Diyala Journal of Engineering Sciences

Journal homepage: https://djes.info/index.php/djes

ISSN: 1999-8716 (Print); 2616-6909 (Online)

Analysis of the Causes of Contractor Delays in Construction Projects Using Fuzzy AHP

Suha Falih Mahdi, Rouwaida Ali*, and Abbas Mahde Abd

Department of Highway and Airport Engineering, College of Engineering, University of Diyala,32001, Ba'aqubah , Diyala, Iraq

ARTICLE INFO

Article history:
Received August 8, 2024
Revised December 21, 2024
Accepted January 8, 2025
Available online June 1, 2025

Keywords:
Construction projects
Causes for delays
Contractors- Delay
Fuzzy analytic hierarchy process

ABSTRACT

Construction project delays are a recurring problem that have a big influence on stakeholder satisfaction, project budgets, and schedules. The fuzzy Analytic Hierarchy Process (AHP) is used in this study to discover, classify, and rank delay causes as it relates to contractor-induced delays. Seventy components were first discovered and categorized into six groups: finance, project management, materials, equipment, external factors, and manpower. This was done using a thorough process that included literature reviews, case studies, expert interviews, and surveys. Financial considerations have the highest weight (0.36743), followed by project management (0.23959) and material-related factors (0.1601), according to the fuzzy AHP model. The results highlight how important it is to deal with payment delays and to mitigate them through efficient project planning, material procurement, and equipment maintenance. This study offers a thorough framework for comprehending and controlling delays caused by contractors, along with useful suggestions to enhance efficiency and reduce risks.

1. Introduction

Over the years, delays in building projects have cast their shadow over the construction sector all over the world. Delays in the execution of construction projects are regarded as the most important problem that affects the construction sector, economy, organizations, and individuals [1]. The failure in finishing and delivering construction projects as scheduled in contracts could result from several factors. This situation will lead to one of the following: payment of compensation for losses, cancellation or termination of contracts, or a combination of both [2]. In many cases, delays in building projects result in arguments and debates that halt entire projects [3]. Contractors in various countries, including Saudi Arabia, reported delays due to labor shortages and low productivity, economic and financial circumstances, faults in scheduling and organizing, and site negligence and poor administration [4, 5]. In Dubai, the primary reasons for delays caused by contractors are the preparation of procedure arguments, the contractor's financial allocations for the project, the insufficient supervision of human resources, communication difficulties, and the lack of skilled staff and experts [6]. Meanwhile, the most crucial causes of construction delays in India that have been identified include the shortage of devoted efforts, inefficient site managers, poor site interaction, inaccurate planning, the ambiguity of the project scope, shortages of collaboration among individuals, and improper funding [7,8]. Experts in the field,

* Corresponding author.
E-mail address: rowedahhussien@gmail.com
DOI: 10.24237/djes.2025.18207

without specifying countries, have added several other factors that could contribute to construction delays: climate circumstances; poor engagement; the lack of participation and disagreements among those involved; inefficient or inappropriate planning; the lack of supplies; financial difficulties; payment delays; equipment/plant shortages in supplies; the lack of experience, qualifications, and competence of project participants; shortages of workers; and poor site management [9, 10, 11]. These variables contribute to delays in time schedules and excessive costs, increased risk, client dissatisfaction, and safety flaws [12]. Causes for delays can be related to firm growth, business size, and the lack of experts, which in return lead to delays in coordination and communication among stakeholders and employees, procurement negligence, and site operating shortages [13]. Large enterprises are also more prone to financial difficulties than small firms. Delays in delivery were studied from another perspective by using other criteria, such as clients, designers, and external and environmental factors [14, 15, 16]. The primary reasons for customer-related delays include multiorder adjustments; changes; and external factors, including fluctuations in project input prices and inclement weather conditions [17]. The persistent issue of delays in construction projects has a remarkable effect on the industry. This introduction highlights how worldwide, delays in construction projects lead to increased costs and time extensions that badly affect project success and stakeholders' interests. Factors contributing to delays also include insufficient planning that does not consider external variables, such as natural disasters, and inconclusive project ownership. Moreover, a distinction must be made between nonexcusable delays, which are typically caused by contractors or suppliers, and excusable delays, which are caused by unexpected events beyond control [18]. Nevertheless, experts have yet to agree on the importance of every delay component. However, studies have found considerable variances in this regard [19], with some experts arguing that owners are accountable for only three key reasons of delays [19] and others stating that delays from the contractors' side are the most important. Furthermore, surveys conducted on contractors, advisors, and clients found that among causes behind delays, contractors are the most important.

Reasons for delays must be fully identified to enhance industry practices throughout construction projects, especially during periods of widespread urbanization and rapid expansion in the construction sector [20,21]. Investigations have also found that in Thailand, the principal reasons for delays in the steel construction sector include material supply, unissued paperwork, design revisions after finalization, the poor performance of subcontractors, the lack of skilled employees, and shortcomings in design. Another study [22] on the problem of delays in building and safety in Bangladesh concluded that unskilled workers, accidents on construction sites due to the lack of protection, inadequate supplies, and the failure of equipment are the basic causes of delays. Other studies also discovered that the root causes of delays are not universal or identical but instead vary depending on the country and project type. Unexpected causes for delays are found only in some specific countries and regions [23, 24]. This situation is just another instance of inconsistency across studies regarding delays in construction projects [25]. Previous studies have indicated that although delays in construction projects occur across the world, their causes and repercussions vary on the basis of locations and settings within the construction sector. A previous work highlighted the importance of the construction industry in economic development; focused on the widespread issue of delays affecting project timelines and costs; and pinpointed key factors, such as poor contract documentation, material price fluctuations, customer focus deficiencies, delayed payments, disputes between stakeholders, and design errors and the underestimated economic consequences of delays [26]. In most real-world cases, certain decision facts can be accurately analyzed, whereas others cannot. Individuals, although they are rather good at qualitative prediction, are bad at generating quantitative forecasts [27]. Confusion in choice judgments leads to uncertainty in alternative ranking and difficulty in detecting demanded consistency.

Laarhoven and Pedrycz presented the fuzzy analytic hierarchy process (AHP) in 1983 [28]. With the exception of the conversion of verbal assessments into numerical ratings, the fuzzy AHP approach does not differ from the standard AHP method. The fuzzy AHP algorithm is used to calculate the weights of certain criteria. It can handle inputs that are fuzzy and analyze the possible outcome of the output by using fuzzy values and the resulting AHP hierarchy. In the field of science, fuzzy AHP has become one of the most notable MADM techniques [29, 30] for finding final solutions while also absorbing criteria.

