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RESEARCH PAPER

A New Bi-Objective Green Construction Model for Multi Project Supply Chain Management Under Uncertainty

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ABSTRACT

The construction supply chain is presently the focus of considerable interest among numerous project-related businesses. Strong project management is essential for the effective completion of a project, since restricted budgets and time constraints are considered for each project. The research uses multi-objective linear programming to create a mathematical model of the building supply chain. The primary aims of the present investigation are to limit the expenses associated with logistics and to diminish the release of greenhouse gases caused by transportation. Given the reality of managing several projects concurrently, the model provided comprises a network of projects. Following the completion of each project, an inspection is arranged to assess its level of success. Estimating the costs of a project relies on several variables. In reality, there are always uncertainties highlighted in several studies about the uncertainty of cost and time parameters. This research incorporates many characteristics concurrently to simulate real-world settings and address the issue of uncertainty. The expression of uncertainty for all costs, activity length, inspection, supplier capacity, and resource demand are represented by triangular fuzzy numbers. Ultimately, the precision of the model's performance has been verified using a numerical illustration.

KEYWORDS: *Construction project; Project scheduling; Multi-projects; Green supply chain; Supplier selection; Fuzzy uncertainty.*

1. Introduction

Project management is crucial for every construction project since these projects are continuously changing and require a well-planned approach to ensure success [1]. It is particularly important to manage expenses in the construction industry, which spent up to 11.4 trillion US dollars globally in 2018, with an estimated rise to 14 trillion dollars in 2025 [2]. Consequently, cost overruns, scheduling delays, and irrational project scope expansion may all result in construction project failures [3]. These projects are becoming increasingly complex, requiring coordinating the management of time, money, and resources into a single framework [4, 5]. To ensure the efficient provision of resources, four fundamental responsibilities must be considered in construction supply chain management, as the major aims of supply chain management are to satisfy customer requests on time and minimize costs [6]. Scheduling delays are a widespread concern in most building projects globally, particularly in large projects, which not only delay the delivery of the final product to the client but may significantly impact cost, time, and quality[7, 8]. In fact, only 55% of projects are completed on time, indicating that project constraints, such as resource and time constraints, are not sufficiently considered [9]. Therefore, it is critical to identify the key elements and decisions before building a supply chain. Researchers are actively striving to

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minimize supply chain barriers that impede progress towards these objectives [10]. Since supplier performance in terms of cost, quality, delivery, and service is essential to achieving supply chain goals, effective supplier management is the key to effective supply chain management, which begins with identifying potential suppliers. Making informed supplier selections substantially reduces purchasing costs while also increasing the competitiveness of the business [11].

Construction is one of the industrial sectors with the highest environmental impact, producing 30% of the solid waste generated in the European Union. Thus, green supply chain management is instrumental in assisting companies in reaching their financial goals while minimizing environmental risks and improving environmental performance [12].

Minimizing the adverse environmental impacts associated with transportation and its pollutants is the supply chain's primary objective for green projects. Therefore, the type and amount of vehicles with the lowest emission levels must be specified, taking into account factors such as the weight and amount of cargo and the number of journeys made [13, 14].

The main cause of project complexity is the uncertainty involved due to each project's individuality, which poses a risk of program interruptions [15]. Such uncertainties may arise from various factors, including delays in activities, non-availability of resources, delayed arrival of materials, changes in lead times and due dates, and requirement of additional activities. Missing deadlines, idle resources, increased inventory, and system rework are a few consequences of the disrupted schedule, which leads to increased costs [16]. This limitation of deterministic time has drawn criticism and hence, a better approach is to account for uncertainties. Fuzzy approaches and scenario-based techniques are popular ways of capturing uncertainties [17]. Fuzzy modeling adopts a two-step approach of discovering input-output connections and input variables among the potential input candidates and assigning the corresponding membership functions to them [18].

This study described the goals of a bi-objective mathematical linear programming model that simultaneously considers the uncertainties in multiple factors like costs, inspection times, activity times, and demand. The first goal involves reducing supply chain expenses such as purchasing costs, ordering, transportation, and operational delays while also minimizing emissions caused by vehicle movement. The second goal involves coordinated planning of projects, supplier selection, and vehicle selection that takes environmental factors into account after project quality inspection. The third goal is to account for demand uncertainties for fluctuating costs, activity duration, and inspection duration. Section 2 of the study discusses building supply chains and green principles along with a summary of quantitative initiatives and research gaps. Section 3 presents a problem description, assumptions, sets, parameters, and decision variables along with a mathematical model that seeks to reduce supply chain costs and transportation pollution under both deterministic and non-deterministic circumstances. Section 4 offers sensitivity analyses of various outcomes and numerical examples with fuzzier data. Finally, Section 5 presents the findings of the study and recommendations for future research.

2. Literature Review

This section evaluates the literature on Construction supply chain management and Uncertainty in the project supply chain.

2.1. Construction supply chain management

The main goal of construction planning is to efficiently schedule tasks and allocate resources within a set timeframe, as well as adapt to the complexity of project operations, according to Essam et al. [19, 20]. The recent focus in the field has been on developing techniques to help projects succeed in all stages, from planning to completion, as meeting deadlines and staying within budgets are increasingly competitive [21]. However, delays are common and Assaf et al. identified potential explanations of such delays [22]. Managing materials procurement and project schedule difficulties simultaneously are some of the most critical aspects of project management. Order quantity is crucial because with effective management, material shortages and accompanying inefficiencies are minimized. However, poor procurement management and limited supply result in project completion delays. To address this, Patoghi et al. proposed a model that incorporates resource-constrained project scheduling (RCPSP) and considers an ordering problem [23]. Limited storage space on construction sites is a frequent occurrence according to Zhang et al.; thus, they developed a bi-objective optimization model to resolve project scheduling and material ordering problems due to limited storage capacity [24].

Due to increasing competition, the importance of the supply chain has become even more prevalent [25]. Construction supply chains are temporary and custom chains involving businesses from diverse industries, making integration challenging [6, 26]. For this reason, integrated construction supply chain management, proposed by Cheng et al. as an efficient approach, has become increasingly popular [27]. Participants in the supply chain involved in construction projects include owners, designers, contractors, and suppliers with separate businesses often contributing. Construction experts are aware of supply chain management, but new implementation methods and a deeper understanding are needed [28-30]. The construction project supply chain's procurement decisions impact project scheduling as resources are required. Abdzadeh et al. show how the integration of project scheduling with supplier selection and transportation routing generates value throughout the entire project supply chain [31].

