Development of Barriers and Strategies for Implementing Lean Supply Chain Management in Coastal Wall Construction Projects

Arif Luqman Hakim
Department of Civil Engineering, Hasanuddin University, Gowa, Indonesia
arifluqmanhakim@gmail.com

Rosmariani Arifuddin
Department of Civil Engineering, Hasanuddin University, Gowa, Indonesia
rosmarianiarifuddin@unhas.ac.id (corresponding author)

M. Asad Abdurrahman
Department of Civil Engineering, Hasanuddin University, Gowa, Indonesia
asad@unhas.ac.id

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ABSTRACT

The demand for efficient implementation of construction projects is a significant challenge. This demand reflects the limited project resources, which encourage innovation in developing lean systems. One example of such innovation is the integration of lean construction management and Supply Chain Management (SCM), known as Lean Supply Chain Management (LSCM), which aims to improve time and cost efficiency in various construction projects. Unfortunately, the implementation of LSCM often encounters obstacles during construction. Therefore, this research aims to identify and analyze the stages of the LSCM cycle, the main obstacles encountered, and strategies for improving LSCM implementation in foundation work for coastal protection projects. To achieve these objectives, the research method begins with a literature review, followed by case studies, perception questionnaires, and in-depth interviews, which are then analyzed using the Relative Importance Index (RII) method. The results indicate that the primary obstacles include product returns from customers, materials received that do not match the requested specifications, occupational health and safety risks, suppliers failing to fulfill material delivery commitments, and changes in orders or requests. The implementation of LSCM strategies, such as Kaizen, Value Stream Mapping (VSM), Pull System, and 5S (Sort, Arrange, Clean, Standardize, and Maintain), effectively reduces delays and minimizes waste in procurement. This study's results act as a guide for all parties, which contributes to improving the performance of supply chain integration and lean principles in construction projects.

Keywords-Lean Supply Chain Management (LSCM); coastal wall; construction project

I. INTRODUCTION

The construction industry is inefficient [1]. Many construction activities add no value and cause waste, such as waiting, unnecessary movement, and poor inventory management [2]. The industry is also highly fragmented, project-based, and slow in technology adoption—this lack of integration results directly in inefficiency, project delays, and cost overruns. Consequently, sustainable SCM is a strategy used to mitigate these issues. Effective SCM integration requires fulfilling five key requirements: low cost, easy installation, customizable information access, compatibility with external systems, and simple connectivity [3].

Lean construction was introduced to increase customer value by reducing waste and improving process flow [4]. The lean concept is an efficient philosophy for production systems, as its tools control waste and anticipated uncertainties [5]. Although the concept is applied on-site, modern construction faces challenges due to its fragmented supply chain, involving many parties whose complexity increases the risks of delays and higher costs [6].

To address this fragmentation, the concept of lean construction was broadened into LSCM. The efficiency of information systems moderates the effect of lean supply chain on supply chain performance and firm performance [7]. This highlights the need to strike a balance between physical material efficiency and information efficiency to achieve optimal performance [7].

SCM is a vital component in the success of a project. It has been integrated with a more environmentally friendly approach and utilizes resources involving multiple organizations [8]. In addition, enhancing synergy and effectiveness in the construction industry supply chain is also very significant [9, 10], especially in the context of the lean construction philosophy. Furthermore, the core lean philosophy, which focuses on waste reduction, must be applied to every step of SCM. Waste in the construction supply chain often manifests as waiting (waiting for materials), inventory (excess stock), and overprocessing (excessive coordination). The lean supply chain concept strategically targets this waste, aiming to reduce operational costs and enhance performance [11]. One of the critical issues in the supply chain concerns the impact of delays on inventory levels and demand fulfillment.

The success of LSCM relies on the interactions between partners. Supply chain collaboration has a verified positive impact on SCM performance, acting as an effective risk mitigation tool. In construction, this collaboration is crucial for managing uncertainties in delivery, quality, and changing orders that often result in cost overruns and delays. The integration of Lean principles into SCM is an essential solution, defined as LSCM. The latter aims to create a responsive, Just-in-Time (JIT) supply chain with minimal inventory. This is achieved through close collaboration and coordination among partners. However, implementation in developing countries presents obstacles. Specifically, large-scale infrastructure projects, such as embankment construction, often face challenges like a lack of standardization and low adoption of digital technology [12].

