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Optimization of Material Logistics in Civil Engineering Supply Chains: A Case Study Approach

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ABSTRACT

Civil construction projects heavily depend on the smooth and timely movement of construction materials, hence material logistics being a paramount driver of project success. Procurement inefficiencies, transportation, storage, and handling inefficiencies at sites often lead to cost escalation, delays, and wastage of resources. Process improvement in these areas has thus become unavoidable to attain efficiency, sustainability, and competitiveness in construction supply chains. The current research suggests a framework of integrated optimization based on a Genetic Algorithm (GA) to solve compartmentalized supply chains, volatile demand, and spatial limitations at project locations. The approach includes procurement scheduling, site planning, and facility relocation based on dynamics to reduce Total Logistics Cost (TLC), integrating ordering, financing, stock-out, and handling costs. A medium-scale office building project was used for a case study with respect to reinforcing steel, AAC blocks, and curtain wall systems. The optimized model reduced TLC by 17.8% compared to baseline planning, and considerable savings were realized through customized procurement cycles, dynamic storage allocation, and reduced resource travel. Sensitivity analysis validated the strength of the model under diverse site and supply conditions. The findings underscore the fact that integrating data-driven procurement with spatial optimization guarantees cost-saving, reduces risks, and increases sustainability for civil engineering supply chains.

Keywords: Material Logistics, Supply Chain Optimization, Genetic Algorithm, Civil Engineering.

INTRODUCTION

The construction industry actually drives economies, infrastructure, and urbanisation globally. Civil engineering products, whether a house, an office building, or a large project, like highways, bridges, and dams, rely on materials being delivered to a site on time [1].

Achieving successful outcomes in these types of ventures is entirely dependent on how you manage the supply chain, or material logistics [2]. Material logistics is the process of sourcing, moving, storing, and distributing construction materials.

Material logistics is a critical part of ensuring that projects run smoothly, costs are minimised, and overall quality maintained.

If any part of the logistics process is flawed, there will be delays, increased costs, material wastage, and even project failure [3, 4].

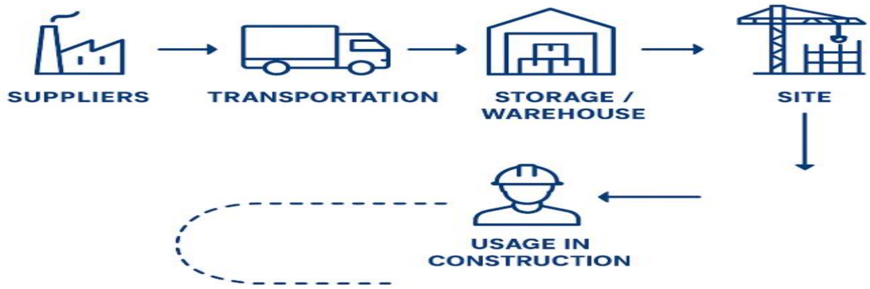

Figure 1: Representation of Construction Material Supply Chain

The intricacy of construction operations has increasingly embodied the requirement for supply chain optimization in recent decades. Typical material logistics practices follow a manual process of scheduling ordering, lack any sort of real live monitoring capabilities, and offer no coordination between the key participants that don't react to issues arising in the construction process [5]. All physical products enter upstream and downstream material flows component systems requiring systematic processes that minimize material flows as much as possible in our built world. This material flow inevitably includes variability in material costs, demand, site conditions, and variation on the timing of delivery to the project site. Optimization, for our case here, means, in general terms, the activity of finding the best way of dealing with material delivery and receiving in a timely cost effective yet wasteful minimal way to the level of quality [7]. Optimization for the material logistics case is a complex proposition to say the least. There are many choices to be made on planning for inventory, transport routes, procurement schedules, storage schedules, and resources [8]. Too much inventory means more holding costs, potential waste as materials depreciate. Too little inventory means stoppages because there are no materials and delays to completing the project on schedule. Transport choices also matter - which vehicle, what route, which day or time we choose to place an order [9].

Figure 2: Challenges in Material Logistics

Getting logistics right in this field really calls for knowing the whole supply chain inside out. That, plus pulling in stuff like math models, simulations, and tech solutions based on information systems [10]. And in civil engineering, supply chain tweaks matter even more now with everyone pushing for green building worldwide. There's this big push to cut down carbon emissions, save on resources, and make things more energy-smart. So, construction companies are hunting for ways to trim costs while also dialing back the harm to the environment [11, 12]. Efficient handling of materials cuts out extra trips, stops waste from happening, and gets sustainable practices going strong. Better logistics mean smoother project timelines too. They boost how well workers get things done. Plus, clients end up happier overall. All that builds up a company's edge in the market [13].

The case study method is very practical and informative to investigate cases of logistics optimization issues affecting material and their solutions. A study of real cases can highlight the potential realities and bottlenecks relative to theoretical models, and actual interventions in logistics [14]. By examining a specific series of cases involving individual projects, patterns can be identified, the viability of optimization approaches can be determined, and sound practical advice can be given [15]. Case studies also provide information about context-specific factors like site location, project size, contractor capacity, local supply market conditions likely to impact the decision logistics significantly [16].

