Research Article

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A spherical fuzzy AHP model for contractor assessment during project life cycle

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Abstract: Measurement of construction performance is essential to a clear image of the present situation. This monitoring by the management team is necessary to identify locations where performance is exceptionally excellent or poor and to identify the primary reasons so that the lessons gained may be exported to the firm and its progress strengthened. This research attempts to construct an integrated mathematical model utilizing one of the recent methodologies for dealing with the fuzzy representation of experts' knowledge and judgment considering hesitancy called spherical fuzzy analytic hierarchy process (SFAHP) method to assess the contractor's performance per the project performance parameters (cost, schedule, quality, leadership, and change management). At the same time, most project control systems are currently applied through software like Primavera P6 or MS Project. These look at a project's cost and schedule status by following the earned value analysis for finding the performance. Based on decision makers' preferences, the analytic hierarchy process (AHP) may be used to arrive at the optimum conclusion. AHP approaches are discussed, including AHP, grey-AHP, fuzzy-AHP, and SFAHP weights comparison. Calculation results showed that the spherical fuzzy approach differs significantly from the other approaches where it considers the decision maker's hesitation when making linguistic multicriteria decisions and then, as a result, recommends applying periodically for performance measurement. This model can be viewed as a valuable way to help the decision-making stakeholders in the construction sector do the best job about critical issues at a suitable time.

Keywords: analytic hierarchy process, grey AHP, spherical fuzzy, performance assessment

1 Introduction

The term "project success" might indicate different things for various people. Success is defined in multiple ways depending on the business, project, or individual. As per Pariff and Sanvido, succeeding is an unquantifiable perceptual impression that varies according to management objectives, human qualities, and project stages. Owners, designers, consultants, contractors, and subcontractors all have project goals and success criteria [1]. The construction project's success is a primary concern for most communities, governments, and users [2].

According to Chan and Chan [3], the definition of success for the project is constructed to provide criteria and standards that will assist project participants in completing projects with the desired outcomes. The nature of most businesses is dynamic, and the construction sector is no different, so its environment has gotten more rapid as technology, finances, and development procedures have become more unpredictable [3]. Companies are well aware of their difficulties and have found it necessary to establish systematic performance evaluation methodologies to acquire a competitive edge [4]. Any effort to enhance performance must begin with a clear understanding of the project status and where management wants to go, so that they cannot claim to be doing well until they know how well they are currently doing [5].

To assure project success, we need to design the planning and controlling project to make sure that the project works appropriately and is finished within constraints. This requires integrating and quantifying a wide range of performance factors.

Most project controls systems are currently applied through software like Primavera P6 or MS Project. These look at a project's cost and schedule status by following the earned value analysis for finding the performance indicators.

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2 Research methodology

The research methodology that will be followed in this research is shown in Figure 1.

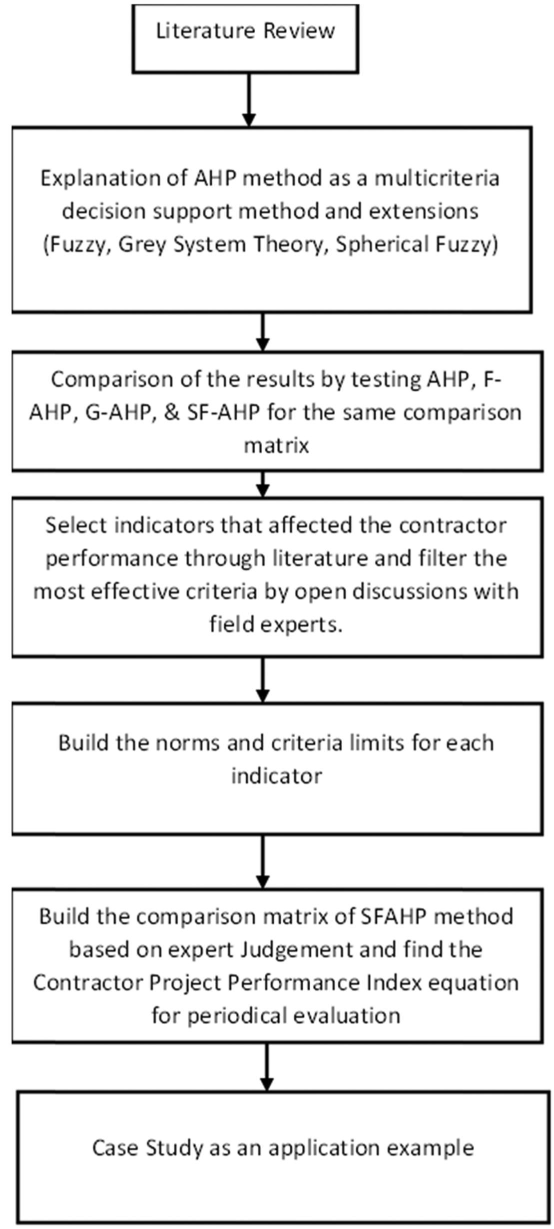

Figure 1: Research methodology.

