

Research On Supply Chain Management for Engineering Projects

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Abstract. Against the backdrop of global engineering projects becoming increasingly large-scale, complex, and international, their supply chains—as temporary, location-fixed, and long-cycle complex systems—face inherent dynamism and uncertainty. This leads to persistent industry challenges such as cost overruns and schedule delays. Traditional management models struggle with risk mitigation and cross-organizational coordination, while emerging technologies remain applied in isolated pockets, failing to systematically address information silos and data barriers. This paper systematically examines the unique characteristics of engineering project supply chains and delves into their three core management dimensions. In procurement and supplier management, organizations must balance centralized versus decentralized approaches and global versus local sourcing while building strategic partnerships to enhance resilience. For logistics and inventory management, attention should focus on “last-mile” delivery and adopt a hybrid push-pull strategy to balance risk and efficiency. In information flow and collaboration management, organizational barriers must be overcome through models like integrated project delivery. The study further highlights that digital technologies—including BIM, IoT, big data, and blockchain—serve as key enablers for enhancing supply chain visibility, collaboration, and trustworthiness. Moreover, in response to sustainability agendas and external disruption risks, building supply chain systems that integrate green practices with resilience strategies has become an inevitable trend.

Keywords: Project Supply Chain, Collaborative Management, Supply Chain Resilience.

1. Introduction

Globally, engineering projects are rapidly evolving toward massive scale, heightened technical complexity, and increased international participation. Against this backdrop, the project supply chain—as a quintessential complex adaptive system—presents core challenges to successful project delivery due to its inherent dynamism and uncertainty. Unlike manufacturing supply chains characterized by standardized production, engineering project supply chains exhibit essential traits such as temporary organizations, fixed locations, and extended cycles. These factors result in significantly more intricate network structures and substantially greater coordination difficulties [1].

This complexity directly fuels persistent challenges in project management practice: cost overruns and schedule delays have become industry norms. Supply chain failures are a key contributing factor. On one hand, sharp fluctuations in raw material prices and frequent global supply chain disruptions have exposed the limitations of traditional supply chain management models in risk anticipation and response capabilities. On the other hand, information disconnects and coordination failures between design, procurement, and construction phases have led to widespread “information silos.” This not only causes issues like delayed material delivery and on-site rework but also hinders data-driven precision decision-making [2].

Although emerging technologies like Building Information Modeling (BIM), the Internet of Things (IoT), and big data offer potential pathways to enhance supply chain visibility and collaboration, their adoption remains largely fragmented. Integration barriers between heterogeneous systems and the absence of unified data standards prevent the full realization of technology-enabled value. Concurrently, the increasingly urgent sustainability agenda demands that engineering project supply chains strike a balance between cost, schedule, and environmental impact. How to reconfigure supply chain models under carbon reduction constraints has emerged as a pressing new challenge. This study systematically explores the unique characteristics of engineering project supply chain

management, its core management processes, the application of digital technologies, and aspects of sustainable and resilient development.

2. Overview of Engineering Project Supply Chains

Supply chain management for engineering projects exhibits fundamental differences compared to traditional manufacturing, differences rooted in the inherent characteristics of engineering projects themselves. First, engineering projects are distinctly one-off and unique. Each project is based on specific geographical conditions, design standards, and client requirements. This means its supply chain cannot be standardized like repetitive production; instead, it must provide highly customized solutions while maintaining full flexibility. Second, project organizations are inherently temporary. Collaborative groups comprising owners, general contractors, subcontractors, and suppliers are formed solely for specific projects and disband upon completion. This transience poses inherent challenges to deep collaboration and trust-building among supply chain members, often resulting in loose relationships and information silos.

Furthermore, the operational model of engineering projects is characterized by fixed locations and mobile resources. Production facilities (i.e., construction sites) are stationary, while all essential resources—including personnel, machinery, building materials, and capital—must be precisely and timely directed to these fixed locations. This feature imposes extremely high demands on logistics planning and on-site material management; delays at any stage directly lead to uncontrolled schedules and costs. Finally, projects typically span extended cycles and carry high risks. From planning and design through construction to final delivery, projects often span several years. During this period, the supply chain is exposed to numerous external risks, including market volatility, regulatory changes, geological uncertainties, and natural disasters. Consequently, risk management becomes a central concern in supply chain management.

