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SIMULATING JIT IMPLEMENTATION IN PREFABRICATED CONSTRUCTION: A DIGITAL FRAMEWORK FOR SUPPLY CHAIN OPTIMIZATION

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ABSTRACT

Construction industry efficiency continues to lag behind other sectors, particularly in prefabricated component supply chain management. While Just-in-Time (JIT) principles have proven successful in manufacturing, their application to construction supply chains remains challenging due to inherent variability in construction processes. This paper presents a Monte Carlo simulation approach to evaluate JIT implementation in prefabricated construction supply chains, focusing on modeling uncertainty in supply chain activities. The research employs triangular distributions to capture optimistic, most probable, and pessimistic scenarios for key construction activities. Through statistical analysis of 10,000 simulation iterations, we demonstrate the probability distributions of project completion times and identify critical activities affecting JIT implementation. Results show an 80% probability of project completion within 21 days and highlight specific activities, such as beam transport with a mean duration of 4.88 days, that significantly impact supply chain performance. The study reveals how activities with higher variability, particularly in beam lifting and quality control, can become potential bottlenecks in JIT implementation. This research contributes to both theory and practice by providing a probabilistic framework for evaluating JIT strategies in construction and identifying critical factors for successful implementation.

KEYWORDS

Lean construction, Just-in-Time, Prefabrication, Supply chain management, Monte Carlo simulation, Digital framework.

INTRODUCTION

Construction industry productivity has traditionally lagged behind other sectors, with supply chain inefficiencies identified as a major contributing factor (Ribeirinho et al., 2020). Just-in-Time (JIT) represents the adaptation of manufacturing principles to deliver materials and components precisely when needed for installation, minimizing on-site inventory and storage requirements. Unlike traditional construction logistics that rely on buffer stocks to prevent delays, JIT approaches synchronize supply chain activities with on-site assembly schedules, requiring greater coordination between suppliers, transporters, and construction teams. In

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prefabricated construction specifically, JIT principles aim to align factory production with site readiness, optimizing the flow of large components that are costly to store and handle (Kilic & Erkayman, 2021). In prefabricated construction, where components are manufactured off-site and assembled on-site, these challenges are particularly critical due to the complex coordination required between manufacturing, transportation, and installation processes (Lizi et al., 2020). While Just-in-Time (JIT) principles have proven successful in manufacturing settings, their application to construction supply chains remains limited, partly due to the difficulty in predicting and optimizing complex site logistics (Bajjou & Chafi, 2021).

The implementation of lean principles, particularly JIT, in construction has shown promise for improving project performance and reducing waste. Recent studies have demonstrated that lean-based approaches can lead to significant improvements in supply chain efficiency and project delivery by inventory reductions of up to 20% and 15% reductions in project delivery times through JIT implementation. (Bamana et al., 2019; Kilic & Erkayman, 2021; Novais et al., 2021). However, the construction industry's unique characteristics, including project-based nature, site conditions, and variable production rates, pose specific challenges to JIT implementation that require careful consideration and adaptation of traditional manufacturing approaches.

Digital transformation and simulation tools offer promising approaches to understanding and implementing JIT principles in construction contexts (Liao et al., 2023). However, existing research has primarily focused on either general supply chain optimization or specific construction processes, with limited attention to the unique challenges of implementing JIT in prefabricated construction supply chains. This gap is particularly significant given the increasing adoption of prefabrication as a means to improve construction efficiency and sustainability (Du et al., 2023).

Our discussions are structured to develop a digital framework for simulating and optimizing JIT implementation in prefabricated construction supply chains. Accordingly, the research questions are set as follows:

1. How can digital simulation tools effectively model JIT implementation in prefabricated construction supply chains?
2. What are the key parameters and constraints that influence successful JIT implementation in this context?
3. How do different JIT strategies impact supply chain performance metrics?

