Journal of Construction Engineering, Management & Innovation Volume 9 Issue 2 (2026) 677

Contents lists available at www.goldenlightpublish.com/journals/jcemi/2-toc

Journal of Construction Engineering, Management & Innovation

Journal homepage: www.goldenlightpublish.com/journals/2/jcemi

A new bi-objective quality-based construction supply chain framework: From purchasing to commissioning

Maryam Izadbakhsh[1], Seyed Farid Ghannadpour[1], Morteza Bagherpour[2,*], Mohammad Mahdavi-Mazdeh[1]

[1] Iran University of Science and Technology, Department of Industrial Engineering, Tehran, Iran
[2] University of Pretoria, Department of Engineering and Technology Management, Pretoria, South Africa

[*] Corresponding author: M. Bagherpour (Morteza.bagherpour@up.ac.za)

https://doi.org/10.31462/jcemi.2026.677
Received 20 January 2026; Revised 8 May 2026; Accepted 9 June 2026; Available online 29 June 2026

Keywords
Construction materials
Quality
Stock control
Technology
Supplier selection

Abstract

Many construction organizations struggle with limited resources and tight budgets for project execution. These firms often rely on non-renewable resources of inconsistent quality or perform summary task in ways that reduce costs but sacrifice accuracy. Consequently, the industry requires a quality management system that tackles resource selection, task performance, and cost control in a single framework. Prior studies addressed quality management in segmented sections of the project supply chain but rarely treated the entire sequence as an integrated process. This study develops a bi-objective linear programming model for a multi-project construction supply chain under two scenarios: one with a discount policy applied to selected suppliers and one without. The model covers every phase, from project initiation and resource procurement through task scheduling and final delivery. It aims to improve the quality of summary task performance, select non-renewable resources that meet specified thresholds, and reduce overall logistics costs by jointly integrating supplier selection, inventory management, summary-task scheduling, shared renewable resources, and quality within a single framework. In this formulation, the quality metric for each summary task corresponds to the level of technology applied; higher-quality outcomes require more advanced equipment or methods. The two-objective model is solved via the augmented ε-constraint method, and its results are demonstrated with a numerical example. Sensitivity analysis examines how changes in cost coefficients and quality thresholds affect optimal decisions. Then, the applicability of the proposed model is illustrated through a numerical example, and its behavior is further examined by changing the key parameters. The results show that the proposed model reduces project delays and improves resource utilization by coordinating supplier selection, procurement timing, and summary-task scheduling within a unified decision-making framework. The analysis also identifies buying cost, ordering cost, inventory holding cost, and required non-renewable resources as the most influential parameters.

1. Introduction

The growth of countries depends significantly on the construction sector. There is a belief that a nation's physical infrastructure determines how quickly its economy develops [1]. Effective cost management is of great importance in the construction sector. Builders and academics have expressed concerns about construction projects that perform poorly in terms of time, cost, and quality, which can significantly affect their outcomes. However, many construction projects fail to meet expectations, often being late, over budget, and of poor quality [2]. In other words, poor quality is common across many projects, which can increase costs and delay projects.

The final product quality in construction is lower than in many other industries [3]. Despite being a critical aspect of construction projects, quality has received less attention. Conventional approaches to scheduling, budgeting, and resource management are often insufficient. Given the growing size and complexity of construction projects in terms of cost and scope, it is essential to integrate these elements into a unified framework [4]. Poor project management can lead to wasted time and resources, potentially causing serious consequences for the company. In this context, construction projects can be seen as supply chains in which all components are managed in an integrated manner.

The supply chain is often called the value chain because each step adds value to the final product, service, or project. The supply chain often involves individuals who directly or indirectly contribute to meeting consumer needs [5]. One key economic and social challenge is the lack of supply chain traceability to verify ethical manufacturing, legal compliance, or product reliability [6]. Typically, supply chain managers seek to enhance the clarity of information regarding both supply and demand. Transparency is characterized by the reliability and availability of information [7]. However, most construction projects suffer from delays, a widespread issue that needs effective planning to overcome [8]. Project scheduling is an exhaustive plan that indicates activities' beginning and ending times while considering resource requirements and relationships between activities [9]. Several parameters, including inventory control and material ordering, influence the project's timetable [10]. Gradually purchasing the necessary raw materials in smaller quantities is a viable approach to reducing inventory expenses. However, this increases the risk that the activity will be delayed and incur higher costs [11]. Therefore, project scheduling and procurement decisions should be made simultaneously to prevent potential negative impacts [12].

In multi-project construction environments, managing cost, quality, and shared resources simultaneously poses major challenges due to the complexity and interdependencies across supply chain stages. Poor quality at any point can cause delays, raise costs, and lead to stakeholder dissatisfaction. To address these issues, this study presents a mathematical model that integrates supplier selection, resource allocation, activity scheduling, and quality assessment into a single framework.

This study develops a bi-objective linear programming model to:

1) A mathematical model with two objectives: maximizing quality (in terms of non-renewable resources purchased from suppliers and the execution of summary tasks) and minimizing supply chain costs (including purchasing, ordering, transportation, operation delays, and task execution).

2) Integrated planning of summary tasks across multiple projects, supplier selection, discount strategies, and shared renewable resources. This integration leads to more efficient use of shared capacities, higher resource productivity, and improved responsiveness to time and budget constraints.

3) Incorporating integrated quality management throughout the procurement of non-renewable resources, execution of summary tasks, and final inspections. The model's quality-oriented approach addresses three levels of the supply chain to ensure compliance with quality standards and final operational requirements.

Section 2 reviews the construction sector's supply chain and quality principles, overviews quantitative studies, and identifies research gaps. Section 3 presents the problem description, model assumptions, and mathematical formulations for maximizing quality and minimizing supply chain cost. Section 4 reports results, examples, managerial insights, and sensitivity analyses. Section 5 summarizes key findings and suggests directions for future research.

2. Literature Review

In this section, the related research is categorized into four main subsections.

2.1. Construction project management

The primary goal of planning any construction project is to allocate resources and schedule activities effectively at the appropriate times [13]. The dynamic, fragmented, and complex structure of the construction industry makes it more challenging to succeed than in other businesses, as it requires collaboration among several stakeholders and effective process management. Therefore, determining the fundamental parameters for the project's success is crucial [14]. One study analyzes a scheduling problem involving various resource-related activities [15]. Enhancing project performance relies heavily on contractors' complete adherence to performance expectations [16]. Construction directors often encounter challenges managing project cash flow, necessitating specialized techniques and appropriate tools to address negative cash flow [17]. Computer simulations are commonly used in scheduling construction projects to anticipate operational performance by simulating process flows and resource selection [18]. In addition, Olubajo and Olubajo reported that integrating construction equipment and digital technologies into offsite logistics can positively and significantly improve the time performance of construction projects [19]. The quality of activities and supplier quality management (SQM) are included in quality management. Managing quality in the construction business is challenging because each project is different, and companies must manage large projects [20]. A significant concern is the continued increase in energy consumption within the construction industry, which poses a significant challenge to China's goals of peaking carbon emissions and achieving carbon neutrality [21].

2.2. Construction supply chain management

Companies today can be ahead of rivals if their supply chains are effective. The construction industry has significant potential for growth by adopting supply chain management practices. However, there are difficulties in its execution, and if they are recognized and overcome, many advantages will be realized [22]. The success of a project hinges on factors such as time and cost, which can fluctuate depending on the resources employed, including the workforce, equipment, and supplies. Moreover, implementing resource leveling techniques to stabilize resource utilization can impact project duration and expenditure [23]. Analyzing the key factors that influence the resilience of a prefabricated building supply chain can help strengthen the overall system [24]. Rahman et al.'s study aims to identify the optimal set of providers for the various renewable resources required for project execution, thereby reducing overall supply chain costs. That study also considers an integrated scheduling problem within supply chain management [25]. Emphasis has been placed on supplier selection and project scheduling coordination to minimize overall project delays. The study considers a project network comprising several simultaneous projects [26]. Supply chain integration is a strategic approach, and many studies have explored methods to facilitate it. Despite their crucial role and extensive marketplace experimentation, minimal attention has been devoted to integrating material providers [27]. In this regard, Asuquo and Ogwueleka found that supply chain integration positively and significantly improves cost performance in public-sector construction projects, particularly through information sharing, long-term collaboration among supply chain partners, and just-in-time delivery [28]. Mathematical modeling and visual representation play an important role in managing building supply chains [29]. One study proposed a construction supply chain model that considers economic and environmental objectives. The model uses a fuzzy logic approach with triangular numbers to represent uncertainty in various factors, including costs, task durations, inspection timing, supplier capacity, and resource demand [30].

2.3. Material supply and procurement

In traditional project planning, suppliers are selected, materials are ordered, and activities are scheduled in advance. This approach can result in the organization's expected profit loss [31]. The difficulty in planning the delivery of the necessary materials and resources is one of the factors contributing to project delays. Work disruptions, long-term increases in raw material costs, and customer dissatisfaction can all result from these issues. As a result, a supply chain network with a project warehouse and a sub-warehouse for inventory management was proposed [32]. A unified structure should be considered to address project scheduling and material ordering challenges while incorporating environmental concerns [33]. A two-level supply chain for construction materials between suppliers and construction workshops in an uncertain environment has been examined [34]. Order quantity is essential, as ordering materials on time can help get started with activities and avoid extra expenses [35]. In addition, Polat highlighted that supplier selection is a critical decision in construction projects, as the delivery of the right quantity of materials at the right time and with the desired quality is essential for overall project performance [36].

Moreover, a comprehensive evaluation of the inventory supply chain is essential for determining the optimal production quantity and manufacturing rate [37]. Taleizadeh et al. propose an economic model for managing the production and inventory of a single product under standard demand functions across three scenarios involving a distributor, a producer, and a retailer [38]. A behavioral and a strategic benefit may be derived from strategic inventories, which lower average wholesale prices and lessen the double marginalization effect [39]. Automated delivery is a commonly adopted sharing approach in supply chains, where a provider dispatches goods to a customer based on the customer's selection of a fixed shipment amount to be delivered on prearranged dates [40]. Chen et al. introduce a project supply chain model that spans multiple yields and time lengths, considering uncertainties related to provider volume and material requests [41].

2.4. Quality management in construction projects

The examination of quality management within the supply chain in the construction sector was prompted by the heightened public scrutiny in China, particularly in response to concerns regarding poor building quality [27]. Expenses and quality are fundamental and conflicting factors of construction project management. The study indicated that enhancing the overall profit of a construction project required optimizing the balance between quality and cost [42]. Planning is crucial in an environment with several projects. As a result, they suggest a method for scheduling numerous projects and the issue of ordering materials that also evaluates the effectiveness of tasks [12]. Also, research is investigating how integrating quality influences the collaborative model of material transportation and multi-project planning [43]. Based on some studies, an inspection committee should review each project's quality at completion [44].

Table 1 outlines recent studies within the domain of project supply chain.

3. Research Methodology

This section presents two mathematical model scenarios based on the previously outlined problem. The first scenario emphasizes quality-oriented decision-making in a multi-project supply chain. The second scenario extends the model by incorporating supplier discount strategies. The basic formulation is adapted from the model proposed by RezaHosseini et al. [10].

3.1. Problem definition

The two primary objectives of construction projects are quality and cost. Ignoring quality can lead to rework and additional expenses for the company. Balancing cost and quality are increasingly complex, and most organizations struggle to manage both effectively. As a result, there is a growing need for a supply chain that integrates supply, execution, and project completion. This model considers quality management and costs throughout the entire chain.

Table 1. The table of previous articles

NUM	Reference	Year	Number of projects		Decision variables				Quality management			Resource Type	
			Single project	Multi-project	Inventory management	Supplier selection	Project scheduling	Discount	Supply	Execution	Inspection	Renewable	Non-renewable
1	Chen et al.	2018		✓		✓	✓				✓	✓	✓
2	Golpîra et al.	2019		✓	✓	✓							✓
3	Habibi et al.	2019	✓		✓		✓	✓				✓	✓
4	Fuad Rahman et al.	2019	✓			✓	✓					✓	✓
5	RezaHoseini et al.	2020		✓		✓	✓				✓	✓	✓
6	Mohammadnazari et al.	2020	✓		✓	✓	✓						✓
7	Patoghi et al.	2021	✓		✓		✓	✓		✓		✓	✓
8	Mirghaderi et al.	2021		✓	✓								✓
9	Asadujjaman et al.	2021	✓		✓	✓	✓					✓	✓
10	Abdzadeh et al.	2022		✓		✓	✓	✓			✓	✓	✓
11	Habibi et al.	2023		✓	✓		✓	✓		✓		✓	✓
12	Abdzadeh et al.	2023		✓		✓	✓	✓		✓	✓	✓	✓
13	Chen et al.	2024	✓			✓							✓
14	This paper	2024		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Thus, a network includes several ongoing projects, each comprising distinct summary tasks. Each project requires non-renewable resources, as well as renewable resources. Every non-renewable resource is provided by several suppliers, denoted by a specific index in the model. Each supplier provides only one resource type, and in the second scenario, a specific discount policy is applied. The procurement division identifies the resources essential for the project by aligning them with the scheduling of summary tasks and the project's demand volume. This process ensures that summary tasks commence once the required non-renewable resources become available.

Additionally, a suitable supplier must be selected based on the quality of the non-renewable resources they provide. Once a supplier receives an order for a specific period, preparation and delivery time are required. Each period has a different cost associated with ordering and purchasing materials, with lower costs for earlier purchases. Therefore, supplier selection across different projects can reduce costs and duration. Multiple projects are managed simultaneously in the execution section, each with summary tasks. Distinct quality modes can be used for each summary task, each with a different cost. The cost of execution rises as execution quality increases. Delays in resource delivery may prevent the timely start of summary tasks. Therefore, implementing a method to minimize delays can significantly improve project performance. Each project also has a set of renewable resources to share among different summary tasks. However, these tasks cannot be conducted concurrently with the same renewable resources. In other words, a summary task can commence only when all its preceding tasks have been completed and all the renewable and non-renewable resources linked to it are accessible. Finally, a quality inspection is conducted to verify that the final output meets the required standards.