Fuzzy AHP is an excellent strategy for dealing with the uncertainty and vagueness of subjective experiences and perceptions during human decision-making procedures. By using fuzzy AHP, decision makers can compare findings on the basis of accurate judgment rather than fragile value assessment, making their experience comfortable and assured. In line with the concept of comparative judgment, selection makers, at a specific level, quantitatively predict uncertain repercussions and proceed to conduct pairwise comparison with the decision maker at the next higher level [31]. Fuzzy AHP includes the different effects of uncertainties on dual comparisons by merging estimated ratio scores with local priorities by following priority synthesis requirements. It assesses the weight of each factor by using five language phrases, namely, 1- equally important, 2- moderately significant, 3- strongly significant, 4- very strongly significant, and 5- extremely significant, with the numerical values of 1, 3, 5, 7, and 9 [32]. Multiple criteria decision-making is considered an advanced decision-making method that includes quantitative and qualitative elements. The fuzzy view has become increasingly important and suitable for the decision-making environment that is gradually becoming increasingly complicated and includes participants, whose judgments are not scientific and not objective [33]. When variables are immeasurable, accurate results or assessments are impossible. In other words, having accurate models that imitate real-world issues by using fragile data or single numerical numbers is impossible because of the ambiguity in human judgments that are not described in a precise number. Fuzzy AHP is named "fuzzy" [34,35] because of the benefits indicated above in dealing with uncertain and imprecise judgments by addressing linguistic factors. The fuzzy AHP approach is commonly employed to tackle multiple criteria in decision-making in various sectors. For example, it is used to determine the accessibility and appropriateness of right rail station placements [36]; assess service quality improvement and supplier selection criteria for e-commerce-based and small or medium enterprises [37]; evaluate and choose the priorities for green supply chain supervision techniques [38]; discover the obstacles that prevent the widespread utilization of green technologies in energy [39]; and evaluate and select road maintenance management strategies [40]. Given that materials play a vital role in project completion, their provision at a specific time by contractors would be crucial [41]. Materials not only represent a substantial cost in construction projects but also need careful management throughout all phases of projects; such management requires good planning and scheduling. In cases of material shortages, contractors may be forced to depend on high-cost suppliers to prevent project delays. Changes in material specifications initiated by contractors awaiting owner approval can also lead to project delays [42]. Equipment constitutes a key aspect that can affect project progress. They are categorized into operational tools, like cranes and graders, that remain on-site and nonoperational equipment for material transportation, such as pallets. Considering their regular use, contractors typically own such equipment. Selecting the appropriate equipment type is also a critical responsibility of contractors because equipment failures can result in project delays and slowdowns [42]. Manpower, which involves the necessary human resources for a project, is another factor influencing project completion timelines.

Failure to select the quantity and quality of the workforce appropriately can considerably affect project quality, cost, and progress and lead to project failure.

Poor project finance management by contractors can also lead to project delays, especially in cases wherein difficulties arise in paying direct and indirect costs [43]. These costs include materials, labor, contractor expenses, supervision, and storage. Payments due to suppliers combined with financial constraints can further impede project progress. Ensuring sufficient funding for project completion is highly necessary. Effective project management is essential for timely project completion, with poor project management performance often causing delays [43]. Project management, which encompasses planning, coordinating, scheduling, supervising, and resources, is highly crucial to achieve project objectives efficiently [43]. External factors, such as weather conditions, represent common reasons that are beyond the control of project stakeholders for unexpected delays in project completion [44]. These factors can considerably influence project timelines because they are unpredictable and must be considered during the project planning and execution phases.

2. Previous studies

A literature review by Funke et al. [18] investigated the major delays in construction projects in selected construction industries worldwide. Elsherbiny et al. [26] used a literature review; workshops with contractors, clients, and consultants; and a questionnaire. Assafi [41] applied the relative importance index (RII) to identify the primary construction delay factors that hamper construction projects in Bangladesh. Antoniou and Tsioulpa [45] performed a literature review to analyze the causes of delays, costs, and quality risks of claims and their effects on project completion. Moreover, Aljawad et al. [46] used quantitative research analysis methods for rating relative importance to provide insights into the most effective causes that can cause projects to extend beyond the contract date completion during the phases of planning, design, and implementation.

All previous studies that focused mainly on identifying delays employed qualitative, quantitative, integrated, or comparative analysis methods to identify and prioritize delay factors. Each method has its strengths and defects, and the choice of analysis method often depends on research objectives, available data, and the level of depth and breadth required to understand construction delays. Our work focuses on applying the fuzzy AHP to identify and prioritize delay factors attributed to contractors in construction projects. While this work and a previous study emphasized the importance of analyzing delay factors, this work dives deeply into a specific methodology, namely, fuzzy AHP, to offer a detailed and thorough examination of contractor-related delays in construction projects. This research addresses this gap by employing fuzzy AHP, which integrates fuzzy logic to manage uncertainty and refine the accuracy of factor prioritization. By allowing experts to express their opinions in degrees rather than fixed values, fuzzy AHP provides an adaptable approach, capturing subtle distinctions between delay factors that traditional methods might miss.

The contribution of this study lies in offering a delicate analysis of the cause of contractor-related delays, giving a clear and context-sensitive understanding that can support targeted strategies to reduce the potentiality of delays. This study centers around the following research questions: First, what are the primary causes of delays caused by contractors in construction projects? This question seeks to identify and categorize the most important factors contributing to project delays from the contractor's perspective, such as financial issues, project management inefficiencies, or material shortages. Second, how can fuzzy AHP improve the prioritization and assessment of these causes for delays compared with traditional methods? This question focuses on how contractor-related delay factors vary in importance across different contexts, such as project size, type, or region.

Therefore, the objective of this research is to investigate the fundamental causes and their components in contractor-caused delays in construction projects by adopting the fuzzy AHP technique.

3. Methodology

The data received from the questionnaire were analyzed using an appropriate method, which may lead to the success of this study. This questionnaire can be classified into two types: the first is devoted to general information about the individuals of the sample and the second is devoted to questions about causes for delays in construction projects from the perspective of contractors. The data gathered through the questionnaire were examined and treated in accordance with the research's purpose. After distributing 80 questionnaires to the sample, the researcher was able to collect only 66 forms. Taking into consideration that four questionnaires were excluded because they were incomplete, the response rate was 62 ÷ 80 =77.5%.