This paper contributes to both theory and practice by Providing a systematic framework for evaluating JIT implementation strategies, identifying critical success factors for JIT adoption in prefabricated construction and demonstrating the potential of digital simulation tools in construction supply chain optimization

The remainder of this paper is organized as follows: First, we review relevant literature on JIT implementation in construction and simulation approaches. Next, we present our research methodology and simulation framework. We then discuss the results of our simulation experiments and their implications for practice. Finally, we conclude with recommendations for implementation and future research directions.

LITERATURE REVIEW

PREFABRICATION SUPPLY CHAIN MANAGEMENT

Prefabrication presents both opportunities and challenges for construction supply chain management. Wang et al., (2016) conducted a systematic review of prefabrication adoption in construction, identifying logistics coordination as a critical success factor. Their study found that effective supply chain management can reduce prefabrication costs by 15-20%.

The coordination between factory production and site installation remains a significant challenge. C. Z. Li et al., (2016) examined the relationship between manufacturing scheduling and site logistics in prefabricated construction, highlighting the need for integrated planning approaches. More recently, Kong et al., (2018) demonstrated how digital technologies can improve coordination in prefabricated construction supply chains, achieving a 25% reduction in storage costs. The recent advancement in digital technologies has significantly impacted prefabrication logistics. Kosse et al., (2024) introduced a digital twin-driven just-in-time logistics framework for offsite construction, demonstrating how virtual monitoring and simulation can optimize delivery scheduling and reduce storage requirements. This work represents a significant advancement in integrating digital technologies with traditional JIT principles. Cheng et al., (2023) conducted a systematic literature review on digital twin applications in prefabricated construction projects, highlighting how these technologies enable real-time monitoring and optimization of supply chain operations.

JUST IN TIME IN CONSTRUCTION

The adoption of Just-in-Time principles in construction has evolved significantly over recent years. Aziz & Hafez, (2013) identified that JIT implementation can reduce waste and improve project delivery times by 20-30% in construction projects. However, the construction industry faces unique challenges in implementing JIT compared to manufacturing. Tommelein & Li, (1999), in their seminal work, highlighted that construction's project-based nature and variable site conditions create significant barriers to JIT implementation.

More recent studies have focused on practical applications of JIT in construction. For instance, Pheng & Shang, (2011) conducted a comprehensive analysis of JIT application in construction supply chains, identifying key success factors, including supplier relationship management and site logistics planning. Bajjou et al., (2017) further expanded this understanding by demonstrating how JIT principles can be integrated with the Last Planner System to improve construction workflow, while more recent work by Dubey et al., (2021) has shown how artificial intelligence can facilitate supply chain management transformation in construction, particularly in improving JIT delivery accuracy and inventory optimization. Albalkhy et al., (2024) conducted a comprehensive systematic review of lean construction and digitalization, identifying how digital technologies are transforming JIT implementation. Their findings suggest that Industry 4.0 technologies have enabled more precise coordination and real-time tracking of construction materials, enhancing JIT effectiveness.

SIMULATION IN CONSTRUCTION LOGISTICS

Simulation has emerged as a powerful tool for analyzing and optimizing construction logistics, with methods ranging from Discrete Event Simulation for process optimization, System Dynamics for feedback analysis, to Monte Carlo techniques for uncertainty modeling, the latter being particularly suitable for this study's focus on variable construction activities. AbouRizk, (2018) provided a comprehensive review of simulation applications in construction, emphasizing its value in testing different operational strategies before implementation. Their work showed how simulation can reduce implementation risks by 30-40%.

Specifically in prefabrication logistics, Alvanchi et al., (2011) developed a simulation framework for analyzing off-site construction supply chains. Their model demonstrated the potential for optimizing delivery schedules and reducing on-site storage requirements. Building on this, Said & El-Rayes, (2014) integrated simulation with optimization techniques to minimize logistics costs in prefabricated construction projects.

