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Modern Strategies for Delay Reduction and Resource Optimization in Construction

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Abstract: This review paper presents a thorough examination of the multi-project scheduling and resource management (MPSRM) model integrated with queuing theory, p-hub median models, and parallel machine scheduling to optimize supply networks in construction projects. It further extends to investigate the global challenge of construction delays-a key contributor to cost overruns and legal disputes and highlights concrete works optimization as an impactful preventive strategy. Drawing from bibliometric analyses and multiple case studies worldwide, this paper details how integrated approaches can reduce costs, improve schedules, enhance quality and safety, and advance sustainability in construction projects across diverse regions. The goal is to provide an exhaustive reference that bridges theoretical advancements with practical solutions to advance sustainable construction management.

Keyword: Construction Project Management, Delay Mitigation Strategies, Resource Optimization, Schedule and Cost Control, Digital Construction Technologies.

I. INTRODUCTION

With increasing complexity and geographical dispersion of construction projects, companies face daunting challenges in network design, resource allocation, and scheduling. Delays and cost overruns remain critical barriers to project success worldwide, often stemming from fragmented supply chains and inefficient resource management. The hub location problem (HLP), essential in logistics, collaborates with queuing theory and scheduling optimization to create frameworks that minimize transportation delays and costs. Concurrently, the prominent use of concrete in infrastructure exacerbates carbon emissions and project delays; hence, optimizing concrete works is pivotal to address environmental and economic concerns. This review paper discusses the innovative hybrid MPSRM model presented by Cheraghi et al. (2022), illustrating how combining classical optimization with queueing theory and fuzzy methods leads to robust solutions in multi project scenarios. Additionally, it explores research trends in concrete works optimization emphasizing material composition, structural design, construction techniques, and scheduling acceleration to mitigate delays.

II. LITERATURE REVIEW

The hub location problem (HLP) takes a central role in construction logistics, guiding the optimal placement of distribution points to minimize total transportation cost and delay. O'Kelly's pioneering work in the mid-1980s laid the foundations for discrete p-hub median problems, which Campbell (7 994, 1996) further extended by considering freight containers and network designs. Alumur and Kara (2008) provide comprehensive reviews exhibiting the evolution of HLP, while recent literature integrates queuing theory to model congestion and delays realistically, notably through MMcn multi- class queues (lshfaq and Sox, 2012; Rahimi et al., 2016). Cheraghi et al. (2022) uniquely integrate MMcn queuing, p-hub median models, and parallel machine scheduling with fuzzy interactive programming to handle real-world complexities, including multiple projects, resource constraints, transport mode selection, and budgetary limitations. This amalgamation addresses limitations of previous siloed approaches and presents a framework adaptable to diverse industries.

Table 1: Comparison of Cost and Time Performance Before and After Applying the MPSRM Model

Parameter	Before Optimization	After Optimization	Improvement (%)
Total Transportation Cost (USD Million)	48.25	46.13	5%
Average Project Delay (Days)	60	42	30%
Equipment Idle Time (Hours/Month)	120	80	33%
Carbon Emission (Ton CO_2)	2100	1800	14%
Overall Efficiency Index	0.68	0.82	+21%

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Concrete Works Optimization and Delay Mitigation

Concrete, as the foundational building material globally, commands extensive attention due to its environmental impact and predominance in construction delays. Global research reveals variable regional issues affecting delay causes, for instance, contractor inefficiencies in Saudi Arabia, payment delays in Egypt, supply chain issues in India, and design constraints in Malaysia.

Optimization strategies in concrete works include multi-objective genetic algorithms for reinforced concrete design, leveraging artificial intelligence for optimal mix proportions, employing supplementary cementitious materials (SCMs) such as fly ash, silica fume, and recycled plastic waste, and advancing construction methods including prefabrication and BIM technology. Schedule acceleration methods like crashing and fast-tracking are studied to balance time savings versus extra costs.

Bibliometric analyses indicate that China and India lead in concrete optimization research output, followed by emerging interests from Middle Eastern countries, whereas Indonesia and several developing regions lag, highlighting potential technology transfer opportunities to address project delays effectively.

Construction Project Performance in Nigeria

Challenges in Nigeria's construction industry span poor governance, lack of skilled labor, inadequate infrastructure, and low technology adoption including BIM and digital tools. These issues worsen delay impacts, cost inflation, safety risks, and project quality. Empirical studies reveal strategic interventions involving contract oversight, workmanship quality, specification compliance, proactive monitoring, safety culture, resource planning, and timely project completion significantly enhance project performance in the Nigerian context (Ogunde et al., 2020; Abbas et al., 2018).

Problem Statement

Managing multiple concurrent projects, each with its own unique site conditions, workforce, material sourcing, and scheduling needs, complicates raw material allocation and transportation sequencing. The Iranian dam projects case study exemplifies such complexity where seven projects sourced from multiple regional mines require optimal hub selection, delivery schedules, and transportation mode choices constrained by access roads, budget limits, and heavy machinery availability.

Simultaneously, global construction faces widespread delays driven by inefficient concrete works, necessitating integrated scheduling and concrete optimization frameworks to reduce overall costs and negative environmental impacts.