This study aims to formulate a model for integrated quality management within the construction supply chain. The proposed model integrates several components, including the supply of non-renewable resources, supplier selection based on appropriate quality modes, scheduling summary tasks for each project, inventory management, and final quality inspection. Since the objective is to balance cost and quality, the problem is formulated as a bi-objective optimization model that maximizes quality and minimizes costs.

Although procurement decisions constitute an important part of the proposed framework, the model is not limited to procurement cost minimization. Instead, it minimizes the total cost of the entire project system by jointly optimizing procurement, inventory, transportation, summary task execution, and project scheduling decisions. Since each summary task can start only when its required non-renewable resources are available and all predecessor constraints are satisfied, procurement decisions directly affect the start time of successor activities, project completion time, and delay penalties. In this way, the model captures the downstream impact of procurement on all project summary tasks and minimizes the overall project cost across the full construction supply chain.

3.2. Problem assumptions

- The network is made up of several current projects. This assumption reflects the real-world nature of construction companies, where multiple projects are often managed simultaneously within a shared supply chain network.
- Each project consists of a collection of summary tasks that include predecessors. This structure mirrors typical project planning practices in construction, where projects are broken down into dependent summary tasks to ensure logical sequencing and workflow management.
- Project summary tasks are independent but face predecessors' constraints since they are part of the same project. This assumption captures the internal logic of project scheduling: summary tasks execute independently but must still respect the sequence imposed by their predecessors to maintain project integrity.
- Each project's summary task can be completed using different execution modes. This reflects real-world conditions where tasks can be executed using various methods or technologies, each with different quality, cost, and duration implications.
- In the execution section, the modes of summary tasks are defined only based on the level of mechanized tools used. Therefore, higher modes correspond to more mechanized execution methods, which are assumed to reduce task duration in the context of this study.
- Every project requires all kinds of resources. This assumption ensures that the model accounts for comprehensive resource planning, as construction projects typically depend on a combination of materials, labor, and equipment.
- Each non-renewable resource has a set of predetermined providers at its disposal. This list reflects standard procurement practices in construction, where approved or available suppliers are defined in advance based on contracts, quality standards, or market availability.
- Each resource is associated with distinct supplier groups, and each supplier exclusively provides one resource type. This assumption simplifies the supply chain structure by assigning each supplier to a specific resource type. It reflects real practices where suppliers often focus on a single category of materials or equipment, making coordination and quality control more manageable. This assumption improves model tractability; however, it may limit the direct applicability of the model in settings where suppliers can provide multiple resource types simultaneously.
- Each supplier provides a required non-renewable resource with different quality modes. This assumption reflects real procurement scenarios in which suppliers can offer the same material or resource at varying quality grades, allowing

project managers to choose based on cost, performance, and project requirements.

- Every project possesses a specific array of renewable resources that can be utilized across multiple summary tasks. This allocation reflects typical resource management practices in construction projects, where renewable resources, such as labor or equipment, are shared across tasks within the same project to maximize utilization and efficiency.
- Summary tasks utilizing identical renewable resources cannot be carried out simultaneously in any project. This assumption ensures realistic scheduling by preventing the simultaneous use of the same renewable resource across tasks, mirroring actual resource constraints and avoiding overallocation.
- A summary task can only be started if all the required resources are available. This aligns with practical construction constraints: a task cannot begin unless all necessary resources—labor, equipment, and materials—are fully available, to avoid interruptions or inefficiencies during execution.
- A quality control team can inspect a project once all summary tasks have been finished. This assumption reflects standard project workflows, in which the final inspection is conducted after all major tasks are completed to assess overall quality and determine project readiness for handover or certification.
- The general demand must be satisfied in any situation. This assumption ensures the fulfillment of project requirements and reflects real-world obligations where construction projects must meet predefined demands regardless of cost or resource constraints.
- The project's summary tasks continue without interruption. This assumption simplifies scheduling by excluding potential disruptions and aligns with ideal project planning scenarios in which tasks proceed continuously once started, ensuring efficient resource use and timely completion. While this assumption simplifies the scheduling structure, it may reduce the model’s generalizability in real construction environments where interruptions, idle times, or unexpected stoppages can occur during task execution.
- In the second scenario, each supplier has a distinct discount policy. This assumption reflects real-world commercial practices, in which suppliers offer different discount strategies to incentivize larger orders or long-term contracts, thereby affecting procurement decisions in cost-sensitive projects.
- For the distribution of non-renewable resources, only one kind of vehicle is considered, which has a specific capacity. This assumption simplifies transport modeling by using only one vehicle type with a fixed capacity. At the same time, it still includes the main limits of transportation in real projects. It also shows real cases of companies using their own fixed types of vehicles to deliver project materials. This simplification facilitates the transportation formulation, but it may limit the model’s applicability in projects that use heterogeneous fleets with different capacities, costs, and availability conditions.
- Each project has its own warehouse with a different capacity. This setup mirrors real-life scenarios in which each project site has unique storage space, with its own size limitations. This approach facilitates tailored inventory management for each project based on available space.
- Each summary task's requirement for non-renewable resources is eliminated from the inventory as soon as it starts. When a task starts, the required non-renewable resources are immediately removed from inventory. It helps track resource usage more clearly and prevents double-counting the same resources.

3.3. Mathematical model for Scenario 1: Quality consideration in a multi-project supply chain

This section presents the first scenario, which focuses on incorporating quality considerations into the supply chain management of multiple construction projects. The proposed framework accounts for key quality-related factors across procurement, execution, and final inspection stages. The scenario is structured by presenting a comprehensive bi-objective mathematical model. While the model formulation is included in this section, the complete definitions of all symbols and notations used are provided in the Appendix for clarity and ease of reference.

The bi-objective model is solved using the augmented ε-constraint method. In this approach, the cost objective is optimized while the quality objective is converted into a bounded constraint with different ε levels to generate Pareto-optimal solutions. Therefore, the two objectives are not merged through direct weighted aggregation, and no additional normalization of the objective values is required in the present formulation.

3.3.1. Definition of symbols

The notations, sets, and indices used in the mathematical formulation of Scenario 1 are introduced in this section to facilitate understanding of the model structure (Table 2).

3.3.2. Mathematical model formulation

In this section, the formula pertaining to Scenario 1 is presented with comprehensive and detailed explanation.

$$
\begin{aligned}
Min\ Z_1 = {} & \sum_{s\in S(r)} \sum_{m\prime} \sum_{p\in P} \sum_{t\epsilon T} C^{buy}_{s,m',t}\, qu_{s,m\prime,p,t} + \sum_{s\in S(r)} \sum_{m\prime} \sum_{p\in P} \sum_{t\epsilon T} C^{ord}_{s,m',t}\, x_{s,m',p,t} + \sum_{s\in S(r)} \sum_{p\epsilon P} \sum_{t\epsilon T} di_{s,p}\, C^{tra}_{s,p}\ N_{s,t,p} \\
& + \sum_{p\epsilon P} C^{del}_{p}(TD_p) + \sum_{r\epsilon R} \sum_{p\epsilon P} \sum_{t\epsilon T} C^{mnc}_{r,p,t}\ I_{r,p,t} + \sum_{a\in A} \sum_{m} \sum_{t\in T} z_{a,m,t}\, C^{exe}_{a,m}
\end{aligned}
\tag{1}
$$

Table 2. The table of model notation for the first scenario

Sets and Indices	
$p, q \in P$	A number of current projects
$A(p), p\epsilon P$	The grouping of summary tasks is essential for the completion of the project p
$A = \cup_{p\epsilon P}, A(p)$	The collection of all summary tasks
$R(a), a\epsilon A$	Non-renewable resources needed to complete the summary task a
$R(p) = \cup_{a\epsilon A}, R(a)$	The collection of non-renewable resources needed for the project p
$R = \cup_{a\epsilon A}, R(a)$	The collection of all non-renewable resources
$S(r), r \in R(p)$	The collection of suppliers providing a non-renewable resource r
$S = \cup_{r\epsilon R}, S(r)$	The collection of all suppliers providing non-renewable resources
$R'(p), p\epsilon P$	The grouping of renewable resources utilized within project p
$A'(r') \subset A(p), r'\epsilon R'(p)$	The group of summary tasks within project p that necessitate a renewable resource r'
$E(p), p\epsilon P$	The set of predecessor constraints for project summary tasks $(a, b) \in E(p)$
$t \epsilon T$	Time unit t
M	The collection of execution modes for each summary task a
M'	The collection of modes that each non-renewable resource r requires
Parameters	
$D_{a,p,r}, p\epsilon P, r \in R(a), a\epsilon A$	The consumption level of non-renewable resource [45] r is contingent upon the type of resource required for carrying out summary task a within project p
$DD_p, p\epsilon P$	The due date of the project p to finish all summary tasks and perform inspection
$Ca_s, s\epsilon S$	Supplier capacity s
$t_s^{pre}, s\epsilon S$	The preparation time provided by the supplier s
$t_{s,p}^{tra}, s\epsilon S, p\epsilon P$	Shipping time from supplier s to project p (The day is considered)
$t_p^{rev}\ p\epsilon P$	Inspection time of project p (The day is considered)
$d_{a,m}, a\epsilon A(p)$	The duration needed to complete the summary task a in mode m (The day is considered)
$C_{s,m',t}^{ord}$	Ordering cost per time unit t from supplier s in mode m'
$C_{r,p,t}^{mnc}$	Inventory holding cost of non-renewable resource r over time unit t for project p
$C_{s,m',t}^{buy}$	The buying cost per unit in time t from the supplier s in mode m'
$C_{s,p}^{tra}$	Shipping cost from supplier s to project p
C_p^{del}	Delay cost of the project p
μ	Big number
Ca^{vcl}	The capacity of a vehicle
Ca_p^{inv}	The capacity of a project p
$Di_{s,p}$	The distance between supplier s and project p
$\rho_{a,m}, a\epsilon A(P)$	Predefined quality score assigned to executing summary task a in mode m
$\rho'_{s,m'}, s\epsilon S(r)$	Predefined quality score assigned to supplier S providing a non-renewable resource r in mode m'
$C_{a,m}^{exe}$	Execution cost of each summary task a in mode m
Bud	The total budget allocated for completing all projects
Decision variables	
$x_{s,m',p,t}, s\epsilon S(r), p\epsilon P, r \in R(p), t \epsilon T$	Binary variable, if supplier s over time unit t in mode m' is used for project p, 1, otherwise 0
$y_{a,b}, a, b \in A'(r'), a \neq b, r' \in R'(p), p \in P$	The binary variable takes a value of 1 if activity a is scheduled before activity b; otherwise, it takes a value of 0 when activities a and b share a renewable resource l in projects p
$z_{a,m,t}$	Binary variable, if the summary task a in mode m over time unit t is started, 1, otherwise 0
$I_{r,p,t}$	The inventory level of a non-renewable resource r over time unit t for each project
$qu_{s,m',p,t}, s\epsilon S, p\epsilon P, t \epsilon T$	The quantity of non-renewable resources that is received from a supplier s in mode m' for the project p over time unit t
$ST_a, a \in A$	Start time of a summary task a
$CT_p, p\epsilon P$	Completion time of the project p
$TD_p, p\epsilon P$	Delay in productivity of project p
$N_{s,p,t}$	The quantity of vehicles needed to transport an order from supplier s to project p
DT_p	The review completion time for project p project review DT_0 indicates the starting time of the initial survey

$$Max\ Z_2 = \sum_{a \in A} \sum_{m} \sum_{t \in T} z_{a,m,t}\, \rho_{a,m} + \sum_{s \in S(r)} \sum_{m\prime} \sum_{p \epsilon P} \sum_{t \in T} x_{s,m',p,t}\, {\rho'}_{s,m\prime} \tag{2}$$

S.T:

$$\sum_{p \epsilon P} \sum_{m\prime} qu_{s,m\prime,p,t} \leq Ca_s \qquad \forall s \in S, t \epsilon T \tag{3}$$

$$I_{r,p,t} = I_{r,p,t-1} + \sum_{s \in S(r)} \sum_{m\prime} qu_{s,m\prime,p,t} - \sum_{a \in A(p)} \sum_{m} D_{a,p,r}\ z_{a,m,t} \qquad \forall\ t \epsilon T, p \in P, r \in R(P) \tag{4}$$

$$\sum_{r \epsilon R(P)} I_{r,p,t} \leq Ca_p^{inv} \qquad \forall\ t \epsilon T, p \in P \tag{5}$$

$$\sum_{m\prime} qu_{s,m\prime,p,t} \leq N_{s,p,t} \times Ca^{vcl} \qquad \forall s \in S(r), p \in P, t \epsilon T \tag{6}$$

$$qu_{s,m\prime,p,t} \leq \mu \times x_{s,m',p,t-(t_s^{pre}+t_{s,p}^{tra})} \qquad \forall\, p \in P, s \in S(r), m', t \geq t_s^{pre} + t_{s,p}^{tra} + 1 \tag{7}$$

$$\sum_{s} \sum_{m\prime} \sum_{p} \sum_{t \in t \leq t_s^{pre}+t_{s,p}^{tra}} qu_{s,m\prime,p,t} = 0 \tag{8}$$

$$\sum_{s \in S(r)} \sum_{m\prime} X_{s,m\prime,p,t} \leq 1 \qquad \forall p \in P, t \epsilon T, r \in R(P) \tag{9}$$

$$ST_a + \sum_{m} \sum_{t \epsilon T} d_{a,m}\, z_{a,m,t} \leq ST_b \qquad \forall (a,b) \in E(p) \tag{10}$$

$$ST_a + \sum_{m} \sum_{t \epsilon T} d_{a,m}\, z_{a,m,t} - \mu(1 - y_{a,b}) \leq ST_b \qquad a,b \in A'(r'), a \neq b, r' \in R'(p) \tag{11}$$

$$ST_b + \sum_{m} \sum_{t \epsilon T} d_{b,m}\, z_{b,m,t} - \mu(y_{a,b}) \leq ST_a \qquad a,b \in A'(r'), a \neq b, r' \in R'(p) \tag{12}$$