The relatively high response rate was due to the personal delivery of forms. The questionnaire was distributed at different workplaces belonging to The Ministry of Construction and Housing. The educational attainment of the individuals of the sample by percentage were MA: 30%, BSc: 33%, PhD: 20%, and others: 17%. The sample specializations in percentages were civil engineers 30%, architectural engineers: 17%, mechanical engineers: 13% electrical engineers: 7%, contractors: 20%, and others: 13%. The framework of the model was created by using a procedural approach. Contractor delays were summarized in a procedural manner to respond to facts and comprehend them well.

Figure 1 depicts the suggested framework for contractor delays. This framework consists of eight processes: The initial process involves identifying the factors affecting contractor delays in construction projects. These factors can be identified through a study and its analysis by review, case studies, brainstorming, and interviews with experts. The second process involves categorizing factors into main factors and subfactors in accordance with expert interviews. In the third process, a questionnaire was created on the basis of the various stages of the cycle of the analysis of delays in construction. This questionnaire was designed in such a manner that the participants comprehended the objectives of the research. In the fourth process, factors were arranged in accordance with their individual importance by using the RII. In the fifth process, factors with relative importance of more than 80% were selected. The sixth process involved creating a hierarchical structure with the overall objective of minimizing construction project delays while taking into account all of the factors that have been identified to be likely to cause delays for the entire project. In the seventh process, a fuzzy AHP–based model was created to examine delays. In the eighth process, the weight of critical delays was identified to cut them down. Data was gathered as follows to investigate the fundamental causes of delays:

1. The literature review related to contractor delays in construction projects was based on data from research papers and studied to present a precise summary of the existing research.
2. Ten case studies were conducted on construction projects in the public and private sectors, and questionnaire factors were gathered from these cases
3. Through brainstorming, two sessions were conducted with the engineering staff participating in the building projects taken as case studies. A total of 70 factors that influenced these projects were collected.
4. Interviews were performed with construction experts with more than 20 years of experience. Various factors were combined, deleted, and added, resulting in a total of 21 factors grouped into six groups.
5. The questionnaire was constructed by using a five-point Likert scale. In this scale, 1 indicates "strongly agree," 2 indicates "agree," 3 indicates "neutral," 4 indicates "strongly disagree," and 5 indicates "disagree" to identify the importance of the factors influencing contractor delays and the effect of every factor on each phase of the project. This questionnaire was subsequently provided to engineers from the public

and private sectors. Only 62 of the 80 questionnaires provided were found to be valid.

6. The questionnaire was analyzed by using the statistical software SPSS V26 to calculate the relative relevance of every factor. The questionnaire findings were checked for validity and reliability and exceeded 95%. The RII was used in data analysis. It assigned a rating to each item in a specific section of the questionnaire, as shown in Equation (1) [47].

$$RII = \frac{\sum W}{(A*N)} \qquad (1)$$

$$RII = \frac{5(n_5)+4(n_4)+3(n_3)+2(n_2)+n_1}{5(n_5+n_4+n_3+n_2+n_1)}$$

where W: The weight assigned by respondents to each component (range from 1 to 5), A: Represents the highest weight (equals 5), N represents the total number of respondents.

In this study, relative index analysis was used to rank the criteria on the basis of their relative relevance. The weighted average for the two groups was calculated by using the ranking (R) of the relative indices (RII). In accordance with Akadiri (2011), five important levels were transformed from the RI values shown in Table1.

Table 1: Relative Importance Index RII levels [47]

RII	Importance level
$0.8 \leq RI \leq 1$	High
$0.6 \leq RI \leq 0.8$	High-medium
$0.4 \leq RI \leq 0.6$	Medium
$0.2 \leq RI \leq 0.4$	Medium- low
$0 \leq RI \leq 0.2$	Low

Table 2 shows the fuzzy AHP model set for the current investigation. This model comprises three successive levels. The first level of the hierarchy represents the model's goal, namely, factors affecting contractor delays in construction projects. The second level of the hierarchy includes the six major categories of effect-related factors.

Similarly, the third level of the hierarchical model consists of all the 21 effect-related subfactors in delays caused by contractors in construction projects. The relative weights of each factor were computed by using a nine-point scale comparison matrix as recommended by Saaty [48]. Table 3 shows a scale with values ranging from 1¼ (fairly important) to 9¼ (completely vital).