3 Background

3.1 Construction performance

The goal of planning and controls for construction, an essential function of project management, is to make sure that the project works appropriately and is finished on time. Proper construction project progress monitoring necessitates integrating and quantifying a wide range of performance factors. Currently, most project-control systems only look at a project's cost and schedule status. They do not look at other important characteristics of project performance, such as leadership, quality, and changes, which can be as critical as cost and schedule. While attempting to measure the performance of a project, only a few management processes can do so, having to take into account how the project is doing. Even when two project managers (PMs) utilize the same data, they can arrive at different conclusions about how well the same project performed [6]. Even though many people use key success indicators (KPIs) to analyze the performance of the business, there are some theoretical and empirical limits to their use. Because each indicator only evaluates a portion of the business's activities, a thorough performance review must be based on examining many indications [7].

Another disadvantage of employing a collection of KPIs is that they cannot be utilized directly to generate improvement objectives. Each indicator must be compared to a reference value without respect for other components of the business activity that are not included in the hand. Performance measuring is a critical field of knowledge. Indeed, it is the driving force behind project management development [8]. However, most performance studies focus on KPIs that quantify the project results. These traditional metrics lack insight into the mechanisms for performance improvement, leaving them ineffective for internal management decision-making [9,10]. In other words, a performance management plan that considers project KPIs cannot be sustained in the current competitive and complicated context. PMs must take a proactive approach for managing the project's performance rather than a reactive one [11].

Proactive approaches to performance management were proposed in light of these concerns. This strategy requires forward measurement, intending to determine the condition of the process that leads to improved results [8].

3.2 Design of performance measurement

Designing performance measurement helped generate appropriate, oriented performance indicators, while modeling system dynamics revealed how interdependencies among system components affect performance output.

An effective problem-solving technique will aid in analyzing system performance, identifying restrictions, and devising an improvement strategy [12]. Khan and Wibisono demonstrated how this complexity could pose a problem for decision-makers. First, decision-makers may select the most critical performance indicators from various options [13].

An improperly chosen indicator may present a distorted image, resulting in local minimum or misaligned solutions. In addition, inadequate indicators may drive all stakeholders to concentrate only on short-term development initiatives [14]. In addition, conflicting financial and social goals might result in silo thinking, limiting system effectiveness [12]. If decision-makers do not realize the root causes of a system's poor performance, they may be unable to resolve the issue [15].

In addition, Sarshar *et al.* stated that the industry can still evaluate the construction process systematically, prioritize business requirements, and allocate resources efficiently [16].

3.3 Success criteria for projects

According to Munns and Bjeirmi [17], a project accomplishes a specific objective through actions and tasks that consume resources [3]. As per the Oxford Dictionary (2022), a criterion is a standard or principle against which something is judged or by which a judgment is determined. The success definition, as per the Oxford Dictionary, is a "favorable outcome or the gaining of fame or prosperity." When these two terms are combined, "project success criteria" refers to "a collection of principles or regulations that ensures beneficial results within a certain context."

As Lye [18] points out, designing performance management systems entails examining the interrelated interactions between contextual variables and performance measurements. It is essential to choose performance indicators carefully to minimize the performance deviation and manage the tradeoff between financial and reliable concerns; all key stakeholders should view dynamic linkages between performance metrics. This visibility fosters collaboration inside the system, catalyzing system-wide improvement initiatives rather than local in scope. In addition, Cuthbertson and Piotrowicz [19] stated that performance measurement is a context-dependent procedure adapted to unique circumstances.

4 Multicriteria decision-making tools

The primary responsibility of a PM team in the construction industry is to complete the project within the agreed-upon time, cost, and quality restrictions [20]. As the construction process grows more challenging over time, controlling all project components demands a bird's eye view of the project's life cycle. In addition, most construction companies today use a document-based project management strategy, in which people are hired to collect data from different project stakeholders. So, a lot of construction data are usually collected in the field and organized in a way that does not consider how it will help manage the construction process. This shortfall is much more apparent in developing countries, where recurring cost overruns, low productivity, high waste, and lengthy delays in completing construction projects remain significant issues [21]. Therefore, using the analytic hierarchy process (AHP) method by construction management was one of the techniques implemented to solve that shortfall.

The following sections explain AHP with extensions related to fuzzy and uncertainty representations.

4.1 AHP method

AHP, which Saaty invented in 1988, is a highly effective tool for making multicriteria decisions and has been widely used to weight customer requirements. It has been used in many construction-related studies, including risk assessment and identification, sustainability assessment, and KPIs [22–24]. The standard form of AHP was used in a lot of different decision support tools, including the selection of projects [25], prioritization, resource allocation [33], performance measurement [26], conflict resolution, and quality management [34], as well as strategic planning and policy formulation [27]. Estimated the relative relevance of client needs using a conjoint analysis approach. This technique compares customer needs pairwise to ascertain their relative significance [28].