$$CT_p \geq ST_a + \sum_{m} \sum_{t \epsilon T} d_{a,m}\, z_{a,m,t} \qquad \forall a \in A(p) \tag{13}$$

$$DT_p \geq CT_p + t_p^{rev} \qquad \forall\, p \in P \tag{14}$$

$$TD_p \geq DT_p - DD_p \qquad \forall p \in P \tag{15}$$

$$ST_a \leq \mu(1 - \sum_{m} Z_{a,m,t}) + t \qquad \forall a \in A(p), t \epsilon T \tag{16}$$

$$ST_a \geq -\mu(1 - \sum_{m} Z_{a,m,t}) + t \qquad \forall a \in A(p), t \epsilon T \tag{17}$$

$$\sum_{t \epsilon T} \sum_{m} z_{a,m,t} = 1 \qquad \forall a \in A(p) \tag{18}$$

$$\begin{aligned} &\sum_{s \in S(r)} \sum_{m\prime} \sum_{p \in P} \sum_{t \epsilon T} C_{s,m',t}^{buy}\, qu_{s,m\prime,p,t} + \sum_{s \in S(r)} \sum_{m\prime} \sum_{p \in P} \sum_{t \epsilon T} C_{s,m',t}^{ord}\, x_{s,m',p,t} + \sum_{s \in S(r)} \sum_{p \epsilon P} \sum_{t \epsilon T} di_{s,p}\, C_{s,p}^{tra}\ N_{s,t,p} \\ &\quad + \sum_{p \epsilon P} C_p^{del}(TD_p) + \sum_{r \epsilon R} \sum_{p \epsilon P} \sum_{t \epsilon T} C_{r,p,t}^{mnc}\ I_{r,p,t} + \sum_{a \in A} \sum_{m} \sum_{t \in T} z_{a,m,t}\, C_{a,m}^{exe} \leq Bud \end{aligned} \tag{19}$$

$$x_{s,m',p,t}, y_{a,b}, z_{a,m,t} \in \{0,1)$$

$$qu_{s,m\prime,p,t}, ST_a, CT_p, DT_p, TD_p, N_{s,p,t}, I_{r,p,t} \geq 0$$

This study proposes an integrated model for quality management within the construction supply chain, addressing a recently recognized challenge. Eq. (1) defines the primary objective function, which aims to minimize the total project cost, including expenses related to procurement, ordering, transportation, project delays, inventory maintenance, and the execution of summary tasks. This objective captures the total economic effect of both procurement and downstream project execution decisions within a unified construction supply chain framework. Eq. (2) represents the second objective function aimed at improving the quality of task execution across the projects. In this study, Eq. (2) is defined as a composite quality index that incorporates two separate quality components, namely supplier-side quality and execution-side quality. These two components arise from different decision layers of the construction supply chain and are represented by distinct variables in the model. Therefore, they are aggregated linearly in the quality objective to evaluate their combined contribution to overall project quality while preserving the linear structure and tractability of the proposed bi-objective optimization model [46-48]. Eq. (3) ensures that the total amount of resources shipped from each supplier to all projects in a given period does not exceed the supplier's capacity for that quality level and time. This prevents infeasible procurement plans by linking purchasing decisions directly to the available production capacity of each supplier. Eq. (4) presents the inventory balance. It tracks the inflow of procured resources and the outflow caused by the start of summary tasks in each project and period. Eq. (5) restricts the inventory level in each time unit and each project to the corresponding warehouse capacity. This ensures that procurement decisions remain consistent with the physical storage limitations of each project site. Eq. (6) ensures that the total quantity of resources delivered by each supplier (in all quality modes) to each project during time “t” does not exceed the vehicle capacity. If a supplier is selected for a project, resource delivery is permitted as specified in Eqs. (7) and (8), subject to preparation and shipping lead time. No delivery can occur before this time. These equations link the supplier selection decision to actual resource arrival and ensure that materials become available only after the required lead time has passed. Eq. (9) restricts supplier selection so that only one supplier and one quality mode can be chosen for each project at each time unit. As a result, the model avoids simultaneous assignment of multiple suppliers or multiple supply quality modes to the same project-period combination. Eq. (10) defines the precedence relationship among summary tasks. It guarantees that each successor summary task can start only after the completion of its required predecessor within the same project. The predecessor and successor of two summary tasks with a shared renewable resource are determined by Eqs. (11) and (12). Together, these two constraints prevent overlapping execution of summary tasks that compete for the same renewable resource. Eq. (13) calculates the project’s finish time, and Eq. (14) accounts for the completion time, including the final inspection. In this way, the model distinguishes between the end of execution activities and the final delivery time after quality inspection is completed. Eq. (15) calculates the project delay based on scheduled and actual completion times. This allows delay penalties to be incorporated directly into the cost objective whenever the due date is violated. Eqs. (16) and (17) are used to compute the start time of each summary task. These constraints connect the binary task-start decision to the continuous start-time variable and ensure temporal consistency in the schedule. Eq. (18) ensures that each summary task in every project begins in only one period. Therefore, each summary task is assigned a unique execution start, which avoids fragmented or repeated task initiation across periods. Finally, Eq. (19) ensures that the project's total cost does not exceed the approved budget. This constraint guarantees that all procurement, inventory, transportation, delay, and execution decisions remain financially feasible.

3.4. Mathematical model for Scenario 2: Quality consideration in a multi-project supply chain with a discount policy

This section presents the mathematical formulation for Scenario 2, which extends the initial model by incorporating a supplier discount policy. The aim is to analyze how discount strategies impact cost-quality trade-offs within a multi-project construction supply chain. Only the constraints that have been modified or newly introduced compared to Scenario 1 are presented in this section.

3.4.1. Definition of symbols

This section presents the symbols and notations specific to the second scenario, incorporating the supplier discount strategy into the supply chain model (Table 3).

3.4.2. Mathematical model formulation

The formula for Scenario 2 is explained in full detail.

$$\begin{aligned} Min\ Z_1 = & \sum_{s \in S(r)} \sum_{m\prime} \sum_{p \epsilon P} \sum_{t \epsilon T} \sum_{k} C^{buy}_{s,m',k,t}\, qu_{s,m',k,p,t} + \sum_{s \in S(r)} \sum_{m\prime} \sum_{p \epsilon P} \sum_{t \epsilon T} C^{ord}_{s,m',t}\, x_{s,m',p,t} \\ & + \sum_{s \in S(r)} \sum_{p \epsilon P} \sum_{t \epsilon T} di_{s,p}\, C^{tra}_{s,p}\ \ N_{s,t,p} + \sum_{p \epsilon P} C^{del}_{p} (TD_p) + \sum_{r \epsilon R} \sum_{p \epsilon P} \sum_{t \epsilon T} C^{mnc}_{r,p,t}\ \ I_{r,p,t} \\ & + \sum_{a \in A} \sum_{m} \sum_{t \epsilon T} z_{a,m,t}\, C^{exe}_{a,m} \end{aligned} \tag{20}$$

S.T:

$$\sum_{p \epsilon P} \sum_{m\prime} \sum_{k} qu_{s,m',k,p,t} \le Ca_s \qquad \forall s \in S, t \epsilon T \tag{21}$$

$$I_{r,p,t} = I_{r,p,t-1} + \sum_{s \in S(r)} \sum_{m\prime} \sum_{k} qu_{s,m',k,p,t} - \sum_{a \in A(p)} \sum_{m} D_{a,p,r}\ \ z_{a,m,t} \qquad \forall\ t \epsilon T, p \in P, r \in R(P) \tag{22}$$

$$\sum_{m\prime} \sum_{k} qu_{s,m',k,p,t} \le N_{s,p,t} \times\ Ca^{vcl} \qquad \forall s \in S(r), p \in P, t \epsilon T \tag{23}$$

$$qu_{s,m',k,p,t} \le \mu \times x_{s,m',p,t-(t^{pre}_{s}+t^{tra}_{s,p})} \qquad \forall\ p \in P, s \in S(r), m', k, t \ge t^{pre}_{s} + t^{tra}_{s,p} + 1 \tag{24}$$

Table 3. The table of model notation for the second scenario

Sets and Indices	
k	Set of discount ranges
Parameters	
$C^{buy}_{s,m',k,t}$	The cost per unit of each purchase made from a supplier s over time unit t in mode m' within a discount range k
$U_{s,k}$	The maximum value within the discount range associated with supplier s
Decision variables	
$qu_{s,m',k,p,t}$	The quantity of non-renewable resources received from supplier s in mode m' and discount range k for project p in time unit t
$\gamma_{s,k,p,t}$	Binary variable, if the purchase amount in the k-th discount range from supplier s for project p reaches its upper limit, 1, otherwise 0

$$\sum_{s}\sum_{m\prime}\sum_{p}\sum_{t\in t\le t_s^{pre}+t_{s,p}^{tra}}\sum_{k} qu_{s,m',k,p,t}=0 \tag{25}$$

$$\sum_{s\in S(r)}\sum_{m\prime}\sum_{p\in P}\sum_{t\epsilon T}\sum_{k} C^{buy}_{s,m',k,t}\, qu_{s,m',k,p,t}+\sum_{s\in S(r)}\sum_{m\prime}\sum_{p\epsilon P}\sum_{t\epsilon T} C^{ord}_{s,m',t}x_{s,m',p,t}+\sum_{s\in S(r)}\sum_{p\epsilon P}\sum_{t\epsilon T} di_{s,p}\, C^{tra}_{s,p}\ N_{s,t,p}$$
$$+\sum_{p\epsilon P} C^{del}_{p}(TD_p)+\sum_{r\epsilon R}\sum_{p\epsilon P}\sum_{t\epsilon T} C^{mnc}_{r,p,t}\ \ I_{r,p,t}+\sum_{a\in A}\sum_{m}\sum_{t\epsilon T} z_{a,m,t}\, C^{exe}_{a,m}\le Bud \tag{26}$$

$$\sum_{k}\gamma_{s,k,p,t}\le 1 \qquad \forall\, p\in P, s\in S(r), t \tag{27}$$

$$U_{s,k-1}\gamma_{s,k,p,t}\le\sum_{m\prime} qu_{s,m',k,p,t}\le U_{s,k}\gamma_{s,k,p,t} \qquad \forall\, p\in P, s\in S(r), t, k \tag{28}$$

$$Constraints\ (2,5,9,10,11,12,13,14,15,16,17,18)$$
$$\gamma_{s,k,p,t}\in\{0,1)$$
$$qu_{s,m\prime,p,t}\ge 0$$

Eq. (20) defines the first objective function by applying a discount strategy to the buying cost. This allows the model to evaluate how supplier discount policies affect the overall cost structure of the construction supply chain. Eq. (21) ensures that the quantity of non-renewable resources purchased within the discount range from each supplier across all projects in a given time does not exceed the supplier's capacity for that quality level. Thus, discounted procurement decisions remain bounded by the supplier's actual delivery capability. The updated inventory balance, accounting for discount-based procurement, is presented in Eq. (22). This equation preserves the same inventory logic as Scenario 1 while incorporating the effect of purchasing quantities under different discount ranges. Eq. (23) defines the revised vehicle capacity for transporting discounted resources. Therefore, the transportation limitation remains active even when procurement quantities are split across discount intervals. Eqs. (24) and (25) specify the shipping lead time following the application of the discount strategy. These constraints ensure that discounted purchases are still subject to the same preparation and transportation delays as regular procurement decisions. Eq. (26) introduces the updated budget constraint reflecting the impact of discounts. Accordingly, the model evaluates whether the reduced procurement cost under discount policies improves overall budget feasibility. The amount of procured non-renewable resources is limited by Eq. (27) since it is within a discount range. This constraint allows only one discount range to be selected for each supplier, project, and time period. Eq. (28) restricts the value of procured non-renewable resources to fall within the range defined by the supplier's discount thresholds. In this way, the purchased quantity is forced to remain consistent with the lower and upper bounds of the selected discount level. In the proposed formulation, the discount policy is modeled as an all-unit discount, meaning that once a purchase quantity falls within a selected discount range, the corresponding discounted unit price applies to the total purchased quantity in that range.

4. Results and Analysis

In this section, the results generated by the model are presented. Additionally, a scalar example is provided to illustrate the applicability of the proposed model and to analyze its decision-making behavior under the two scenarios. Subsequently, the model results are analyzed.

4.1. Numerical example

The numerical example is developed as a case-inspired illustration based on the structure of industrial construction projects undertaken in the context of Piramoon System Qeshm Company. Piramoon System Qeshm is considered in this study as an engineering and construction-oriented company involved in industrial electromechanical and control-system projects, where project delivery requires the coordination of engineering, procurement, integration, installation, supplier selection, inventory planning, and final quality inspection.

To make the numerical example more representative of construction project practice, three construction projects are considered: Assaluyeh, Ferdowsi, and Zanjan. Each project is decomposed into four construction-related summary tasks, namely Engineering, Supply, Integrating, and Installation. These summary tasks represent aggregated work packages commonly observed in industrial construction and electromechanical project delivery. The use of summary tasks, rather than a large number of detailed activities, is adopted to keep the mixed-integer programming model computationally tractable while preserving the main planning relationships among procurement, resource availability, task execution, and project completion.

The two non-renewable resources required by the projects are Control Panel and Header, and Valve and Connection. Control Panel and Header are supplied by three alternative suppliers: Teyf Tablo, Tablosazan, and Elte. Valve and Connection is supplied by two alternative suppliers: Swagelok and Parker. In addition, two renewable resources are considered in the execution stage: the mechanical engineering team and the electrical engineering team. These renewable resources are shared among the summary tasks and therefore affect the feasible scheduling of construction activities.

The numerical values used in the example are scaled and adjusted to fit the size of the mathematical model and to allow exact solution using the selected optimization environment. However, the structure of the case, including the project names, construction-related summary tasks, resource types, supplier groups, and renewable resources, reflects the planning logic of real-world industrial construction projects. Therefore, the example demonstrates how the proposed model can support integrated decision-making in construction projects by linking supplier selection, procurement timing, inventory management, renewable resource allocation, task scheduling, quality mode selection, and final inspection.