Although it has been confirmed that LSCM is a crucial solution, its implementation in developing countries—particularly in large-scale infrastructure and maritime projects—remains under-examined empirically. There is a significant knowledge gap regarding how lean principles can be effectively integrated into the supply chains of projects that face logistical challenges, such as coastal locations, massive material volumes, and limited digitalization. Moreover, few studies have quantitatively ranked the dominant barriers to LSCM in the Indonesian context, which hinders the development of targeted improvement strategies.

To address this gap, the present study focuses on the Coastal Protection Dike Construction Project (Phase-A Location 1 Package 2) of National Capital Integrated Coastal Development (NCICD) program in Indonesia. Using this project as a case study, the study aims to: i) identify the stages and processes of LSCM integration in coastal infrastructure projects; ii) rank the dominant barriers to LSCM implementation; and iii) formulate effective improvement strategies to optimize LSCM adoption.

The key distinction of this study from previous LSCM research lies in its specificity: prior studies have addressed LSCM broadly across construction projects, whereas this research focuses specifically on a coastal wall construction project, with particular attention to the supply chain of spun pile procurement. The findings contribute scientifically by enriching empirical evidence of LSCM in maritime infrastructure projects in Indonesia, while providing practical guidance for stakeholders to enhance sustainable supply chain efficiency.

II. RESEARCH METHODOLOGY

This research was conducted using a combination of qualitative and quantitative approaches through a series of systematic stages, beginning with problem identification and formulation to determine the study's focus. Figure 1 shows the research flow diagram for LSCM implementation.

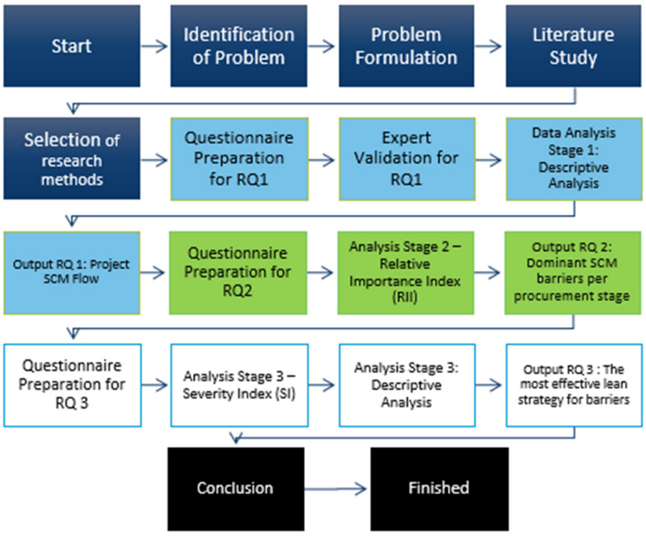

Fig. 1. Research flow diagram for LSCM implementation.

A. *Research Design*

This research employs a descriptive quantitative approach, utilizing a case study method. The quantitative approach is used to measure and rank the relative importance of waste and inhibiting factors. The case study focuses on the NCICD Coastal Protection Dike Construction Project (Phase-A Location 1 Package 2), providing an in-depth contextual analysis of the LSCM phenomenon in a large infrastructure project.

B. *Population and Sample*

The research population comprises all personnel directly involved in SCM and project operations at the case study project. The research sample includes experts selected using purposive sampling techniques. This technique was chosen to ensure that the respondents possess adequate knowledge, expertise, and experience related to logistics, procurement, and construction implementation. The respondents include individuals holding strategic and operational roles such as Project Managers, Procurement/Logistics Managers, Site Engineers, Field Supervisors, and other technical and administrative personnel.

A total of 32 respondents participated in this study, selected based on their direct involvement in the NCICD Phase-A

Coastal Protection Project (Location 1, Package 2). The respondents were chosen through structured questionnaires that utilized a Likert scale to capture accurate and measurable perceptions regarding the research variables.

The sampling justification is based on the principle that personnel with substantial exposure to construction operations and supply chain processes are best equipped to provide reliable data. Therefore, purposive sampling is considered appropriate because the selected respondents represent various levels of education (bachelor's degree and master's degree), job positions (ranging from managers to technical and administrative staff), and diverse work experience (from 3 years to more than 15 years). This variation ensures that the data collected reflect an understanding of the operational conditions and challenges within the project's supply chain ecosystem.