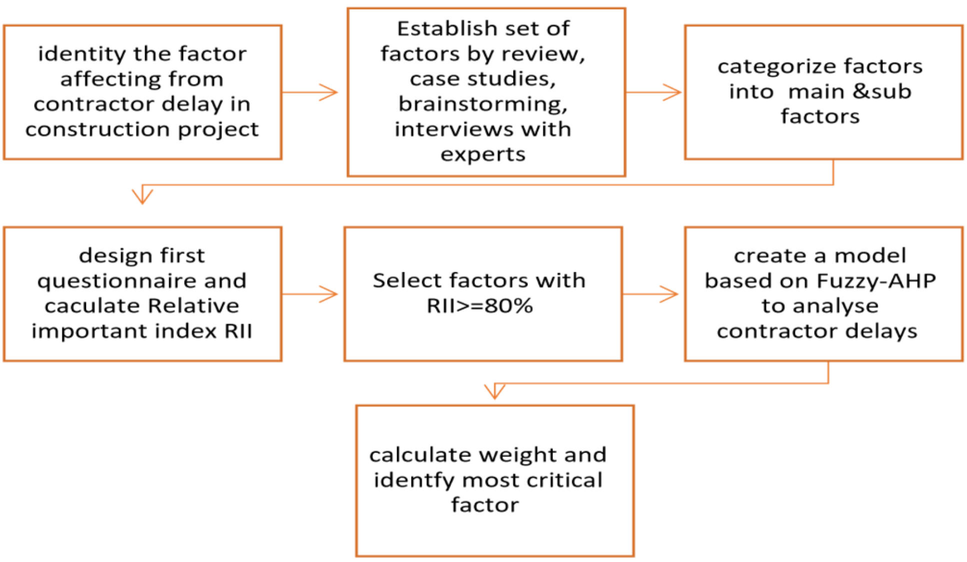

Figure 1. Proposed framework for contractor delays

Table 2: Three levels of the fuzzy AHP model

First level	Second level	Third level	Symbol
Factors affecting delays caused by contractors in construction projects.	A. Factors related to materials	1. Lack of required materials 2. Delays in supplying materials to work sites	LM DM
	B. Factors related to equipment	1. Shortage of equipment 2. Equipment breakdown 3. Low skill level of equipment operators	SH EQ L.L
	C. Factors related to manpower	1. Shortage of labor 2. Low labor productivity 3. Personal disputes between workers and management teams	LW LLP PD
	D. Factors related to finances	1. Complications in financing 2. High operational costs and overhead 3. Low profit margins 4. Delays in payments to subcontractors	COM.F HO LP PD
	E. Factors related to project management	1. Poor site management 2. Poor project planning/scheduling 3. Lack of/poor communication with construction parties 4. Incompetence of key staff 5. Poor performance of subcontractors	PS PPP LC IN PPS
	F. Factors related to external factors	1. Lack of experience of contractors 2. Accidents on sites 3. Delays in site mobilization by contractors 4. Delays in the preparation of shop drawings and incorrect drawings	LE ACC.SITE D.SITE D.P

Table 3: Triangular fuzzy number of linguistic variables and fuzzy scales [48]

Importance intensity	**Linguistic variables**	**Scale of fuzzy numbers**
1	Equally important	(1, 1, 1)
2	Equally to moderately important	(1, 2, 3)
3	Moderately important	(2, 3, 4)
4	Moderately to strongly important	(3, 4, 5)
5	Strongly important	(4, 5, 6)
6	Strongly to very strongly important	(5, 6, 7)
7	Very strongly important	(6, 7, 8)
8	Very strongly to absolutely important	(7, 8, 9)
9	Absolutely important	(9, 9, 9)

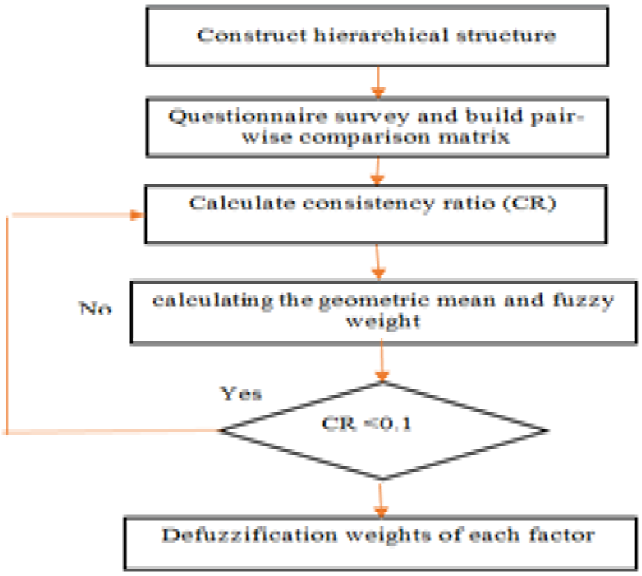

Figure 2. Steps of the proposed approach (own work)

As illustrated in Figure 2, fuzzy HAP is implemented as follows: a hierarchical structure is constructed by using literature-based criteria and subcriteria. In this structure, let A be the ratio comparison matrix, with a_{ij} denoting its members. Equation (2) shows that p is the vector of importance created by matrix A, whereas n is the matrix dimension (equal to the number of elements). The relationships between these components are formed, and their relative importance is assessed by pairwise comparisons using TFNs ranging from 1 to 9. Experts use five TFNs ($\tilde{1}$, $\tilde{3}$, $\tilde{5}$, $\tilde{7}$, $\tilde{9}$) with matching ranks to identify ambiguity in qualitative judgments [48-50]. The questionnaire survey was delivered to 10 decision experts who were selected as the target group and had adequate previous work experience. The experts filled out a customized questionnaire to rate the relevance of criteria and subcriteria in a pairwise comparison matrix. The pairwise comparisons were performed by utilizing a set of values {1/9, 1/7, 1/5, 1/3, 1, 3, 5, 7, 9}. These judgments were expressed as fuzzy triangular numbers ($\tilde{a}_{ij} = [l_{ij}, m_{ij}, u_{ij}]$)[51]. After the pairwise comparison matrices were created by using fuzzy scales, the criteria and subcriteria were transformed into a triangular fuzzy scale that reflected expert assessments. Equation (3) shows the fuzzy geometric mean that is often used in fuzzy multiple criteria decision-making to aggregate expert assessments [52, 53]. Defuzzification is a procedure performed to transform a number that is fuzzy into just one crisp value. The center of the region changes a fuzzy weight into a nonfuzzy value and has been widely used in defuzzification via Equations (6),(7), and (8) [54, 55]. A ratio comparison matrix should be transitive and reciprocal [56,57]. However, given the inherent subjectivity of human judgment, the initial matrix A does not have to exactly follow these constraints [58].

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix} \quad (2)$$

Fuzzy geometric mean value (ri): $ri = (ai11 \otimes ai22 \otimes ai33 \ldots\ldots\ldots \otimes ainn)1/n,$ (3)

$$CI = \frac{\lambda_{\max} - n}{n-1}, \quad (4)$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}. \quad (5)$$

Fuzzy weights

$$W_i = r_i\,(r1 * r2 * r_n)\hat{}\ {-1}, \quad (6)$$

$$\text{Normalized weight} = \frac{wi}{\sum_{n}^{i-1} w}. \quad (7)$$

$$x' = \lambda x. \quad (8)$$

Equation (4) determines the consistency ratio (CI), which quantifies the consistency of the judgments. Equation (5) divides the CI by the random consistency ratio (RI) [59]. Table 4 displays the random consistency ratio values based on the number of matrix elements [60]. If the CR is not less than 0.1, the replies are not acceptable and are deemed to be completely random assessments; it is advised that the judgments be reviewed or that respondents offer their replies again [61]

Table 4: Random consistency ratio (RI) [59]

Matrix size	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

4. Results

One of the most prevalent techniques for calculating reliability is the use of Cronbach's α constant, which ranges from 0 to 1, with constants close to 1 indicating a high degree of dependability[62]. Table 5 shows a categorization of dependability based on the value of Cronbach's α [62].