For simplicity of presentation, the summary tasks are denoted by symbols a1 to a12. Each project consists of four construction-related summary tasks, namely Engineering, Supply, Integrating, and Installation. Accordingly, a1–a4 represent these four summary tasks for the Assaluyeh project, a5–a8 represent the same summary tasks for the Ferdowsi project, and a9–a12 represent the corresponding summary tasks for the Zanjan project. Each summary task can be performed in three modes: low, medium, and high. In this study, these modes refer only to the level of mechanized tools used in task execution. A higher mode represents the use of more mechanized tools, which increases execution speed and therefore reduces task duration. This is a problem-specific modeling assumption adopted in this paper and is not intended to be a general characteristic of all construction projects.

Type 1 non-renewable resource is delivered to the project sites by suppliers 1 to 3, each offering different quality levels, capacities, purchase and ordering costs, preparation times, and shipping durations. Similarly, suppliers 4 and 5 provide type 2 non-renewable resources under varying quality, capacity, cost, and delivery time conditions. Each supplier also offers a volume-based discount policy.

Moreover, the third project is assumed to include renewable resources shared between summary tasks 11 and 12. In Scenario 2, three discount ranges are considered for each supplier as an illustrative volume-discount policy for the numerical example. No discount is applied in the first range, while 20% and 40% discounts are assigned to the second and third ranges, respectively, in order to examine the effect of increasing discount intensity on procurement decisions. No discount is applied if the purchase amount falls within the first range. However, 20% and 40% discounts are applied if the amount falls within the second and third ranges. Suppliers 1 and 4 offer higher discounts at lower purchase volumes than other suppliers due to differences in the length of their discount ranges. Fig. 1 illustrates the structure of this construction supply chain.

Table 4 presents the parameters associated with each supplier, including production capacity, preparation time, transportation time to the project site, quality level of non-renewable resources, and distance to the site. These parameters vary from one supplier to another.

The quality levels of each supplier's non-renewable resources, as well as the execution modes of summary tasks, have been quantified using preference-based utility scores. Accordingly, the values 10, 30, and 50 correspond to low, medium, and high-quality levels.

The contractor is responsible for ensuring the timely delivery of the project to the employer. In the event of rescheduling that results in delays, the associated delay costs must be borne by the contractor. As a result, Table 5 presents project-specific data, including inspection time, required quantities of non-renewable resources (types 1 and 2), expected project durations, delay costs, and warehouse capacities.

Table 6 presents the ordering costs across different time units, providing a comparative view of how these costs vary over time.

Table 7 presents the purchase cost across different time units.

Table 8 presents the transportation cost of each supplier along with the quality of non-renewable resources.

Table 9 shows the duration of each summary task according to the mode of execution quality.

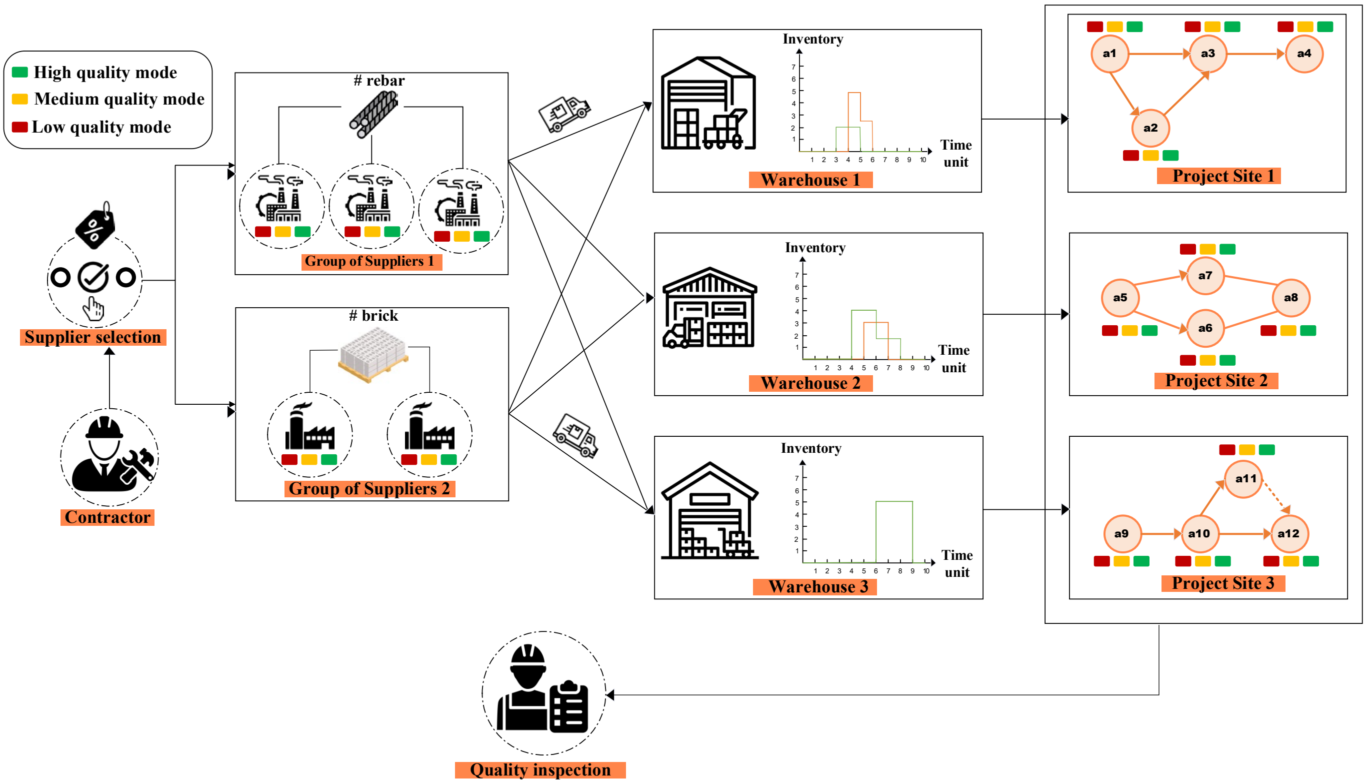


Fig. 1. The construction supply chain of the proposed model

Table 4. Parameters related to the suppliers

Suppliers	Production capacity	Preparation time	Shipping time			Quality modes of non-renewable resources			Distance from the Supplier to the Project Site		
			p_1	p_2	p_3	m'_1	m'_2	m'_3	p_1	p_2	p_3
S_1	95	2	1	2	1	✓	✓	✓	100	100	50
S_2	100	1	2	1	3	✓	✓	✓	300	100	300
S_3	88	3	1	3	1	✓	✓	✓	300	300	200
S_4	120	1	2	2	3	✓	✓	✓	200	100	200
S_5	110	4	3	1	2	✓	✓	✓	250	300	150

Table 5. Parameters related to the project

Projects	Project deadline	Cost of delay	Warehouse capacity	Type 1 non-renewable resource demand	Type 2 non-renewable resource demand	Inspection time
p_1	10	3	200	18	14.5	1
p_2	12	2	190	10.5	15	3
p_3	16	4	175	13.5	13.5	2

Table 6. The cost of ordering in different time units

Suppliers	Modes	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
S1	m'_1	15	15.2	15.4	15.6	15.8	16	16.2	16.4	16.6	16.8
	m'_2	16	16.2	16.4	16.6	16.8	17	17.2	17.4	17.6	17.8
	m'_3	17	17.2	17.4	17.6	17.8	18	18.2	18.4	18.6	18.8
S2	m'_1	16	16.2	16.4	16.6	16.8	17	17.2	17.4	17.6	17.8
	m'_2	17	17.2	17.4	17.6	17.8	18	18.2	18.4	18.6	18.8
	m'_3	18	18.2	18.4	18.6	18.8	19	19.2	19.4	19.6	19.8
S3	m'_1	14	14.2	14.4	14.6	14.8	15	15.2	15.4	15.6	15.8
	m'_2	15	15.2	15.4	15.6	15.8	16	16.2	16.4	16.6	16.8
	m'_3	16	16.2	16.4	16.6	16.8	17	17.2	17.4	17.6	17.8
S4	m'_1	17	17.2	17.4	17.6	17.8	18	18.2	18.4	18.6	18.8
	m'_2	18	18.2	18.4	18.6	18.8	19	19.2	19.4	19.6	19.8
	m'_3	19	19.2	19.4	19.6	19.8	20	20.2	20.4	20.6	20.8

Table 6. Cont'd

S5	m'_1	18	18.2	18.4	18.6	18.8	19	19.2	19.4	19.6	19.8
	m'_2	19	19.2	19.4	19.6	19.8	20	20.2	20.4	20.6	20.8
	m'_3	20	20.2	20.4	20.6	20.8	21	21.2	21.4	21.6	21.8

Table 7. Purchase cost in different time units

Suppliers	Modes	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
S1	m'_1	5	5.2	5.4	5.6	5.8	6	6.2	6.4	6.6	6.8
	m'_2	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8
	m'_3	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8
S2	m'_1	8	8.2	8.4	8.6	8.8	9	9.2	9.4	9.6	9.8
	m'_2	9	9.2	9.4	9.6	9.8	10	10.2	10.4	10.6	10.8
	m'_3	10	10.2	10.4	10.6	10.8	11	11.2	11.4	11.6	11.8
S3	m'_1	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8
	m'_2	8	8.2	8.4	8.6	8.8	9	9.2	9.4	9.6	9.8
	m'_3	9	9.2	9.4	9.6	9.8	10	10.2	10.4	10.6	10.8
S4	m'_1	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8
	m'_2	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8
	m'_3	8	8.2	8.4	8.6	8.8	9	9.2	9.4	9.6	9.8
S5	m'_1	9	9.2	9.4	9.6	9.8	10	10.2	10.4	10.6	10.8
	m'_2	10	10.2	10.4	10.6	10.8	11	11.2	11.4	11.6	11.8
	m'_3	11	11.2	11.4	11.6	11.8	12	12.2	12.4	12.6	12.8

Table 8. Transportation cost to the project site and quality of non-renewable resources

Suppliers	Transportation cost of each supplier			The quality of non-renewable resources		
	P1	P2	P3	m'_1	m'_2	m'_3
S1	1	1	5	10	30	50
S2	3	1	3	10	30	50
S3	3	3	2	10	30	50
S4	2	1	2	10	30	50
S5	2.5	3	1.5	10	30	50

Table 9. The duration of each summary task according to the mode of execution quality

Projects	Summary Tasks	Quality of summary tasks		
		M1	M2	M3
P1	a1	3	2	1
	a2	4	3	2
	a3	3	2	1
	a4	4	3	2
P2	a5	3	2	1
	a6	4	3	2
	a7	3	2	1
	a8	4	3	2
P3	a9	3	2	1
	a10	4	3	2
	a11	3	2	1
	a12	4	3	2

Table 10 outlines the quality and implementation cost of each summary task.

Suppliers offer three different discount ranges. The discount rate increases proportionally to the quantity of non-renewable resources purchased. No discount is applied within the first range. 20% and 40% discounts are applied within the second and third ranges, respectively.

4.2. Results

The augmented epsilon constraint model was solved using the CPLEX solver. The computations were performed on a system with a Core i7 CPU (3.30 GHz) and 16 GB of RAM. The outcomes are presented in this section. After solving the model, the set of Pareto-optimal points was obtained, which enabled the construction of the Pareto frontier.

Table 10. Quality and cost of implementation of each summary tasks

Summary Tasks	The quality of summary tasks			Implementation Cost of summary tasks		
	M1	M2	M3	M1	M2	M3
a1	10	30	50	15	25	32
a2	10	30	50	17	20	35
a3	10	30	50	10	17	20
a4	10	30	50	21	32	40
a5	10	30	50	25	27	30
a6	10	30	50	26	46	52
a7	10	30	50	15	16	20
a8	10	30	50	51	67	87
a9	10	30	50	24	36	49
a10	10	30	50	27	29	33
a11	10	30	50	32	36	38
a12	10	30	50	22	29	34

Since the augmented ε-constraint method was used to generate the Pareto frontier, the trade-off between cost and quality was explored by varying the ε level of the secondary objective rather than by combining the two objectives through weighted coefficients. The objective function values are illustrated graphically in Fig. 2.

Fig. 2 indicates a clear trade-off between total supply chain cost and overall quality. In line with the time–cost–quality trade-off literature in construction projects, improving quality is generally associated with higher cost [42]. However, this relationship is not uniform across the Pareto frontier in the present study. In the lower and middle regions of the frontier, a moderate increase in cost leads to a meaningful improvement in quality, whereas near the extreme high-quality solutions, further cost increases provide only limited additional quality gains. This suggests that the middle Pareto solutions offer a more efficient cost–quality compromise than the two extreme ends of the frontier. Moreover, the comparison between the two scenarios shows that the discount policy mainly improves cost performance, while the quality level is affected more by the selected execution and procurement modes than by the discount itself.

Fig. 2 also suggests the presence of a knee region in the middle part of the Pareto frontier, where a moderate increase in cost leads to a relatively large improvement in quality. In contrast, moving from the middle region toward the extreme high-quality solutions yields only limited additional quality gains, indicating diminishing marginal returns. From a managerial perspective, these middle Pareto solutions may therefore provide a more balanced compromise between cost and quality than the extreme points. This interpretation is consistent with the observed solution structure, where low-cost solutions rely more on lower procurement quality modes, while higher-quality solutions increasingly adopt higher execution modes to reduce delay effects and improve project performance. Since the Pareto frontier was generated using the augmented ε-constraint method for the numerical example, the emphasis of this study is on interpreting the obtained non-dominated solutions rather than benchmarking an approximate Pareto set through performance metrics such as hypervolume.

