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RELIABLE DELIVERY ORDER FOR IMPROVING WORKFLOW IN THE CONSTRUCTION SUPPLY CHAIN

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ABSTRACT

Achieving reliable workflow on-site has long been a priority in the lean construction community, particularly as construction projects become more complex and uncertain. A reliable supply chain between an external supplier and on-site contractor becomes even more critical to project success as the architecture, engineering, and construction (AEC) industry increasingly adopts prefabrication and off-site construction. This paper addresses the increasing need for a reliable supply chain by focusing on ensuring the reliability of delivery orders.

Recent studies on construction supply chains have attested that demand uncertainty leads to diminished reliability in the product flow of the supply chain, more so when external suppliers are not shielded against the uncertainty in the delivery due date. This paper introduces a systematic approach to enhancing delivery order reliability by applying the Last Planner to the order-releasing process. In this paper, we present a set of strategies to improve delivery order reliability, including organizational and contractual structures at the organizational level, supplier involvement in construction scheduling at the project level, and ensuring high-quality delivery orders at the process level. Moreover, we introduce three key quality criteria to enhance delivery order reliability as well as a set of metrics to measure delivery order reliability effectively, specifically DOR(%) and DOR(Δ) as a probabilistic distribution.

KEYWORDS

Supply chain management, Reliable Delivery Order, The Last Planner System, information flow, and production flow

INTRODUCTION

The Architecture, Engineering, and Construction (AEC) industry is rapidly evolving with the adoption of advanced methodologies such as prefabrication and off-site construction (Bernstein, 2005; Ho et al., 2023). As these innovations reshape how projects are delivered, a reliable and cost-efficient supply chain has become more critical than ever to ensure project success (Kim & Kim, 2020; Kim & Kim, 2021). Despite the need for better managing off-site deliveries, prevailing practices within the construction supply chain continue to suffer from significant inefficiencies and unreliable demand flows, which hinder overall project performance (Thurnberg et al., 2017). Although prior research has examined individual aspects of supply chain reliability, such as supplier production scheduling and contractor plan reliability, limited studies have focused on the delivery order as the key communication

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mechanism between suppliers and contractors. Addressing this gap is crucial for improving material flow efficiency and minimizing disruptions in off-site construction projects.

In this paper, we examine the flows of the construction supply chain (i.e., information flow and product flow), focusing mainly on the challenges posed by unreliable information flow, which contributes to misalignment between external suppliers and contractors, leading to low on-time delivery rates and increased production/inventory costs. Especially, this paper focuses on the delivery order, which serves as the supply chain's primary source of information flow. A delivery order refers to a contractor's request for an external supplier to deliver specific materials or products on a designated date, aligned with the construction schedule. Furthermore, we propose strategies and key characteristics of reliable delivery orders to enhance the reliability of information flow in the construction supply chain. The proposed approach is specifically applicable to supply chains where the supplier's lead time is shorter than the look-ahead planning window It is noted that this paper is still a conceptual paper in which the strategies need to be tested in practice. By improving the reliability of information flow, the proposed approach aims to create a more reliable and economical supply chain, ultimately driving better outcomes for construction projects.

FLOW IN CONSTRUCTION SUPPLY CHAIN

Reliable workflow on-site is crucial for the success of construction projects, as highlighted in numerous lean construction publications (Ballard, 2000; Kim & Ballard; 2010, Kim, 2017). The Last Planner System is a planning methodology for mitigating workflow uncertainty, ensuring through quality assignments that uncertainty in the construction short-term schedule does not cascade down to work crews (Ballard, 2000). Similarly, the project requires a system that prevents any uncertainties in the information flow from impacting external suppliers. The supply chain workflow between a construction contractor and an external supplier involves two critical components: information flow and product flow as shown in Figure 1(Vrijhoef & Koskela, 2002; O'Brien et al., 2002).