When the Alpha Cronbach method was conducted for the questionnaire, the results were shown within the good limits this result confirms the reliability of the questionnaire. of Alpha Cronbach is 0.940

The second part is to find the RII according to equation (1) in order to find the important factors that used in the fuzzy AHP method as shown in Table 6.

Table 5: Reliability cutoff values [62]

Cronbach's alpha	Degree of Reliability
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

Table 6: Factors Affecting Contractors' Delay

	Affecting Factor	RII	Rank
A.	Factors Related to Material		
	Lack of required materials	0.826	1
	Delay in supplying materials to the work site	0.823	2
B.	Factors Related to Equipment		
	Equipment breakdown	0.855	2
	Low level of equipment-operator’s skill	0.843	3

c.	Shortage of equipment	0.887	1
	Factors Related to the Manpower		
	Shortage of labor	0.850	1
	Lack of workforce motivation	0.807	3
	Low labor productivity	0.844	2
d.	Factors Related to Financial		
	Complications in the financing	0.855	1
	High operational costs and overhead	0.825	4
	Low-profit margin	0.850	2
	Delays in payments to subcontractors	0.835	3
E.	Factors related to Project Management		
	Poor site management	0.835	1
	Poor project planning/Scheduling	0.818	4
	lack/poor communication with construction parties	0.813	5
	incompetence of key staff	0.824	2
	Poor performance of subcontractors	0.819	3
e	Factors Related to External Factors		
	Lack of experience by contractors	0.847	1
	Accident on Site	0.827	3
	De lays in the site mobilization by the contractor	0.809	4
	Delay in preparation of shop drawings, incorrect drawings	0.832	2

The RII for the factors were selected in accordance with its percentage. It was used to prioritize factors on the basis of their perceived importance. An RII threshold of 80 was used to identify factors that were considered highly significant by respondents to reduce the number of factors from 70 to 21 for the following reasons:

1. Quantitative assessment: RII provides a numerical value that reflects the relative importance of each factor, facilitating their comparison.
2. Focus on key factors: Setting a threshold of 80% helps focus on the most critical factors, ensuring that resources and attention are directed where they can make the most impact.
3. Decision-making support: By highlighting the factors above this threshold, informed decisions can be made on the basis of what stakeholders believe to be most important.
4. Stakeholder engagement: RII captures the perspectives of a diverse group of respondents, enhancing buy-in and

ensuring that decisions are reflective of collective priorities.

The steps below would be typically followed to illustrate the results of a pairwise comparison matrix obtained by using Super Decisions software:

1. Create a pairwise comparison matrix: This step involves comparing each factor against every other factor to determine their relative importance.
2. Input data into Super Decisions: The comparisons are entered into the software to calculate weights.
3. Generate results: Super Decisions provides normalized weights and consistency ratios.
4. Convert crisp values into fuzzy values for the fuzzy AHP to work with: The weights of criteria are calculated by using the geometric mean method by following steps [63] to cover the fuzzy geometric mean value r_i:

A1*A2*An = (l1,m1,U1*(l2,m2,u2)*(ln,mn,un) = (l1*l2**ln,m1*m2*…..*mn,u1*u2*…..*un)^1 n, (3) [64]

where n is the number of criteria.

Table (7) shows the fuzzy geometric means.

Table 7: Fuzzy geometric means for the main factors

	MF	EF	MF1	FF	PMF	EF	Geometric mean
MF	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	(2,3,4)	(2,3,4)	(1.122,2.039,2.749)
EF	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	(1,2,3)	(1,1.871,2.498)
MF1	(1,2,3)	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	(1,1.871,2.498)
FF	(1,2,3)	(1,2,3)	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)	(1,1.871,2.498)
PMF	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(2,3,4)	(1.871,2.498,3.174)
EF	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(1.871,2.498,3.174)

Fuzzy weights were calculated by using Equation (4) and are shown in Table 8

$W_i = r_i$ (r1* r2*rn)^−1. (4) [65]

Table 8: Fuzzy weights

	MF	EF	MF1	FF	PMF	EF	Fuzzy Weight
MF	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	(2,3,4)	(2,3,4)	(0.067,0.164,0.357)
EF	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	(1,2,3)	(0.060,0.143,0.325)
MF1	(1,2,3)	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	(0.060,0.143,0.325)
FF	(1,2,3)	(1,2,3)	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)	(0.060,0.143,0.325)
PMF	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(2,3,4)	(0.107,0.201,0.413)
EF	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(0.107,0.201,0.413)

The center of area of weights was calculated by using Equation (1), and normalized weights were calculated as follows, see Table 9:

Normalized weight = $\frac{wi}{\sum_{n}^{i-1} w}$. (5) [66]

Table 9: Fuzzy normalized weights

	MF	EF	MF1	FF	PMF	EF	Fuzzy Weight
MF	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	(2,3,4)	(2,3,4)	(0.067,0.164,0.357)
EF	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	(1,2,3)	(0.060,0.143,0.325)
MF1	(1,2,3)	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	(0.060,0.143,0.325)
FF	(1,2,3)	(1,2,3)	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)	(0.060,0.143,0.325)
PMF	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(2,3,4)	(0.107,0.201,0.413)
EF	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(0.107,0.201,0.413)

The first step is to generate a pairwise matrix as in Table 10.

Table 10: Pairwise comparison matrix

	Equmpmnet1	External Factors	Financial	manpower1	Material1	Project Management
Equmpmnet1	1	2	4	6	3	3
External Factors	0.5	1	0.5	3	0.333333	0.166667
Financial	0.25	2	1	2	0.5	0.333333
manpower1	0.166667	0.333333	0.5	1	0.25	0.5
Material1	0.333333	3.000003	2	4	1	0.5
Project Management	0.333333	5.999988	3.000003	2	2	1

4.1 Main Factors of contractor's delay

Figure 3 presents the findings of fuzzy AHP analysis for main factors. In contrast to the assigned weights, the factors determining contractor delays in construction projects show considerable variances. Financial factors rank first on the list given their significant weight of 0.36743. These factors play a critical role in decision-making processes concerning cost management, underscoring their prioritization in this context. Furthermore, project management is highlighted with a weight of 0.23959. It plays a vital role in ensuring that projects are carefully planned and executed. Inadequate planning, poor scheduling, or ineffective project monitoring can all contribute to delays. Materials have a value of 0.1601, which highlights their substantial effect on project outcomes. Issues, such as material shortages, quality problems, or delays in material deliveries, can all lead to project delays. Furthermore, equipment elements have a weight of approximately 0.0941 and are crucial for project progress. Equipment breakdown, maintenance delays, or inadequate access to necessary equipment can all result in construction delays. External factors, though weighing less (0.08588) than other factors, still play a role in project delays. These factors may include the inadequate expertise of contractors, accidents on job sites, regulatory hurdles, weather conditions, or delays caused by external stakeholders. Finally, although manpower has a weight of 0.05282, it should not be underestimated. Issues, such as labor shortages, inadequate skill levels, or poor workforce management, can all contribute to delays in construction projects. These weights are critical for evaluating which factors influence contractor delays in building projects.