Existing construction logistics research has outlined several optimization strategies, such as just-in-time (JIT) delivery, lean construction practices, network design optimization, and digital technologies like Building Information Modeling (BIM) coupled with supply chain management software [17]. JIT delivery, for example, minimizes the cost of inventory by coordinating the arrival of materials and construction timing, whereas lean construction methods aim to remove non-value-adding activities and reduce delays. Advanced simulation and modeling software enable planners to predict potential disruption, examine alternative substitute logistic scenarios, and select best-fit methods [18]. Despite these developments, however, there are still hindrances to the widespread adoption of optimized logistics, such as resistance, absence of appropriate expertise, and absence of adequate integration among actors [19, 20]. Accordingly, civil engineering supply chain material logistics optimization is an important field of research, with widespread implications for project efficiency, cost control, and sustainability. By concentrating on warehousing, dispatching, and movement of materials, construction activities are in a position to attain better scheduling, minimization of wastage, and increased productivity. The case study method represents a real-world way to analyze current logistics practices, define the gaps or missing links and provide tailored and cost-effective alternatives or recommendations. The present study aims to contribute to the knowledge base by developing empirical data and managerial recommendations, which will establish effective provision for optimal material logistics, and effective implementation of civil engineering projects that enhance sustainable practices in construction or a construction industry that promotes sustainable construction.

LITERATURE REVIEW

Material logistics is paramount to effective civil engineering construction projects, and efficient and timely material delivery directly affects a project's productivity, cost, and quality. The complex nature of civil engineering construction projects and greater demands for cost minimization and sustainability necessitate optimizing material logistics and resulting waste in construction supply chains. Optimizing material logistics in this context incorporates on-site processing, transportation, procurement, storage, and planning to deliver materials in a timely manner, in the right quantity, and at the least cost. The implementation of innovative technologies, systematic frameworks, and decision support systems have become unavoidable to mitigate the challenges of everchanging construction circumstances, material shortages, and uncertainty in material demand. It is well documented in multiple studies on project performance improvement that the design of a material supply chain model is important and a poorly designed material supply chain model will negatively impact a project's performance. Awaad et al. (2024) [21] emphasized that poor communication, coordination, and integrated functional specialization are sure to delay material delivery, waste productivity, and produce cost overruns in road construction projects. Their research created a MSC model that ensures timely delivery of materials, which optimizes the efficiency and quality of the project. Similarly, Seppänen et al. (2017) [22], found that traditional construction logistics research addresses only half of the problem, as traditional research primarily emphasizes material delivery and or storage with little regard for its effects on labor productivity and indirect costs. They advocate for a holistic or global logistics planning process that includes process improvement, lean thinking, and evidence-based decision-making.

Alternative advancements in construction logistics optimization include algorithmic and technological interventions. Hossen et al. (2024) [23] assessed meta-heuristic algorithms, which have been used successfully in previous construction logistics research: Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), and Simulated Annealing (SA). They achieved significant cost saving from PSO and ACO, without specific details on cost savings. Alanazi et al. (2022) [24] described an IoT-based framework for road works, which provided real time feedback loops to optimization models on the ground, aiming for material cost reductions of up to 40%. Similarly, Buhaievskyi et al. (2025) [25] and Jiang et al. (2023) [26] developed comprehensive decision-support and adaptive control structures that involve production constraints, stochastic demand, routing of deliveries, and cash flow planning, relying on simulation and Deep Reinforcement Learning (DRL) techniques. Other research, including Ateş et al. (2021) [27] and Salehi et al. (2013) [28], investigated decision-support systems and goal/linear programming models to minimize material procurement, storage, and transport. These studies together reflect the increased use of advanced computational software and intelligent systems to maximize logistics efficiency, save costs, and guarantee timely material supply.

In addition, various research places high value on on-site material management and automation in operational excellence. Said et al. (2010) [29], Said et al. (2011) [30], and Pan et al. (2011) [31] developed models that, while simultaneously optimizing decisions on material supply, site layout, and storage, minimized logistics costs and also avoided project delays. Rudraksh et al. (2025) [32] and Yang et al. (2024) [33] built on this by adding prefabrication logistics as well as lean construction concepts, proving greater efficiency in resource use and cost savings. Huemer et al. (2025) [34] added autonomous off-road forklifts to facilitate better on-site material handling, largely eliminating labor dependence and operational hazards. These studies as a group suggest that integrated planning, technology uptake, automation, and adaptive control systems are essential in maximizing material logistics in civil engineering supply chains. The overall evidence concludes that a case study strategy that implements these approaches in real-world applications offers pragmatic advice for decision-makers as well as guidelines for best practices in material logistics optimization.