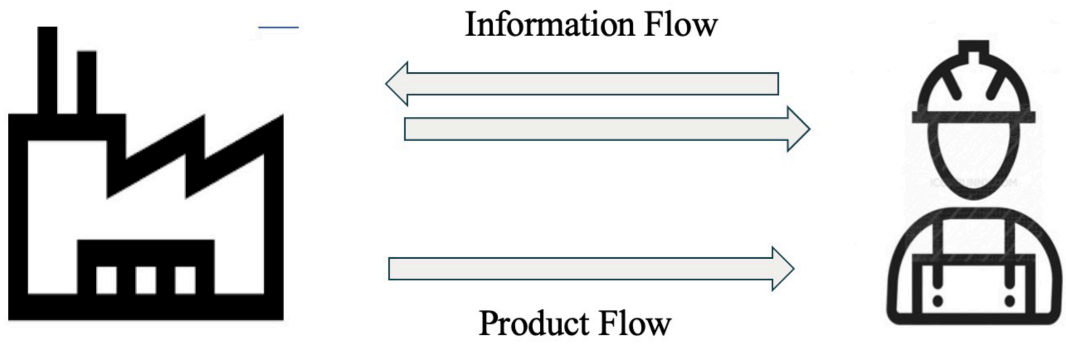

Figure 1: Flows in a Construction Supply Chain (Vrijhoef and Koskela, 2002)

Product flow refers to the movement of prefabricated products from external suppliers or fabricators to on-site contractors (O'Brien et al., 2002). It also addresses the production at the shop and logistics to the contractors on-site. The information flow between a construction contractor and an external supplier encompasses two primary elements: (1) the demand or delivery order, which includes product specifications, quantity, and delivery deadlines, and (2) the supplier's capacity and lead time. Both flows must be coordinated to prevent delays and ensure the timely delivery of products, ultimately contributing to reliable on-site workflow performance and project success.

For product flow, prefabricated products must be delivered on time and fully compliant with specifications, allowing contractors to install them as needed without delays or excessive on-site inventory. When there are changes in delivery dates, external suppliers need to respond to demand changes. In this regard, various scheduling techniques for the suppliers have been proposed and tested accounting for delivery date uncertainty (Du et al., 2020; Kim & Kim, 2024; Kim et al., 2022; Kim et al., 2020; Ko & Wang, 2010; Wang & Hu, 2018; Zhang et al., 2023). Gao et al. (2024) proposed a dynamic scheduling with real-time monitoring to improve the workflow reliability in the supply chain. However, most of these models assume that suppliers have access to reliable probabilistic data on due date changes. This reliance poses a critical challenge: contractors need to issue reliable delivery orders or inform the contractors of probabilistic distributions of potential changes in the dates of deliveries of specific orders. In the absence of such data, suppliers encounter significant obstacles in developing robust production schedules, undermining the reliability of the supply chain.

In contrast, information flow focuses on the timely transmission of reliable information on demand, such as product specifications, design changes, delivery schedules, delivery orders, and lead time. Reddy & Raso (2022) underscored that communication barriers among stakeholders significantly contributed to inefficiencies in construction projects, particularly in the dynamics between suppliers and contractors (Reddy & Rao, 2022). Boateng (2019) demonstrated that the inherent complexity of construction projects often led to fragmented communication, which adversely affected project schedules and overall economic outcomes. The reliability of information flow significantly impacts the performance of product flow. For example, Kim & Kim (2022) show that a 5% change in the delivery due date can lead to more than a 10% variation in the actual lead time, demonstrating the strong interdependency between these two flows. Vidalakis et al. (2013) also demonstrated that the supplier's lead time becomes increased even when initial demand variability is relatively small. Specifically, delivery delays from suppliers can extend significantly compared to cases where demand variability exceeds 200%. Their findings suggest that the supplier's lead time increases substantially when delivery dates change. This paper focuses on the delivery order, which conveys critical information such as the delivery due date, as its reliability directly influences the workflow of the supply chain.

