Journal of Civil Aspects and Structural Engineering

www.case.reapress.com

J. Civ. Asp. Struct. Eng. Vol. 2, No. 3 (2025) 212–220.

Paper Type: Original Article

Identifying and Ranking Factors Affecting the Quality of Construction Projects Using the Fuzzy Delphi and Fuzzy ANP Approaches

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Citation:

Received: 02 May 2025 *Revised: 15 June 2025* *Accepted: 26 August 2025*	Zare, H. (2025). Identifying and ranking factors affecting the quality of construction projects using the Fuzzy Delphi and Fuzzy ANP approaches. *Journal of civil aspects and structural engineering,* 2(3), 212–220.

Abstract

This research aims to identify and rank the factors influencing the quality of construction projects. The present study is based on a mixed research method, in which a combination of qualitative and quantitative methods was used. From the perspective of the purpose, it is an applied research because the results of the present study are used to increase the quality of construction projects. In terms of data collection method, the present study is a descriptive survey research, and in terms of data analysis method, it was classified as quantitative research. The statistical population of the present study was all experts and activists in the field of construction in Tonekabon city, from which 10 people were selected using the convenience sampling method. Data analysis was performed using the Fuzzy Delphi Method and Fuzzy AHP. The results of the Fuzzy Delphi analysis showed that 10 criteria including the employer's justification in terms of project quality, the employer's justification in terms of project time, the project manager's activity, the quality of project planning, the constructability of the designs, Monitoring project workshop activities, selecting and monitoring contractors, communication and cooperation between implementation agents, proper financial management, and selecting the best contractor are the most influential factors in improving the quality of construction projects in Tonekabon County. The ranking and importance of each criterion were determined using the Fuzzy AHP method. The results showed that the employer's justification in terms of project time with a weight of (0.122) was in first place, the project manager's activity and the ability to build designs with a weight of (0.108) in second place, the quality of project planning with a weight of (0.108) in third place, Communication and cooperation between implementation factors were ranked fourth with a weight of (0.100), sound financial management with a weight of (0.099) in fifth place, supervision of project workshop activities with a weight of (0.095) in sixth place, selection and supervision of contractors with a weight of (0.095) in seventh place, justification of the employer in terms of project quality with a weight of (0.0818) in eighth place, and selection of the best contractor with a weight of (0.809).

Keywords: Construction project quality, Critical success factors, Fuzzy Delphi method, Fuzzy AHP, Construction management, Tonekabon.

1 | Introduction

In today's world, given the many developments in construction projects, especially in the field of construction, along with the use of new and up-to-date technologies, tight global competition, and attention to service quality, the need for a stronger system is felt to be able to provide the product or service provided in a short

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10.48314/jcase.vi.60

time and at the lowest cost and with high quality. Therefore, it can be claimed that Total Quality Management (TQM) plays an important role, and its application in construction projects is essential.[1]

The main goal of TQM is to strive to lower total costs and increase the quality and speed of providing products and services. Leadership, employer satisfaction, employee participation, continuous improvement of the investor participation process, and performance measures are among the primary concepts of TQM in construction projects. TQM, which is the same as comprehensive quality management, is actually an intelligent, calm, and continuous practice that has a powerful impact on achieving the organization's goals and ultimately brings satisfaction to the employer as the beneficiary, increased efficiency, and increased competitiveness in investing in projects [2].

Quality can encompass all parts and sub-parts of a project. In this approach, top management organizes the strategy and operations related to meeting the client's needs and develops close collaboration among the project team [3].

TQM is a type of management method that originated in the 1950s but has gained popularity since the 1980s. From this perspective, TQM is a method by which management and employees are involved in the continuous improvement of the production of goods and services in a project. TQM is the result of a combination of management and quality tools, the primary goal of which is to increase service quality and reduce losses. It has been accepted as a paradigm by many organizations around the world [4].

The quality movement began in almost all countries with quality improvement projects in manufacturing. Over time, it was used in service sectors such as banking, insurance, and even in non-profit organizations such as educational institutions, health institutions, and construction and infrastructure projects [5].

After World War II, industrial and service managers in various countries were forced to close their production and service units due to a lack of information, a lack of attention to quality, and a lack of proper use of their components in the operational process [6].

At a time when Western countries were experiencing unemployment and economic recession, Japanese companies took a significant step towards increasing production and creativity and gaining a greater market share by applying the ideas of quality theorists such as Deming, Juran, Feigenbaum, and Ishikawa [7].