C. Instruments and Measurement Scales

Primary data were collected through structured questionnaires. The questionnaires were designed for two main purposes:

- Identification and Frequency of Barriers: Respondents were asked to assess the frequency or level of barriers encountered in the spun pile procurement process.
- Identification of LSCM Implementation: From the results of the respondents' questionnaires, a subsequent analysis was conducted regarding efforts to address each barrier encountered in the procurement of spun piles using the LSCM approach.

To measure the level of barriers that arise at each stage of SCM in the procurement of spun piles, a Likert scale was used, as presented in Table I, with values ranging from 1 to 5, corresponding to 'strongly disagree' and 'strongly agree'.

TABLE I. LIKERT SCALE

No	Level of agreement	Score
1	Strongly disagree	1
2	Disagree	2
3	Neutral	3
4	Agree	4
5	Strongly agree	5

D. Data Analysis Techniques

Data were obtained from the questionnaire results, which were then analyzed using the RII method. The latter is utilized to rank the types of barriers identified based on the respondents' assessments. It also enables researchers to identify the primary barriers in the spun pile procurement stages.

The RII formula is:

$$RII = \frac{\Sigma W}{A \times N} \quad (1)$$

where W denotes the weight given by each respondent for a variable, A denotes the maximum weight value on the scale, and N represents the total number of respondents.

The RII values range from 0 to 1. The higher the RII value, the higher the level of the obstacle variable as per the respondents. The RII calculation results are then ranked from the highest to the lowest to determine the order of priority.

After obtaining the RII ranking, qualitative descriptive analysis is used to discuss and interpret the implications of the ranking, relate it to the actual conditions of the project (case study), and formulate recommendations for the appropriate LSCM implementation strategy.

III. RESULTS

A. Stages of Spun Pile Procurement

The spun pile embankment construction in the Ancol Barat – Seafront Segment is a major item of work, accounting for 59.55% of the total work, where one of its components is the procurement of spun piles (diameter D = 1200 mm, thickness t = 150 mm, length L = 24 m, K600 cement type 5, including CT schedule 80 steel connectors), which involves the process of acquisition from production at the factory to delivery of the product to the construction site. This process is carried out in accordance with the required technical specifications and ensures readiness for the next processes. The stages of the spun pile procurement process are:

1) Preliminaries

- Job Safety Analysis
- Submissions of approval for spun pile columns, including drawings, specifications, and brochures, to the project director and consultant for approval.

2) Execution

- Once approved, the spun piles are ordered from the vendor selected by the executing contractor according to the approval.
- The vendor produces spun piles at the factory according to the approved specifications and the agreed schedule
- Spun piles from the factory are transported using a flat-bed truck to the work site
- Spun piles are placed in a temporary stacking area at the stockyard near the work site before being taken to the work site

3) Finished

Gradually, the spun piles were transported to the installation site, where they were driven according to the requirements.

B. Analysis of Barriers in the Procurement Process of Spun Piles

To analyze the barriers in the procurement process of spun piles, a literature review was conducted to collect data and identify the barriers that occur in the construction stages. This review involved by reviewing books, journals, previous research, and reports related to the study. The barrier variables are presented in Table II.

TABLE II. BARRIERS IN THE PROCUREMENT PROCESS OF SPUN PILES

Variable	Sub-variable	Code	Indicator	Reference
X.1. Plan	Supply, demand, and production	X.1.1.1	Demand prediction due to inaccurate sales forecast	[13]
		X.1.1.2	Order or request changes	
	Production planning	X.1.2.1	Procurement of materials that has not yet been realized	
		X.1.2.2	Limited production personnel	
		X.1.2.3	Weak planning and preparation before production	
		X.1.2.4	Mismatch between existing factory stock and production demand	
X.2. Source	Procurement of materials	X.2.1.1	Decrease in production capacity of several vendors	
		X.2.1.2	Supplier performance evaluation is not update	
	Testing of materials	X.2.2.1	Materials received do not match the request	
	Inspection of materials	X.2.3.1	Defective production during manufacturing	
	Acceptance of materials	X.2.4.1	Supplier not fulfilling material delivery commitments	
X.3. Make	Production process	X.3.1.1	Disruption in the centrifugal process	
		X.3.1.2	Occupational Health and Safety (OHS) risk	
		X.3.1.3	Lack of concrete casting equipment	
		X.3.1.4	Unskilled workforce	
		X.3.1.5	Stock discrepancies	
		X.3.1.6	Low workforce productivity	
		X.3.1.7	Damage to printing machines	
	Handling and management of production results	X.3.2.1	The quality of production results does not meet standards	
		X.3.2.2	Land lease permit has expired	
		X.3.2.3	Errors occur when existing products are stacked	
X.4. Deliver	Shipping and after-sales service	X.4.1.1	Unavailability of transportation facilities for delivery	
		X.4.1.2	Delay of products reaching the customer	
		X.4.1.3	Uncertainty of the delivery date for transported products	
	Invoice management	X.4.2.1	Delivery delays due to payment issues with the supplier	
X.5. Return	Product returns due to non-compliance	X.5.1.1	The material received does not match the request	
		X.5.1.2	Product returned by the customer	

