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# Study on construction material allocation policies: A simulation optimization method

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## ABSTRACT

Due to uncertainty in both demand and supply, material shortages are difficult to completely avoid. To reduce the effect on the schedule and cost performance of construction projects, managers should allocate limited material among activities effectively. Motivated by observations of construction practices, this paper investigates the integration of supply logistics and site logistics issues and develops a framework to model inventory replenishment and allocation decisions jointly. On the basis of the activity feature information (e.g., schedule, cost, and demand), we propose five allocation policies to support the integrated inventory management process: schedule-based, cost-based, demand-based, schedule-cost-based, and schedule-demand-based policies. Meanwhile, a genetic algorithm (GA)-based simulation optimization method is utilized to solve the integrated inventory model and find the optimal inventory level under a given allocation policy. Based on a large set of fictitious project networks with different path difference (PD), a computational analysis is conducted to make detailed interpolicy comparisons. It is shown that for a project network with a small (or large) PD value, the schedule-based (or schedule-cost-based) policy is the most appropriate choice.

## 1. Introduction

Statistically, the cost of materials can constitute 50% to 60% of the total cost of a construction project [1–3], and efficient management is essential to achieving the specified schedule and cost goals. In some projects, such as the Three Gorges Project in China [4], a centralized material management mode is implemented to address the issues surrounding some bulk materials for which there is massive demand and which are required by multiple activities. Specifically, under this mode, the owner must take charge of all the issues of material planning, purchase, transportation, storage, and allocation. This management mode can help monitor material flow, facilitate information transmission and exchange, establish a strict quality control system, and reduce procurement cost [5].

Although the centralized material management mode helps greatly in engineering practices, challenges remain. Due to the variability of project environment and dynamic of project progress, the demand for material is stochastic and nonstationary (changing from period to period). Additionally, under the consequence of instability in material production and transportation, supply yield uncertainty exists among upstream suppliers. The supply yield uncertainty usually leads received replenishment deviate from released order. Jointly influenced by these two characteristics, the mismatch between supply and demand arises frequently and leads to a material shortage between activities. The shortage will finally result in poor performance regarding the project schedule and cost. One effective way to address this situation is to hold an inventory buffer. In a centralized materials supply chain, however, managing the inventory buffer becomes very complex. The manager must make two important decisions: 1) how much inventory to keep, and 2) how to allocate the available material to on-going activities if shortages arise.

The two abovementioned management issues are equally important to the project schedule and cost performance. Inventory replenishment and allocation should jointly address the uncertain and dynamic factors in both the off-site supply network and on-site project network. In engineering practice, however, the material allocation decision usually depends on the experience and intuition of the managers, as well as separation with the inventory replenishment decision. This material management mode ignores the critical and mutual interdependency between these two material management issues and frequently leads to overstock or understock situations. Hence, the schedule and cost performance of the project may not be satisfactory. Accordingly, there is a

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pressing research need to consider the supply logistics and site logistics issues together, and model the integrated process of inventory replenishment and allocation under nonstationary stochastic demand and uncertain supply yield.

To date, a number of research studies have been conducted about this type of inventory control problem in manufacturing and retail supply chains. Among these studies, an important category of allocation policies is priority policy. In case of material shortages, the available inventory is allocated based on a priority list, in which each activity is assigned a corresponding priority. Swaminathan and Srinivasan [6], Zhang [7] and Alptekinoglu et al. [8] studied the priority allocation policy. In a single-period inventory model with stationary demand and zero lead-time, they analyzed different types of priority allocation policies and developed algorithms to compute the optimal inventory level and allocation policy. These approaches, however, cannot solve the inventory control problem directly in construction industry due to the complexity of material supply chain. Specifically, the main problem is embodied in the two following aspects: 1) the material demand is nonstationary; and 2) the materials-related delay cost of each activity largely relies on its location in the project network. As stated by the second point, when a materials-related delay occurs, an activity in the critical path will run up both the time-dependent direct cost (TDDC) of the activity itself and schedule liquidated damage cost (SLDC) of the project, while an activity in the non-critical path will only cause its own TDDC. These characteristics make inventory replenishment and allocation decisions more challengeable.