4.2 Fuzzy-AHP method

Typically, pairwise comparison algorithms use crisp real numbers. Expert judgments of pairwise comparisons, on the other hand, are frequently subjective and imprecise [29]. Kwong and Bai [30] solved this limitation by presenting a fuzzy-AHP technique based on the extended analysis for estimating the importance weights of customer needs during the quality function deployment process. Sun *et al.* and Zheng *et al.* [31] presented another application of the integrated fuzzy-AHP model: expert selection for evaluating R&D projects and safety evaluation [28]. Therefore, including fuzzy approaches within the AHP framework appears viable for dealing with expert evaluations [29].

Except for the fuzzier formulation of pairwise comparisons, the proposed fuzzy-AHP model has the same phases as the standard AHP model. Frequently, the four steps are necessary for an AHP model [25,28]:

- Define an issue by developing a model representing the problem's essential aspects and relationships.
- In pairs, compare items by producing judgments about their knowledge or thoughts.
- Quantify the judgments using relevant numbers.
- Using these numbers, determine the hierarchy's components' priority.

The fuzzy triangular membership function is mathematically defined as follows [28]:

$$\mu(x) = \begin{cases} 0, & x < 1, \\ \dfrac{x-1}{m-1}, & l \le x \le m, \\ \dfrac{u-x}{u-m}, & m \le x \le u, \\ 0, & x > u. \end{cases} \tag{1}$$

4.3 Grey systems theory GST

Professor Deng presented his initial study on grey theory concepts in 1982 [32,47]. Grey systems theory (GST) is a successful approach for addressing discrete data issues and inadequate knowledge under uncertain settings, as shown in Figure 2. A system is grey if a portion of it has known data and another contains unknown data [34]. Uncertainty characteristics in prediction issues may be grouped into two categories: inadequate information and data mistakes. The distinctions between existing uncertain theories are frequently based on the nature of various uncertainties. Fuzzy and grey system theories share certain fundamental number sets [35,48].

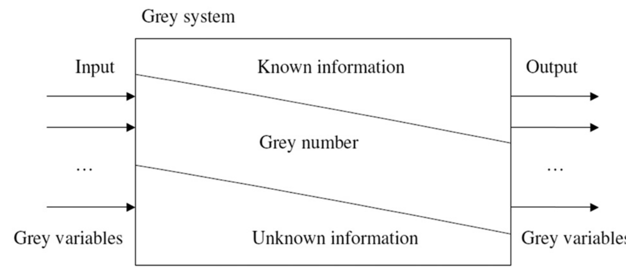

Figure 2: The concept of a grey system [37].

Typically, fuzzy mathematics represents situations where experts describe their uncertainty by a membership function, and Table 1 presents the differences between Grey and other different uncertainty approaches [35,36]. GST can be used when there are not enough experts, the data are not enough, or there are only a few examples, and it is impossible to figure out the membership function because there are not enough examples. GST is better than fuzzy theory because it takes into account uncertain situations. In other words, GST is better than fuzzy theory in uncertain environments.

As a result, a grey set is a collection of data sets that can be described using grey relations, grey numbers, and grey matrices, among other techniques. If Z is a reference set, then in Eq. (2), two $M_x(Z)$ symbols indicate the grey set's upper and lower bounds.

$$\begin{cases} \bar{M}_x(Z) : Z \to [0,1] \\ \underline{M}_x(Z) : Z \to [0,1] \end{cases} \quad \bar{M}_x(Z) \ge \underline{M}_x(Z)\,. \tag{2}$$

If $\bar{M}_x(Z) = \underline{M}_x(Z)$, then the grey set will be a fuzzy set that indicates GST inclusion over the fuzzy condition and its ability to deal with problems of fuzzy nature.

4.4 Advanced fuzzy extensions

Since its inception in 1965, fuzzy sets have gained widespread popularity in nearly every scientific discipline. Many other fuzzy set types have been added to the family

Table 1: A comparison of grey system with other different uncertainty approaches [35,36]

Uncertainty research	Grey system	Fuzzy math.	Prob. statistics	Rough set
Research objects	Poor information	Cognitive	Stochastic	Boundary
Basic set	Grey number set	Fuzzy set	Cantor set	Approximate set
Describe method	Possibility function	Membership function	Density function	Upper, lower appr.
Procedure	Sequence operator	Cut set	Frequency	Dividing
Data requirement	Any distribution	Known membership	Known distribution	Equivalent rel.
Emphasis	Intension	Extension	Intension	Intension
Objective	Law of reality	Cognitive expression	Historical law	Approx. approaching
Characteristics	Small data	Depend on experience	Large sample	Information form