CHALLENGES DUE TO UNRELIABLE SUPPLY DEMAND

In construction projects, contractors on-site generate demand that external suppliers or manufacturers must meet. This demand is generally communicated through a delivery order, which includes critical information such as product specifications, quantity, and delivery deadlines. Reliable delivery orders from suppliers are crucial for reliable workflow in the supply chain. Reliable delivery orders ensure that materials are available when needed, reducing the risk of project delays and minimizing disruptions to workflow (Koskela, 2000). This reliability is particularly vital in the construction industry, where material delays can lead to unexpected costs and, ultimately, project failure (Fredriksson & Thunberg, 2020). Additionally, poor coordination and lack of real-time information sharing between contractors and suppliers are key factors contributing to unreliable deliveries, underscoring the importance of integrating supplier information into planning processes (Al-Werikat, 2017; Kim & Rhee, 2024). Studies have also shown that a lack of reliable site production systems, including material deliveries, can significantly hinder supply chain performance, reinforcing the need for reliable information flow scheduling (Thunberg & Fredriksson, 2018; Kim & Rhee, 2024; Kim et al., 2023). To address these challenges, some researchers advocate for a contractor's plan reliability and reliable delivery order to improve delivery reliability, ensuring that materials arrive as planned (Kim et al., 2023). Therefore, maintaining reliable delivery orders is essential for the seamless execution of construction projects and the overall success of the supply chain.

There is literature on improving the workflow in the construction supply chain. Bhore (2022) investigated the factors contributing to material delivery time variance in prefabricated construction but did not address how to improve the reliability. Zhang & Zhang (2024) propose an automated delivery management system under uncertainty to minimize cost and emissions. Howwever, their approach assumes that uncertainty in information flow persists rather than seeking to minimize it at its source. Chauhan et al. (2018) integrate takt planning with prefabrication to enhance industrialized construction efficiency, primarily addressing production flow rather than information flow reliability. In coordinating the workflow between a contractor and a supplier, incentive payments have been used (Kim and Kim, 2024; Zeng et al. 2022). Those previous studies investigated ways to improve supply chain coordination, but they have not addressed how to reduce the uncertainty of delivery orders at the source, given the inherent uncertainty in information flow.

Typically, the specifications (e.g., quality, size) and the order quantity remain consistent unless there are significant changes on-site, such as a design change. However, the delivery due date is far more susceptible to variation as the construction context, such as the construction schedule, directly influences it. These dynamic delivery requirements can result in misalignment between production capabilities and actual demand on-site, creating additional production costs and inventory costs (Ko, 2010), which are typically absorbed by suppliers (Mohamed, 2021). Further evidence from our survey (Ho et al., 2022) shows that 30-40% of delivery orders experience changes in delivery due dates. Fabricators and suppliers are tempted to estimate these potential costs ahead of time and incorporate them into their bidding prices to mitigate such financial risks. This practice leads to an increase in the overall project cost, further straining budgetary constraints.

Recent investigations highlight the urgent need for industry stakeholders and academic institutions to make supply chain demand more reliable (Kim & Rhee, 2024; Kim et al., 2023). Achieving reliability in supply chain demands can significantly enhance the efficiency and cost-effectiveness of the construction supply chain. As inventory and production costs decrease and on-time delivery rates improve, the supply chain becomes more streamlined and reliable. This transformation will create a more reliable and economical supply chain. Such improvements will not only enhance supply chain management but also reduce overall project costs, benefiting all parties involved in construction projects.