TABLE III. RII ANALYSIS RESULTS

Code	Sub-variable	RII Score	Rank
X.5.1.2	Product returned by the customer	0.788	1
X.5.1.1	The material received does not match the request	0.756	2
X.3.1.2	OHS risk	0.725	3
X.2.4.1	Supplier not fulfilling material delivery commitments	0.700	4
X.1.1.2	Order or request changes	0.694	5
X.4.1.2	Delay of products reaching the customer	0.694	5
X.3.1.1	Disruption in the centrifugal process	0.688	7
X.4.1.3	Uncertainty of the delivery date for transported products	0.688	7
X.2.1.1	Decrease in production capacity of several vendors	0.681	9
X.2.3.1	Defective production during manufacturing	0.675	10
X.3.1.7	Damage to printing machines	0.669	11
X.3.1.5	Stock discrepancies	0.663	12
X.1.1.1	Demand prediction due to inaccurate sales forecast	0.656	13
X.2.2.1	Materials received do not match the request	0.656	13
X.4.2.1	Delivery delays due to payment issues with the supplier	0.656	13
X.1.2.3	Weak planning and preparation before production	0.650	16
X.1.3.1	Sudden changes in production plans	0.650	16
X.2.1.2	Supplier performance evaluation is not update	0.650	16
X.3.2.1	The quality of production results does not meet standards	0.650	16
X.3.1.6	Low workforce productivity	0.631	20
X.1.2.1	Procurement of materials that has not yet been realized	0.625	21
X.1.2.4	Mismatch between existing factory stock and production demand	0.625	21
X.3.1.3	Lack of concrete casting equipment	0.606	23
X.1.2.2	Limited production personnel	0.600	24
X.4.1.1	Unavailability of transportation facilities for delivery	0.600	24
X.3.1.4	Unskilled workforce	0.594	26
X.3.2.3	Errors occur when existing products are stacked	0.575	27
X.3.2.2	Land lease permit has expired	0.544	28
X.4.1.2	Delay of products reaching the customer	0.694	5

C. Analysis of Handling Efforts Using the LSCM Approach

Attempts to address barriers are developed based on the LSCM principles, focusing on eliminating non-value-added waste in the supply chain. This analysis begins by determining the relative importance of each barrier using the RII method, followed by the preparation of an LSCM solution matrix. Before proceeding to the RII analysis, a reliability test was conducted to ensure the internal consistency of the questionnaire items. The Cronbach's Alpha value of 0.987 indicates excellent reliability, confirming that all 28 items are suitable for further analysis.

RII analysis is used to rank barriers based on respondents' perceptions of them. To provide a more precise understanding, the RII calculation results rank the barriers from the highest to the lowest, as portrayed in Table III.

Table III shows that X.5.1.2 (Product returned by the customer) has the highest RII value (0.788), followed by X.5.1.1 (Material received does not match the request), with an RII of 0.756, and X.3.1.2 (Occupational health and safety risk), with an RII of 0.725. Subsequent barriers include X.2.4.1 (Supplier not fulfilling delivery commitments) (0.700), X.1.1.2 (Order or request changes), and X.4.1.2 (Delay of products reaching the customer), both at 0.694, followed by X.3.1.1 and X.4.1.3 (0.688). The remaining barriers are listed in descending order of RII scores, as evidenced in Table III.