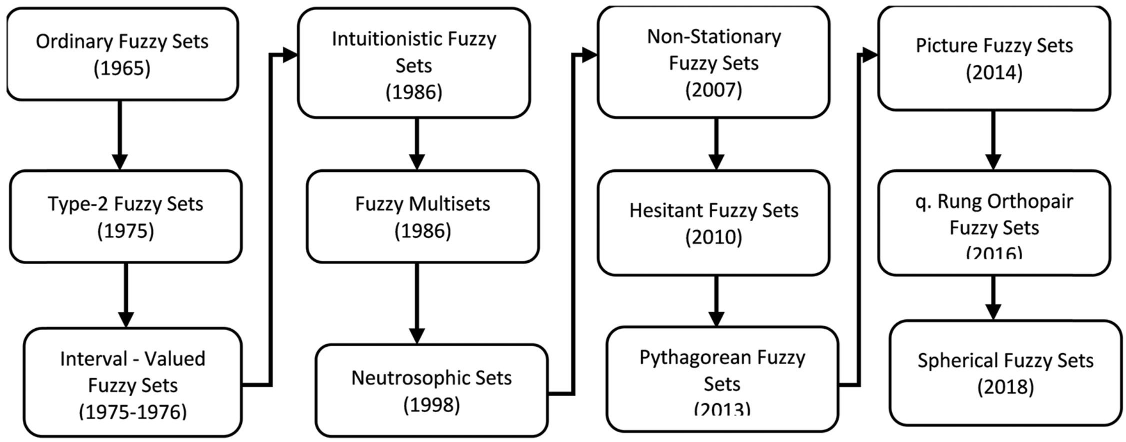

Figure 3: Fuzzy sets extensions [39].

of standard fuzzy sets: type 2 fuzzy sets, interval-valued fuzzy sets, intuitionistic fuzzy sets (IFS), fuzzy multisets, neutrosophic fuzzy sets (NS), nonstationary fuzzy sets, hesitant fuzzy sets, Pythagorean fuzzy sets (PFS), picture fuzzy sets, orthopair fuzzy sets, and spherical fuzzy sets (SFS) [5,38]. It begins with conventional fuzzy sets and progresses to newly designed varieties of fuzzy sets, as shown in Figure 3 [39]. Figure 4 shows the IFS, PFS, NS, and SFS geometric representations [38].

5 Spherical fuzzy sets

It is possible to design SFS that are built on the hesitancy π of a decision-maker regardless of membership μ and

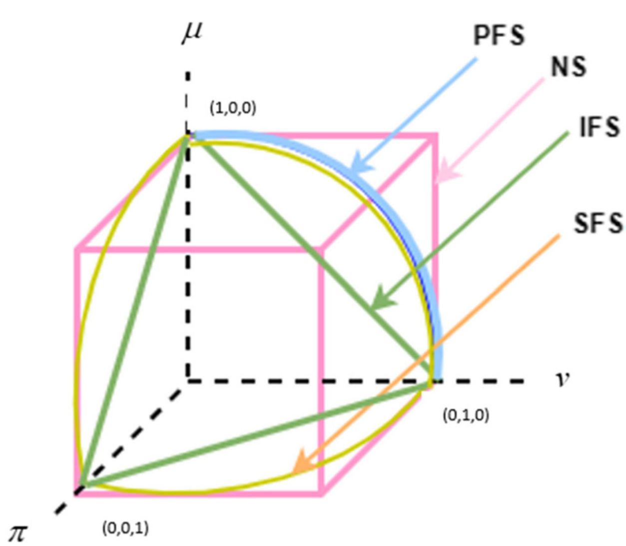

Figure 4: IFS, PFS, NS, and SFS geometric illustrations [38].

nonmembership υ degrees, provided that the following condition is met:

$$0 \le \mu_A^2(u) + \upsilon_A^2(u) + \pi_A^2(u) \le 1 \; \forall u \in U. \quad (3)$$

On the sphere surface, Eq. (3) will be

$$\mu_A^2(u) + \upsilon_A^2(u) + \pi_A^2(u) = 1 \; \forall u \in U. \quad (4)$$

By deriving a membership function on a spherical surface and separately assigning its parameters to a broader domain, SFS enables decision-makers to generalize various extensions of fuzzy sets [39].

A SFSs $\tilde{A}_S$ of the universe U is given by:

$$\tilde{A}_S = \{\langle u, (\mu_{\tilde{A}_S}(u), v_{\tilde{A}_S}(u), \pi_{\tilde{A}_S}(u)) | u \in U\}, \quad (5)$$

where

$$\mu_{\tilde{A}_S}(u) : U \to [0,1], \quad v_{\tilde{A}_S}(u) : U \to [0,1],$$
$$\pi_{\tilde{A}_S}(u) : U \to [0,1].$$

For each u to $\tilde{A}_s$, the refusal degree is calculated based on the values of the membership degree $\mu_{\tilde{A}_S}(u)$, non-membership $v_{\tilde{A}_S}(u)$, and hesitancy $\pi_{\tilde{A}_S}(u)$ as follows [38,39]. Refusal degree is calculated as follows [55,56]:

$$\chi_{\tilde{A}_S}(u) = \sqrt{1 - \mu^2_{\tilde{A}_S}(u) - v^2_{\tilde{A}_S}(u) - \pi^2_{\tilde{A}_S}(u)}. \quad (6)$$

5.1 Zadeh's SFS extension principle [39,41]:

For $i = 1,\ldots,n$, U_i be a universe and let $V \ne 0$.