Despite significant advancements in construction material logistics, several gaps remain in existing research. Most studies have focused on isolated aspects such as material delivery, storage, or procurement optimization, often neglecting the holistic integration of the entire supply chain with real-time data and dynamic project conditions. Although meta-heuristic algorithms, IoT-based platforms, and decision-support systems have been promising in cutting costs and enhancing efficiency, their real-world application to real-world civil construction projects is limited. Furthermore, few researches have rigorously integrated on-site automation, resource-adaptive control, and lean construction concepts to optimize at the same time material flow, labor productivity, and project cash flows. There is also a shortage of empirical case studies that substantiate the efficacy of integrated logistics optimization models across different project sizes, uncertainties, and resource limitations. This serves to emphasize the need for robust, data-driven frameworks to connect theoretical models with actual applications in such a way as to deliver sustainable, cost-optimized, and timely material logistics in civil engineering supply chains.

Problem Formulation

Effective material logistics in civil construction works is still a major challenge owing to fragmented supply chains, uncertain material demand, and low integration between planning, procurement, and on-site materials handling. Material delays, inefficient inventory control, and coordination failures between suppliers, contractors, and project teams commonly lead to cost overruns, lower labor productivity, and poor project quality. Although various optimization models, meta-heuristic algorithms, and IoT-based frameworks have been proposed, their practical applicability under dynamic real-world conditions is limited. Furthermore, there is insufficient empirical evidence demonstrating the effectiveness of integrated approaches that combine advanced computational techniques, adaptive control of resources, and on-site automation for optimizing material logistics. Therefore, the problem can be formulated as the need to develop a comprehensive, data-driven, and case-validated framework that ensures timely, cost-effective, and efficient flow of materials across all phases of civil engineering projects while minimizing waste and maximizing productivity.

MATERIAL AND METHODS

Case Study Selection

For the empirical validation of the proposed optimization framework, a medium-scale civil engineering project was selected as the case study. The project comprised the construction of two multi-storey office buildings executed in sequential stages, thereby offering a representative setting to analyze logistics challenges across different phases of construction.

The material scope of the project included reinforcing steel, autoclaved aerated concrete (AAC) blocks, and curtain wall systems. These materials were deliberately chosen as they exemplify critical categories in construction logistics:

Reinforcing steel as a long-lead structural material with high demand throughout the project duration.

AAC blocks as a space-intensive material requiring significant storage area on-site.

Curtain wall systems as a high-value material with strict delivery and installation schedules.

Besides considering material flows in the wider project context, the case study also looked at the placement of temporary facilities, for example, cranes, site offices, yards, and storage areas. The incorporation of temporary facilities was essential in capturing the dynamics of spatial constraints and resettlement expenses affecting material-handling choice. The case study was chosen because it represents the intricacies normally faced in civil engineering supply chains, such as varying demand for materials, constrained availability of storage, and interactions between purchasing and site layout planning. It therefore offers a good foundation for analyzing the efficacy of the proposed optimization model.

Data Collection

To ensure the robustness of the optimization model, comprehensive data were collected from the selected project site. The data inputs encompassed both quantitative and qualitative parameters critical to logistics planning in civil engineering supply chains. The following categories of information were obtained:

Material Demand Schedules

Stage-wise consumption rates were compiled for major materials, including reinforcing steel, AAC blocks, and curtain wall systems. These demand schedules were aligned with the project’s baseline program to capture fluctuations across different construction stages.

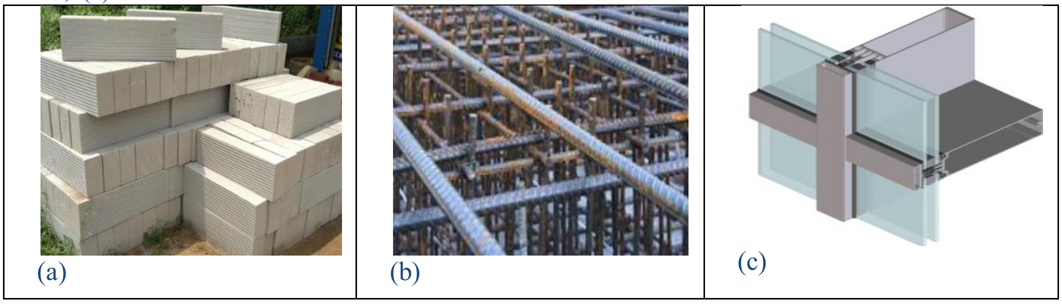

Figure 2: Material Used- (a) AAC blocks (b) Reinforcing steel, (c) Curtain wall systems

Procurement Data

Detailed procurement-related costs were collected, including purchase price variations by order size, delivery charges, and supplier capacity limitations. This dataset facilitated the evaluation of trade-offs between bulk procurement and just-in-time delivery strategies.

Storage Requirements: The footprint dimensions and stacking rules for each material were documented to determine space utilization. Safety clearance data (e.g., minimum separation distances from buildings and cranes) were also integrated to comply with site safety regulations.

Logistics-Related Costs: Costs associated with material handling, resource travel between facilities, and relocation of temporary facilities were estimated. Handling costs were derived from equipment capacity, labor rates, and average travel distances within the site.