The concept of the "green supply chain" emerged in the late 1990s and is becoming increasingly prevalent in business literature, particularly in management and operation disciplines, as sustainability gains importance [32, 33]. Reducing greenhouse gas emissions is one way to address environmental concerns and achieve a greener supply chain [34]. This goal can also be achieved by selecting green suppliers [35]. Ojo et al. identify green supply chain management as a solution to industry sustainability issues, but there are obstacles, such as suppliers resisting changes and a lack of knowledge about negative environmental impacts [36]. Five elements of the supply chain, namely green design, green procurement, green production, green management, and green information, can be examined to determine green supply chain implementation challenges [37]. Badi et al. studied green supply chain management in the construction industry and found that it has a significant environmental responsibility [12]. Liu utilized artificial intelligence to decrease carbon emissions and protect the environment in the supply chain [38].

2.2. Uncertainty in the project supply chain

The complexity and uncertainty of the project's various components may hinder the growth of businesses [37]. For example, demand at construction sites may be uncertain, and the risk of unpredictability may increase costs and greenhouse gas emissions. Salari et al.'s two-objective mathematical model takes demand uncertainty into account to balance the driver's workload and reduce the overall supply chain cost, and delivery time [39]. Nouri et al.'s green supply chain model aims to minimize costs, greenhouse gas emissions, and risk factors through the use of fuzzy analytical hierarchy [34]. Chen et al. used fuzzy uncertainty in their multi-objective mixed-integer linear programming model to account for material pricing, supplier capacity, and subsequent delays [40]. In their work, Chen et al. investigated material costs, supplier capacity, and the consequent delays as factors inside fuzzy scenarios [40]. In their study, Chen et al. have examined material costs, supplier capacity, and the consequent delays as factors inside fuzzy scenarios [41]. Lin et al. performed a research on the coordination of a building supply chain with the goal of achieving sustainable development in conditions that lack clarity or certainty [42].

A list of quantitative papers on project supply chain over the last several years is presented in Table 1.

Tab. 1. Summary of quantitative articles in the construction supply chain

NU.	Reference	Year	Number of projects		Supplier selection	Project scheduling	Project inspection	Green supply chain	Uncertainty
			Single project	Multi-project					
1	Kian et.	2017			✓			✓	✓
2	Noori et.	2019			✓			✓	✓
3	Patoghi et.	2021	✓			✓			✓
4	Zhang et.	2021	✓			✓			
5	Mirghaderi et.	2021		✓					✓

6	Abdzadeh et	2022		✓	✓	✓	✓		
7	Salari	2022	✓						✓
8	Lin et	2022	✓						
9	Essam et.	2023	✓			✓			
10	Liu	2023	✓					✓	✓
11	chen et.	2023	✓		✓	✓			✓
9	This paper	2023		✓	✓	✓	✓	✓	✓

Based on the evaluated papers, it is evident that no research has yet examined the uncertainty associated with this set of parameters. Hence, this research primarily concerns the examination of uncertainty in a multitude of parameters. Also, no article has included supplier selection, inspection and uncertainty at the same time in multi-project mode whith green considerations.

3. Methodology

This section outlines the problem definition, mathematical model formulation, and proposed model development under uncertainty.

3.1. Problem definition

One of the critical aspects of the building supply chain is effective planning and coordination between procurement and implementation to ensure that each activity receives the required raw materials timely. The use of renewable resources such as manpower and equipment along with the demand for non-renewable materials could benefit construction projects. To minimize costs, this study selects a supplier from a range of suppliers who offer a single type of renewable resource in the model, thereby advancing towards implementing a green supply chain.

The research aims to minimize the harmful effects of building projects on the environment by reducing the emissions generated during transportation between different supply chain components. A mathematical model is developed, considering a group of current projects and two categories of suppliers supplying raw materials and non-renewable resources, respectively. The raw materials are subdivided into two types, with each supplier offering a single type. Activities require both renewable and non-renewable resources that cannot be carried out concurrently since these resources can be shared by several activities.

All activities start only after acquiring the necessary renewable and non-renewable resources, and each activity's completion has a prerequisite relation FS, followed by a thorough project inspection. The study has two objectives - ensuring the timely availability of resources and implementing operations within the anticipated time and budget. To reduce logistical costs and minimize pollution caused by transportation, many aspects such as demand parameters, activity durations, inspection durations, supplier production capacities, and expenditures like ordering costs, purchase costs, delay costs, and transportation costs are all included in the mathematical model.

Finally, the supply chain network is illustrated in Figure 1.