Let $f{:}X_{i=1}^{n-1} U_i \to V$ be a mapping, where $y = f(z1, \ldots, zn)$.

Let zi be a linguistic variables on U_i for $i = 1,\ldots,n$. Assume that i, $\tilde{A}_{Si}$ is a SFS on U_i and then, the output of mapping f is $\tilde{B}_S$. For $y \in V$, the set $\tilde{B}_S$ is a SFS on V defined as follows:

$$\tilde{B}_S(y) = \left\{ \max_{Z(y)} \left(\min_{i=1}^{n} \mu_{\tilde{A}_{si}}(u_i) \right),\ \min_{Z(y)} \left(\max_{i=1}^{n} \nu_{\tilde{A}_{si}}(u_i) \right), \right.$$
$$\left. \min_{Z(y)} \left(\min_{i=1}^{n} \pi_{\tilde{A}_{si}}(u_i) \right) \forall u_i \in U_i,\ i = 1, \ldots, n \right\}, \quad (7)$$
$$\text{if } f^{-1}(y) \neq 0,$$

where $Z(y) = f^{-1}(y)$.

For operators such as addition and multiplication,

$$\tilde{A}_S \oplus \tilde{B}_S = \left\{ z, \left(\max_{Z=x+y} \min\{\mu_{\tilde{A}_s}(x),\ \mu_{\tilde{B}_s}(y)\} \right), \right.$$
$$\left(\min_{Z=x+y} \max\{\nu_{\tilde{A}_s}(x),\ \nu_{\tilde{B}_s}(y)\} \right), \left(\min_{Z=x+y} \min\{\pi_{\tilde{A}_s}(x), \right. \quad (8)$$
$$\left. \left. \pi_{\tilde{B}_s}(y)\} \right) \right\},$$

$$\tilde{A}_S \otimes \tilde{B}_S = \left\{ z, \left(\max_{Z=x*y} \min\{\mu_{\tilde{A}_s}(x),\ \mu_{\tilde{B}_s}(y)\} \right), \right.$$
$$\left(\min_{Z=x*y} \max\{\nu_{\tilde{A}_s}(x),\ \nu_{\tilde{B}_s}(y)\} \right), \left(\min_{Z=x*y} \min\{\pi_{\tilde{A}_s}(x), \right. \quad (9)$$
$$\left. \left. \pi_{\tilde{B}_s}(y)\} \right) \right\}.$$

The geometric mean of spherical weighted for $w = (w_1, w_2, \ldots, w_n)$; w_i [0, 1]; $\sum_{i=1}^{n} w_i = 1$, is defined as follows:

$$\begin{aligned} \text{SWGM}_w(\tilde{A}_{S1}, \ldots, \tilde{A}_{Sn}) &= \tilde{A}_{S1}^{w_1} + \tilde{A}_{S1}^{w_2} + \ldots + \tilde{A}_{Sn}^{w_n} \\ &= \left\{ \prod_{i=1}^{n} \mu_{\tilde{A}_{si}}^{w_i}, \left[1 - \prod_{i=1}^{n} (1 - \nu_{\tilde{A}_{si}}^2)^{w_i} \right]^{1/2}, \right. \quad (10) \\ & \left. \left[\prod_{i=1}^{n} (1 - \mu_{\tilde{A}_{si}}^2)^{w_i} - \prod_{i=1}^{n} (1 - \nu_{\tilde{A}_{si}}^2 - \pi_{\tilde{A}_{si}}^2)^{w_i} \right]^{1/2} \right\}. \end{aligned}$$

Table 2 shows the linguistic terms and their spherical fuzzy numbers with AHP score values.

Table 2: Spherical fuzzy representation of linguistic scale and their AHP score values [40]

AHP score	Linguistic scale	SF- [μ ν π]
9	AMI – absolutely more importance	[0.9 0.1 0.1]
7	VHI – very high importance	[0.8 0.2 0.2]
5	HI – high importance	[0.7 0.3 0.3]
3	SMI – slightly more importance	[0.6 0.4 0.4]
1	EI – equally importance	[0.5 0.5 0.5]
1/3	SLI – slightly low importance	[0.4 0.6 0.4]
1/5	LI – low importance	[0.3 0.7 0.3]
1/7	VLI – very low importance	[0.2 0.8 0.2]
1/9	ALI – absolutely low importance	[0.1 0.9 0.1]

Table 3: Pairwise comparison table

	AC1	AC2	AC3	AC4	AC5
AC1	(EI)	(SMI)	(HI)	(VHI)	(AMI)
AC2	(SLI)	(EI)	(SMI)	(HI)	(VHI)
AC3	(LI)	(SLI)	(EI)	(SMI)	(HI)
AC4	(VLI)	(LI)	(SLI)	(EI)	(SMI)
AC5	(ALI)	(VLI)	(LI)	(SLI)	(EI)

5.2 Consistency check

The consistency of decision-makers' evaluations should verify. In calculating the consistency ratio (CR), an appropriate random consistency index value was picked based on the matrix's size n. Then, the traditional CR is verified, and a threshold of 10% is defined [41].