The results of the RII analysis indicate that product returns (X.5.1.2) are the most critical barrier in LSCM implementation, followed by material mismatches and occupational health and safety risks. A deeper examination suggests that product returns occur more frequently in coastal projects due to several factors. These projects often involve longer transportation routes, which increase the risk of damage during delivery. Additionally, exposure to high humidity, saltwater, and variable weather conditions can compromise product quality, leading to a higher frequency of customer returns. Material mismatches (X.5.1.1) may also be exacerbated in these settings by limited local supplier options and variations in material standards, making accurate fulfillment more challenging. Furthermore, delays in delivery (X.4.1.2) and supplier non-compliance (X.2.4.1) are likely compounded by logistical constraints typical of coastal areas, such as port handling, access roads, and inter-island shipping schedules. These factors collectively explain why specific barriers, particularly those related to product quality and delivery, show higher RII values in coastal projects, highlighting the need for targeted supply chain interventions, such as enhanced packaging, supplier selection, and transportation planning.

D. Relationship between Barriers, LSCM Waste, and Handling Efforts

Attempts to address barriers are developed based on the identification of non-value-added waste in the supply chain. Table IV presents the correlation between 28 identified barriers, the relevant types of LSCM waste, and proposed handling efforts oriented toward lean principles (eliminating waste).

TABLE IV. ANALYSIS OF HANDLING ATTEMPTS AND THE LSCM APPROACH

Code	Sub-variable	Proposed lean principles	Mitigation explanation
X.5.1.2	Product returned by the customer	First-Time Quality (Jidoka) and Kaizen	Overcoming waste Defect and Extra-Processing (Rework). Focusing on improving the root causes of production processes and quality (Kaizen) so that the products are not returned [14].
X.5.1.1	The material received does not match the request	Supplier Partnership and Input Standardization	Overcoming waste, defects, and waiting. Building partnerships with suppliers and establishing unambiguous input specifications to ensure that materials are of the right quality (Right First Time) [15].
X.3.1.2	Occupational health and safety risk (OHS)	5S (Seiri, Seiton, Seiso, Seiketsu, Shitsuke) and Standard Work	Overcoming waste Non-Utilized Talent and Motion. Creating a safe, orderly work environment (5S) with standard procedures (Standard Work) to prevent incidents and production disruptions [16].
X.2.4.1	Supplier not fulfilling material delivery commitments	JJIT and Vendor Managed Inventory (VMI)	Overcoming waste from Waiting and potential Inventory (excess stock as a buffer). Building a JIT system with integrated suppliers (VMI) to ensure timely delivery and high frequency [17].
X.1.1.2	Order or request changes	Heijunka (Level Scheduling) and Pull System	Overcoming the wastes of overproduction and extra processing. Leveling the production schedule (Heijunka) and producing/shipping only based on actual demand (Pull System) to reduce sudden fluctuations [16].
X.4.1.2	Delay of products reaching the customer	VSM and JIT	Overcoming the wastes of Waiting and Transportation. Mapping the entire value stream (VSM) to identify and eliminate sources of waiting time (non-value-added time) in logistics [18].
X.3.1.1	Disruption in the centrifugal process	Kaizen (Continuous Improvement) and Total Productive Maintenance (TPM)	Overcoming waste from Defects and Waiting. Implementing TPM for planned machine maintenance to reduce machine downtime that causes process disruptions [19].
X.4.1.3	Uncertainty of the delivery date for transported products	Kanban System and Flow	Overcoming waste from Waiting and Extra-Processing (repetitive communication). Implementing visual Kanban to limit work in progress and ensure a smooth process (Flow) so that delivery dates are certain [16].
X.2.1.1	Decrease in production capacity of several vendors	Supplier Relationship Management (SRM) and Dual Sourcing	Overcoming waste in Waiting and Transportation. Implementing SRM for long-term capacity collaboration, as well as Dual Sourcing to mitigate single-capacity risks [20].
X.2.3.1	Defective production during manufacturing	Poka-Yoke (Mistake Proofing) and Jidoka	Overcoming defect waste. Implementing Poka-Yoke (error prevention) at critical production points to automatically stop the process when defects are detected (Jidoka) [14].
X.3.1.7	Damage to printing machines	TPM	Overcoming waste, Waiting, and Defects. Focusing on preventive, predictive, and autonomous maintenance to keep machine conditions always optimal and reduce breakdowns [21].

