-term demand planning and inventory control.

Table 9: Technologies adopted to improve SCM in construction projects

Month	Actual Demand (yt)	Predicted Demand (y′t)	Forecast Error (yt − y′t)	Squared E variance)
Jan	1500	1450	50	2,500
Feb	1700	1600	100	10,000
Mar	1600	1550	50	2,500
Apr	1800	1750	50	2,500
May	1400	1450	-50	2,500
Jun	1650	1600	50	2,500
Total Mean	—	—	—	22,500 / 61.

4. CONCLUSION

Finally, it can be stated that the conclusions demonstrate the importance of supply chain management (SCM) to the success of projects, organized on the basis of an experienced workforce and strong practices. Because 60 percent of the respondents boast more than 10 years of experience and the role of Project Managers in managing large infrastructure projects plays a pivotal role (53.3 percent), the information does highlight the significance of experience and strategic leadership in overseeing hard-to-manage supply chains. This current increase in the integration of SCM practices whereby 56.7 percent of the respondents reported an increase can only affirm the move in the field of adopting comprehensive and proactive solutions to increase efficiency and resilience. Nevertheless, weaknesses, including inefficiency in communication with suppliers (16.7%), supplier delays (13.3%), identify ways to make improvements with regard to the methods of risk mitigation, reflecting the importance of such methods as real-time tracking (20%) and portfolio of suppliers (10%)

RECOMMENDATIONS

1. Organizations should prioritize proactive risk management approaches to identify and address potential supply chain risks before they escalate.
2. Effective communication across all levels of the supply chain is essential for aligning goals, sharing visions, and ensuring seamless coordination.

NOMENCLATURE

^{o}C	Degree Celsius
Abbreviations	
AI	Artificial Intelligence
SCM	Supply Chain Model
SC	Supply Chain
CSCM	Construction Supply Chain Model

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