6 Comparison of the results

To understand the difference among the four processes mentioned earlier, the author will use five criteria assumed pairwise that lead to a significant weight for the first criterion in the AHP method as an expert nonhesitancy to test the impact of fuzzy, grey, and spherical fuzzy methods on results. As presented in Table 3, the criteria AC1–AC5 represent five criteria for the pairwise comparison matrix.

Table 4 shows the calculations final results for the four processes, while Table 5 shows the results comparisons with AHP methods and clearly indicates that spherical fuzzy AHP significantly differs from the other processes.

7 A multiattribute performance evaluation for PA

Project evaluation and life cycle are depicted schematically in Figure 5. As illustrated, a project can be evaluated

Table 4: AHP, F-AHP, G-AHP, and SF-AHP calculation results

	AHP	F-AHP	G-AHP	SF-AHP
AC1	0.503	0.477	0.497	0.292
AC2	0.260	0.278	0.263	0.241
AC3	0.134	0.141	0.136	0.195
AC4	0.068	0.070	0.069	0.154
AC5	0.035	0.035	0.035	0.117

Table 5: F_AHP, G_AHP, and SF_AHP comparative analysis results with AHP

Indicator	Diff% F-AHP with AHP	Diff% G-AHP with AHP	Diff% SF-AHP with AHP
AC1	−2.6%	−0.5%	−21.0%
AC2	1.7%	0.2%	−1.9%
AC3	0.7%	0.2%	6.1%
AC4	0.2%	0.1%	8.6%
AC5	0.0%	0.1%	8.2%

from conception to completion and entry into operation stages.

Using project assessment (PA) in the project development's initial stages will lead planners to use the right/best ways to manage the elements that make the plan successful [41]. Implementing a PA helps identify areas of weak managerial performance and resource misalignment with the project's goals and priorities, while the project is in progress. Steps will be taken to rebalance the management approach and correct any deficiencies that have been discovered [42].

Traditional project management control tools include information about incurred costs, measured work, and estimated completion dates, among other things. Thus, they often reflect the amount of work accomplished and the amount of time elapsed, among other things. PA is concerned with the state of managerial techniques (the enabling elements). PA considers that the way enabling factors are controlled has a significant but not exclusive impact on project outcomes. However, there is typically a gap between the time it takes to improve a project's management and the time required to see the results through project progress review [42]. Figure 6 shows periodical reporting and assessment during the construction project life cycle; in addition, Table 6 shows the calculation of the indicator for the project performance.

According to the terminology, rework is anything done onsite without a change order, such as repeating field activities or removing previously installed work as part of the project, and the owner has detected no change in the scope [43,44]; and work accepted with cost deduction CD due to not complying with contract documents.

Table 6: Indicators calculation for the project performance

	Progress assessment	Indicator calculation	Description
AC1	Index for cost performance	ICP = BCWP/ACWP	The efficiency of the cost performance for the project
AC2	Index fox quality performance index	IQP = (rework + cost deduction CD)/ phase cost	Consistency in the use of standards and processes for projects
AC3	Index for schedule performance	ISP = BCWP/BCWS	The efficiency of the schedule performance for the project
AC4	Index for leadership	IL = Judgmental	Range from 1 to 10
AC5	Index for change management	ICM = (OC + VO)/OC	Index for variation orders

BCWP = Budgeted cost of work performed: the total budgeted cost of completed work [45].
ACWP = Actual cost of work performed: the total cost of the work completed to date [45].
BCWS = Budgeted cost of work scheduled: the budgeted cost of scheduled work (as specified in the budget) to date [45].
IQP = field construction rework index: direct and indirect field rework costs divided by the total cost of the field construction phase.

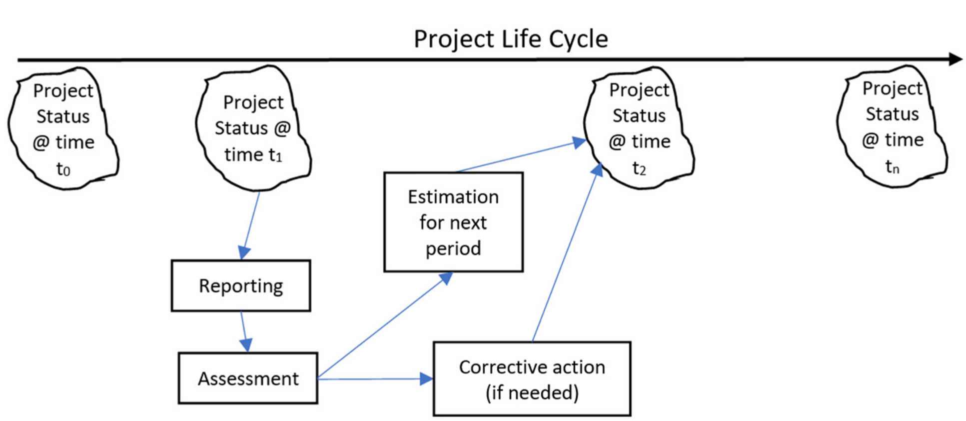

Figure 5: Role of project assessment during project life cycle.