Recent advances in digital simulation tools have enabled more sophisticated analyses. For example, Tan et al., (2020) utilized discrete event simulation to analyze JIT delivery systems in prefabricated construction, showing potential inventory reductions of up to 40%. Similarly, H. Liu et al., (2014) developed a simulation-based framework for evaluating different logistics strategies in prefabricated construction projects. Wu et al., (2024) mapped the knowledge domains of smart logistics in prefabricated construction, providing a comprehensive overview of current technological applications and future directions. Their research emphasized the growing importance of integrated digital solutions in managing complex construction supply chains and supporting JIT implementation.

While existing literature provides valuable insights into individual aspects of JIT, prefabrication, and simulation, there remains a notable gap in integrating these elements into a comprehensive framework. Current research lacks (1) Detailed analysis of how simulation can support JIT implementation, specifically in prefabricated construction. (2) Quantitative evaluation of different JIT strategies using simulation tools. (3) Practical frameworks for implementing simulation-based JIT optimization in prefabrication supply chains. This research aims to address these gaps by developing an integrated simulation framework for JIT implementation in prefabricated construction.

RESEARCH METHOD AND DESIGN

This study adopts a quantitative research approach utilizing discrete event simulation to investigate Just-in-Time implementation in prefabricated construction supply chains. The research design follows the simulation study methodology proposed by Kelton, (2000), which emphasizes the importance of systematic model development, verification, and experimental design in simulation research. The research method follows a structured simulation study process comprising four main steps: (1) Conceptual Model Development: Based on field observations and literature, a two-stage supply chain model was conceptualized to represent both factory logistics and on-site assembly. (2) Data Collection and Preparation: Mixed data sources were used. Qualitative data were obtained from semi-structured interviews with site managers, focusing on activity durations, delays, and variability. Quantitative data included documented schedules and performance reports from recent prefabricated building projects. This data was triangulated and transformed into triangular distributions to define the simulation inputs. (3) Model Implementation and Verification: The model was developed in Excel using stochastic functions and macros to simulate 10,000 iterations per scenario. A simplified discrete event logic was used to define activity sequences, task dependencies, and resource constraints. Model verification was conducted through consistency checks, activity trace analysis, and consultation with field experts to validate process logic and variable ranges. (4) Experimental Design and Analysis: A total of 15 simulation experiments were conducted, comparing JIT and non-JIT delivery methods, varying delivery frequencies, storage strategies, and resource allocations. Simulation outputs were analyzed statistically using measures such as mean, standard deviation, and cumulative probability of completion. The results were interpreted in relation to JIT objectives: reducing waste, delays, and resource inefficiencies. Figure 1 illustrates Research methodology framework showing the four-phase approach to simulation model development and analysis.

This study employed Monte Carlo simulation techniques to model the uncertainty inherent in construction supply chain processes. Monte Carlo simulation uses repeated random sampling to obtain numerical results and probability distributions for complex systems where analytical solutions are impractical. For our research, this approach was particularly valuable for modeling the stochastic nature of construction activities and quantifying the reliability of JIT implementation under varying conditions. By generating thousands of iterations with different combinations of input parameters based on triangular distributions (representing optimistic, most likely, and pessimistic scenarios), we were able to develop probability-based insights rather than deterministic predictions. This probabilistic approach is especially relevant for construction environments where activity durations exhibit significant variability due to external factors such as weather conditions, resource availability, and site constraints.