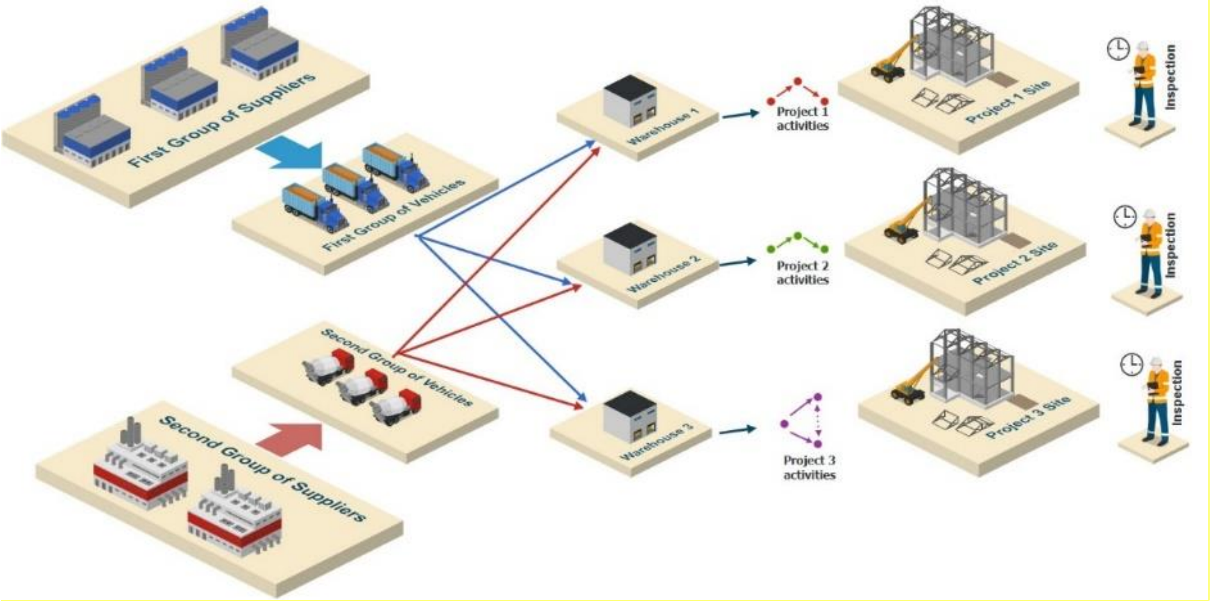

Fig. 1. Research supply chain network

3.1.1. Problem assumptions

- The network comprises several concurrently running projects.
- Each project consists of a collection of interdependent activities.
- All project activities are independent of one another.
- Each non-renewable resource has a set of suppliers that have been predetermined. There is only one resource that each supplier provides, and there are different supplier groups for each resource.
- Activities and relations fall under the category of FS prerequisites.
- Project operations are completed without pause.
- Only the vehicles designated for each resource are available on each route.
- There is a set number of vehicles allowed on each route.
- It is not feasible to be supplied by two providers; the need for each source for each
- project must be satisfied by one supplier of that source.
- One sort of resource is transported by each group of vehicles.

3.1.2. Definition of symbols

Sets and indices

$p, p' \epsilon P$	A number of ongoing projects
$A(p), p\epsilon P$	The set of activities to complete for Project P
$A = \cup_{p\epsilon P}, A(p)$	Set of all activities
$NR(a), a\epsilon A$	Set of non-renewable resources required for activity a
$NR(p) = \cup_{a\epsilon A}, NR(a)$	The set of non-renewable resources required by the project P
$NR = \cup_{a\epsilon A}, NR(a)$	Set of all non-renewable resources
$S(nr), nr \in NR(p)$	Set of suppliers for a non-renewable resource nr
$S = \cup_{r\in R}, S(nr)$	Collection of all suppliers for non-renewable resources
$R(p), p\epsilon P$	Project Renewable Resources Collection P
$A'(r) \subset A(p), r\epsilon R(p)$	The set of activities in the p project that require a renewable resource r

$F(p), p\epsilon P$	The set of prerequisite constraints for project activities $(a,b) \in F(p)$ (for $a,b \in A(p)$ means that activity a must be completed before activity b start)
V	Set of vehicles
$V_{nr}, V_{nr} \subset V$	A set of vehicles carrying the type nr source

Parameters

$Dem_{p,nr}$ $, p\epsilon P, nr \in NR(a), a\epsilon A$	The quantity of non-renewable resource nr needed to complete the activities in project p depends on the type of resource in certainty conditions (the quantity might be expressed in terms of weight, volume, or number). It shows the number of materials.
$\widetilde{Dem}_{p,nr}$ $, p\epsilon P, nr \in NR(a), a\epsilon A$	The value of non-renewable resource nr used to perform project p activities relies on the kind of resource under uncertain conditions. (optimistic, probable, pessimistic)
$DP_p, p\epsilon P$	Due date of project p to complete all activities and perform inspection. It shows a time period.
Cap_s $, s\epsilon S$	The capacity of the supplier s in conditions of certainty. It shows the number of materials.
$\widetilde{Cap}_s$ $, s\epsilon S$	Supplier capacity in fuzzy conditions (optimistic, probable, pessimistic)
$t_s^{pre}, s\epsilon S$	Delivery time of the order by the supplier s. It shows a time period.
$t_{s,p}^{tra}, s\epsilon S, p\epsilon P$	Shipping time from supplier s to project p (The day is considered). It shows a time period.
$Dur_a, a\epsilon A$	Duration of the activity a (The day is considered). It shows a time period.
$\widetilde{Dur}_a, a\epsilon A$	Duration of activity a in fuzzy conditions (optimistic, probable, pessimistic)
$t_p^{ins}, p\epsilon P$	The duration of the inspection (The day is considered). It shows a time period.
$\tilde{t}_p^{ins}, p\epsilon P$	The duration of the inspection in fuzzy conditions (optimistic, probable, pessimistic)
Bud	Available budget to provide all non-renewable resources. $
C_s^{ord}	The cost of ordering from supplier s in certainty conditions. $
$\tilde{C}_s^{ord}$	The cost of ordering from supplier s in fuzzy conditions (optimistic, probable, pessimistic)
C_s^{buy}	The price per unit purchased from supplier s in certain conditions. $
$\tilde{C}_s^{buy}$	The price per unit purchased from supplier s in fuzzy conditions (optimistic, probable, pessimistic)
C_p^{del}	The cost of project delay p in certainty conditions. $
$\tilde{C}_p^{del}$	The cost of project delay p in fuzzy conditions (optimistic, probable, pessimistic)
$C_{v,s,p}^{tra}$	Transportation cost by vehicle v from supplier s to project p in certain conditions. $
$\tilde{C}_{v,s,p}^{tra}$	Transportation cost by vehicle v from supplier s to project p in fuzzy conditions (optimistic, probable, pessimistic)
M	A big favorite constant
$Vo_v, v\epsilon V_{nr}$	The amount of materials transported by type v. It shows the number of materials.
π_v	Vehicle Pollution Rate v
$Di_{s,p}$	Distance between supplier s and project p. The unit is meter.
W_v^{max}	Maximum vehicle capacity per route. It shows the number of materials.