Given these unique characteristics, classical supply chain management theories require specific evolution and adaptation when applied to engineering projects. First, the supply chain structure in engineering projects is far from a simple linear relationship. Instead, it constitutes a complex, dynamic “supply network” involving multi-tiered, multi-disciplinary participants. The management focus must shift from controlling linear processes to coordinating the efficient operation of the entire network.

Second, the widely adopted SCOR model reveals limitations in engineering contexts. Its “manufacturing” segment corresponds to on-site “construction and installation”—activities characterized by minimal standardization and high environmental dependency. The ‘distribution’ segment encompasses complex logistics from global suppliers to fixed construction sites, while the “returns” process is largely inapplicable. Thus, critical application and modification of this model are essential.

To address waste and uncertainty in engineering projects, Lean and Agile management philosophies have been introduced and integrated [3]. Lean focuses on identifying and eliminating various forms of waste in construction, such as waiting time, excess inventory, and process defects. Its tools, like Just-in-Time production and the Last-Minute Planning system, aim to achieve precision in logistics and information flow. Concurrently, agile principles emphasize adapting to inevitable changes and uncertainties during project execution. By accelerating information feedback and enhancing decision-making flexibility, agile approaches boost overall supply chain responsiveness and build more resilient supply systems. The integration of these two philosophies—the “Lean-Agile” strategy—is emerging as a cutting-edge approach to optimizing engineering project supply chain performance.

3. Core Management Functions in Engineering Project Supply Chains

3.1. Procurement and Supplier Management

Recent research has deepened the understanding of procurement strategy decision-making in engineering projects. Regarding the trade-off between centralized and decentralized procurement, centralized procurement offers advantages in achieving economies of scale through demand aggregation and standardization [4]. However, decentralized procurement demonstrates greater flexibility in responding to locally specific demands and addressing regional market fluctuations when project sites are dispersed or demand variations are significant.

Regarding decisions between global and local procurement, research trends emphasize considerations of supply chain resilience. Studies indicate that while global procurement offers cost and technological advantages, its longer, more complex supply chains render it more vulnerable to external shocks [5]. Conversely, while local procurement may lack initial price competitiveness, its value in shortening delivery cycles, reducing logistics complexity, and enhancing supply chain visibility is increasingly recognized in high-uncertainty project environments.

In supplier relations, value-based strategic partnerships can significantly improve project performance across cost, schedule, and quality by fostering risk-sharing and innovation incentives. To address challenges posed by the temporary nature of engineering project organizations, establishing framework agreements based on long-term cooperation intentions can maintain stable collaborative relationships within dynamic project environments, thereby overcoming the short-termism inherent in one-off collaborations.

3.2. Logistics and Inventory Management

Research on engineering logistics management continues to focus on its inherent specificity and complexity. Zhou et al. highlighted compliance risks in cross-border logistics and interface efficiency issues in multimodal transport, identifying these as critical bottlenecks causing overall logistics delays [6]. For on-site “last-mile” delivery, the synergistic importance of route optimization and site layout planning is emphasized, as inefficient planning directly leads to construction interruptions and cost overruns.

Inventory management models have yielded new insights from comparative studies of push versus pull systems. While pure pull systems (e.g., just-in-time production) theoretically enable zero inventory, their implementation in engineering practice demands exceptionally stable information flows and highly reliable suppliers—any minor disruption can halt entire production systems. Therefore, Abdul-Rahman et al. advocate a hybrid strategy: implementing enhanced pull management on critical paths while applying optimized push strategies for non-critical or long-lead-time materials to balance risk and efficiency [7]. Furthermore, studies on vendor-managed inventory (VMI) and consignment systems indicate that their successful implementation heavily relies on high levels of trust and transparent information-sharing mechanisms among participating parties [8].

Information Flow and Collaborative Management

The issue of “information silos” remains widely recognized as a core obstacle hindering supply chain efficiency in engineering projects. Recent empirical research confirms that inconsistencies and delays in information transmission between design, construction, and procurement phases are among the primary causes of on-site rework and schedule delays.

To promote collaboration, academia continues exploring ways to break down organizational barriers through process and contract design. Integrated Project Delivery (IPD), as an innovative project delivery approach, has garnered sustained attention. Miller et al. demonstrated that this approach effectively leverages key suppliers' expertise by integrating them into early design phases. This optimizes construction solutions and feasibility, thereby reducing subsequent engineering changes and conflicts at the source [9]. Furthermore, effective collaboration relies not only on contractual frameworks but also on establishing unified communication protocols and shared working standards—foundational elements for ensuring seamless information flow among all parties [10].