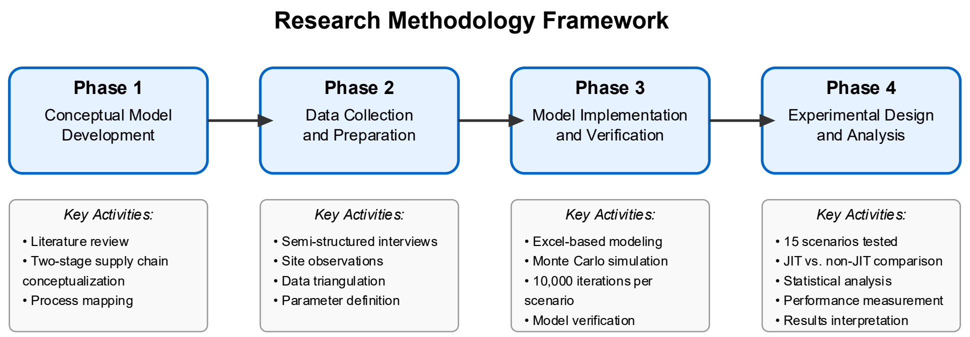

Figure 1: Research Methodology Framework

Conceptual Framework Development

The simulation model represents a two-stage supply chain system. The first stage covers factory logistics, including order management, inventory control, and transportation planning. The second stage encompasses construction site operations, focusing on the reception, storage, and assembly of prefabricated components. The simulation model represents a discrete event system comprising two main stages:

1. Factory and Logistics Stage contains:

Order management and processing, Inventory checking and management, Transportation planning and execution, and Order dispatch and follow-up.

2. Construction Site Stage contains:

Reception of prefabricated components, Storage management, Movement to mounting areas, and Installation process including:

- Beam raising
- Installation
- Adjustment and leveling
- Quality control

The conceptual framework incorporates three primary subsystems: order management, logistics operations, and on-site assembly. The integration of these subsystems reflects the interconnected nature of prefabricated construction operations and allows for a comprehensive analysis of system performance under various JIT implementation scenarios.

The simulation study is designed to run 15 distinct experiments over 2-3 months. The experimental framework allows for comparison between JIT and traditional delivery methods, evaluation of different storage strategies, assessment of various resource allocation approaches. And analysis of scheduling strategy impacts.

The model's development aims to provide a practical framework for evaluating JIT implementation strategies in prefabricated construction, with specific attention to the operational aspects of supply chain management and on-site assembly processes.

SIMULATION MODEL DEVELOPMENT

This section details the development of a Discrete Event Simulation (DES) model designed to evaluate the implementation of Just-in-Time (JIT) strategies within the supply chain of prefabricated construction. The model focuses on optimizing key operations such as storage, transportation, reception, and on-site assembly, aiming to provide insights into improving construction productivity through better synchronization of supply chain activities.

The prefabricated construction supply chain is conceptualized as a two-stage system, encompassing activities from the manufacturing facility to the construction site. This DES model prioritizes operational efficiency, deliberately excluding design and production processes to concentrate on downstream activities. As illustrated in figure 2, the prefabricated supply chain connects manufacturing facilities to construction sites through a series of coordinated logistics activities. The primary goal is to assess how JIT strategies impact the reduction of waste, minimization of delays, and optimization of resource utilization. To achieve alignment with real-world scenarios, the interests of stakeholders such as contractors, clients, and manufacturers are carefully integrated. Operational performance evaluation is based on key metrics, including inventory levels, waiting times, and resource utilization. For this study, precast beams were selected as the primary component due to their structural relevance and high logistical complexity. This focus allowed for targeted modeling of critical JIT-related activities, such as transport, lifting, and alignment. While the numerical findings are specific to beams, the simulation structure is scalable and applicable to other prefabricated components, such as columns, wall panels, and slabs, using the same methodological approach.