Decision variables

$, nr \in NR(p)x_{s,p}, s\epsilon S(nr), p\epsilon P$	Binary variable, if provider s 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, if activity a is scheduled before activity b, is 1, Otherwise, 0 if a and b have a common renewable resource l in projects r
$z_{p,p'}, p' \in \{0\} \cup P, p \in P, p' \neq p$	Binary variable, if project p' is checked before project p, 1, otherwise 0 ([43] if there is a virtual project)
$q_{s,p}\ , s\epsilon S, p\epsilon P$	Amount of source sent and purchased from supplier s for project p. It shows the number of materials.
$ST_a, a \in A$	Start time of activity a. It shows a time unit.
$CT_p, p\epsilon P$	Project completion time p. It shows a time unit.
$DT_p, p\epsilon P$	Delay in productivity of project p. It shows a time unit.
$CT_p^{ins}, p \in \{0\} \cup P$	Completion time of p project review CT_0^{ins} showing starting time of first survey. It shows a time unit.
$N_{v,s,p}$	Number of types v vehicles required to carry an order from supplier s to project p

3.2. Mathematical model formulation

$$MinZ1 = \sum_{s\in S(nr)} \sum_{p\epsilon P} C_s^{buy} \times q_{s,p} + \sum_{s\in S(nr)} \sum_{p\epsilon P} C_s^{ord} \times x_{s,p} + \sum_{v\in V(nr)} \sum_{s\in S(nr)} \sum_{p\epsilon P} C_{v,s,p}^{tra} \times N_{v,s,p} + \sum_{p\epsilon P} C_p^{del} \times DT_p \tag{1}$$

$$MinZ2 = \sum_{v\in V(nr)} \sum_{s\in S(nr)} \sum_{p\epsilon P} Di_{s,p} \times \pi_v \times N_{v,s,p} \tag{2}$$

Constraint (1) represents the first objective of the problem to reduce project costs. $\sum_{s\in S(nr)} \sum_{p\epsilon P} C_s^{buy} \times q_{s,p}$ shows purchase costs, $\sum_{s\in S(nr)} \sum_{p\epsilon P} C_s^{ord} \times x_{s,p}$ shows ordering costs, $\sum_{v\in V(nr)} \sum_{s\in S(nr)} \sum_{p\epsilon P} C_{v,s,p}^{tra} \times N_{v,s,p}$ shows transportation costs, and $\sum_{p\epsilon P} C_p^{del} \times DT_p$ shows delay expenses.

The second objective, as shown in constraint (2), aims to limit pollution caused by transportation, related to the distances and the number of vehicles.

S.T:

$$\sum_{p\epsilon P} q_{s,p} \leq Cap_s \qquad \forall s \in S \tag{3}$$

$$\sum_{p\epsilon P} q_{s,p} \geq Dem_{p,nr} \qquad \forall\ p \in P, nr \in NR(P) \tag{4}$$

$$q_{s,p} \leq Mx_{s,p} \qquad \forall s \in S(nr), p \in P \tag{5}$$

$$\sum_{s\in S(nr)} x_{s,p} = 1 \qquad \forall p \in P \tag{6}$$

$$\sum_{s\in S(nr)} \sum_{p\epsilon P} C_s^{buy} \times q_{s,p} + \sum_{s\in S(nr)} \sum_{p\epsilon P} C_s^{ord} \times x_{s,p} + \sum_{v\in V(nr)} \sum_{s\in S(nr)} \sum_{p\epsilon P} C_{v,s,p}^{tra} \times N_{s,t,p} \leq Bud \tag{7}$$

$$ST_a \geq \sum_{s\in S(nr)} (t_s^{pre} + t_{s,p}^{tra}) \times x_{s,p} \qquad \forall a \in A(p), p \in P, nr \in NR(a) \tag{8}$$

$$ST_a + Dur_a \leq ST_b \qquad \forall (a,b) \in F(p), p \in P \tag{9}$$

$$ST_a + Dur_a - M(1 - y_{a,b}) \leq ST_b \qquad a, b \in A'(r), a \neq b, r \in R(p), p \in P \tag{10}$$

$$ST_b + Dur_b - M(y_{a,b}) \leq ST_a \qquad , b \in A'(r), a \neq b, r \in R(p), p \in P \tag{11}$$

$$CT_p \geq ST_a + Dur_a \qquad \forall a \in A(p), p \in P \qquad (12)$$

$$CT_p^{ins} \geq CT_p + t_p^{ins} \qquad \forall p \in P \qquad (13)$$

$$CT_p^{ins} \geq CTins_{p'} - M(1 - z_{p,p'}) + t_p^{ins} \qquad \forall p \in \{0\} \cup P, p \in P, p \neq p' \qquad (14)$$

$$\sum_{p \in \{0\} \cup P, p \neq p'} z_{pp'} = 1 \qquad \forall p' \in P \qquad (15)$$

$$\sum_{p \in P} z_{0,p} = 1 \qquad (16)$$

$$\sum_{p \in P, p \neq p'} z_{pp'} \leq 1 \qquad \forall p' \in P \qquad (17)$$

$$DT_p = CTins_p - DP_p \qquad \forall p \in P \qquad (18)$$

$$\sum_{s \epsilon S(nr)} q_{s,p} \leq \sum_{v \in V(nr)} \sum_{s \epsilon S(nr)} N_{v,s,p} \times Vo_v \qquad \forall p \in P \qquad (19)$$

$$N_{v,s,p} \leq M \times x_{s,p} \qquad \forall p \in P, s \in S, v_{nr} \epsilon V \qquad (20)$$

$$\sum_{p \in P} N_{v,s,p} \leq W_v^{max} \qquad s \in S, v_{nr} \epsilon V \qquad (21)$$

$$x_{s,p}, y_{a,b}, z_{p,p'} \in \{0,1\} \qquad (22)$$

$$q_{s,p}, ST_a, CT_p, TD_p, N_{s,p,t}, I_{r,p,t} \geq 0 \qquad (23)$$

The total number of orders from each supplier for each project must not exceed that seller's capability, based on constraint (3). According to constraint (4), the total number of orders placed with suppliers of non-renewable resource NR for project P must exceed the project's demand for that product. When a supplier is chosen for a project, constraint (5) demonstrates that the supplier may place an order for that project. One supplier should be chosen for each type of resource in each project, as demonstrated by constraint (6). According to constraint (7), the overall cost of purchase orders and transportation should be less than the approved budget. Take note that there is a single budget for all active projects. Projects can only begin once their non-renewable resources have been acquired and delivered, as per constraint (8). Resource prerequisites for a project are listed in constraint (9). Constraints (10) and (11) prevent similar activities using renewable resources from starting at the same time. Constraint (12) provides the project's implementation time, while constraint (13) outlines the inspection deadline. According to constraint (14), if the project p' inspection begins before the project p' inspection, the latter will take place first. Constraints (15), (16), and (17) illustrate the importance of inspection in relation to projects. The length of the delay in the execution of each project is displayed in Constraint (18). According to constraint (19), each project's total number of resources transported by each kind of vehicle from each supplier must exceed the project's total number of orders for those resources. When the vehicle is chosen by the supplier S for the project P is shown in constraint (20). The maximum available vehicle is displayed in constraint (21). Constraint (22) shows binary variables, while constraint (23) presents positive variables.