PROPOSED APPROACH FOR RELIABLE DELIVERY ORDER

PROPOSED STRATEGIES FOR RELIABLE DELIVERY ORDER

Achieving reliable delivery orders from on-site contractors is foundational for achieving a reliable supply chain between an external supplier and an on-site contractor. However, ensuring such reliability extends beyond simply adhering to ordering rules at the production unit level. Especially, there is a limitation of the existing lean solutions, which primarily focus on the coordination with trade contractors on-site. Unlike subcontractors, external suppliers often have little to no proximity to the contractor, making them more difficult to control. They are not directly accountable for the project’s workflow or project performance, which limits the effectiveness of existing solutions. Given these differences, it demands a holistic approach that integrates procurement and production planning strategies. Below are three proposed strategies to enhance reliability in delivery orders:

Develop Organizational and Contractual Structure to Foster Relationships

The initial strategy focuses on the organizational level. The relationship between contractors and off-site fabricators is often weaker than that between general contractors (GC) and subcontractors on-site. While GCs have considerable authority to coordinate the production plans of subcontractors, on-site contractors typically lack similar efforts for supplier chain coordination between on-site contractors and external suppliers (Kim et al., 2023). Kim & Rhee (2024) assert that the contractural arrangement is needed for better coordination between on-site contractors and external suppliers. Innovative contractual frameworks and organizational structures are needed to bridge this gap to establish stronger collaboration and mutual accountability between contractors and off-site fabricators. Such structures should promote trust, transparency, and alignment in production objectives.

Involve the External Suppliers in the Construction Short-term Scheduling Process

The second strategy focuses on the project management level. To ensure seamless coordination, both external suppliers and on-site contractors must have visibility into each other's production dynamics, including capacity constraints and schedule uncertainties. Lean community supports having external suppliers engaged in lookahead planning to understand and remove constraints to generate reliable delivery orders (Ballard, 2000). While systems like the Last Planner System emphasize involving external suppliers, their participation remains rare in practice (Garcia & Murguia, 2021). Suppliers need to provide updated lead times and capacity constraints in the look-ahead planning process, while on-site contractors should share real-time construction progress and potential schedule risks. This two-way exchange of information enhances predictability and reduces misalignments (Figure 2). Currently, many commercial contracts pose no penalties for the buyers (i.e., on-site contractors) who issue call-offs with frequent changes, which discourages consistent and transparent information sharing (Kim & Rhee, 2024). Leveraging the relationship-building structures proposed in the first strategy can facilitate this integration.

Release Quality Delivery Orders

Effective delivery order releases depend on informed decision-making, supported by the information exchanges outlined in the second strategy. Contractors must determine the "last responsible moment" to release orders, accounting for installation schedules, lead times, and safety buffers. On the other hand, suppliers need to develop their production schedules considering the uncertainties of construction schedules. By collaborating to establish clear communication protocols, both parties can reduce the likelihood of delays and excessive inventory, ensuring a reliable supply chain flow between an external supplier and an on-site contractor (Kim et al., 2023).

When releasing a delivery order, on-site contractors should ensure the order meets defined quality criteria, as discussed in the subsequent section. This alignment fosters consistency and reliability across the supply chain.