X.3.1.5	Stock discrepancies	5S and Accurate Inventory (Recording Accuracy)	Overcoming waste in Searching/Motion and Inventory (ghost stock). Implementing 5S in the warehouse and conducting inventory cycle audits to ensure physical and system accuracy [22].
X.1.1.1	Demand prediction due to inaccurate sales forecast	Sales and Operations Planning (S and OP) and Data Analytics	Overcoming waste, overproduction, and inventory. Improving forecast accuracy through a collaborative S and OP process supported by data analysis of historical demand trends [15].
X.2.2.1	Materials received do not match the request	Supplier Partnership and Input Standardization	Emphasizing Defect and Waiting waste. The importance of clear specifications and supplier quality audits [15].
X.4.2.1	Delivery delays due to payment issues with the supplier	Process Automation and Standard Work (SOP)	Overcoming Extra-Processing waste (manual processes) and Waiting (delayed payments). Standardizing and automating the procure-to-pay process to accelerate the payment cycle [22].
X.1.2.3	Weak planning and preparation before production	Standard Work (SOP) and Plan-Do-Check-Act (PDCA)	Overcoming extra-processing waste and defects. Ensuring all preparation steps (materials, machines, personnel) are standardized and validated before production begins (PDCA) [16].
X.1.3.1	Sudden changes in production plans	Heijunka and Pull System	Overcoming waste from Overproduction and Extra-Processing. Leveling demand and limiting production based on actual pull [16].
X.2.1.2	Supplier performance evaluation is not update	SRM and Automated Performance Metrics	Overcoming Non-Utilized Talent waste (managers do not have accurate data) and Defects. Building an automated and regular metric system to ensure that supplier performance is evaluated and improved in real-time [20].
X.3.2.1	The quality of production results does not meet standards	Poka-Yoke and Jidoka	Overcoming waste defects. Focusing on error prevention (Poka-Yoke) and self-detection (Jidoka) to ensure in-line quality [14].
X.3.1.6	Low workforce productivity	Kaizen and Cross-Functional Training	Overcoming waste from Non-Utilized Talent and Motion. Using Kaizen to eliminate non-value-added steps and improve operator skills (Cross-Training) for flexibility [19].
X.1.2.1	Procurement of materials that has not yet been realized	Kanban and Flow	Overcoming the waste of Waiting. Using the Kanban system (visual signals) to ensure that material orders are automatically triggered when stock reaches the minimum level, maintaining the smooth flow of the procurement process [17].
X.1.2.4	Mismatch between existing factory stock and production demand	Inventory Accuracy and Input Standardization	Overcoming waste inventory (excess/unutilized stock) and extra processing (searching for stock). Ensuring stock accuracy and standardizing material types to reduce variation [22].
X.3.1.3	Lack of concrete casting equipment	TPM and Flexible Capacity	Overcoming waste in Waiting and Motion. Using TPM to optimize the use of existing equipment and plan the printing equipment capacity flexibly based on demand [21].
X.1.2.2	Limited production personnel	Cross-Functional Training and Heijunka	Overcoming non-utilized talent waste. Train staff cross-functionally so that they can fill gaps in other areas, supported by workload leveling (Heijunka) [19].
X.4.1.1	Unavailability of transportation facilities for delivery	Total Logistics Management and Supplier Partnership	Overcoming Transportation and Waiting waste. Integrating logistics planning with suppliers/transport partners to ensure the availability of facilities that align with the JIT schedule [15].
X.3.1.4	Unskilled workforce	On-the-job Training (OJT) and Standard Work	Overcoming waste defects and non-utilized talent. Providing structured OJT based on Standard Work to improve competencies and work quality [19].
X.3.2.3	Errors occur when existing products are stacked	5S and Handling Standard	Overcoming waste, defects, and motion. Implementing 5S in the storage area and establishing clear handling standards to prevent product damage when stacked or moved [22].
X.3.2.2	Land lease permit has expired	VSM and Holistic Planning (Long-term Planning)	Overcoming Waiting and Extra-Processing waste (re-negotiation). Mapping the VSM for non-production processes (administration) and integrating lease permit planning into long-term SCM planning [18].

Table IV presents a detailed correlation between the identified barriers, the types of lean waste, and the proposed mitigation strategies. This solution matrix provides strategic guidance to ensure that mitigation efforts are systematically focused on eliminating non-value-added activities, thereby supporting a more efficient and structured implementation of LSCM in the field.