3.3. Model development under uncertainty

Construction projects are susceptible to errors due to environmental changes, leading to inaccurate estimates. Thus, the model takes into account the non-deterministic parameters' optimistic, likely, and pessimistic scenarios, estimated using the triangular fuzzy approach.

In this paper, the fuzzy parameters in objective functions are estimated by expected value model (EVM) that are calculated by $E[\xi] = \int_0^{+\infty} Cr\{\xi \geq r\}\, dr - \int_{-\infty}^{0} Cr\{\xi \leq r\}\, dr$. If one of two integrals have limited answer, expected value for triangular fuzzy number by (a,b,c), is calculated as follows [44]:

$$E[\xi] = (a + 2b + c)/4 \qquad (24)$$

It is possible for estimation of fuzzy parameters in constraints to use credibility measure (CR) and chance constraint programming (CCP). The credibility measure of a fuzzy event $H \in \Omega(\Psi)$ is defined on $(\varPsi, \varOmega(\varPsi), Pos)$ as $Cr\{H\} = 0.5(Pos\{H\} + Nec\{H\})$. In other words, credibility measure is the average of *Pos* and *Nec* measures [44].The properties of the credibility (*Cr*) measure are presented as follows:

- $Cr\{\emptyset\} = 0, Cr\{\varPsi\} = 1$
- $\forall H \in \varOmega(\varPsi) \Rightarrow 0 \leq Cr\{H\} \leq 1$
- $\forall H \in \varOmega(\varPsi) \Rightarrow Cr\{H\} + Cr\{H^C\} = 1$
- $\forall H, Q \in \varOmega(\varPsi), H \subseteq Q \Rightarrow Cr\{H\} \leq Cr\{Q\}$
- $\forall H, Q \in \varOmega(\varPsi) \Rightarrow Cr\{H \cup Q\} \leq Cr\{H\} + Cr\{Q\}$
- $\forall H \in \varOmega(\varPsi) \Rightarrow Pos\{H\} \geq Cr\{H\} \geq Nec\{H\}$

It should be underlined that the *Cr* measure is self-dual and it capable to be supported a compromise attitude of the DM over both extremes [44].The *Cr* measure of fuzzy events $\{\tilde{\alpha} \leq \gamma\}$ and$\{\tilde{\alpha} \geq \gamma\}$ are shown in Equations (25) to (26), respectively:

$$Cr\{\tilde{\alpha} \leq \gamma\} = \begin{cases} 0, & if \alpha_1 \geq \gamma; \\ \dfrac{\gamma - \alpha_1}{2(\alpha_2 - \alpha_1)}, & if \alpha_1 \leq \gamma \leq \alpha_2; \\ \dfrac{\gamma + \alpha_3 - 2\alpha_2}{2(\alpha_3 - \alpha_2)}, & if \alpha_2 \leq \gamma \leq \alpha_3; \\ 1, & if \alpha_3 \leq \gamma. \end{cases} \tag{25}$$

$$Cr\{\tilde{\alpha} \geq \gamma\} = \begin{cases} 1, & if \alpha_1 \geq \gamma; \\ \dfrac{2\alpha_2 - \alpha_1 - \gamma}{2(\alpha_2 - \alpha_1)}, & if \alpha_1 \leq \gamma \leq \alpha_2; \\ \dfrac{\alpha_3 - \gamma}{2(\alpha_3 - \alpha_2)}, & if \alpha_2 \leq \gamma \leq \alpha_3; \\ 0, & if \alpha_3 \leq \gamma. \end{cases} \tag{26}$$

According to the *Cr* measure and CCP, the deterministic counterparts and equivalent crisp ones of fuzzy chance constraints under desired confidence level ξ are presented in Equations (27) to (28) as follows:

$$Cr\{\tilde{\alpha} \leq \gamma\} \geq \xi \Leftrightarrow \begin{cases} (1 - 2\xi)\alpha_1 + (2\xi)\alpha_2 \leq \gamma, if \xi \leq 0.5; \\ (2 - 2\xi)\alpha_2 + (2\xi - 1)\alpha_3 \leq \gamma, if \xi > 0.5. \end{cases} \tag{27}$$

$$Cr\{\tilde{\alpha} \geq \gamma\} \geq \xi \Leftrightarrow \begin{cases} (2\xi)\alpha_2 + (1 - 2\xi)\alpha_3 \geq \gamma, if \xi \leq 0.5; \\ (2\xi - 1)\alpha_1 + (2 - 2\xi)\alpha_2 \geq \gamma, if \xi > 0.5. \end{cases} \tag{28}$$

In this formula, a is an occurrence under optimistic conditions, b is an occurrence under optimistic conditions, and c is an event under pessimistic circumstances. Term a is presented with Index 1, Term b with Index 2, and Term c with Index 3 when writing non-deterministic parameters. The following are the research's uncertain parameters:

$\widetilde{Dem}_{p,nr} = (Dem^1_{p,nr}, Dem^2_{p,nr}, Dem^3_{p,nr})$	The amount of consumption of non-renewable resource nr to complete activities in project p depends on the type of resource in fuzzy conditions.
$\widetilde{Cap}_s = (Cap^1_s, Cap^2_s, Cap^3_s)$	Supplier capacity in fuzzy conditions
$\widetilde{Dur}_a = (Dur^1_{p,nr}, Dur^2_{p,nr}, Dur^3_{p,nr})$	Duration of activity a in fuzzy conditions
$\tilde{t}^{ins}_p = (t^{ins,1}_p, t^{ins,2}_p, t^{ins,3}_p)$	Duration of inspection in fuzzy conditions
$\tilde{C}^{ord}_s = (C^{ord,1}_s, C^{ord,2}_s, C^{ord,3}_s)$	Cost of ordering from supplier s in fuzzy conditions
$\tilde{C}^{buy,1}_s = (C^{buy,1}_s, C^{buy,2}_s, C^{buy,3}_s)$	The cost of each purchase unit from supplier s in fuzzy conditions
$\tilde{C}^{del}_p = (C^{del,1}_p, C^{del,2}_p, C^{del,3}_p)$	Delay cost of project p in fuzzy conditions

$\tilde{C}^{tra}_{v,s,p} = (C^{tra,1}_{v,s,p}, C^{tra,2}_{v,s,p}, C^{tra,3}_{v,s,p})$	Transportation cost by vehicle v from supplier s to project p in fuzzy conditions

4. Numerical Results

In this section, the numerical results are discussed and in two subsections, the numerical values of the parameters and the sensitivity analysis are given.

4.1. The values of each parameter

In this section, a mock case study is conducted to evaluate the applicability of the model. For this purpose, a network is created comprising three projects, each with three separate activities. Additionally, Five suppliers are considered, with the first three providing the first type of source and the latter two providing the second type. The manufacturing capacity and ordering and purchasing costs of each supplier are taken into account. To evaluate these factors, three different scenarios has been taken: optimistic, likely, and pessimistic. Table 2 shows the values used for these parameters.

Tab. 2. Production capacity of each supplier, purchase price and ordering price

	$\widetilde{Cap}_s$			$\tilde{C}^{ord}_s$			$\tilde{C}^{buy}_s$		
	optimistic	probable	pessimistic	optimistic	probable	pessimistic	optimistic	probable	pessimistic
s1	110	95	80	15	20	40	5	6.5	8.5
s2	115	100	90	20	25	35	4.5	5	6
s3	95	90	85	20	25	35	5	6.5	8
s4	140	135	120	25	28	30	7	8	9
s5	125	120	110	23	25	29	6	7	9

After placing the order, preparation takes time. Table 3 specifies the distance between suppliers and projects, as well as the time it takes for goods to be transported from each supplier to each project. The first supplier has the longest preparation period for the first type of material, while the fourth supplier has the longest preparation period for the second type of material.

Tab. 3. Preparation and transportation time and distance

	t^{pre}_s	$t^{tra}_{s,p}$			$Di_{s,p}$		
		p1	p2	P3	p1	p2	P3
s1	14	2	2	1	100	100	50
s2	11	6	2	6	300	100	300
s3	10	6	6	4	300	300	200
s4	15	4	2	4	200	100	200
s5	12	5	6	5	250	300	150

An inspection period has been established for the projects to ensure their successful completion. The project will also incur a penalty in the event of a delay. Table 4 presents the values of these two factors estimated in three scenarios: optimistic, probable, and pessimistic.

Tab. 4. Information and parameters related to each project

	$\tilde{t}^{ins}_p$			$\tilde{C}^{del}_p$		
	optimistic	probable	pessimistic	optimistic	probable	pessimistic
p1	7	11	14	1	3	5
p2	10	16	17	1.5	2	3
p3	15	19	21	1	4	8

Each project requires a specific combination of resources from the first and second types. The source takes this need into consideration under three different situations of uncertainty, as shown in Table 5.

Tab. 5. Information about demand

	$\widetilde{Dem}_{p,nr}$					
	$NR1$			$NR2$		
	optimistic	probable	pessimistic	optimistic	probable	pessimistic
p1	30	50	60	30	40	45
p2	25	35	50	40	50	60
p3	35	45	60	25	45	70

Six different types of vehicles are considered to transport non-renewable resources- the first three being type 1 resource carriers and the second three being type 2 resource drivers.

Each vehicle's non-renewable resource capacity is limited. Additionally, transportation costs for non-renewable resources from each supplier to each project will differ depending on the source type selected.

Between Activities 8 and 9, only Project 3 shares renewable resources. Each project will proceed along its critical path based on the activity's length and the links between the activities that are prerequisites. Project 2 will be completed first, followed by Project 1, and then Project 3, according to the data used in this study. The examination of each project will begin as soon as it is finished. Based on the assumption of certainty, Fig. 2 depicts the projects' timeline.

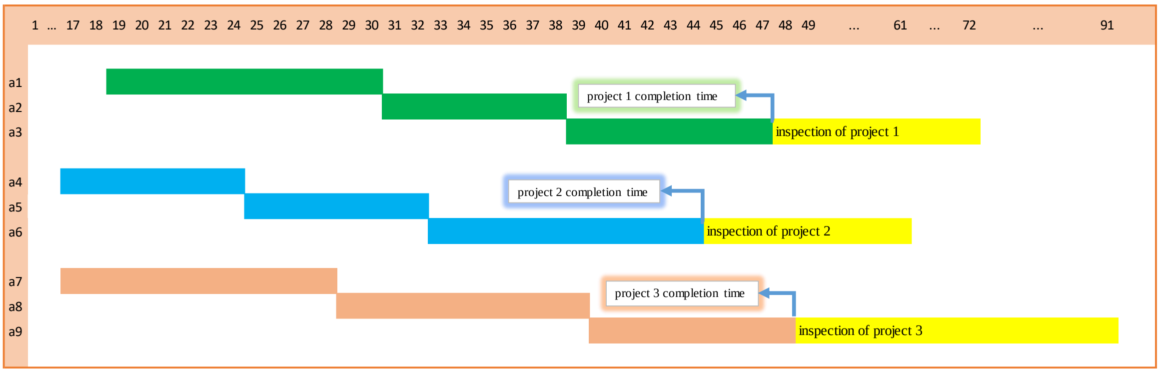

Fig. 2. projects' timetable on the assumption of certainty

The sequence of these two activities is ambiguous due to the vagueness surrounding the activities' duration and the sharing of renewable resources between the two activities in the third project. As expected, activities take longer to complete, and the project completion announcement takes more time when there is uncertainty. Fig. 3 shows these modifications.