4.2 sub- Factors of contractors delay

A. Factors related to materials

In Figure 4, a weight of 0.85714 is assigned to delays in supplying materials to work sites, indicating its high importance, whereas a weight of 0.14286 is given to the lack of required materials. These weights suggest that addressing delays in material supply should be prioritized over addressing the lack of required materials. Carefully considering these two factors throughout project phases is essential to mitigate potential issues. By focusing on preventing delays in material supply and ensuring the availability of necessary materials, addressing these factors early on can help in preventing disruptions, ensuring smooth project execution and ultimately leading to successful project outcomes.

B. Factors related to equipment

Figure 5 shows that the shortage of equipment has a weight of 0.64912, making it the most influential factor in this category. The factor of sufficient time for equipment breakdown has a weight of 0.27895. At the same time, the factor of the low skill level of equipment operators is weighed at 0.07193. These weights indicate the importance of addressing the shortage of equipment as a primary concern, with managing the equipment breakdown and enhancing the skills of equipment operators being the next most important. Effectively managing these factors is essential for ensuring smooth operations, reducing downtime, and improving overall efficiency in construction projects.

C. Factors related to manpower

Figure 6 reveals that the lack of workforce has the highest weight (0.59393) among the factors related to manpower, making it a highly critical element. Personal disputes between workers and management teams have a weight of 0.24931. Meanwhile, low labor productivity has a factor of 0.15706. These weights highlight the important causes contributing to the poor management of manpower by contractors. Addressing issues related to the lack of workforce, personal disputes between workers and management, and low labor productivity is crucial for effective manpower management in construction projects.

D. Factors related to finances

Figure 7 illustrates that delays in payments to subcontractors (weight: 0.6798) is the most critical factor causing contractor delays. Late payments to subcontractors can disrupt project timelines, leading to delays in project completion. Next, low profit margin, which has a weight of 0.5332, can impose a financial strain on contractors, affecting their ability to invest in resources, materials, and manpower required for timely project completion. High operational costs and overhead (weight: 0.16388) can affect a contractor's financial stability and profitability. Managing and reducing these costs is essential to maintain project efficiency and prevent delays. Finally, complications in financing are assigned a weight of 0.103. This factor encompasses challenges, such as securing loans, project funding delays, or financial uncertainties. These issues can hinder project progress and lead to delays. By addressing and mitigating these key factors—such as improving payment processes to subcontractors, optimizing profit margins, controlling operational costs, and streamlining financing procedures, contractors can enhance their project management practices, reduce delays, and improve overall project efficiency. Prioritizing these areas can lead to smooth project execution and successful project outcomes.

E. Factors related to project management

Figure 8 indicates that inadequate project planning and scheduling are one of the most important causes (weight: 0.38405) of contractor delays. Poor site management (weight: 0.32169) can result in confusion, rework, and eventually cost overruns during construction. Furthermore, the failures of important staff members (weight: 0.14455) can dramatically affect the results of projects and impede development. The poor performance of subcontractors (weight: 0.103) can introduce issues and additional expenses during procurement and construction. Lastly, a lack of or poor communication with construction parties (weight: 0.0467) can result in misunderstandings, delays, and inefficiencies in project execution.

Addressing these critical subfactors is essential for successful project management, cost control, and timely project completion. Construction projects can be well positioned for success by focusing on improving project planning, enhancing site management practices, ensuring competent staff, fostering strong subcontractor performance, and promoting effective communication among all project stakeholders.

F. Factors related to external factors

Figure 9 shows that delays in site mobilization by the contractor are assigned a weight of 0.46638. This factor remarkably influences project timelines because it affects the readiness of sites for construction activities. The lack of experience among contractors (weight: 0.38397) is influenced by various factors, such as wage levels and labor market trends. It can affect the quality and efficiency of work performed by contractors. Accidents on sites have a weight of 0.09084. Ensuring a safe working environment is crucial to prevent injuries and disruptions that can impede project progress. Moreover, delays in preparing shop drawings and incorrect drawings have a weight of 0.05881.

These issues can lead to external delays caused by contractors, affecting project timelines and potentially increasing costs. Addressing these factors requires proactive risk management, effective communication among project stakeholders, adherence to safety protocols, and ensuring that contractors have the necessary expertise and resources to execute their tasks efficiently.

Table 11 summarizes the final weights assigned to each factor. By multiplying the weights of each element by the weight of the main factor, delays in payments to subcontractors are found to have the highest importance, with a weight of 0.2497. This factor is then followed by low profit margin, which has a weight of 0.1959, along with other contributing variables.

Thresholds can vary depending on application and the method used but are often set on the basis of expert judgment or specific criteria for projects. If the inconsistency value is above the threshold, decision making might benefit from a review of pairwise comparisons. The inconsistency value in fuzzy AHP provides insight into the coherence and logical soundness of fuzzy pairwise comparisons. Keeping this value low is essential for ensuring that the results of fuzzy AHP are reliable and accurately represent the preferences of decision-makers.

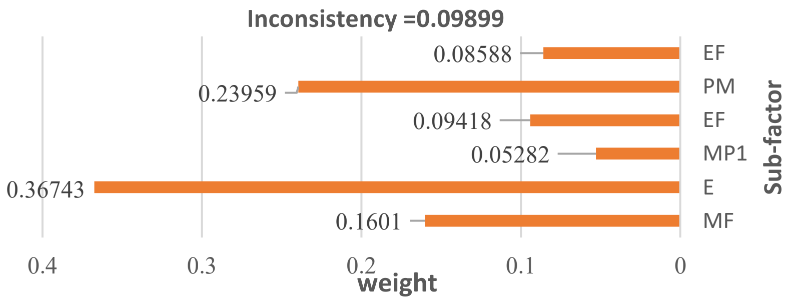

Figure 3. Weighted results for the main factors.