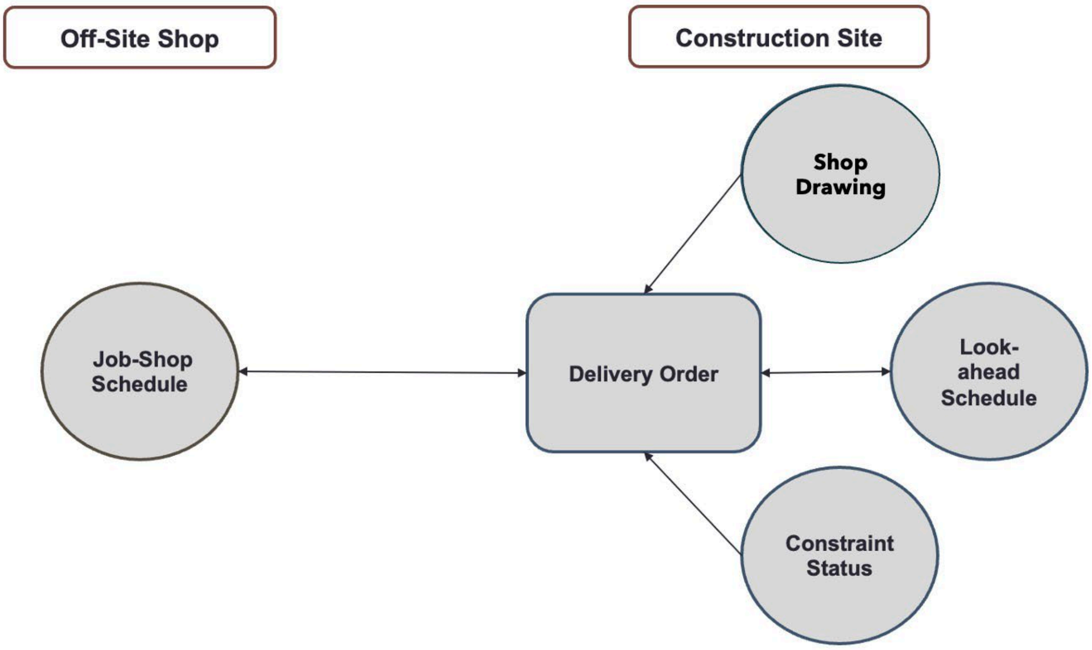

Figure 2: Two-Way Exchange of Information for Reliable Delivery Order

KEY CHARACTERISTICS OF QUALITY DELIVERY ORDER

The key performance dimension of a delivery order released from a contractor is its quality—that is, the degree to which the order meets specific criteria necessary to improve the reliability of information flow. A high-quality delivery order helps reduce the uncertainty of the information flow, shields the external supplier from last-minute changes, and allows the supplier to optimize resources effectively to meet the contractor's requirements. As with the Last Planner System in on-site workflow management, where quality assignments meet the definition, soundness, sequence, and size criteria, the quality of delivery orders is critical to ensuring the reliable flow of materials through a supply chain.

However, achieving the same level of certainty for off-site made-to-order products can be more challenging than for on-site assignments. This is because the forecast period for off-site production is typically much longer than for on-site crew assignments. To address this, the concept of progressive refinement needs to be applied: deferring the final details of delivery orders till the last responsible moment while continually refining them over time. By doing so, the delivery order can progressively align with the evolving buyer's needs, reducing the risk of late-stage changes or call-offs.

In communicating a delivery order, the order should clearly specify three essential components: (1) what is to be delivered, (2) the quantity of materials or components, (3) the delivery date. In the course of the delivery order, the contractor (i.e., buyer) should take into account the fabricator's most up-to-date lead time to determine the latest possible date for releasing the delivery order, ensuring timely procurement and production planning. Through progressive refinement, a contractor's delivery order should meet the following criteria:

Approved Design/Submittal

The first component of the delivery order is what to be produced: a detailed description of what is to be delivered, as defined by the fabrication engineering drawings (Koskela, 2000). The shop drawing and/or submittals relevant to the order must be fully approved by all necessary stakeholders. While it is still possible for design changes to occur even after approvals, ensuring this step is completed represents the best effort on the buyer's part to minimize the risk of changes that could disrupt production or delivery schedules.

Right Amount

The second component of the delivery order is the quantity of materials or components to be delivered, which must align with the demand generated by the contractor while accounting for on-site uncertainties (Joglekar & Levesque 2013; Vrijhoef & Koskela, 2000). Although the minimum required amount for a specific construction task is desirable in the JIT principle for installation, the contractor must determine the optimal quantity by considering potential variations in site conditions. By carefully assessing on-site needs and current inventory levels, the right amount of material or product should selected, minimizing over-ordering or shortages that could disrupt installation.

Right Delivery Due

The third component of the delivery order is the delivery due date. delivery due dates are set based on actual installation needs while factoring in site uncertainties rather than strictly adhering to JIT's just-in-time principle. Therefore, the delivery due should consider both the installation schedule and any constraints that may affect the readiness of the job site (Arbulu & Ballard, 2004).