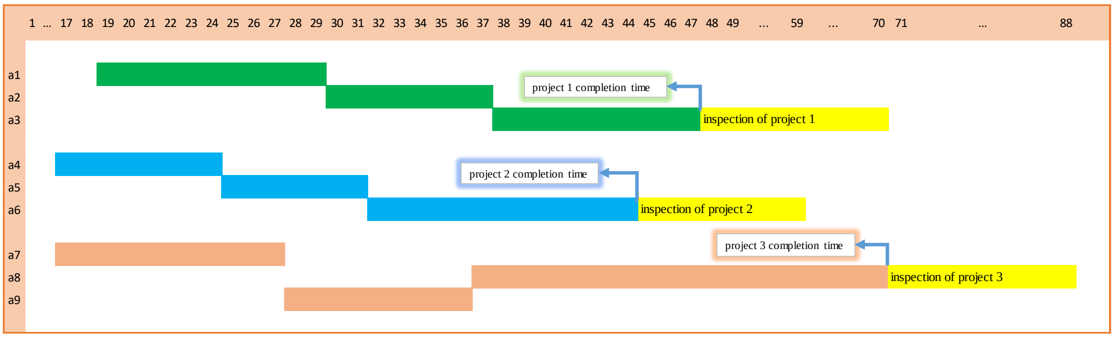

Fig. 3. projects' timetable on the assumption of uncertainty

A spending cap of 50,000 units and a carbon emission rate of one is considered. Using the data discussed above, the model was developed using GAMS software, and the results were examined. Based on the results, when model is implemented by crisp parameters, cost objective is 2899.5 and emission objective is 2350. Also, when model is implemented by above fuzzy parameters, two objective’s function are displayed in table 6 and are depicted in fig 4.

Tab. 6. results of objectives

ξ	Cost	Emission
0	2,144.25	1,650
0.05	2,229.038	1,650
0.1	2,312.075	1,650
0.15	2,392.113	1,750
0.2	2,480.9	2,100
0.25	2,556.938	2,100
0.3	2,659.975	2,350
0.35	2,738.762	2,350
0.4	2,815.8	2,350
0.45	2,894.588	2,350
0.5	2,970.625	2,350
0.55	3,089.275	2,950
0.6	3,156.05	2,950
0.65	3,176.513	3,200
0.7	3,246.225	3,350
0.75	3,310.438	3,350
0.8	3,374.4	3,350
0.85	3,533.175	3,500
0.9	3,599.95	3,500
0.95	3,687.725	3,800
1	3,751.5	3,800

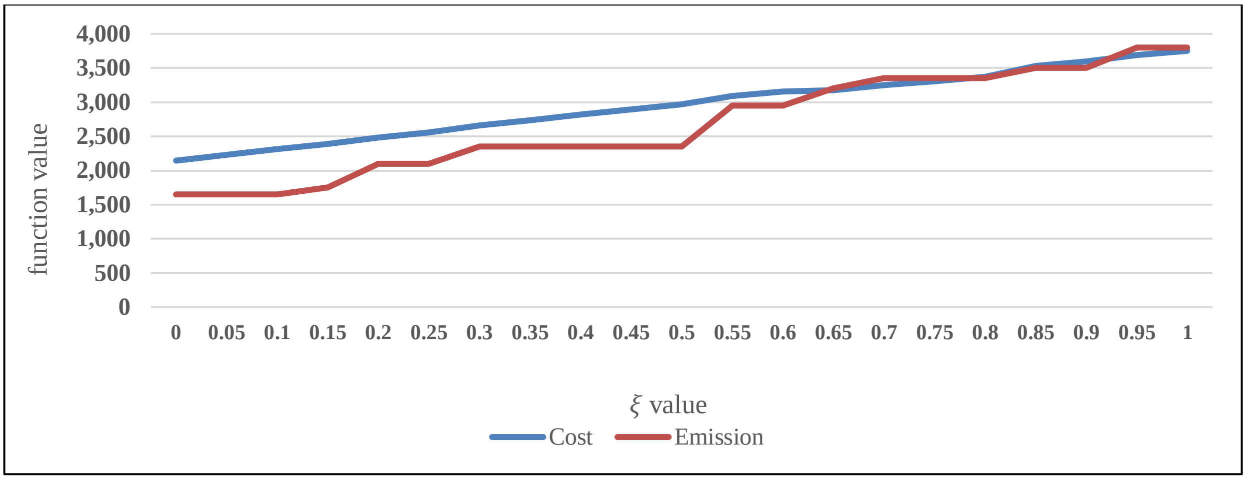

Fig. 4. Cost and emission functions values for different ξ

Fig. 4 displayed cost and emission function are increased by increasing ξ from zero to one. It is proved that if ξ increases, the optimal values of the two functions become worse because the uncertainty is increased.

4.2. Sensitivity analysis

To validate the model, a sensitivity analysis is performed on several parameters. Initially, the parameters are increased tenfold with a 20% effect factor and then re-read the value of the model's objective function, which includes the objective functions of cost and pollution, in each succeeding increase. According to the findings, the value of the final goal function increases as activity time and inspection time increase, as seen in Figure 5.