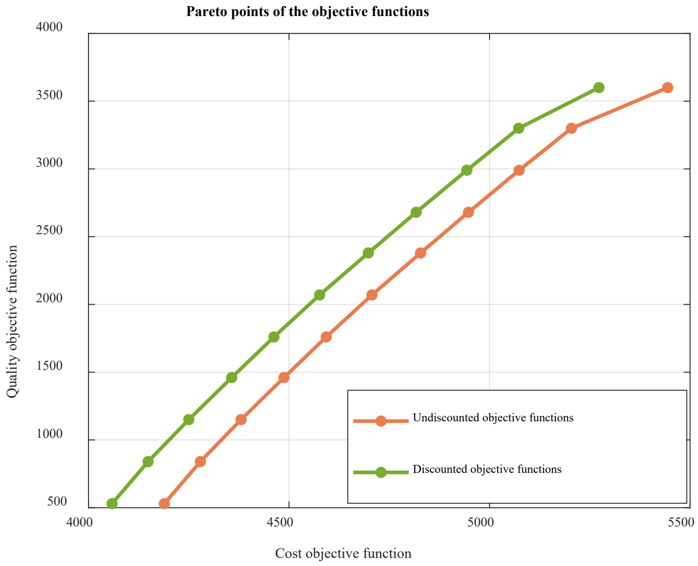


Fig. 2. Pareto points based on cost and quality functions

Fig. 3 illustrates the discount rates applied to each non-renewable resource type. The first and third projects applied the second discount tier for type 1 resources and the third tier for type 2 resources. In contrast, no discounts were applied in the second project for either resource type due to insufficient purchase volume.

The model determines the most cost-effective time to purchase each resource, accounting for the time required for preparation and shipping before suppliers deliver the order. The model tends to procure and store resources earlier since maintaining inventory is generally more economical than repeated purchasing and ordering. It also selects appropriate quality modes for each supplier based on timing and cost factors.

Fig. 4 presents the selected quality modes for types 1 and 2 non-renewable resources across all projects. The results indicate that suppliers 1 and 4 were selected to provide type 1 and type 2 resources, respectively, due to their lower costs and shorter lead times. Among the type 1 suppliers, Supplier 1 offers the most competitive price. Similarly, supplier 4 is the more cost-effective option for type 2 resources. Moreover, delay penalties are incurred if a project fails to meet its planned deadline.

At the first Pareto point, all resources are allocated using quality mode 1 (lowest quality), reflecting a cost-oriented strategy. Conversely, the highest quality mode (mode 3) is selected at the final Pareto point, prioritizing quality over cost. Quality mode 1 is generally preferred for both resource types, as higher-quality alternatives entail significantly higher procurement costs.

The Gantt chart of summary tasks and the inventory levels of each project per time are shown in Fig. 5. In this figure, Project 1 is represented in orange, Project 2 in green, and Project 3 in blue. The inspection periods for each project are highlighted in gray.

The earliest feasible delivery of the required non-renewable resources determines the start time of each summary task. A red line indicates the planned completion time for each project. If a project exceeds this deadline, a delay cost will be incurred.

Furthermore, the required quantities of non-renewable resources and the inventory levels for each project are illustrated across all periods. The inventory level is zero at the beginning and end of the planning horizon. No summary task can commence before period 3, as the required non-renewable resources have not yet arrived. The first and second summary tasks start at period 4, consuming part of the received resources, while the remaining quantity is stored as inventory. This process continues throughout the project timeline until all tasks are completed.

To further examine the structural behavior of the model under extreme conditions, two illustrative stress-test scenarios are considered in this section by assigning very large values to selected cost parameters. These scenarios are not intended to represent typical market conditions, but to verify whether the model responds in a logically consistent way when one cost component becomes dominant.

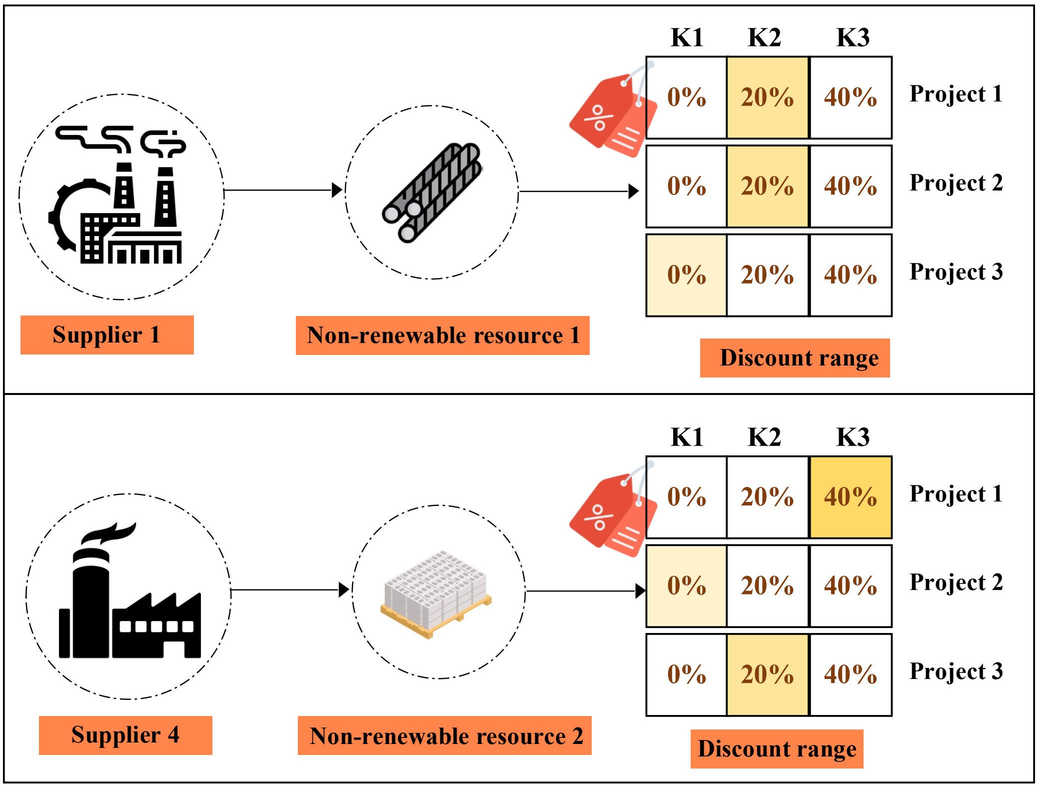


Fig. 3. Selected discount ranges for each project

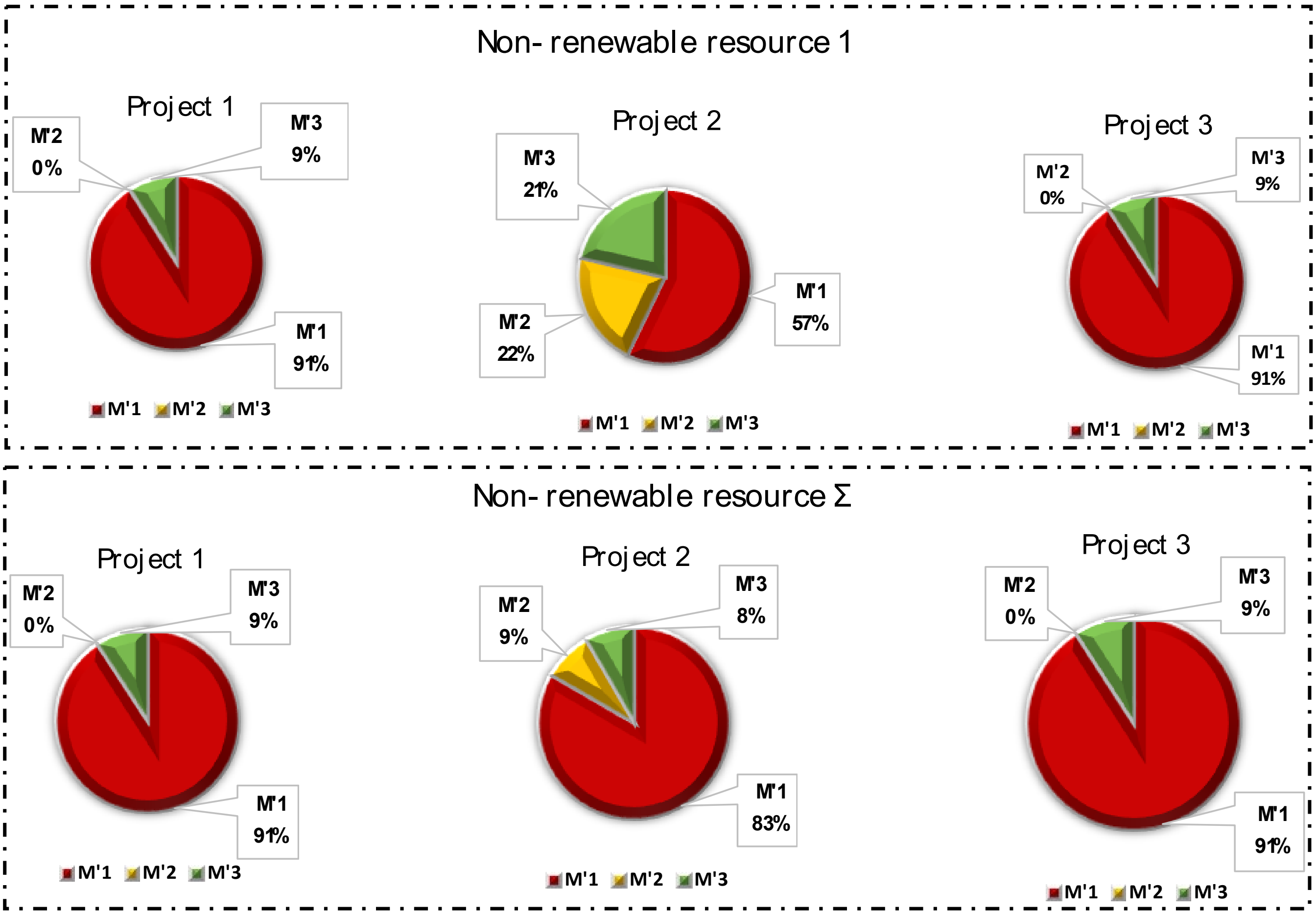


Fig. 4. Quality mode of selected non-renewable resources

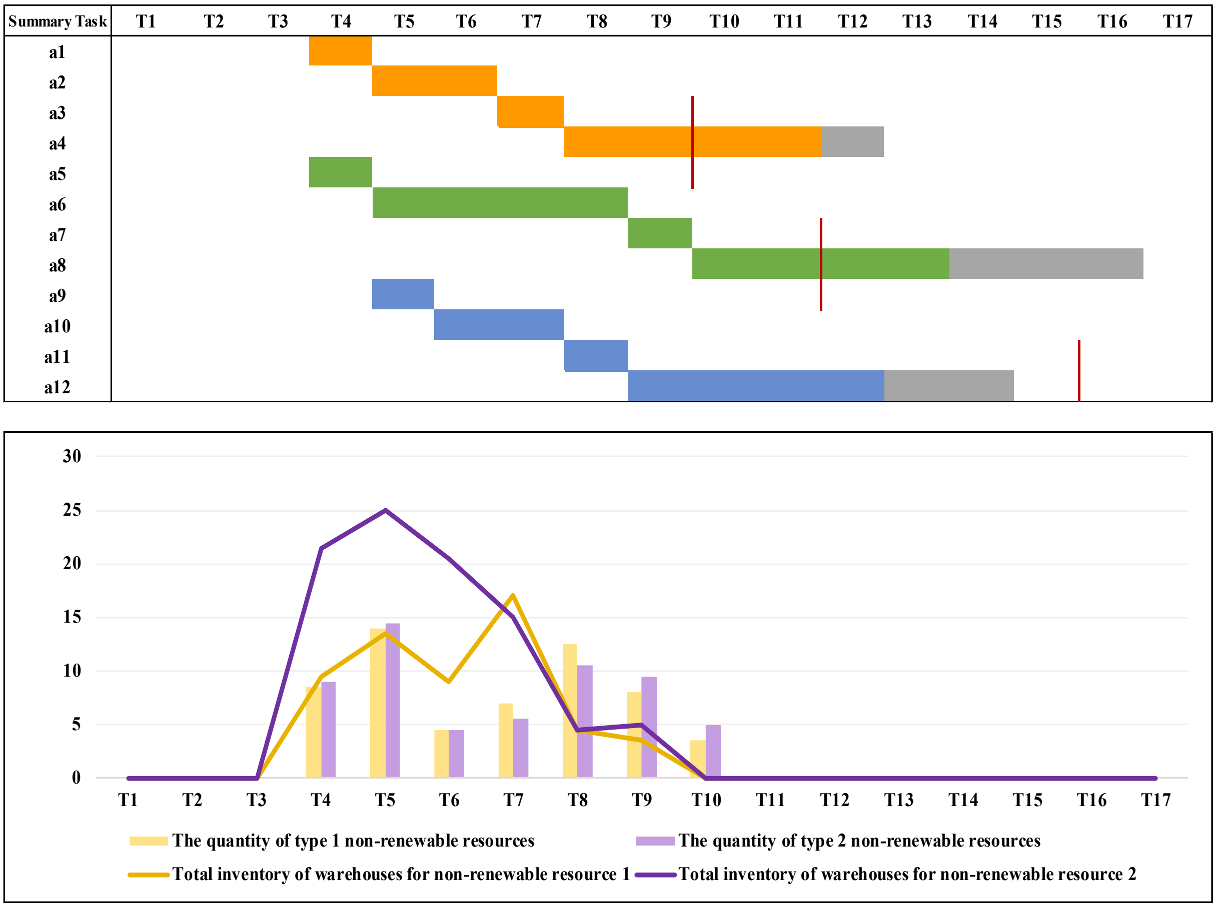


Fig. 5. Gantt chart of activities along with required resources and inventory of warehouses

As shown in Fig. 6, when the inventory holding cost is set to a very large value (100 times its base value), the inventory level drops to zero, and resources are delivered precisely at the time they are needed. This stress-test scenario confirms that the model avoids inventory whenever storage becomes economically unattractive.

Additionally, the model selects the fifth supplier for the third project due to its long preparation and shipping times, requiring earlier ordering. The timing of summary tasks is also slightly adjusted, as reflected in the updated Gantt chart. Although the first and second projects experienced delays, the third project was completed on schedule.