Financial Parameters: Economic variables, including daily interest rates, liquidated damages for delays, and time-dependent indirect costs, were included to capture the financial implications of procurement and storage decisions.

To systematize the collected data, a structured input framework was developed (Table 1). This framework ensured that all logistics-related parameters were consistently represented for subsequent modeling and optimization.

Table 1: Collected Data Inputs

Category	Data Elements	Purpose in Model
Material demand	Stage-wise demand for steel, AAC blocks, curtain walls	Basis for procurement scheduling
Procurement costs	Purchase price (bulk vs. small orders), delivery charges, supplier capacity	Optimization of ordering cost
Storage requirements	Material footprint (Lx × Ly), stacking rules, safety clearance distances	Determination of on-site storage space allocation
Logistics-related costs	Handling rates, transportation distances, facility relocation costs	Estimation of layout and handling costs
Financial parameters	Daily interest rate, liquidated damages, indirect costs	Calculation of financing and stock-out penalties

Model Development

The optimization model was developed by extending the "Construction Logistics Planning (CLP)" framework and adapting it to the broader context of civil engineering supply chains. Unlike conventional approaches that consider procurement and layout independently, the proposed model integrates both components into a unified framework, thereby addressing their critical interdependencies.

The model considers two primary categories of decision variables:

Procurement Variables

The procurement variables in the model are represented as the Fixed-Ordering Periods ($FOP_{m,t}$), where m denotes the material type and t corresponds to the project stage. These variables determine the replenishment holding time (FOP) of each inventory item, whether it is a daily JIT (just in time) delivery, or a bulk procurement strategy with a longer hold time. An appropriate FOP choice is significant because it determines the balance between the risks of stock-out from frequent, but small, replenishment orders, against the financing and storage costs of carrying larger inventory buffers through bulk procurement strategy.

Layout Variables

The layout variables are defined by the ongoing spatial location and orientation of both material storage areas and temporary facilities, i.e., the location and orientation through each stage of the project. This aspect of site organization recognizes construction sites are not static and that layout variables have affected the evolution of the project by respecting safety setbacks and operation distances and access constraints while maintaining consideration of moves of relocatable facilities, such as site offices and lay down yards. The layout variables allow for the modeling of transition costs and spatial interactions so that, as the project evolves, the configuration of site organization can respond efficiently.

Table 2: Decision Variables in the Optimization Model

Category	Notation	Description
Procurement	$FOP_{m,t}$	Fixed-ordering period for material m at stage t
Procurement	$Q_{m,n,t}$	Order quantity of material m, order n, in stage t
Layout	$(X_{f,t}, Y_{f,t})$	Coordinates of facility or storage zone f at stage t
Layout	$\theta_{f,t}$	Orientation angle of facility f at stage t

Objective Function

The proposed model seeks to minimize the "Total Logistics Cost (TLC)", which represents the cumulative cost of material procurement, financing, stock-out risks, and site layout operations. The optimization objective is expressed as:

$$TLC = OC + FC + SC + LC$$

Ordering Cost (OC)

Ordering cost represents the combined expenditure on material purchase and delivery to the construction site. It captures the trade-off between frequent small orders (higher delivery costs, fewer bulk discounts) and large bulk orders (lower unit cost, but higher inventory holding).

$$\mathrm{OC} = \sum_{t=1}^{T} \sum_{m=1}^{M} \sum_{n=1}^{NOR_{m,t}} \left[Q_{m,n,t} \cdot PCR_{m,t}(Q_n) + DLC_{m,t}(Q_n) \right]$$

Financing Cost (FC)

Financing cost reflects the interest or opportunity cost associated with capital tied up in stored inventory. It increases with larger stock levels and longer holding durations.

$$\mathrm{FC} = \sum_{d=1}^{NCD} \sum_{m=1}^{M} (CS_{m,d} - CD_{m,d}) \cdot PCR_m^{avg.} \cdot DIR$$

where $CS_{m,d}$ is cumulative supply, $CD_{m,d}$ is cumulative demand, $PCR_m^{avg.}$ is average purchase rate, and DIR is daily interest rate.

Stock-Out Cost (SC)

Stock-out cost quantifies the penalties and time-dependent losses due to material shortages that cause delays in critical project activities. It incorporates both liquidated damages and indirect project costs.

$$\mathrm{SC} = \mathrm{MRPD} \cdot (\mathrm{LQD} + \mathrm{TDIC})$$

where MRPD is materials-related project delay, LQD is liquidated damages, and TDIC is time-dependent indirect costs.

Layout Cost (LC)

Layout cost covers expenses linked to material handling, resource travel, and relocation of temporary facilities. It ensures that spatial arrangements remain cost-effective throughout different project stages.

$$\mathrm{LC} = \mathrm{MHC} + \mathrm{RTC} + \mathrm{SRC}$$

where MHC is material handling cost, RTC is resource travel cost, and SRC is site reorganization cost.

This formulation enables the model to capture both direct procurement costs and indirect logistics impacts, ensuring a holistic optimization of supply chain operations in civil engineering projects.