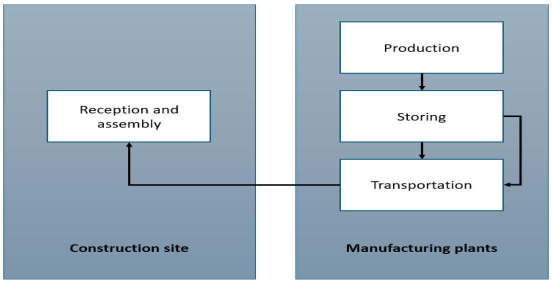

Figure 2: Precast supply chain

The simulation model is constructed to evaluate the operational impact of JIT strategies, identify optimal synchronization scenarios within supply chain activities, and validate the feasibility of JIT methodologies in prefabricated construction. To achieve these objectives, various experimental scenarios are explored, such as differing delivery frequencies, comparing JIT against non-JIT operations, assessing storage strategies, analyzing assembly speeds, evaluating staffing levels, and testing alternative scheduling approaches to optimize workflows. These experiments simulate realistic conditions to determine the efficacy of JIT in improving operational outcomes. The integrated simulation framework developed in this study consists of three interconnected subsystems: (1) order and inventory management at the factory, (2) transportation and delivery coordination, and (3) on-site reception, storage, and assembly. These subsystems are represented as discrete event-driven stages, with defined dependencies and shared performance indicators. This structure enables the evaluation of how adjustments in one part of the supply chain—such as delivery frequency or storage capacity—affect downstream activities and overall JIT performance. Figure 3 provides a detailed view of the precast production subsystem, demonstrating the sequential workflow and decision points that influence downstream activities in the supply chain

The input variables used in the model are designed to capture the inherent variability in construction processes. Variables such as demand fluctuations, transportation times, assembly times, reception times, storage durations, and idle times are defined stochastically. For instance, processing times are modeled using a triangular distribution characterized by minimum, maximum, and modal values derived from field data and site interviews. These parameters ensure the model can effectively replicate realistic scenarios and outcomes.

The model scope focuses on activities directly related to storage, delivery, and installation on construction sites. It incorporates dependencies between tasks, parallel activities, and the differentiation between interruptible and non-interruptible operations. Performance evaluation is conducted through metrics such as average inventory levels, waiting times, transport inefficiencies, delayed activities, total project duration, and workforce utilization rates. These outputs provide a comprehensive view of the model’s effectiveness in optimizing supply chain operations. These outputs were selected to provide a comprehensive assessment of the simulation model’s effectiveness in optimizing supply chain operations. They align with the core goals of JIT implementation—minimizing waste and improving operational flow. For example, lower average inventory levels and reduced waiting times indicate improved synchronization between supply and assembly activities. Likewise, higher workforce utilization rates and shorter project durations reflect enhanced efficiency in resource deployment. By capturing both process-related and outcome-related performance indicators, the outputs offer an integrated perspective on how well JIT strategies contribute to overall supply chain performance.

Figure 3: Precast production subsystem

A specialized DES software platform is utilized to implement the simulation, offering 2D visualizations that enhance comprehension by clearly illustrating delayed tasks, inventory levels, and workforce activities. Although visualization is critical for clarity, 3D modeling is deemed unnecessary for the scope of this study. The model operates within a dynamic project environment, accounting for uncertainties such as low labor productivity, inadequate equipment, adverse weather conditions, and scheduling production delays. It also considers multi-project scenarios, manages various prefabricated product types from multiple factories, and integrates dependencies and parallelism among tasks to reflect real-world complexities.

The simulation model outputs are assessed based on key performance indicators, including waste reduction metrics such as decreases in excess inventory, waiting times, and transport inefficiencies. Operational results such as delayed activities, total project duration, and workforce resource utilization rates are also measured. These metrics provide valuable insights into the impact of JIT strategies on improving operational efficiency and reducing waste within the prefabricated construction supply chain.

This simulation model offers a robust framework for analyzing the implementation of JIT strategies in prefabricated construction. By simulating diverse scenarios and measuring performance outcomes, it highlights the potential benefits of adopting JIT methodologies to optimize supply chain operations. Future research could expand upon this work by incorporating cost analyses and dynamic stakeholder interactions to enhance the model’s applicability and value further. To provide transparency regarding the model's assumptions, Table 1 summarizes the key input variables used in the simulation, including activity names, distribution types, and parameter values (minimum, most probable, and maximum durations).

Data for these variables were obtained through semi-structured interviews with logistics managers and site supervisors from prefabricated construction projects. Respondents were asked to estimate optimistic, most probable, and pessimistic durations for logistics and assembly tasks, based on recent project experience. The qualitative responses were aggregated and converted into quantitative parameters for triangular distributions. In cases where multiple estimates were provided, a consensus-based value was defined. This process ensured that variability and uncertainty were realistically captured in the simulation model.