In this paper, our goal is to integrate the inventory replenishment and allocation decisions, and propose several easy-to-use allocation policies to support the inventory management process. Specifically, by using the activity feature information, five allocation policies are designed, which are schedule-based, cost-based, demand-based, schedule-cost-based, and schedule-demand-based policies. Then, a quantitative description indicator for the project network, path difference (PD), is proposed to measures the difference between the critical path and longest noncritical path. Meanwhile, under a given allocation policy, a GA-based simulation optimization method is utilized to calculate the optimal inventory level so as to minimize the total cost. Under a design process controlled by carefully varying the PD value, a large amount of fictitious project networks are generated and used for a computational analysis. Through the insights provided by this study, project managers can choose the most appropriate policy according to the PD value of the network and improve the project's performance.

It should be noted that due to uncertainty in both demand and supply yield, it is difficult to study the inventory problem analytically. Because it can address various types of uncertain parameters and their distributions, the simulation optimization methodology can solve this type of stochastic optimization problem effectively [9]. This method is therefore utilized to analyze and solve the inventory model. Moreover, due to nonstationary demand, the optimal allocation policy might change the priorities in a chaotic way and has no distinct characterization. It is also very complex and difficult to implement in practice. Therefore, we focus on proposing several easy-to-use allocation policies and find the most appropriate policies for the project networks with different characteristics.

The remainder of this paper is organized as follows. Section 2 presents a literature review. The detailed problem description, notation, and mathematical model are outlined in Section 3. Section 4 presents the five allocation policies, PD indicator, and GA-based simulation optimization method. A numerical analysis is conducted to evaluate the performance of the proposed policies in Section 5. Section 6 concludes this study.

## 2. Literature review

### 2.1. Construction supply chain management

Judging from the manufacturing industry's experience, Koskela [10] applied the new production philosophy (lean production, JIT/TQC, etc.) to construction. During the same period, O'Brien and Fischer [11] explicitly introduced supply chain management (SCM) into construction. From these beginnings, research that focuses on construction supply chain management (CSCM) garnered an enormous amount of attentions. Vrijhoef and Koskela [12] analyzed the four roles of CSCM and provided improved understandings of the nature of construction supply chain problems. Akintoye et al. [13] identified the views of main contractors on CSCM and discussed barriers to successful application of SCM in construction. Saad et al. [14] demonstrated a number of weaknesses in the progress of construction towards the adoption of SCM relationships and implied directions for improvement. Since these early papers, a number of subsequent studies have been conducted that seek to address CSCM issues, which are categorized into two main groups: first, adopting information technologies to support the management process; and second, enhancing management processes based on simulation and optimization methods.

For the first category, various information technologies are used to support the integration process and visual monitoring of CSCM. Razavi and Haas [15] utilized active RFID tags to calibrate the location estimation of materials on construction sites and provided accuracy and robustness data for construction material management. Shin et al. [16] developed an RFID/WSN-based intelligent construction supply chain information management framework to support JIT delivery. Ko et al. [17] proposed a cost-effective materials management and tracking system based on a cloud-computing service integrated with RFID. Pradhananga and Teizer [18] used GPS to track construction site equipment and analyzed and planned operations based on the collected data. Su et al. [19] developed a GIS-based material layout evaluation model to optimize the construction site layout plans. Irizarry et al. [20] integrated BIM and GIS to track the supply chain status and provide warning signals to ensure the delivery of materials. Wang et al. [21] investigated the potential applications of blockchain in construction engineering management, in which concludes the blockchain-enabled construction supply chain management. Although IT applications are able to improve the efficiency of information flow, they cannot completely eliminate uncertainty in construction supply chains. Model-based CSCM studies are also needed, including the material procurement and inventory allocation problems.

For the second category, different approaches and methodologies have been adopted to develop the CSCM models. Fang and Ng [22] analyzed the major cost elements related to construction logistics through the activity-based costing (ABC) approach and utilized a genetic algorithm to generate the material supply planning. Said and El-Rayes [23] proposed a construction logistics planning model that jointly optimizes the critical planning decisions of material procurement and material storage on construction sites. In a subsequent work, Said and El-Rayes [24] extended their framework to develop a new automated multi-objective construction logistics optimization system that is capable of simultaneously planning material supply and storage, activity scheduling, and facilities layout. Xu et al. [25] analyzed the interaction between the (off-site) material supply chain and (on-site) project activity network, and developed an integrated approach to optimize material safety-stock and project crashing decisions. All the above models can support informed decisions and bring competitive advantages. These works do not, however, involve the centralized material management mode and the related inventory allocation problem.