Optimization Algorithm

The problem was modeled as a non-linear combinatorial optimization and solved using a "Genetic Algorithm (GA)", chosen for its robustness in handling large-scale, multi-variable, and non-linear search spaces. The GA encodes procurement and layout decisions as chromosomes, evaluates them using a fitness function, and iteratively improves solutions through evolutionary operators.

Algorithm 1: Genetic Algorithm for Logistics Optimization
Input: Project data (material demand, procurement costs, storage constraints, financial parameters, site layout geometry)

Output: Optimal procurement plan and facility layout minimizing TLC.
Initialize population of chromosomes representing random solutions $(FOP_{m,t},\ X_{f,t}, Y_{f,t}, \theta_{f,t})$.
Evaluate Fitness of each chromosome: $Fitness = \frac{1}{TLC}$
where TLC = OC + FC + SC + LC
Repeat until termination condition is satisfied:
a. Selection: Choose parent chromosomes based on fitness (roulette-wheel or tournament).
b. Crossover: With probability 0.8, exchange segments between selected parents to generate offspring.
c. Mutation: With probability 0.05, randomly alter decision variables (FOP values or layout coordinates).
d. Elitism: Retain the best-performing chromosomes in each generation to preserve solution quality.
e. Fitness Evaluation: Recalculate TLC for new population.
Termination: Stop if convergence is achieved or maximum number of generations is reached.
Output Optimal Solution: Report procurement periods and layout decisions with the minimum total logistics cost.

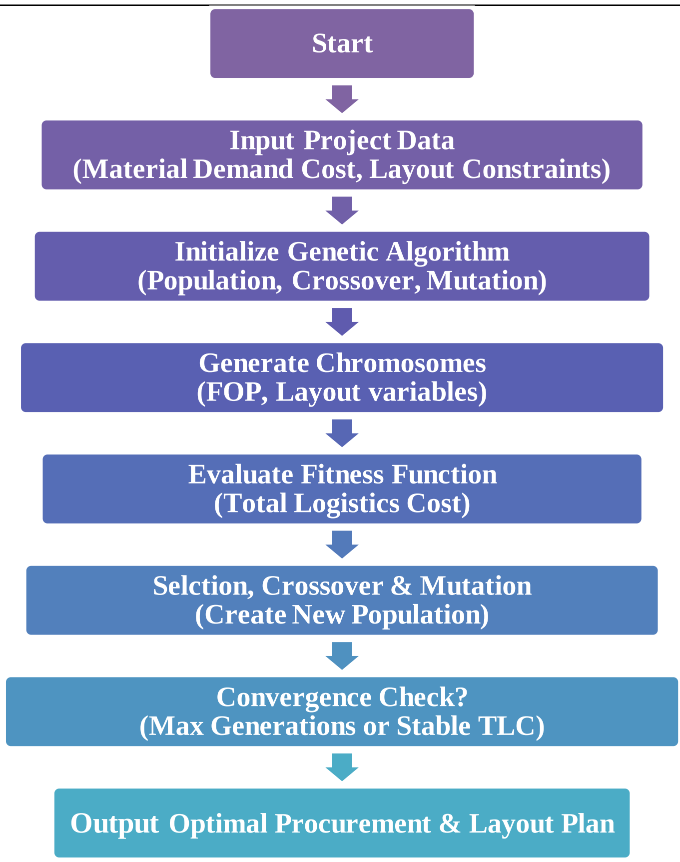

Figure 4: Flowchart of the Optimization Model Using Genetic Algorithm

Optimization Procedure

The Genetic Algorithm (GA) was initialized with a population size of 1,500 chromosomes, each encoding procurement and layout decisions through the variables $FOP_{m,t}, (X_{f,t}, Y_{f,t},)\ and\ \theta_{f,t}$. The evolutionary search process consisted of selection, crossover, mutation, and elitism, ensuring continuous improvement of solution quality across successive generations.

At each iteration, the fitness of a chromosome was evaluated using the inverse of the TLC. This ensured that solutions with lower logistics costs were assigned higher fitness values, thus increasing their probability of survival in subsequent generations.

The optimization process continued until convergence was achieved. Convergence was assessed either by reaching a maximum number of generations or when the relative improvement in TLC between two consecutive generations was below a pre-defined threshold ϵ:

$$\Delta TLC = \frac{\left|TLC^{(g)} - TLC^{(g-1)}\right|}{TLC^{(g-1)}} \leq \epsilon$$

where $TLC^{(g)}$ represents the best cost obtained in generation g.

To further validate the performance of the model, a sensitivity analysis was conducted. Key parameters, including ordering frequency, available storage capacity, and delivery delays, were systematically varied, and their impact on logistics costs was quantified as:

$$\Delta TLC_p = \frac{TLC_p^* - TLC_{base}^*}{TLC_{base}^*} \times 100\%$$

where TLC_p^* denotes the optimized cost under parameter variation p, and TLC_{base}^* denotes the baseline optimized cost.

This procedure identified the optimal procurement and layout strategies while also providing insights into the sensitivity of logistics performance under dynamic site conditions and supply chain uncertainties.