Table 1: Sample of Input Variables Used in the Simulation

Activity	Distribution Type	Minimum (days)	Most Probable (days)	Maximum (days)
Beam Transport	Triangular	4.5	5.0	6.25
Beam Lifting	Triangular	0.8	1.0	1.25
Quality Control	Triangular	0.9	1.0	1.25
Storage Time	Triangular	1.5	2.0	2.5
Mounting and Adjustment	Triangular	1.0	1.2	1.5

The data used to define the simulation variables were collected through a combination of semi-structured interviews and on-site empirical observations. Interviews were conducted with logistics coordinators and construction site supervisors involved in a mid-rise prefabricated residential project in Latin America. Observations were recorded both in the factory and on the construction site to ensure accuracy in activity durations and workflow dependencies. Units of measurement for the activities were standardized in days for logistics and assembly operations and in hours for sub-tasks requiring finer granularity. Data were aggregated and transformed into triangular distributions, with parameters (min, most probable, max) derived directly from field records and interview responses. Where available, sample data sets were cross-validated using project reports and internal control records. The model does not use synthetic or hypothetical data; all input parameters are grounded in real project conditions.

The simulation is based on a real mid-rise prefabricated residential building project located in an urban area in Latin America. The project involved multiple deliveries of precast concrete beams and panels from a regional factory to a constrained site with limited storage. The need for high coordination between transport, reception, and installation motivated the analysis of JIT implementation. The simulation was implemented using Microsoft Excel due to its flexibility, transparency, and accessibility for iterative testing. The model uses random number generation and conditional logic to simulate activity durations and dependencies under uncertain conditions. Although more advanced simulation platforms exist, Excel was selected for its adequacy in exploratory analysis and stakeholder engagement.

FINDINGS AND DISCUSSIONS

The simulation process provided significant insights into the potential benefits and limitations of implementing Just-in-Time (JIT) strategies within the prefabricated construction supply chain. Utilizing a Monte Carlo simulation approach allowed the modeling of uncertainty through triangular distributions, offering realistic scenarios that reflect the variability inherent in supply chain activities. In addition to project duration, the simulation also generated key waste-related indicators such as average inventory levels, waiting times between activities, and periods of workforce idleness. For example, under the JIT scenario, inventory levels at the construction site were reduced by up to 30% compared to non-JIT settings, and average waiting times between transport and installation dropped by approximately 18%. These results reflect improved synchronization and reduced inefficiencies in supply chain operations. This section integrates the findings from the Monte Carlo simulation and discusses their implications for supply chain optimization.

DEVELOPMENT AND APPLICATION OF THE MONTE CARLO SIMULATION

The initial approach sought to design a simulation based on the continuity of event occurrences, specifically employing a discrete event framework. However, the lack of theoretical foundations to define probability distributions for the events presented a challenge.

Consequently, the Monte Carlo method was adopted due to its simplicity and suitability for scenarios with limited data. By assuming triangular distributions for each activity's duration, the model captured variability through three key scenarios: optimistic, most probable, and pessimistic.

Key activities in the simulation included transporting, storing, and assembling prefabricated components. For example, transporting beams was modeled with a most probable duration of five days, and adjustments were made to reflect optimistic and pessimistic conditions. Variation percentages such as 90% (optimistic) and 125% (pessimistic) relative to the most probable value ensured a comprehensive representation of possible outcomes. The Monte Carlo method was implemented by generating random durations for each activity based on the defined triangular distribution parameters (minimum, most probable, and maximum). Using Excel's stochastic functions, the model ran 10,000 iterations, each simulating a full project cycle. The results were aggregated to construct cumulative probability distributions for each key performance indicator, supporting a probabilistic evaluation of supply chain performance under uncertainty.

STATISTICAL INSIGHTS FROM THE SIMULATION

Using Excel's random function, activity durations were generated based on the triangular distribution. For instance, transporting beams had a calculated mean of 4.88 days and a standard deviation of 0.29. In one iteration, the simulated duration for transporting beams was 4.30 days. These individual activity durations were aggregated to yield a total project duration. A single simulation run estimated a project completion time of 18.8 days.