While other parameters remain constant, the purchasing price is set to a very large value (100 times its base value). As illustrated in Fig. 7, placing frequent orders becomes less economical than maintaining inventory under these conditions. Accordingly, the model shifts to bulk purchasing and temporary warehousing. This stress-test scenario confirms that the model prefers inventory accumulation when repeated procurement becomes excessively expensive.

This change also affects the scheduling of summary tasks. In the original schedule, Projects 1 and 2 started in period 4, and Project 3 at period 5. After the change, project 1 maintained its original start time, while projects 2 and 3 began in period 5. Only project 2 benefits from a one-day reduction in duration, while the delays in projects 1 and 3 remain unaffected.

Fig. 8 graphically illustrates the selected quality modes for each summary task. The selection of each mode is based on a trade-off between execution time, quality, and cost. In manual execution modes, higher quality levels may result in longer durations due to more detailed work. In contrast, higher-quality modes often involve mechanized execution, reducing the time required to complete the task while increasing quality and execution costs.

The data shows that most summary tasks are performed in quality mode 3, representing the highest quality level. This mode is often preferred as it enables faster task completion, contributing to on-time project delivery despite its higher cost. Choosing the third quality mode is more cost-effective than incurring delay penalties, even if it requires a higher execution cost.

4.3. Sensitivity analysis

Multiple factors can increase or reduce construction project supply chain costs. In the sensitivity analysis, input parameters are varied to evaluate their impact on the objective functions and identify the most influential ones. If significant variations are observed in response to parameter changes, further investigation and model adjustment may be required.

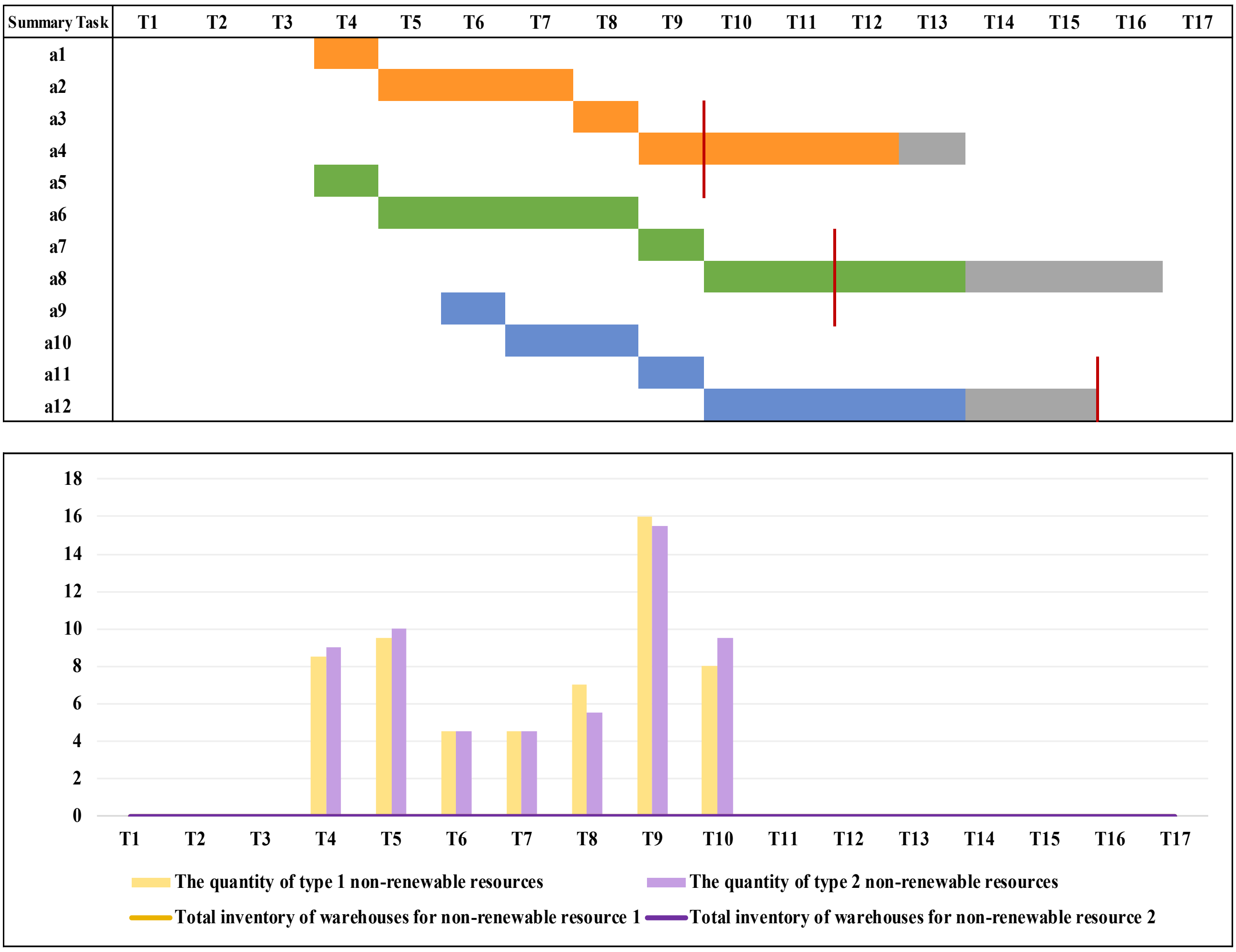


Fig. 6. Gantt chart of activities along with inventory of warehouses with the increase in inventory holding cost

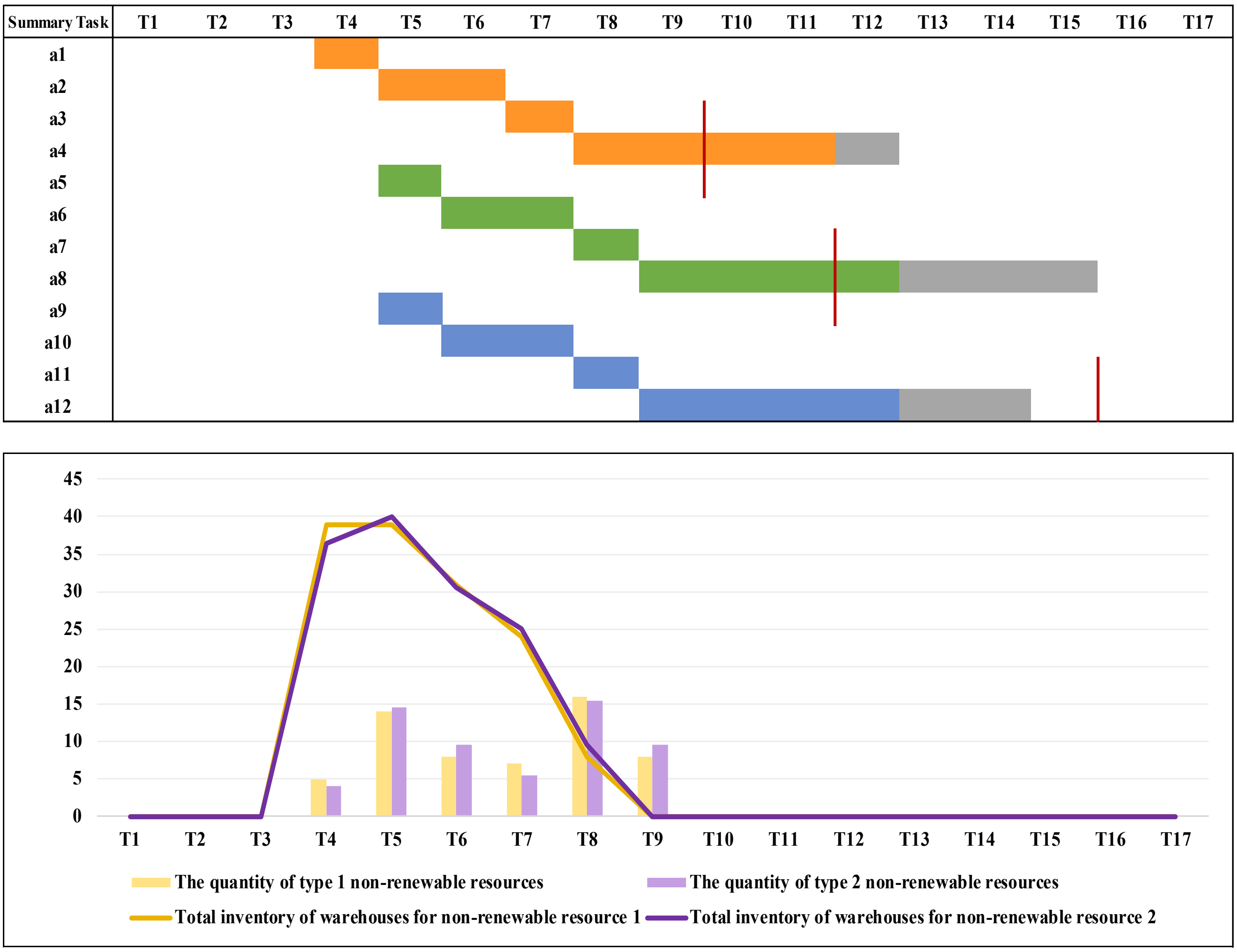


Fig. 7. Gantt chart of activities along with inventory of warehouses, with the increase in buying cost

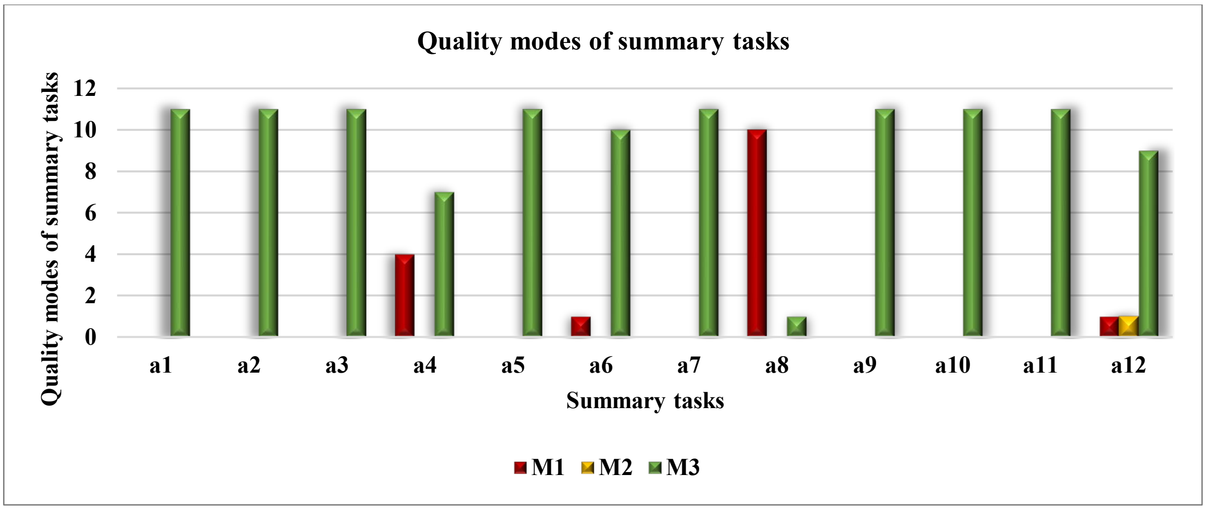


Fig. 8. Selected quality modes for each summary task

Fig. 9 shows notable fluctuations in the purchase and ordering cost parameters. In each figure, the right-hand graph shows changes under a constrained budget (5600 units), while the left-hand graph shows results under an unconstrained budget (8000 units).

When purchase or ordering costs increase, the model tends to place bulk orders at the beginning of the planning horizon, as inventory holding remains more economical than multiple smaller purchases.

Under an unconstrained budget with increased costs, all Pareto points show a slight increase in the cost objective function. However, cost values decrease when budget constraints are applied in regions where projected costs exceed the available budget.

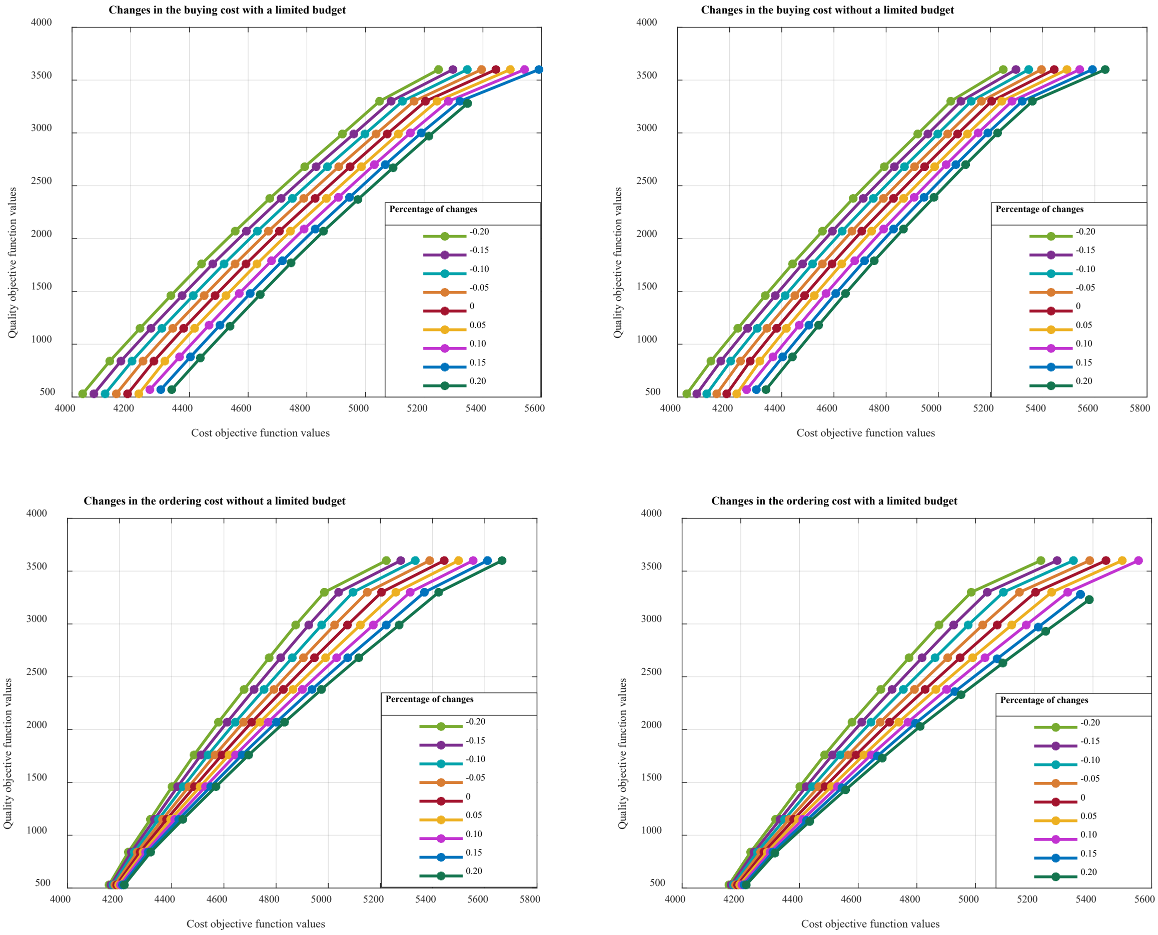


Fig. 9. Changes in objective functions after an alteration in buying and ordering prices

The selected quality modes influence the behavior of the quality objective function. Without a budget constraint, its value increases slightly before stabilizing as higher-quality resources are chosen. Conversely, the quality objective function fluctuates under budget restrictions due to limited feasibility in selecting premium options.