RESULTS AND ANALYSIS

The proposed optimization framework was implemented on the case study project. The results are presented in terms of procurement scheduling, layout optimization, cost reduction, and sensitivity analysis.

Procurement Optimization

The optimization process confirmed the need to select the procurement cycles for each material based on material characteristics and constraints imposed by the project site. The genetic algorithm identified unique FOPs for in-place reinforcing steel, on-site AAC blocks, and curtain wall systems, which is shown in Table 3.

Table 3: Optimized Procurement Cycles for Major Materials

Material	Optimal FOP (days)	Strategy	Rationale
Reinforcing Steel	14–21	Bulk procurement	Ensures buffer for structural activities, reduces delivery frequency
AAC Blocks	3–7	Short-cycle replenishment	Minimizes storage congestion during peak demand
Curtain Wall Systems	1–3	Just-in-time (JIT)	Aligns delivery with installation, avoids high storage costs

The results reaffirm the idea that procurement decisions must consider material characteristics rather than be generalized. In the case of reinforcing steel, it is better to buy in bulk so that continuous structural work can proceed, for AAC blocks, short-cycle deliveries provide some buffering to site constraints and congestion, curtain wall systems utilize a JIT approach to minimize the consequences of storing too much material for a timely installation and potential cost risks. A hybrid procurement approach can minimize the risk of stock-outs against the financial and spatial costs of holding inventory, which is important if working on projects with mixed material demands and site storage limitations.

Layout Optimization

The optimization of temporary facilities and storage areas was significant in enhancing site logistics. The model minimized costs of reorganization while improving materials handling through the effective dynamic location of storage and staging areas through a facility's lifecycle.

Table 4: Layout Optimization Results across Project Stages

Stage	Facility Adjustment	Impact on Logistics
Early	Storage zones near crane locations	Reduced handling distance, improved efficiency
Mid	Relocation of fabrication yard	Freed up central site space for AAC blocks
Late	Reallocation of curtain wall staging area	Minimized travel distance for façade installation

In the initial phase, locating storage areas close to the crane working zones improved lifting productivity while decreasing travel distances. In the second, phase, the fabrication area was moved to free up central site space better suited for storing AAC blocks, which consume more storage space than any other product used during the project. In the last phase, staging areas for curtain wall systems were relocated closer to where the assembly occurred to save on transport distances, and more importantly for this project, take advantage of avoiding multiple trip relocations. These changing activities, not only made the lifting and handling processes easier, but improved space utilization across all activities throughout the project. Overall, the revised layout achieved more than a 15% reduction in Resource Travel Cost (RTC) compared to the baseline, establishing how critical spatial optimization is in conjunction with procurement activities for improving efficiency in construction logistics datasets.

Cost Analysis

The optimized logistics strategy significantly reduced the Total Logistics Cost (TLC) compared to baseline practices. Major cost contributors included ordering, layout, financing, and stock-out costs.

Table 5: Cost Breakdown of Optimized Logistics Plan

Cost Component	Value (USD)	Share of TLC (%)
Ordering Cost (OC)	1,150,000	48.9%
Financing Cost (FC)	320,000	13.6%
Stock-Out Cost (SC)	280,000	11.9%
Layout Cost (LC)	600,000	25.6%
Total Logistics Cost	2,350,000	100%

As presented in Table 5, the major costs were ordering cost (48.9%), layout cost (25.6%), financing cost (13.6%), and stock-out cost (11.9%) with a total of USD 2,350,000. The model realized savings of 17.8% in total logistics cost (TLC), demonstrating the effect of optimized procurement, improved inventory management, and enhancement of warehouse layout. Ordering cost accounted for the largest share of the total cost, indicating that savings could have been realized by improving bulk purchasing negotiations and arrangements with suppliers. The layout cost savings were valuable in improving the material flow in the warehouse and the efficient use of storage space through improved organization. The financing cost savings and stock-out management provided opportunities to manage and eliminate these unnecessary costs. Overall, this analysis indicated that small changes in major logistics component can produce a significant increase in the efficiency of supply chains, reduce operating costs, and facilitate more cost-competitive and reliable management of materials.

Sensitivity Analysis

Key parameters were deliberately changed to test the robustness of the logistics model. A shorter ordering frequency reduced TLC by 5% through lower financing costs but increased delivery costs more, while a longer ordering frequency raised TLC by 4% due to increased inventory holding costs. Reductions in storage capacity (+12%) and delivery delays (+10%) produced a considerable increase in the TLC, with JIT materials considerably impacted. Demand fluctuations (+15%) increased TLC by 8% with a greater impact on reinforcing steel.

Table 6: Sensitivity Analysis Results

Parameter Variation	Effect on TLC	Key Observation
Ordering Frequency (shorter FOP)	–5%	Reduced financing cost, higher delivery cost
Ordering Frequency (longer FOP)	+4%	Increased inventory holding, reduced transport
Storage Capacity (–20%)	+12%	Severe congestion increased handling costs
Delivery Delay (+10%)	+10%	JIT materials most affected (curtain walls)
Demand Fluctuation (+15%)	+8%	Reinforcing steel most sensitive

These results highlight storage capacity as the most influential parameter, followed by delivery delays, demonstrating the necessity of flexible site layouts and resilient procurement strategies.