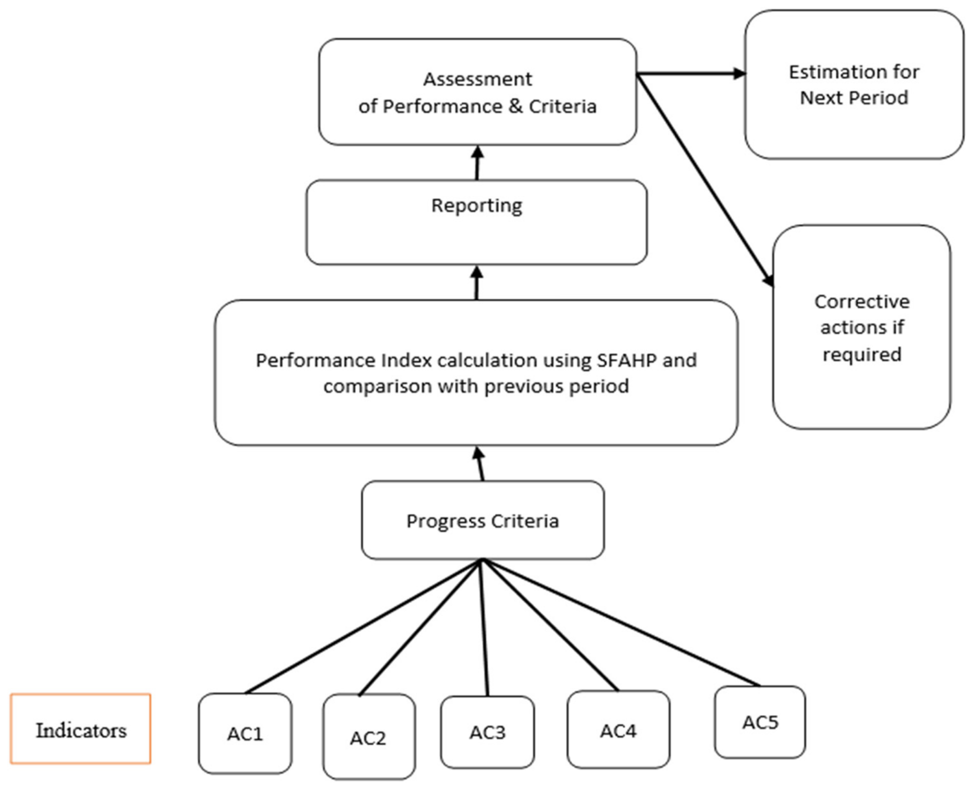

Figure 6: Periodical reporting and assessment during construction project life cycle.

$$\mathrm{CPPI} = w_1 \times \mathrm{AC1} + w_2 \times \mathrm{AC2} + w_3 \times \mathrm{AC3} + w_4 \times \mathrm{AC4} + w_5 \times \mathrm{AC5}, \quad (11)$$

where CPPI is the contractor project performance index, w_i is the weight for indicator i in CPPI, and ACi is the performance indicator

7.1 Index for cost performance

The index for cost performance (ICP) is utilized to measure the project's cost efficiency. Achieve the ICP by dividing earnings by actual costs. Any ICP of more than 1 indicates that there have been cost overruns [46].

7.2 Index for schedule performance

Project scheduling efficiency is measured using the index for schedule performance (ISP). This signifies that the project is behind schedule if ISP goes below 1 [46].

7.3 Index for quality performance

The quality of a project should be constantly monitored and enhanced. Consistency in applying project standards and processes and the material or component's adherence to project specifications are measured using the index for quality performance (IQP). Project process inconsistency leads to excessive amounts of rework, insufficient audits, and nonconformance reports [43,44].

7.4 Index for leadership

Successful projects necessitate a high level of leadership ability. Leadership is critical throughout the project's life cycle. Although good leadership is vital throughout the project's lifecycle, it is essential during the early phases when the emphasis is on conveying the vision and motivating and inspiring project members to achieve high performance [46]. The leadership index is a subjective value assigned by the PM on a scale of 1–10 to the contractor manager's ability and flexibility in guiding the project team and balancing project constraints.

Table 7: Ratings, normalized, and index ranges for the assessment indicators (adapted from ref. [44])

Condition	Rating	Normalized range	IQP	ICP, ISP	IL	ICH
A	Outstanding performance	>1.15	≤0.50	>1.15	9–10	<1*
B	Exceeds target	1.05–1.14	0.51–1.0	1.05–1.14	7–8	1–1.03
C	Within target	0.95–1.04	1.01–2.0	0.95–1.04	5–6	1.04–1.06
D	Below target	0.85–0.94	2.01–4.0	0.85–0.94	3–4	1.07–1.10
E	Poor performance	≤0.84	>4.01	≤0.84	1–2	>1.10

*Negative change order.