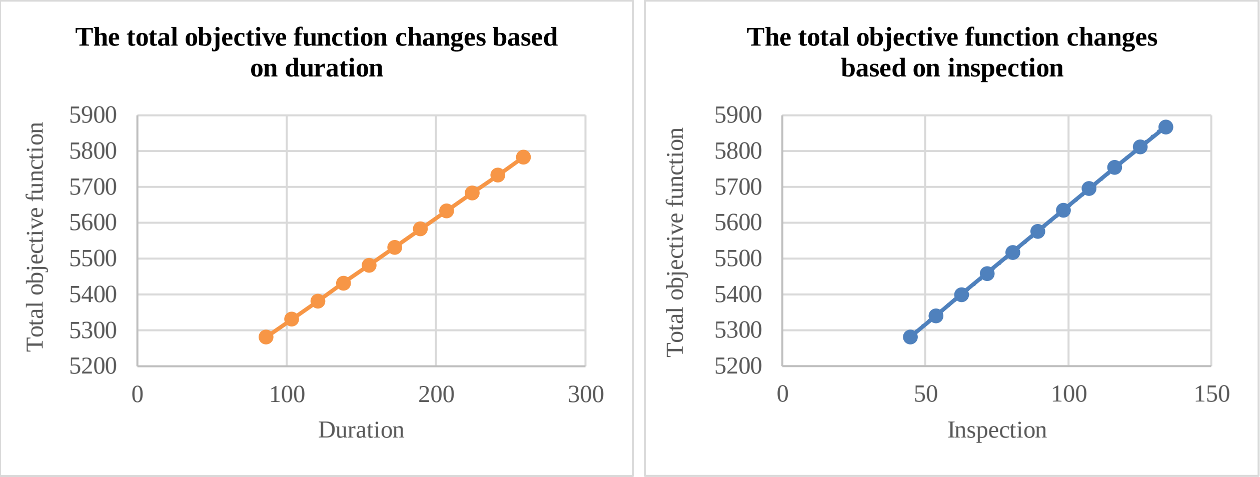

Fig. 5. The total objective function changes based on duration and inspection

The objective function increases initially with increasing demand before plateauing due to suppliers' restricted supply power, as depicted in Figure 6.

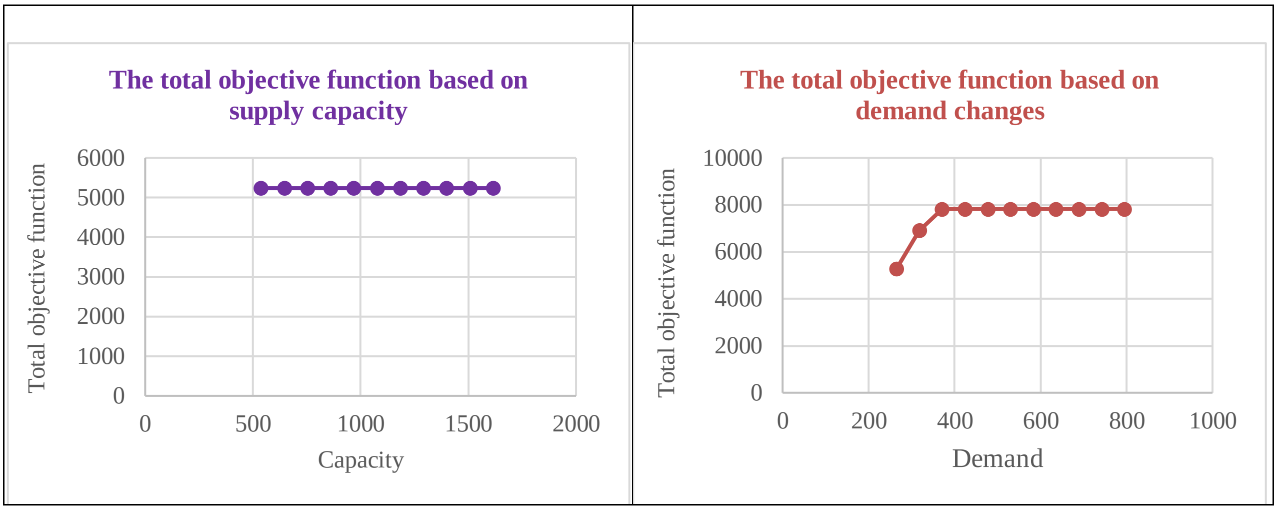

Fig. 6. The total objective function based on supply capacity and demand changes

In Figure 7, an improvement in any of the costs, such as the cost of purchase, delay, delivery, and ordering, leads to an increase in the objective function. It is evident that these costs impact the objective function.

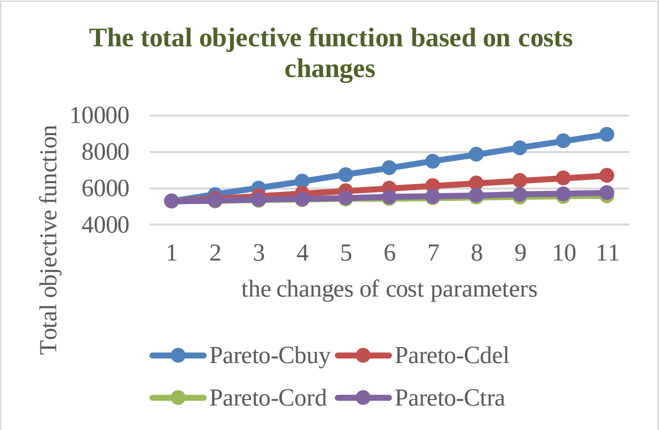

Fig. 7. The total objective function based on costs changes

5. Conclusions

The green construction supply chain has been a recent focus of research, but most studies have focused on qualitative concerns, despite it being a significant challenge in supply chain management. This study introduces a bi-objective linear mathematical model to reduce logistical costs and environmental impacts. The model considers supplier selection as a critical obstacle in the supply chain, considering expenses and criteria related to activity length, inspection length, supply capacity, and demand for resources. A goal programming approach solved the multi-objective model, and a numerical example validated the model's results. The survey indicated that supplier selection is a fundamental element of construction project management and, in cases where several renewable resource suppliers exist, techniques like data envelopment analysis (DEA) should be used to select efficient providers using the appropriate ranking.

The following are summarized principles that managers and supply chain engineers can benefit from, as outlined in the thesis and discussed in the managerial recommendations section:

- Choosing the right supplier, considering its distance from the project site as well as its supply capacity, can lead to the reduction of supply chain costs.
- The number of vehicles, considering the emission rate of these vehicles, is essential in protecting the environment and greening the supply chain.
- Rising uncertainty results in elevated expenses throughout the supply chain. Hence, it is advisable for managers to use their utmost effort in order to ascertain the criteria with more precision.

Although attempts have been made to provide a thorough framework for merging environmentally friendly and efficient multi-project building supply chains, there are possible avenues for further investigation:

- Creating a routing model for the ongoing study.
- Examining the difficulties associated with the creation and implementation of contracts.
- Future studies are advised to address some wastes in the development of the model, such as excessive mobility of human resources, equipment, materials, overproduction waste, and rework waste.

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