CONCLUSION

Optimizing material logistics in civil engineering supply chains is essential to improve project efficiency, reduce costs, and avoid costly delays. This research provided a working model for integrating procurement scheduling, spatial layout, and Genetic Algorithm decision support within an informed framework to address persistent challenges in construction logistics including segmented supply chains, uncertain demand, and restricted space on-site. The case study highlighted the benefits of implementing hybrid procurement strategies based on material characteristics, and relocating temporary facilities dynamically throughout the construction phase in significant cost reductions in material handling, improved use of resources. The reduction of Total Logistics Cost by 17.8% was evident from combining an enhanced decision support system with relevant real world constraining factors. Sensitivity analysis testing has also confirmed the robustness of the integrated framework based upon differing site conditions and justifies an adaptable and flexible planning approach to managing construction projects. In conclusion the research contributes both empirically based knowledge and methodological knowledge to contribute to a self-sustaining pathway for construction firms to improve logistics performance, follow sustainable practices, and remain competitive in a growingly complex civil engineering environment.

REFERENCES

1. Giang, Dang TH, and Low Sui Pheng. "Role of construction in economic development: Review of key concepts in the past 40 years." Habitat international 35, no. 1 (2011): 118-125.
2. Hasim, S., M. A. Fauzi, Z. Yusof, I. R. Endut, and A. R. M. Ridzuan. "The material supply chain management in a construction project: A current scenario in the procurement process." In AIP Conference Proceedings, vol. 2020, no. 1, p. 020049. AIP Publishing LLC, 2018.
3. Firoozi, Ali Akbar, Ali Asghar Firoozi, Yasser Alashker, and Safeer Ahmad. "Advancing civil engineering: The transformative impact of neuromorphic computing on infrastructure resilience and sustainability." Results in Engineering 24 (2024): 103487.
4. Hasaniyan Pourfereidani, Amin, Ardalan Feili, Mohammad Nikmanesh, and Shahryar Sorooshian. "An Analysis of Success in Supply

Chain Management for Construction Projects: Fuzzy Inference System Application." Journal of Soft Computing in Civil Engineering 9, no. 2 (2025): 167-195.

5. Anaba, D. C., A. J. Kess-Momoh, and S. A. Ayodeji. "Optimizing supply chain and logistics management: A review of modern practices." Open Access Research Journal of Science and Technology 11, no. 2 (2024): 020-028.
6. Kanike, Uday Kumar. "Factors disrupting supply chain management in manufacturing industries." Journal of Supply Chain Management Science 4, no. 1-2 (2023): 1-24.
7. Pai, Jagadeesha B., and Sumukh Hungund. "Investigating the mediating roles of inventory management and supply chain disruption factors in logistics performance–An evidence from the construction industry from Coastal Karnataka, India." Results in Engineering 26 (2025): 104822.
8. Tagaro[1], Jomel C., Danica Terese S. Valda, Segundo E. Villa III, and Michiko D. Yasuda[4]. "Logistics Optimization: A Literature Review of Techniques for Streamlining Land Transportation in Supply Chain Operations."
9. Khedr, Ahmed M. "Enhancing supply chain management with deep learning and machine learning techniques: A review." Journal of Open Innovation: Technology, Market, and Complexity 10, no. 4 (2024): 100379.
10. Nguyen, Ngoc-Ai-Thy, Chia-Nan Wang, and Thanh-Tuan Dang. "Advanced Process Optimization in Logistics and Supply Chain Management." Processes 13, no. 6 (2025): 1864.
11. Cataldo, Ieva, Audrius Banaitis, Ashutosh Samadhiya, Nerija Banaitienė, Anil Kumar, and Sunil Luthra. "Sustainable supply chain management in construction: an exploratory review for future research." Journal of Civil Engineering and Management 28, no. 7 (2022): 536-553.
12. Firoozi, Ali Akbar, D. O. Oyejobi, and Ali Asghar Firoozi. "Innovations in energy-efficient construction: Pioneering sustainable building practices." Cleaner Engineering and Technology (2025): 100957.
13. Efendi, Muhammad, Hanie Teki Tjendani, and Esti Wulandari. "Analysis of Building Construction Project Management Using Lean Construction Approach to Determine Cost and Time Waste in the Construction Project of Pondok Pesantren Syifaul Qulub Surabaya." Enrichment: Journal of Multidisciplinary Research and Development 2, no. 12 (2025).
14. Mbago, Musa, Joseph M. Ntayi, Marcia Mkansi, Sheila Namagembe, Benjamin R. Tukamuhabwa, and Noah Mwelu. "Implementing reverse logistics practices in the supply chain: a case study analysis of recycling firms." Modern Supply Chain Research and Applications (2025).
15. Alothaimeen, Ibraheem, and David Arditi. "Overview of multi-objective optimization approaches in construction project management." In Multicriteria optimization-Pareto-optimality and Threshold-optimality. IntechOpen, 2019.
16. Cannas, Violetta Giada, Maria Pia Ciano, Mattia Saltalamacchia, and Raffaele Secchi. "Artificial intelligence in supply chain and operations management: a multiple case study research." International journal of production research 62, no. 9 (2024): 3333-3360.
17. Alsehaimi, Abdullah, Ahsan Waqar, Khaled A. Alrasheed, Abdulrahman S. Bageis, Hamad Almujibah, Omrane Benjeddou, and Abdul Mateen Khan. "Building a sustainable future: BIM’s role in construction, logistics, and supply chain management." Ain Shams Engineering Journal 15, no. 12 (2024): 103103.
18. Abdulraheem, Abdulmalik Olajuwon. "Just-in-time manufacturing for improving global supply chain resilience." Int J Eng Technol Res Manag 2, no. 11 (2018): 58.
19. Yamoah, Lord Emmanuel, Ronald Osei Mensah, and Agyemang Frimpong. "The benefits, challenges and implications for integrating emerging technologies in risk evaluation procedures for supply chains in transportation logistics." Discover Sustainability 6, no. 1 (2025): 476.
20. Attia, El-Awady, Ali Alarjani, Md Sharif Uddin, and Ahmed Farouk Kineber. "Examining the influence of sustainable construction supply chain drivers on sustainable building projects using mathematical structural equation modeling approach." Sustainability 15, no. 13 (2023): 10671.
21. Awaad, Shrouk, Dina M. Mansour, Ibrahim Mahdi, and Ibrahim Abdelrasheed. "Impact of material supply chain on the productivity optimization for the construction of roads projects." Scientific Reports 14, no. 1 (2024): 3294.
22. Seppänen, Olli, and Antti Peltokorpi. "A new model for construction material logistics: From local optimization of logistics towards global optimization of on-site production system." In Annual Conference of the International Group for Lean Construction, pp. 73-82. National Pingtung University of Science and Technology, 2016.
23. Hossen, Rosmita, and Dr Navneet Himanshu. "Optimization of Construction Material Cost through Logistics Planning Using Different Meta-Heuristic Optimization Algorithms: A Comprehensive Study." Decision Making: Applications in Management and Engineering 7 (2024): 42-53.
24. Alanazi, A., K. Al-Gahtani, and A. Alsugair. Framework for Smart Cost Optimization of Material Logistics in Construction Road Projects. Infrastructures 2022, 7, 62. 2022.