7.5 Index for change management

Changes are the most crucial component of any construction project, as they occur among all parties involved. The official method of executing modifications in a project is through a change order, which permits the contractor to implement specified changes. These adjustments frequently result in project disagreements and possible litigation. Thus, the factors that drive change orders and their consequences on construction are crucial for any project [47,48]. The change management index reflects the cost percentage of change orders to the project cost.

Indicator and normalized values are shown in Table 7, along with a sample rating for each. Project professionals answer the following question to complete the judgment matrix *W*: "How much more important is Indicator 1 than Indicator 2 in terms of the total project performance." Group discussion or the use of a questionnaire are used to achieve conclusions.

Table 8 shows that the pairwise comparison reflects the expert judgment for five project performance indicators.

Table 9 shows the crisp weights for performance indicators. The model used permits the users to select from a list of indicators that are considered significant on a given project. These indicators were essential and demanded the project management team's measurement and close monitoring.

As a result, the final equation for the calculation of the contractor performance index is as follows:

$$\begin{aligned}\text{CPPI} = 0.3 \times \text{AC1} + 0.262 \times \text{AC2} + 0.169 \times \text{AC3} \\ + 0.135 \times \text{AC4} + 0.134 \times \text{AC5}.\end{aligned} \tag{12}$$

8 Case study

Table 10 presents the indicators values for two contractors as a part of a monthly report

Tables 11 and 12 show each indicator's normalized calculations with comments evaluating the indicator rate.

Table 8: Performance pairwise comparison table

	AC1	AC2	AC3	AC4	AC5
AC1	(EI)	(SMI)	(VHI)	(AMI)	(VHI)
AC2	(SLI)	(EI)	(VHI)	(HI)	(VHI)
AC3	(VLI)	(VLI)	(EI)	(SMI)	(SMI)
AC4	(ALI)	(LI)	(SLI)	(EI)	(EI)
AC5	(VLI)	(VLI)	(SLI)	(EI)	(EI)

Table 9: SF_AHP crisp weights for indicators

	Crisp weights
AC1	0.300
AC2	0.262
AC3	0.169
AC4	0.135
AC5	0.134

Table 10: Monthly indicators values for two contractors

Indicator	Contractor 1	Contractor 2
ICP	0.95	0.97
IQP	1.35	1.2
ISP	1.05	0.94
IL	6	8
ICM	1.06	1.03

Table 11: Contractor 1 normalized calculations for indicators

Indicator	Value	Normalized value	Comment
ICP	0.95	0.95	Within target
IQP	1.35	0.981	Within target
ISP	1.05	1.05	Within target
IL	6	1.04	Within target
ICM	1.06	1.04	Within target

Table 12: Contractor 2 normalized calculations for indicators

Indicator	Value	Normalized value	Comment
ICP	0.97	0.97	Within target
IQP	1.2	0.967	Within target
ISP	0.94	0.94	Below target
IL	8	1.14	Within target
ICM	1.03	1.14	Exceed target

As per the CPPI equation for evaluation of contractor performance, the results and judgment by the management team are as follows:

CPPI1 = 0.3 * 0.95 + 0.262 * 0.981 + 0.169 * 1.05 + 0.135 * 1.04 + 0.134 * 1.04 = 0.999

Judgment of contractor 1's overall performance within the acceptable range.

CPPI2 = 0.3 * 0.97 + 0.262 * 0.967 + 0.169 * 0.94 + 0.135 * 1.14 + 0.134 * 1.14 = 1.01

Judgment contractor 2 needs a recovery schedule with overall performance within the acceptable range and better than Contractor 1 even when he was behind the schedule.

As a result, the SF-AHP method could establish a construction assessment methodology for contractors' overall performance that can be used in conjunction with standard assessments' information to provide a complete picture of their performances.

9 Conclusion

Measurement of the project's performance is essential to a clear image of the present situation; in addition, the management team should take a proactive approach to manage a project's performance rather than a reactive one. This management team's monitoring can be used in conjunction with standard assessment information to provide a complete picture of their performances by identifying the locations where performance is exceptionally excellent or poor and to determine the primary reasons so that the lessons gained may be exported to the firm and its progress strengthened.

This research constructed a three-dimensional, spherical fuzzy-based relative relevance vector as a recent extension of an ordinary fuzzy set based on the experts' knowledge and judgment for the chosen project performance parameters (cost, schedule, quality, leadership, and change management).

The results analysis shows that the SF-AHP method is effectively used to solve unstructured, distributed project issues and could be used to compare contractors' performance. It utilizes nonlinear fuzzy sets and matrices to create a matrix of relative priorities based on the team's collective judgments and values. SF-AHP computations generate findings that differ from other approaches (AHP, F-AHP, and G-AHP), where they compensate for professional hesitancy and recommend if the individuals responsible for developing weights want to consider this parameter and match the organization's goals.

Despite the benefits of the SF-AHP approach provided in the study, it may not be ideal for every situation since it consumes effort and complexity to gather the data. It may be challenging to agree on weights if we incorporate more than one expert in decision-making. A consensus among the experts on the comparative relevance of each criterion to the overall aim is strongly suggested.

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