MEASURING THE RELIABILITY OF DELIVERY ORDER

Just as the Percent Plan Complete (PPC) is used to measure the performance of a planning system, a similar metric is needed for the order release process, which would evaluate the extent to which these quality characteristics are consistently met. This paper proposes that the reliability of a delivery order can be quantified through three different measures.

The paper proposes a metric of Delivery Order Reliability (DOR) to measure the reliability of a delivery order. Delivery Order Reliability (DOR) can be assessed through two methods. The first method calculates DOR(%) as the ratio of delivery orders with unchanged delivery due dates from issuance to actual delivery, divided by the total number of delivery orders within a specified period (e.g., one month). A higher DOR reflects stability in the delivery order process as well as reliable on-site workflow, indicating that suppliers were shielded from last-minute changes, allowing them to optimize their production and logistics to meet contractor demands.

$$DOR(\%) = \left(\frac{N_{unchanged}}{N_{total}}\right) \times 100$$

Where:

$N_{\mathrm{unchanged}}$ = Number of delivery orders with unchanged delivery due dates from issuance to actual delivery

N_{total} = Total number of delivery orders within the specified period (e.g., one month)

The second method evaluates DOR through the probabilistic distribution of delivery order due dates. Here, the delivery due date in the original order serves as the mean of the distribution, while deviations from this date are measured relative to the mean (Kim & Rhee, 2024). By normalizing the distribution—where the mean is set to zero—this method provides insights into the variability and predictability of delivery order changes. Let X represent the actual delivery date of an order, and let D represent the original delivery due date. The deviation from the original delivery due date can be expressed as:

$$\Delta = X - D$$

To model the probabilistic distribution, we assume that the deviations follow a normal distribution:

$$\text{DOR}(\Delta) = N(0, \sigma^2)$$

Where:

$N(0, \sigma^2)$ represents a normal distribution with a mean of zero

σ^2 represents the variance of the actual delivery dates compared to the planned due dates

Suppliers can use this information to model and adapt their production schedules, ensuring robust performance even under dynamic conditions. Ultimately, the reliability that matters most to buyers is the suppliers' responsiveness to call-offs, specifically in terms of delivering the right materials in the right quantities at the right time while maintaining timeliness, accuracy, and quality.

As with Percent Plan Complete (PPC) in workflow management, high DOR(%) reflects reliable delivery orders; high DOR(Δ) indicates reliable flow in the supply chain. This, in turn, reduces variability and uncertainty in the installation phase, allowing for better project performance. Monitoring these metrics over time helps identify gaps in the delivery order process, enabling contractors to improve supplier coordination and enhance the reliability of the supply chain.

CONCLUSIONS AND MOVING FORWARD

Recent studies on construction supply chains have shown that demand uncertainty reduces the reliability of the product flow in the supply chain. Especially uncertainty in delivery due dates when external suppliers are not shielded. In this paper, we proposed a systematic approach that incorporates strategies at different levels, quality criteria, and measurements to address these challenges.

First, we presented a set of strategies to generate reliable delivery orders. They include organizational and contractual structure at the organizational level, the supplier’s involvement in the construction schedule at the project level, and quality delivery orders at the process level. Second, we introduce three quality criteria to enhance the reliability of delivery orders. These criteria are: approved design/submittal, right amount, right delivery due, and updated lead time. Each delivery order should be tested against these criteria before being released to the external supplier. Third, the proposed system includes a set of metrics to measure the reliability of delivery orders effectively: DOR(%) and DOR(Δ) as probabilistic distribution. They provide a quantitative way to assess the reliability of the delivery order and supply chain.

As more projects adopt prefabrication or off-site construction, achieving a reliable supply chain between on-site contractors and off-site suppliers becomes critical. In this context, our proposal can serve as a foundation for further research on improving supply chain reliability in the construction industry. This paper is still a conceptual paper in which the strategies, including the proposed metric, need to be tested in practice. We hope that our proposal will work as a call for research and practice to advance this domain of construction supply chain.

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