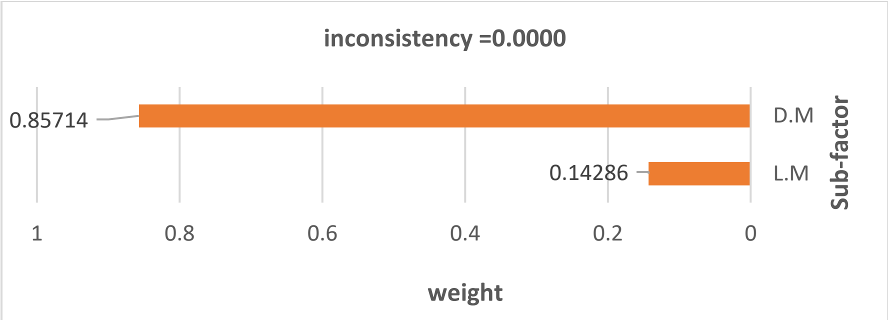

Figure 4. Weighted results for the factors related to material

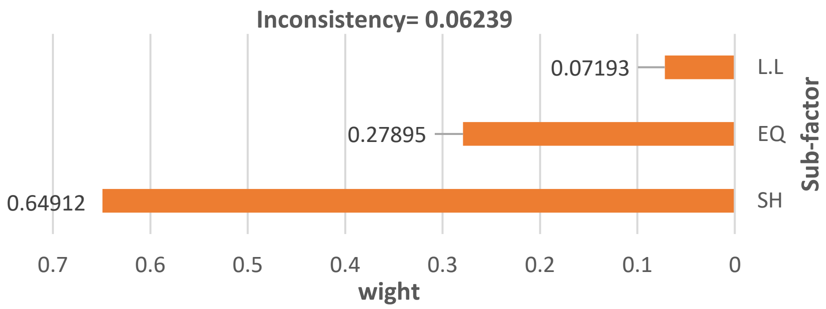

Figure 5. Weighted results for the factors related to equipment

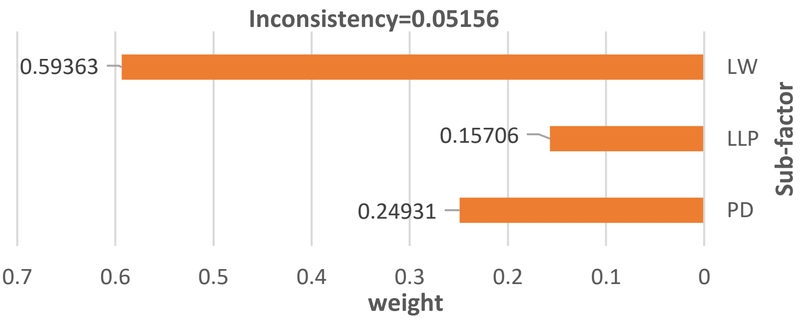

Figure 6. Weighed results for the factors related to manpower

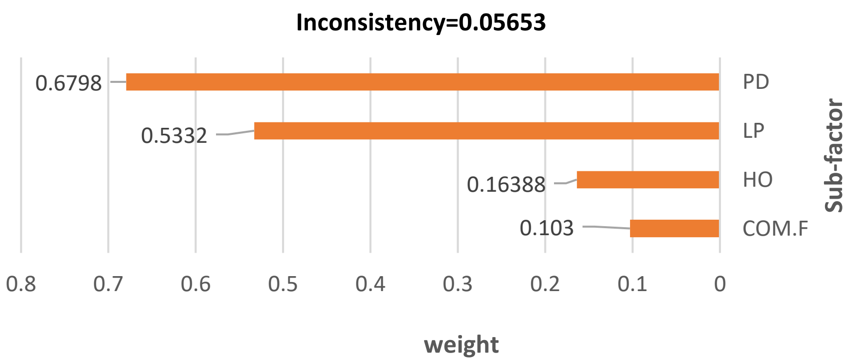

Figure 7. Weighted results for the factors related to the financial.

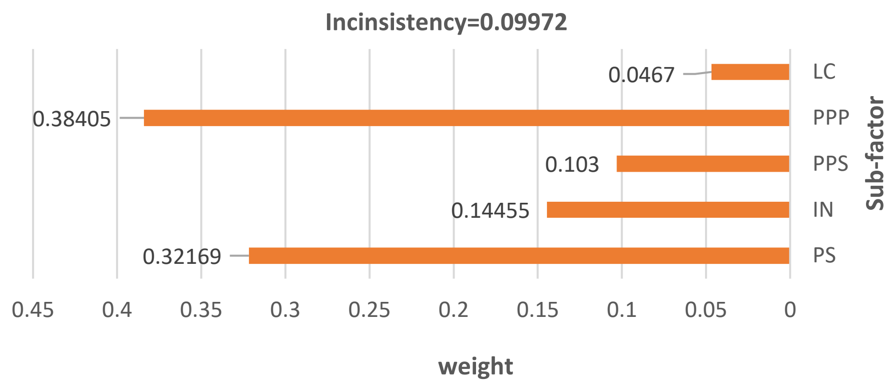

Figure 8. Weighted results for the factors related to project management.

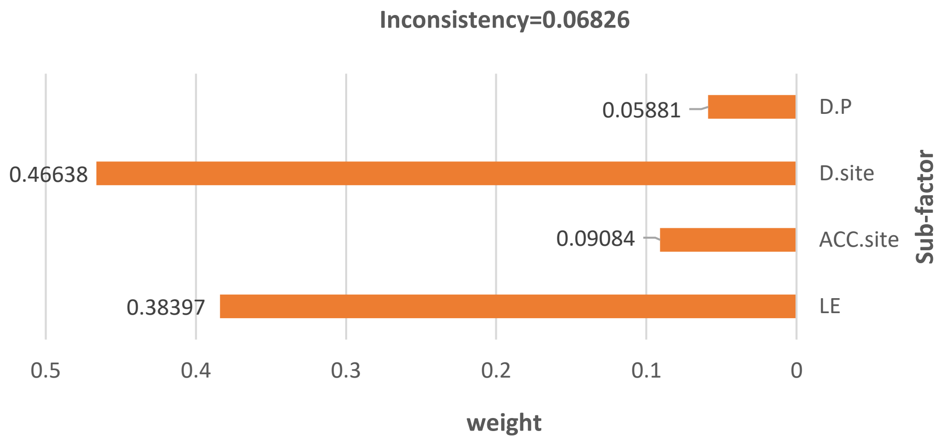

Figure 9. Weighted results for the factors related to external factors.