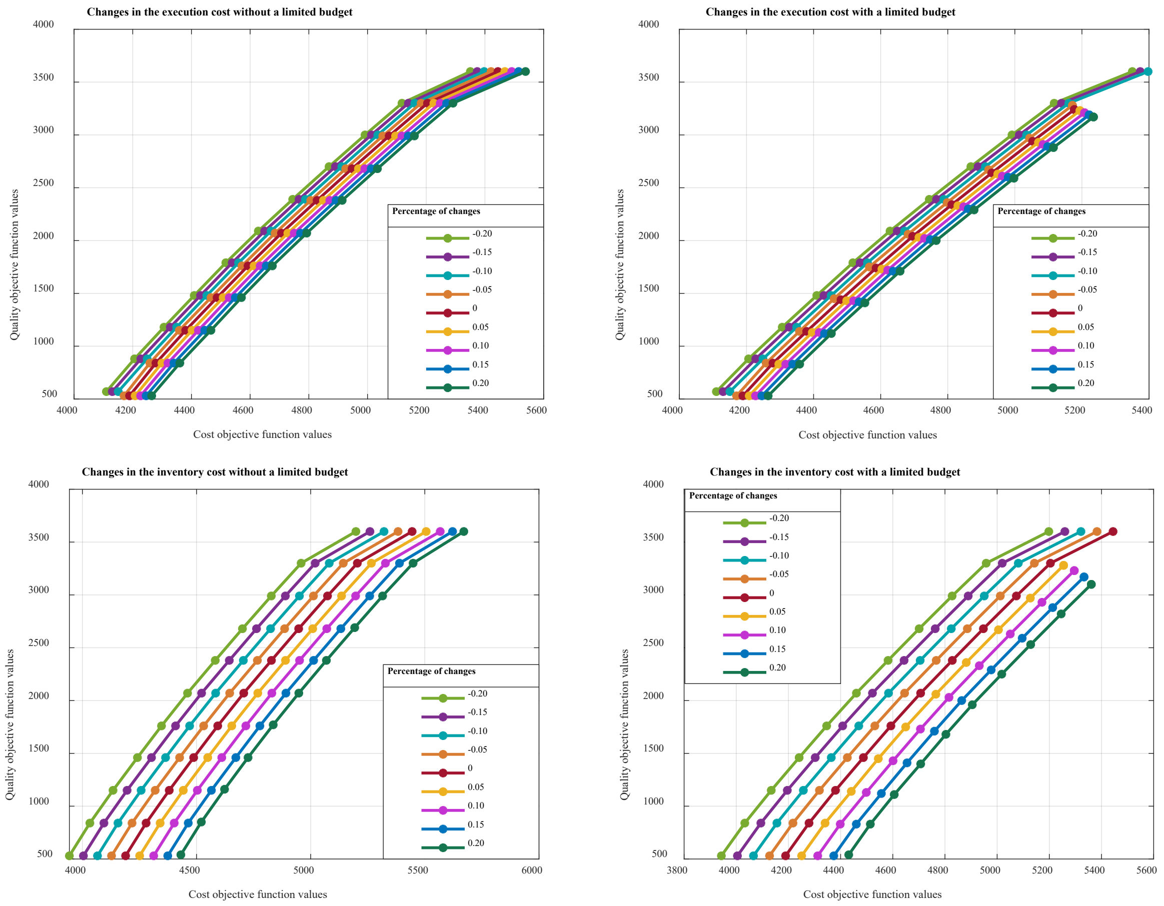
Fig. 10 illustrates the changes in the execution cost of summary tasks under two conditions: an unconstrained budget (8000 units) and a constrained budget (5400 units). When the budget is unconstrained and execution costs increase, the quality objective function initially decreases and stabilizes. This occurs because the model selects lower-quality modes to limit overall cost increases.

In contrast, under a constrained budget, an increase in execution cost leads to a decline in the quality objective function, while the cost objective function shows an upward trend. In such scenarios, summary tasks are executed in lower-quality modes to minimize additional costs.

The figure also compares the impact of changes in inventory holding costs under budget-constrained (5500 units) and unconstrained (8000 units) conditions. Generally, the cost objective function increases as inventory holding costs rise. However, the quality objective function remains unaffected since inventory costs are independent of quality. Under budget constraints, the cost objective function may fluctuate as lower-quality modes are increasingly selected.

Fig. 11 illustrates how changes in the required non-renewable resources for summary tasks affect the objective functions under unconstrained (8000 units) and constrained (5700 units) budgets. An increase in resource demand significantly impacts the cost objective function, as more funds are required to procure additional materials. However, because quality selection does not affect the quantity of resources needed, its influence on the quality objective function is minimal. Under budget constraints, the cost objective function increases with rising demand until a threshold is reached, after which it begins to decline. In this context, reducing quality levels also helps keep total costs within the budget.

The figure also shows how variations in the upper limit of discount ranges affect the objective functions under budget-constrained (5500 units) and unconstrained (8000 units) scenarios. This case exhibits a broader range of variation compared to previous scenarios, making the trends more distinguishable. When the discount threshold is lowered, more non-renewable resources become eligible for discounted pricing, thereby reducing overall expenses.

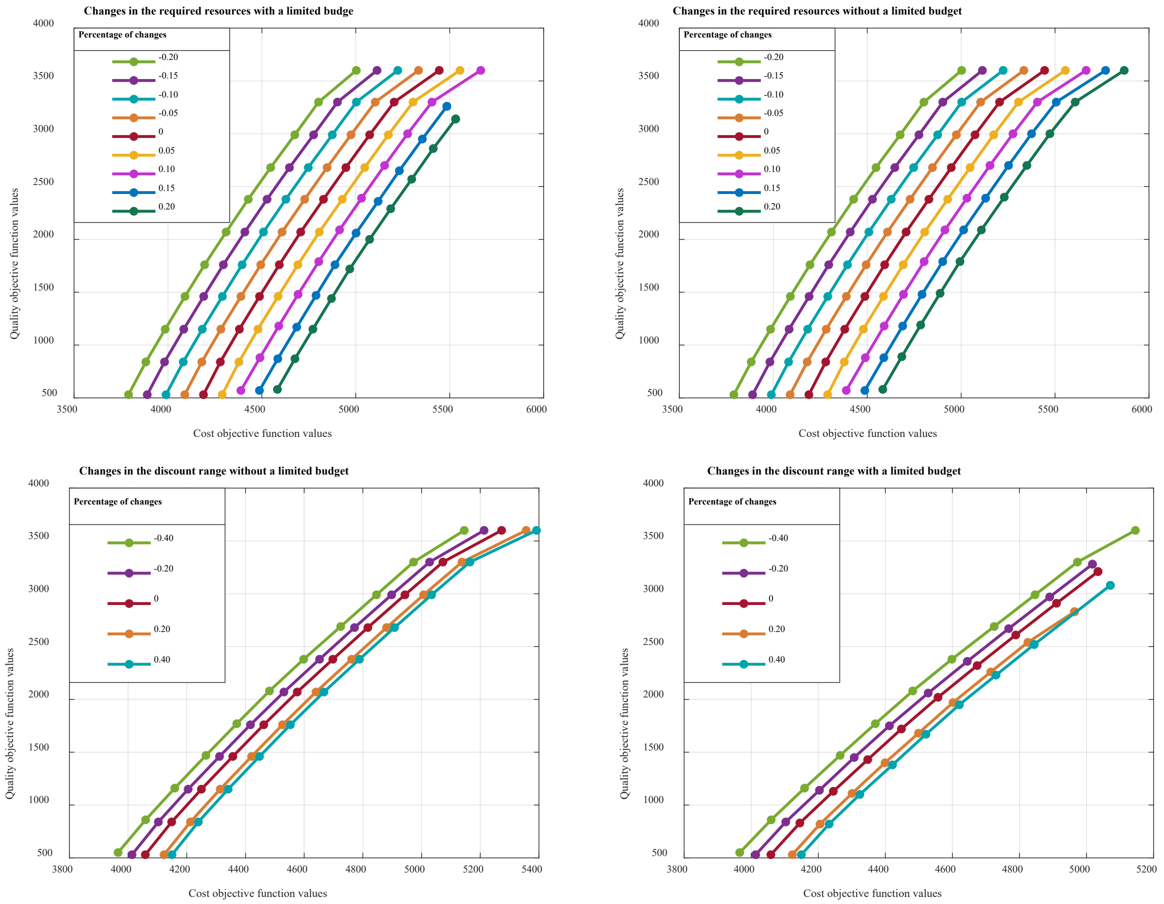

Changes in the execution cost without a limited budget

Changes in the execution cost with a limited budget

Changes in the inventory cost without a limited budget

Changes in the inventory cost with a limited budget

Fig. 10. Changes in objective functions after an alteration in execution and inventory holding prices


Changes in the required resources with a limited budge

Changes in the required resources without a limited budget

Changes in the discount range without a limited budget

Changes in the discount range with a limited budget

Fig. 11. Changes in objective functions after an alteration in limited discount ranges and resources

In certain instances, the quality objective function increases because savings from discounted purchases allow for reinvestment in higher-quality options. However, under strict budget conditions, the quality objective function must decrease to stay within financial limits.

4.4. Research findings and innovation

The key findings of this study are outlined below:

- A slight increase in construction expenses can significantly improve overall quality, supporting a cost-effective balance between quality and cost.
- Based on the results, non-renewable resources are often procured in lower-quality modes due to their strong dependence on ordering and purchasing costs. In contrast, many summary tasks are executed at the highest quality levels to meet project cost and scheduling requirements. There is a clear correlation between the quality level of a summary task and its implementation cost—higher quality generally implies greater cost but shorter duration due to advanced technologies.
- Although suppliers 2, 3, and 5 offer better discount rates for smaller purchase volumes than suppliers 1 and 4, the model still selects suppliers 1 and 4. Multiple criteria guide this choice, including ordering costs, unit price, transportation expenses, proximity to project sites, and material quality. Therefore, changing a single parameter does not typically alter the supplier selection, as the model evaluates all influencing factors holistically.
- The sensitivity analysis identified key influential parameters, such as ordering costs, required quantities of non-renewable resources, purchase prices, and inventory holding costs.
- This research is distinguished by its integrated consideration of quality and cost across the construction supply chain. The proposed model provides a comprehensive framework that addresses quality in every stage—from procurement and resource allocation to execution and final inspection—making it a practical tool for enhancing decision-making in construction management.

4.5. Managerial insights

Based on the numerical results, several practical decision implications can be derived for construction project managers and procurement planners. First, when inventory holding cost becomes very high, the model shifts toward just-in-time deliveries and avoids inventory accumulation, indicating that storage should be minimized when inventory becomes economically unattractive. Second, when purchasing cost becomes dominant, the model prefers consolidated procurement and temporary warehousing rather than repeated small orders. Third, supplier selection is not determined by discount rate alone; lower transportation cost, shorter lead time, and lower base purchasing cost may outweigh more attractive discount thresholds. Fourth, higher execution modes are selected when their additional execution cost is lower than the delay cost that would be incurred under slower modes. Finally, when the expected delay penalty exceeds the additional execution cost of a higher mode, the model prefers the higher execution mode because faster completion becomes more economical than accepting project delay.

Despite the advantages of the proposed model, access to accurate and up-to-date information on supplier characteristics (such as preparation and delivery times) may be limited in real-world settings, which can affect the accuracy of the model's outputs. Moreover, the model assumes homogeneous vehicles, whereas variations in capacity or cost may exist in practice. It should also be noted that the quality objective used in this study is intended as an aggregated decision-support measure for comparing alternative solutions, rather than as a comprehensive physical measure of all dimensions of project quality. Nevertheless, the model's structure is flexible and can be easily extended to incorporate such differences, which could be explored in future research. In addition, the assumptions that each supplier provides only one resource type and that summary tasks proceed without interruption may limit the direct generalizability of the model in more complex construction environments. Since the main contribution of this study is the development of an integrated quality-oriented optimization framework for the construction supply chain, extensive large-scale computational experiments and comparisons with alternative solution approaches were beyond the scope of the current paper and can be addressed in future research.

5. Conclusions

In the construction sector, firms develop and execute multiple projects each year. These projects demand coordination of investment planning, client requirements, engineering design, and contractor expertise to achieve efficient, high-quality outcomes. Firms strive to deliver top-tier services, yet obstacles often arise that a comprehensive model can address. Recent work has called for an integrated view of quality across the construction supply chain, but most studies examine only a single stage. The lack of a decision-support model spanning all phases represents a critical challenge in supply chain management. To meet this need, this study proposes a bi-objective linear programming model that raises overall quality while cutting logistics costs. The model treats inventory control and supplier selection as core decisions and embeds quality checks throughout procurement, execution of summary tasks, and final inspection. Linking these processes guides decision-makers in selecting suppliers, allocating resources, and scheduling tasks to reliably balance cost and quality.