Table 2: Key Factors Affecting Construction Project Performance in Nigeria

Performance Factor	Identified Challenge	Impact on Project Delivery	Recommended Improvement Strategies	Expected Outcome
Governance and Policy	Weak contract enforcement and corruption	Delays, cost overruns, and poor accountability	Strengthen policy frameworks and ensure transparent procurement processes	Improved governance and timely project completion
Skilled Labor Availability	Shortage of trained and experienced workers	Low productivity and poor-quality workmanship	Implement vocational training and certification programs	Enhanced workmanship and improved quality standards
Technology Adoption (BIM, AI, Digital Tools)	Low usage due to high cost and lack of awareness	Inefficient planning and scheduling	Promote digital literacy and subsidize access to technology	Better coordination and reduced rework
Material Supply Chain	Delayed imports and poor logistics	Frequent project stoppages and time loss	Develop local material production and reliable logistics systems	Reduced dependency and timely material delivery
Financial Management	Payment delays and limited access to capital	Cash flow problems and project suspension	Ensure prompt payment cycles and financial transparency	Improved cash flow and continuous project progress
Safety and Compliance	Poor safety culture and lack of monitoring	High accident rates and project interruptions	Enforce safety regulations and conduct regular training	Safer work environments and fewer disruptions

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III. METHODOLOGY

MPSRM Framework

The multi-stage MPSRM model systematically addresses resource allocation and scheduling challenges:

Stage 1 - MMcn Queuing System: This queueing model classifies material deliveries as different classes in a multi-server environment, capturing real congestion and wait time effects between various project sites. It realistically simulates delays arising from limited transportation channels, loading/unloading times, and coordination bottlenecks.

Stage 2 - p-Hub Median Model: This optimization phase determines an optimal subset of project nodes to function as centralized hubs that consolidate material handling to reduce overall transportation costs. This step involves evaluating candidate hub locations under cost and distance trade-offs.

Stage 3 - Parallel Mine Scheduling: Parallel machine scheduling is applied to assign and sequence raw material deliveries from multiple resource mines to the selected hubs and manufacturing plants. It prioritizes resource balancing, capacity constraints, and minimizes overlap and idle time among delivery vehicles.

Stage 4 - Fuzzy Interactive Programming: To resolve the multi-objective nonlinear nature of the problem including cost, time, earliness, and tardiness penalties, fuzzy linear programming is introduced. It pragmatically incorporates uncertainties and competing goals to find tractable solutions suitable for large scale industrial applications.

Concrete Works Optimization Research Method

A systematic literature review and bibliometric analysis approach was employed to map and analyze scholarly work relating to construction delays and concrete works optimization worldwide. Using keyword extraction, trend analysis by publication year and country, and thematic clustering, the research highlights dominant areas such as mix design, structural optimization, sustainability, and scheduling acceleration

Experimental Setup and Procedure

- MPSRM Case Study

The model was applied to an Iranian construction firm managing seven dam projects distributed regionally. Raw material data, mine locations, transportation modes, hub candidate sites, and operational constraints were collected comprehensively. The GAMS optimization platform was employed to evaluate multiple scenarios altering the number of hubs, delivery sequencings, and transport modes. The operational procedure incorporated real-world constraints such as poor road access, machinery limitations, and fluctuating project workloads for robust applicability.

- Concrete Works Review Procedure

Papers spanning multiple continents were collected, focusing on causes of delays in construction and optimization strategies specifically related to concrete works. The review assessed:

- Regional research intensity and focus areas.
- Methodologies involving genetic algorithms, recycling, and prefabrication.
- Benefits achieved in cost/time savings, quality improvements, safety, and sustainability.
- Case studies demonstrating practical innovations and industry adoption barriers.
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IV. RESULTS

- Implementation of three strategically located hub factories reduced overall network transportation costs by 5%, from $48.25 million to $46.13 million.
- Queueing model inclusion improved delivery time predictions and facilitated resource leveling across sites, minimizing idle equipment use.
- Significant decrease in the need for redundant heavy machinery was observed, reducing capital expenditure.
- Simulation validation via GAMS confirmed the model's robustness and practical feasibility. Concrete Works Optimization Findings
- Structural design optimization and advanced material mix designs yielded prominent cost and carbon footprint reductions.
- Use of SCMs and recycled waste (e.g., fly ash and plastic aggregates) improved durability and environmental compliance.
- Prefabrication integrated with BIM technologies accelerated timelines and minimized onsite labor risks/wastes.
- Schedule acceleration methods, although increasing contingency costs, effectively reduced overall project durations with trade-off balancing via genetic algorithms.

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V. DISCUSSION

- By integrating hub location, queuing theory, and parallel machine scheduling within a fuzzy programming environment, the reviewed MPSRM model addresses the logistic complexity of multi project construction networks comprehensively. Traditional one-dimensional models are insufficient for capturing inherent concurrency and congestion; thus, the hybrid model offers a theoretically innovative and operationally applicable solution.
- Concrete works optimization stands as a critical preventive strategy to address delays that frequently cause cascading schedule
- Disruptions and claim disputes. Innovations in material design, construction techniques, and intelligent scheduling contribute significantly to mitigating delays. The synergy of optimized scheduling and concrete works creates a powerful lever toward sustainable project delivery.
- However, technology adoption disparities exist. Developing countries face skills, technology, and infrastructural gaps that retard system implementation despite evident benefits. Future work must focus on capacity building, real-time data integration, and collaborative industry academia partnerships.

VI. SOLUTION

- Adopt integrated scheduling and resource management tools encompassing queuing and hub location optimization tailored to their project portfolios.
- Implement concrete works optimization
- techniques by leveraging Al, multi-objective genetic algorithms, and sustainable materials.
- Utilize digital construction technologies such as BIM and prefabrication to synchronously improve scheduling accuracy and onsite efficiency.
- Invest in workforce training and technology diffusion to bridge operational gaps, especially in developing regions.

VII. CONCLUSION

This comprehensive review validates the critical role of multi-project scheduling/resource management models enhanced with queuing and hub location theories complemented by concrete works optimization to
systematically reduce delays, costs, and environmental impacts in construction. The MPSRM framework applied in Iranian dam projects demonstrates measurable cost and efficiency gains, while global research confirms concrete optimization's preventive value on project delays. Together, these innovations advance the frontiers of sustainable construction practices

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