Table 11. The Final weights performed to each factor

Criteria for contractor Delay	Criteria Weight (W)	Sub-criteria (S)	Sub criteria weight (Ws)	Weight of delay in % = (W)x(Ws)X100
material	0.1601	Lack of required materials	0.14286	0.0228
		Delay in supplying materials to the work site	0.85714	0.1372
equipment	0.09418	Shortage of equipment	0.64912	0.0611
		Equipment breakdown	0.27895	0.0262
		Low level of equipment-operator's skill	0.07193	0.0067
manpower	0.05282	Shortage of labor	0.59393	0.0313
		Low labor productivity	0.15706	0.0082
		Personal disputes between workers and the management team	0.24931	0.0131
financial	0.36743	Complications in the financing	0.103	0.0378
		High operational costs and overhead	0.16388	0.0602
		Low-profit margin	0.5332	0.1959
		Delays in payments to subcontractors	0.6798	0.2497
project management	0.23959	Poor site management	0.32169	0.0770
		Poor project planning/Scheduling	0.38405	0.0920

		lack/poor communication with construction parties	0.0467	0.0112
		incompetence of key staff	0.14455	0.0346
		Poor performance of subcontractors	0.103	0.0246
External factors	0.08588	Lack of experience by contractors	0.38397	0.0329
		Accident on Site	0.09084	0.0078
		Delays in the site mobilization by contractor	0.46638	0.0401
		Delay in preparation of shop drawings, incorrect drawings	0.05881	0.0051

5. Discussion

This study examined contractor-related delays in construction projects by using fuzzy AHP, prioritizing causes for delays on the basis of expert-assigned weightings. The findings shown in Table 5 indicate that among factors, financial factors carry the highest weight (0.36743), followed by project management issues (0.23959), material availability (0.1601), and equipment-related challenges (0.09418). These results align with the findings of previous studies that commonly identified financial and managerial factors as primary causes for delay. For example, Assaf and Al-Hejji emphasized financial issues like cash flow delays, whereas Durdyev and Hosseini highlighted project management issues, such as poor planning and communication. The fuzzy AHP approach also provides nuanced findings, such as the importance of site management and scheduling inefficiencies, that standard AHP methods may overlook. Practical implications for the industry include implementing financial strategies, such as timely payments and cost control, alongside improved site management and communication protocols to mitigate delays, supporting recommendations in existing literature for financial stability and clear timelines. Differences from other studies may reflect regional or project-specific factors, such as supply chain constraints affecting material availability, suggesting that delay mitigation strategies should be tailored to specific contexts. Lastly, this study's focus on contractor-related delays presents a limitation because it excludes factors linked to external stakeholders or client-side delays, thus highlighting the need for future studies to adopt a broad scope or explore hybrid methods for comprehensive analyses and recommendations for each factor.

Financial factors (weight: 0.36743)

Improving contractor payment cycles by ensuring timely payments to subcontractors and suppliers can mitigate financial delays. Implementing transparent financial processes and maintaining healthy cash flow can help in avoiding financial setbacks.

Project management (weight: 0.23959)

Enhancing project planning and scheduling practices can help streamline project management. Clear communication channels, efficient resource allocation, and regular project monitoring can aid in avoiding delays related to project management.

Materials (weight: 0.1601)

Ensuring a robust procurement strategy for materials, maintaining adequate inventory levels, and establishing relationships with reliable suppliers can help prevent delays caused by material shortages. Conducting regular quality checks and having backup suppliers can also be beneficial.

Equipment (weight: 0.09418)

The regular maintenance and timely repairs of equipment and having contingency plans in place for equipment breakdown can assist in reducing delays related to equipment availability. Investing in high-quality equipment and having backup options can also be beneficial.

External factors (weight: 0.08588)

Closely monitoring external factors, such as market fluctuations, regulatory changes, and weather conditions, can help in anticipating and mitigating delays. Developing contingency plans for external disruptions and maintaining flexibility in project timelines can be crucial.

Manpower (weight: 0.05282)

Ensuring the adequate availability of skilled labor, providing training programs to enhance workforce skills, and optimizing workforce planning can help in addressing delays related to manpower shortages. Effective recruitment strategies and fostering a positive work environment can also contribute to timely project completion.

The reason why each secondary factor appears to have a higher weight than others within the primary category is likely due to the specific criteria used in AHP analysis. Factors that are deemed more critical or influential in causing delays are assigned higher weights than others, reflecting their importance in managing and mitigating delay risks in construction projects.

For example, budget allocation delays could be a secondary factor within the financial category. This factor might have a higher weight than other secondary factors within the financial category, indicating its considerable effect on project delays.

A secondary factor like inadequate planning could be another example within the project management category. This factor might be assigned a weight that reflects its critical role in contributing to delays in construction projects.

Each secondary factor within its respective primary category is evaluated and assigned a weight to determine its relative importance in causing delays.

Factors related to financial aspects, project management, materials, equipment, external factors, and manpower are assessed and prioritized on the basis of their relative significance in contributing to delays. This weighting helps in identifying key factors that play a crucial role in causing delays by contractors, enabling improved risk management and prevention strategies in construction projects.

6. 4. Conclusions

This study, which attempted to investigate the factors influencing contractor delays, revealed a substantial association between sets of criteria in building construction projects. The study technique consisted of case studies, expert interviews, questionnaires, and a study of the relevant literature. This work searched for 70 characteristics and classified them into six groups.

The hierarchical structural model was then utilized to create a structural questionnaire that collected realistic data from a panel of experts by using the fuzzy AHP approach. The outcomes of this investigation were analyzed by utilizing fuzzy AHP. The outcomes of the fuzzy AHP analysis highlighted the importance of considering information about the primary reasons for contractor delays. The fuzzy AHP results demonstrated the need to consider details regarding the key reasons for contractor delays in building projects. Such details include finances, project management, materials, equipment, external variables, and labor. In conclusion, the fuzzy AHP method is a useful technique for prioritizing factors affecting contractor delays. This approach allows establishing the weights of these factors.

Overall, this study improves our understanding of contractor delays and demonstrates how effective fuzzy AHP may be when presented with difficult decision-making scenarios.

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