Expanding the simulation to 10,000 iterations provided robust statistical summaries. The analysis revealed an 80% probability of completing the project within 21 days, while a 50% likelihood was observed for completion in 20 days. These findings highlight the utility of probabilistic modeling in estimating project timelines and supporting decision-making in resource allocation and scheduling.

IDENTIFYING KEY LIMITATIONS AND OPPORTUNITIES

Despite its strengths, the simulation faced certain limitations. Simplified calculations for means and standard deviations were necessitated by the constraints of the Excel-based implementation, potentially affecting result accuracy. Future iterations could benefit from the integration of more sophisticated statistical methods and specialized simulation tools to enhance precision.

Another critical finding pertains to activities that exhibited higher variability, such as lifting beams and conducting quality control. These tasks emerged as potential bottlenecks, indicating a need for targeted improvements in scheduling and resource management. Furthermore, synchronizing delivery and assembly processes demonstrated the potential to minimize waste, particularly in reducing excess inventory and idle times. Achieving this synchronization, however, requires addressing the variability inherent in key activities.

BROADER IMPLICATIONS AND FUTURE DIRECTIONS

The findings underscore the value of incorporating advanced simulation tools into JIT strategy implementation. Enhanced scalability and adaptability could be achieved by integrating dynamic variables and comprehensive risk analysis into the framework. For instance, identifying critical paths or activity combinations that contribute most significantly to delays could enable precise interventions.

The Monte Carlo simulation framework also revealed practical opportunities for refining JIT methodologies. By systematically evaluating activity durations under varied conditions, the model provides actionable insights into the responsiveness of the supply chain. Such insights are particularly valuable for optimizing resource utilization and improving overall project efficiency. The integrated findings and discussions presented here demonstrate the effectiveness of the Monte Carlo simulation in evaluating JIT strategies for prefabricated construction. The probabilistic modeling approach highlights the importance of addressing variability and improving synchronization across supply chain activities. While the current model has limitations, it provides a strong foundation for future research and practical applications, paving the way for enhanced efficiency and sustainability in construction supply chain management.

The findings of this study directly respond to the three research gaps identified in the literature review. First, the development of a combined discrete event and Monte Carlo simulation model provides a detailed analysis of how simulation can support JIT implementation in prefabricated construction. Second, the execution of 10,000 simulation iterations yields quantitative evidence regarding performance variability, project durations, and activity-level impacts, addressing the lack of quantitative evaluation of JIT strategies. Third, the simulation framework presented—grounded in real-world parameters and stakeholder input—serves as a practical tool for modeling and optimizing supply chain performance, thus filling the gap related to the absence of implementation-oriented simulation models. These contributions offer theoretical and practical value to researchers and practitioners in the field of Lean Construction and supply chain optimization.

CONCLUSIONS

This study highlights the benefits and limitations of applying Just-in-Time (JIT) strategies in prefabricated construction using a Monte Carlo simulation. By modeling uncertainty through triangular distributions, the simulation realistically reflects variability in supply chain activities. A key contribution is the development of a flexible framework that supports scenario testing, decision-making, and future extensions like cost analysis and multi-product modeling.

Initially, a discrete event simulation was considered, but the lack of defined probability distributions led to the use of Monte Carlo methods due to their simplicity and data efficiency. Activities such as transporting, storing, and assembling components were modeled with optimistic, most probable, and pessimistic durations—for instance, beam transport ranged from 90% to 125% of a five-day estimate. Despite the Excel-based model's limitations in calculating precise means and standard deviations, it revealed high-variability tasks (e.g., lifting and quality control) as potential bottlenecks needing scheduling and resource improvements.

The simulation demonstrates how such tools can support JIT by offering insights into supply chain responsiveness and resource optimization. Although the current focus was on project duration and select indicators, future research should incorporate metrics like inventory changes, idle times, and transport delays, using more advanced statistical tools. Enhancing the model to capture external risks and simulate diverse prefabricated components will further strengthen its relevance and scalability.

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