4. Application of Digital and Intelligent Technologies

Building Information Modeling (BIM) has evolved from a 3D design tool into a core information platform supporting supply chain collaboration in engineering projects. Research by Wang et al. indicates that BIM creates digital asset models incorporating physical and functional characteristics, providing a single source of truth for all supply chain participants [11]. Its real-time updating and sharing capabilities enable visualization of material requirements, delivery schedules, and installation statuses, significantly reducing information asymmetry. Furthermore, BIM-based automated clash detection identifies design conflicts between disciplines before construction, effectively preventing material waste and schedule delays caused by on-site rework [12]. Upstream in the supply chain, deep integration of BIM models with prefabrication enables seamless transfer of design data to manufacturing data, driving the transformation toward a design-manufacturing-assembly integrated model that enhances construction precision and efficiency [13].

The convergence of IoT and big data technologies is profoundly reshaping the operational model of engineering project supply chains. By deploying sensors and RFID tags on structural components, material batches, and heavy equipment, real-time status awareness and tracking of all supply chain elements can be achieved. The vast data generated is processed through big data analytics, yielding deep insights into inventory levels, equipment utilization, and logistics status. This data-driven management approach facilitates a shift from experience-based to predictive decision-making. For instance, analyzing historical data to forecast material consumption patterns enables optimized procurement planning and inventory strategies.

Blockchain technology, as a distributed ledger system, is increasingly revealing its potential within engineering project supply chains. Its decentralized, immutable, and traceable nature is recognized for enhancing transparency and trust in supply chain finance, thereby streamlining payment processes and reducing financing costs. In contract execution, smart contracts can automatically trigger payments based on predefined, verifiable conditions—such as the successful inspection of delivered materials—reducing disputes and delays inherent in traditional contract management. Furthermore, for critical building material traceability, blockchain can record lifecycle information from raw material extraction to final installation, providing a reliable technological foundation for quality traceability and sustainability certification.

5. Sustainable and Resilient Supply Chain Development

Building green supply chains has become a core approach for engineering projects to address environmental regulations and fulfill social responsibilities. Its implementation spans the entire supply chain process. At the source, green procurement requires a comprehensive evaluation of suppliers' environmental performance during selection, prioritizing materials and equipment with environmental certifications. In logistics, low-carbon transportation emphasizes reducing carbon emissions through route optimization, modal shift (e.g., from road to rail), and using low-carbon fuels. At the end of the chain, construction waste management focuses on enhancing reuse rates and reducing landfill disposal through meticulous on-site sorting and advanced recycling technologies. Concurrently, the proportion of recycled materials used—such as recycled aggregates and structural steel—has become a key indicator for measuring a project's sustainability.

Although the value of technologies like BIM, ERP, and blockchain is widely recognized, significant data barriers exist between these heterogeneous systems, resulting in low integration levels. The root cause lies in the absence of cross-platform, industry-wide unified data standards and interaction protocols, perpetuating widespread “data silos” that hinder seamless data flow and value extraction across the entire chain.

Supply chain resilience refers to a supply chain's ability to maintain core functions and rapidly recover to normal or even improved states after experiencing disruptive events. In recent years, global pandemics, geopolitical conflicts, and extreme weather events have elevated resilience as a central focus in supply chain management research. Enhancing resilience begins with the systematic

identification and assessment of potential disruption risks, including analyzing supplier network vulnerabilities and dependencies on critical logistics routes. Developing comprehensive business continuity plans and contingency measures has been proven to significantly reduce response and recovery times following disruptions, making them indispensable components of building resilient supply chains.

6. Conclusion

This study systematically elucidates the core management challenges faced by engineering project supply chains amid complexity, transience, and uncertainty. Findings indicate that breaking down “information silos” through collaborative management, achieving data-driven operations by integrating digital technologies, and establishing a supply system that is both green and resilient are key to enhancing project performance. The core significance of this research lies in providing a systematic integration perspective to address the limitations of traditional management models. Future development hinges on resolving three fundamental issues. First, unified data standards must be established to overcome barriers between diverse technologies. Building upon this foundation, tools like artificial intelligence will be leveraged to achieve more precise forecasting and decision-making. Simultaneously, robust trust must be fostered among participating companies through innovative collaboration models.

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