IV. CONCLUSION

This research confirms that the implementation of Lean Supply Chain Management (LSCM) plays a significant role in improving time and cost efficiency in construction projects, particularly in the procurement stage of spun piles. The analysis using the Relative Importance Index (RII) method identified the five main obstacles that most affect following supply chain performance, namely:

- Product returned by the customer (RII = 0.788)
- The material received does not match the request (RII = 0.756)
- Occupational health and safety risk (OHS) (RII = 0.725)
- Supplier not fulfilling material delivery commitments (RII = 0.700)
- Order or request changes (RII = 0.694)

These barriers were observed to contribute to waste in the form of defects, waiting, overproduction, motion, and unnecessary processing, which may cause delays and reduce operational efficiency.

The application of Lean principles—such as Kaizen, Value Stream Mapping (VSM), JIT, 5S, Heijunka, Pull System, and Total Productive Maintenance (TPM)—provides systematic strategies to address these barriers, ensuring better supply chain responsiveness, collaboration among stakeholders, and improved material quality control on-site. Overall, the findings offer both scientific contributions by quantitatively ranking the dominant barriers in LSCM implementation and practical guidance for contractors, suppliers, and project managers to systematically improve supply chain operations and implement lean practices effectively.

A. Recommendations

LSCM boosts time and cost efficiency in construction projects. To optimize the results, construction industry stakeholders must address key implementation factors.

First, LSCM principles should go beyond research or pilot stages. They must be fully integrated into the company's quality and operational systems. This can be achieved by implementing a continuous improvement (Kaizen) culture at every level of work, including planning, procurement, and material distribution. This ongoing effort enables the organization to consistently identify, analyze, and eliminate waste throughout the project supply chain.

Second, collaboration among the parties involved in the supply chain needs to be strengthened through the use of integrated information systems. Digitizing supply chain processes, for example, by implementing a Vendor Managed Inventory (VMI) system or a real-time data-based management platform, can minimize delivery uncertainty, accelerate decision-making, and enhance the accuracy of information required to manage project materials and logistics.

Third, enhancing human resource capacity and competence is a crucial factor in the successful implementation of LSCM. Continuous training on lean principles, such as 5S, Standard Work, and TPM, should be provided to ensure that field personnel understand the importance of process efficiency, workplace safety, and the timeliness of production and material distribution.

Furthermore, supplier performance evaluation must also be conducted periodically using the Supplier Relationship Management (SRM) approach. A structured and transparent assessment will help ensure that each supplier is capable of meeting on-time delivery commitments with materials that meet the specified quality. Additionally, this system can be used to identify potential risks in the supply chain and determine appropriate mitigation measures before they cause disruptions to the project.

B. Future Work and Limitations

In addition, future implementation of LSCM should also incorporate sustainability-oriented practices and digital transformation. Although this study discusses LSCM principles, environmental considerations—such as waste minimization, carbon footprint reduction, and resource efficiency—were not examined in depth. Integrating sustainability metrics within procurement, logistics, and material handling would strengthen the strategic alignment between LSCM and green construction initiatives.

Similarly, digital technologies, such as Building Information Modeling (BIM), Internet of Things (IoT)– based tracking, and real-time analytics platforms, were not explored in this study, but they represent significant opportunities to enhance visibility and coordination along the construction supply chain. Future work should consider evaluating how these digital tools can support lean operations, improve forecasting accuracy, and optimize material flow in complex construction environments.

Taken together, these recommendations are expected to serve as practical guidelines for project practitioners, academics, and other stakeholders, strengthening the implementation of LSCM as a strategic approach to achieving efficient, productive, and sustainable construction projects.

However, it is essential to acknowledge the limitations of this study when interpreting the proposed recommendations. The research is based on a single case study of a coastal protection building project located within a specific geographic area, which may not fully represent other construction environments or project categories. The sample size is also limited to 32 respondents who are directly involved in supply chain and project operations, which may influence the generalizability of the findings.

In addition, the LSCM strategies proposed in this study are developed primarily through empirical findings and supported by an extensive review of the literature. Although this provides a theoretically grounded basis, the strategies have not yet been validated through advanced methods such as simulations, multi-project benchmarking, or structured expert evaluations. Therefore, future research should incorporate validation mechanisms—such as expert judgment, Delphi studies, or model-based simulation—to strengthen the practical applicability of the proposed strategies.

Future studies are also encouraged to expand the analysis to other large infrastructure projects, such as transportation systems, public facilities, water resource structures, and energy infrastructure, to examine whether the observed patterns remain consistent across different project scales, levels of complexity, and regulatory environments. Broadening the geographic and project-type coverage will allow stronger validation and enhance the generalizability of LSCM-related insights across the construction sector.

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