25. Buhaievskyi, Mykhailo, and Yuri Petrenko. "Planning and optimization models in ready-made concrete production and logistics." Radioelectronic and Computer Systems 2025, no. 2 (2025): 264-279
26. Jiang, Can, Xin Li, Jia-Rui Lin, Ming Liu, and Zhiliang Ma. "Adaptive control of resource flow to optimize construction work and cash flow via online deep reinforcement learning." Automation in Construction 150 (2023): 104817.
27. Ateş, Kübra Tümay, Cenk Şahin, Yusuf Kuvvetli, Bülent A. Küren, and Aykut Uysal. "Sustainable production in cement via artificial intelligence based decision support system: Case study." Case Studies in Construction Materials 15 (2021): e00628.
28. Salehi, Mina, Mohammad Ali Soukhakian, and Mohammad Reza Mozaffari. "Optimization of transport system in cement industry: A Case study in Omid Siman Darab Cement Manufacturing Company." European Online Journal of Natural and Social Sciences 2, no. 3 (s) (2013): pp-747.
29. Said, Hisham, and Khaled El-Rayes. "Optimizing material logistics planning in construction projects." In Construction Research Congress 2010: Innovation for Reshaping Construction Practice, pp. 1194-1203. 2010.
30. Said, Hisham, and Khaled El-Rayes. "Optimizing material procurement and storage on construction sites." Journal of construction engineering and management 137, no. 6 (2011): 421-431.
31. Pan, Nai-Hsin, Ming-Li Lee, and Sheng-Quan Chen. "Construction material supply chain process analysis and optimization." Journal of Civil Engineering and Management 17, no. 3 (2011): 357-370.
32. Rudraksh, K., G. Sharath Reddy, S. Guna Chander, K. Ruthvik Reddy, and Bokka Srinivas. "OPTIMIZATION OF CONSTRUCTION SUPPLY CHAINS." International Journal of Advances in Agricultural Science and Technology 12, no. 3 (2025): 100-108.
33. Yang, Yishu, Ying Yu, Chenglin Yu, and Ray Y. Zhong. "Data-driven logistics collaboration for prefabricated supply chain with multiple factories." Automation in Construction 168 (2024): 105802.
34. Huemer, Johannes, Markus Murschitz, Matthias Schörghuber, Lukas Reisinger, Thomas Kadiofsky, Christoph Weidinger, Mario Niedermeyer et al. "ADAPT: An Autonomous Forklift for Construction Site Operation." arXiv preprint arXiv:2503.14331 (2025).