Furthermore, each summary task and supplier offer multiple quality modes, and the model selects the optimal mode for each decision. A review committee then evaluates each project once all tasks are finished. In the second scenario, the supplier discount policy is applied. The study solves the bi-objective model using the augmented ε-constraint method and validates the solution using a numerical example. Results indicate discounts lower total costs and affect quality only under strict budget limits. Order quantities are set to ensure each summary task starts on schedule, prevent project delays, and reduce inventory and shipping expenses. Suppliers are chosen based on the cost and quality of the service they provide for each non-renewable resource. A Gantt chart illustrates project timelines alongside the selected quality modes for each summary task. As demonstrated, a critical step in construction project management is choosing the supplier and the execution mode for summary tasks based on cost and quality trade-offs. Sensitivity analysis reveals that parameters such as required non-renewable resources, purchase prices, ordering costs, and inventory policies significantly affect the cost objective. From a managerial standpoint, the proposed model provides a rigorous decision-support tool, enabling project managers to base supplier selection, resource planning, and quality oversight on quantitative analysis across multiple projects.

Several avenues exist for extending the proposed model. First, researchers could develop a closed-loop supply chain incorporating repair and rework processes. Second, although this study uses fixed parameters for tractability and clarity in balancing cost and quality, future work might introduce uncertainty, such as supplier delays, quality variability, and inventory risks, to better reflect real-world conditions. Adding these stochastic elements would strengthen the model's resilience and broaden its use in dynamic construction settings. Third, the current model assumes a uniform fleet of transport vehicles to keep the formulation straightforward; subsequent studies could include heterogeneous fleets with varying capacities, costs, and availability to better reflect actual logistics challenges. Moreover, future studies using large-scale instances or approximate multi-objective algorithms may evaluate Pareto-set quality by reporting hypervolume, spacing, or other frontier-quality indicators.

Declarations

Conflict of Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

This research received no external funding.

Author Contributions

M. Izadbakhsh: Investigation, Methodology, Data Collection, Formal Analysis, Visualization, Writing – Original Draft. S. F. Ghannadpour: Conceptualization, Methodology, Supervision, Validation, Writing – Review & Editing. M. Mahdavi-Mazdeh: Supervision, Validation, Writing – Review & Editing. Morteza Bagherpour: Supervision, Validation.

Acknowledgments

I would like to thank Piramon System Company for its valuable contributions to this study.

Data Availability Statement

The data presented in this study are available within the article.

Ethics Committee Permission

Not applicable.

Use of Generative AI and AI-assisted Technologies

The authors used ChatGPT-4.5 solely for language polishing (e.g., grammar check) and have reviewed and take full responsibility for the final content.

References

[1] Takim R, Akintoye A (2002) Performance indicators for successful construction project performance. In: Proceedings of 18th Annual ARCOM Conference, pp. 545–555.

[2] Olanrewaju AL, Bong MZX, Preece C (2022) Establishment of pre-qualification criteria for the selection of subcontractors by the prime constructors for building projects. J Build Eng 45:103644. https://doi.org/10.1016/j.jobe.2021.103644.

[3] Olanrewaju AL, Lee AHJ (2022) Investigation of the poor-quality practices on building construction sites in Malaysia. Organ Technol Manag Constr 14(1):2583–2600. https://doi.org/10.2478/otmcj-2022-0008.

[4] Lucko G, Su Y (2014) Singularity functions as new tool for integrated project management. Procedia Eng 85:339–350. https://doi.org/10.1016/j.proeng.2014.10.559.

[5] Chopra S, Peter M (2014) Supply Chain Management: Strategy, Planning, and Operation, Third Edition.

[6] Hastig GM, Sodhi MMS (2020) Blockchain for supply chain traceability: Business requirements and critical success factors. Prod Oper Manag 29(4):935–954. https://doi.org/10.1111/poms.13147.

[7] Palareti G et al. (2016) Comparison between different D-Dimer cutoff values to assess the individual risk of recurrent venous thromboembolism: Analysis of results obtained in the DULCIS study. Int J Lab Hematol 38(1):42–49. https://doi.org/10.1111/ijlh.12426.

[8] Durdyev S, Hosseini MR (2020) Causes of delays on construction projects: A comprehensive list. Int J Manag Proj Bus 13(1):20–46. https://doi.org/10.1108/IJMPB-09-2018-0178.

[9] Lotfi R, Kargar B, Gharehbaghi A, Hazrati H, Nazari S, Amra M (2022) Resource-constrained time–cost-quality-energy-environment tradeoff problem by considering blockchain technology, risk and robustness: A case study of healthcare project. Environ Sci Pollut Res 29(42):63560–63576. https://doi.org/10.1007/s11356-022-20334-7.

[10] RezaHoseini A, Noori S, Ghannadpour SF (2021) Integrated scheduling of suppliers and multi-project activities for green construction supply chains under uncertainty. Autom Constr 122:103485. https://doi.org/10.1016/j.autcon.2020.103485.

[11] Tabrizi BH, Ghaderi SF (2016) A robust bi-objective model for concurrent planning of project scheduling and material procurement. Comput Ind Eng 98:11–29. https://doi.org/10.1016/j.cie.2016.05.017.

[12] Habibi F, Chakrabortty RK, Abbasi A (2023) Maximizing projects' profitability, environmental score, and quality: A multi-project scheduling and material ordering problem. Environ Sci Pollut Res 30(21):59925–59962.

[13] Kelley JE, Walker MR (1959) Critical-path planning and scheduling. In: Proceedings of the Eastern Joint Computer Conference IRE-AIEE-ACM 1959, pp. 160–173. https://doi.org/10.1145/1460299.1460318.

[14] Demirkesen S, Ozorhon B (2017) Impact of integration management on construction project management performance. Int J Proj Manag 35(8):1639–1654. https://doi.org/10.1016/j.ijproman.2017.09.008.

[15] Lee K, Lei L, Pinedo M, Wang S (2013) Operations scheduling with multiple resources and transportation considerations. Int J Prod Res 51(23–24):7071–7090. https://doi.org/10.1080/00207543.2013.781283.

[16] Yan L, Guo L, Ning Y (2020) Understanding construction contractors' intention to undertake consummate performance behaviors in construction projects. Adv Civ Eng 2020(1):3935843. https://doi.org/10.1155/2020/3935843.

[17] Sharifi MM, Bagherpour M (2016) Optimizing cash-flow-at-risk in construction projects: A cost reduction approach. Period Polytech Civ Eng 60(3):337–344. https://doi.org/10.3311/PPci.7884.

[18] Khanzadi M, Movahedian A, Bagherpour M (2016) Finding optimum resource allocation to optimizing construction project time/cost through combination of artificial agents CPM and GA. Period Polytech Civ Eng 60(2):169–180. https://doi.org/10.3311/PPci.7883.

[19] Olubajo OO, Olubajo RO (2025) Analysing the influence of offsite construction logistics on the performance of construction projects. J Constr Eng Manag Innov 8(1):49-63.

[20] Yousef R, La Scola Needy K, Walsh KD, Da Alves TCL (2015) Supplier quality management inside and outside the construction industry EMJ Eng Manag J 27(1):11–22. https://doi.org/10.1080/10429247.2015.11432032.

[21] Liu F, Ouyang T, Huang B, Zhao J (2024) Research on green building design optimization based on building information modeling and improved genetic algorithm. Adv Civ Eng 2024(1):9786711. https://doi.org/10.1155/2024/9786711.

[22] Kim SY, Nguyen VT (2022) Supply chain management in construction: Critical study of barriers to implementation. Int J Constr Manag 22(16):3148-3157. https://doi.org/10.1080/15623599.2020.1843768.

[23] Kaveh A, Rajabi F (2022) Fuzzy-multi-mode resource-constrained discrete time-cost-resource optimization in project scheduling using ENSCBO. Period Polytech Civ Eng 66(1):50–62. https://doi.org/10.3311/PPci.19145.

[24] Zhang C, He K, Zhang W, Jin T, Ao Y (2023) Study on mechanism of factors affecting resilience of prefabricated building supply chain. Adv Civ Eng 2023(1):8870224. https://doi.org/10.1155/2023/8870224.

[25] Rahman HF, Chakrabortty RK, Ryan MJ (2019) An optimised supplier selection plan for supply chain integrated project scheduling problem. In: Proceedings of 2019 IEEE Technology & Engineering Management Conference (TEMSCON 2019), pp. 1–6. https://doi.org/10.1109/TEMSCON.2019.8813610.

[26] Chen W, Lei L, Wang Z, Teng M, Liu J (2018) Coordinating supplier selection and project scheduling in resource-constrained construction supply chains. Int J Prod Res 56(19):6512–6526. https://doi.org/10.1080/00207543.2018.1436782.

[27] Ben Mahmoud B, Lehoux N, Blanchet P (2024) Integration mechanisms for material suppliers in the construction supply chain: A systematic literature review. Constr Manag Econ 42(1):70–107. https://doi.org/10.1080/01446193.2023.2239381.

[28] Asuquo OE, Ogwueleka AC (2025) Impact of supply chain integration on cost performance in the public sector construction projects. J Constr Eng Manag Innov 8(2):126–145.

[29] Zeng W, Tse MYK, Tang M (2018) Supply chain quality management: An investigation in the Chinese construction industry. Int J Eng Bus Manag 10:1–16. https://doi.org/10.1177/1847979018810619.

[30] Darabad SD, Izadbakhsh M, Ghannadpour SF, Nouri S, Mohammad MM (2024) A new bi-objective green construction model for multi project supply chain management under uncertainty. Int J Ind Eng Prod Res 35(1):1–17. https://doi.org/10.22068/ijiepr.35.1.1813.

[31] Asadujjaman M, Rahman HF, Chakrabortty RK, Ryan MJ (2021) A memetic algorithm for concurrent project scheduling, materials ordering and suppliers selection problem. Procedia Comput Sci 192:717–726. https://doi.org/10.1016/j.procs.2021.08.074.

[32] Mohammadnazari Z, Ghannadpour SF (2021) Sustainable construction supply chain management with the spotlight of inventory optimization under uncertainty. Environ Dev Sustain 23:10937–10972. https://doi.org/10.1007/s10668-020-01095-0.

[33] Habibi F, Barzinpour F, Sadjadi SJ (2019) A mathematical model for project scheduling and material ordering problem with sustainability considerations: A case study in Iran. Comput Ind Eng 128:690–710. https://doi.org/10.1016/j.cie.2019.01.007.

[34] Mirghaderi SD, Modiri M (2021) Application of meta-heuristic algorithm for multi-objective optimization of sustainable supply chain uncertainty. Sadhana Acad Proc Eng Sci 46(1). https://doi.org/10.1007/s12046-020-01554-4.

[35] Patoghi A, Mousavi SM (2021) A new approach for material ordering and multi-mode resource constraint project scheduling problem in a multi-site context under interval-

valued fuzzy uncertainty. Technol Forecast Soc Change 173:121137. https://doi.org/10.1016/j.techfore.2021.121137.

[36] Polat G (2021) A semi-systematic literature review on supplier selection in construction projects. J Constr Eng Manag Innov 4(4):256–266.

[37] Herbon A, David I (2023) Optimal manufacturer's cost sharing ratio, shipping policy and production rate – a two-echelon supply chain. Oper Res Perspect 10. https://doi.org/10.1016/j.orp.2022.100264.

[38] Taleizadeh AA, Noori-Daryan M, Tavakkoli-Moghaddam R (2015) Pricing and ordering decisions in a supply chain with imperfect quality items and inspection under buyback of defective items. Int J Prod Res 53(15):4553–4582. https://doi.org/10.1080/00207543.2014.997399.

[39] Hartwig R, Inderfurth K, Sadrieh A, Voigt G (2015) Strategic inventory and supply chain behavior. Prod Oper Manag 24(8):1329–1345. https://doi.org/10.1111/poms.12325.

[40] Chen S, Lei J, Moinzadeh K (2023) Inventory and supply chain management with auto-delivery subscription. Prod Oper Manag 32(12):4068–4087. https://doi.org/10.1111/poms.14078.

[41] Chen Z, Hammad AWA, Alyami M (2024) Building construction supply chain resilience under supply and demand uncertainties. Autom Constr 158:105190. https://doi.org/10.1016/j.autcon.2023.105190.

[42] Luong DL, Tran DH, Nguyen PT (2021) Optimizing multi-mode time-cost-quality trade-off of construction project using opposition multiple objective difference evolution. Int J Constr Manag 21(3):271–283. https://doi.org/10.1080/15623599.2018.1526630.

[43] Abdzadeh B, Noori S, Ghannadpour SF (2023) A comprehensive mathematical model for quality integration in a project supply chain with concentrating on material flow and transportation. Adv Eng Inform 57. https://doi.org/10.1016/j.aei.2023.102034.

[44] Abdzadeh B, Noori S, Ghannadpour SF (2022) Simultaneous scheduling of multiple construction projects considering supplier selection and material transportation routing. Autom Constr 140. https://doi.org/10.1016/j.autcon.2022.104336.

[45] Hemanth DJ, Kose U (2020) Artificial intelligence and applied mathematics in engineering problems. In: Proceedings of the International Conference on Artificial Intelligence and Applied Mathematics in Engineering (ICAIAME 2019). Springer Nature.

[46] Keeney RL, Raiffa H (1993) Decisions with Multiple Objectives: Preferences and Value Trade-Offs. Cambridge University Press.

[47] Belton V, Stewart T (2012) Multiple Criteria Decision Analysis: An Integrated Approach. Springer Science & Business Media.

[48] Nardo M, Saisana M (2008) OECD/JRC handbook on constructing composite indicators: Putting theory into practice. In: Proceedings of the NTTS (New Techniques and Technologies for Statistics) Seminar.