In addition, Japanese manufacturing and service institutions, in light of proper attention to organizational culture, make appropriate use of industrial, commercial, and Services and proper attention to factors such as behavior management, creating appropriate motivation, and providing a comprehensive information flow among various organizational levels have attempted to solve the problems of units and meet the changing demands of product users by continuously improving quality and reducing their operating costs, and have also made reducing the return on investment period the most important goal of their organization [8].

In fact, TQM is a management philosophy that believes that the two common needs and goals of the company are inseparable [9].

It is used in business, industry, and services, ensuring maximum efficiency and effectiveness, and it consolidates business leadership by applying governance to processes and systems, leading to increased efficiency and error prevention, and assuring the organization that all its goals are aimed at meeting the needs of its employees [10].

2 | Fuzzy Delphi Technique

This technique is a robust process based on a group communication structure that is used in cases where incomplete and uncertain knowledge is available, with the aim of achieving group consensus among experts. In the classical Delphi method, experts' opinions are presented in the form of definite numbers. In contrast, experts use their subjective qualifications to express their views, which reflects the possibility of uncertainty prevailing in these conditions. The probabilistic nature of uncertainty is compatible with fuzzy sets. Therefore, it is better to obtain data in natural language from experts and analyze it using fuzzy sets. In this regard, a proposal was made to integrate the traditional Delphi method with Fuzzy Theory under the name of fuzzy Delphi method .In this method, membership functions are used to represent the opinions of experts. The advantage of the Fuzzy Delphi method is that it considers each of the views and integrates them to achieve group agreement. The implementation steps of this method are a combination of the traditional Delphi method and data analysis of each stage using the definitions of fuzzy set theory. Fuzzification of expert opinions is done using fuzzy numbers. Fuzzy numbers are fuzzy sets that are defined in terms of uncertainty about a phenomenon with numerical data. The Delphi method was first proposed by Dalkey and Helmer in 1963. This technique is a survey method based on the ideas of experts and has three main characteristics, which are:

Anonymous response, controlled repetition, feedback, and finally, statistical group response. This technique is a systematic way to collect and coordinate the informed judgments of a group of experts about a specific question or topic. In many real-world situations, expert judgment cannot be expressed and interpreted as definitive quantitative numbers; in other words, definitive data and numbers are not sufficient to model real-world systems due to the ambiguity and uncertainty inherent in decision-makers' judgments. Meanwhile, to overcome this problem, fuzzy set theory is a suitable tool for dealing with ambiguity and uncertainty in the decision-making process.

Therefore, in this study, the Fuzzy Delphi method has been used to verify and screen the identified indicators. In the Delphi method, since the predictions provided by experts are expressed in the form of definite numbers, it distances them from the truth. In addition, experts use their mental abilities to make predictions, which indicates that the uncertainty in these situations is probabilistic, not a probable one. The probabilistic nature of uncertainty is consistent with fuzzy sets. The Delphi method is used as a tool for effective forecasting and is applicable in a wide range of applications.

For example, in technology (Trend) forecasts, strategy planning, knowledge acquisition, urban systems planning, public policy compilation and planning, market research, large-scale project planning, new product development, systems design, etc. This method is a combination of the Delphi method and fuzzy set theory, which was presented by Ishikawa et al [11].

2.1 | Steps of the Fuzzy Delphi Method

I. Identifying research indicators by using a comprehensive review of the theoretical foundations of the research.

II. Collecting the opinions of decision-making experts: In this step, after identifying the supply chain criteria, a decision-making group consisting of experts related to the research topic is formed and questionnaires are sent to them to determine the relevance of the identified indicators to the primary research and screening topic, in which the linguistic variables in are used to express the importance of each indicator. In this research, triangular fuzzy numbers are used.

III. Verification and screening of indicators: This is done by comparing the acquired value of each indicator with the threshold value. The threshold value is calculated in various ways, but basically, the value of 0.7 is considered the threshold value. To do this, first, the triangular fuzzy values of the experts' opinions must be calculated, and then their fuzzy average must be calculated to calculate the average of the opinions of n respondents. The fuzzy number is calculated for each of the indicators using the relationships stated below.

$$\begin{aligned}
&\tilde{a}_{ij} = (a_{ij}, b_{ij}, c_{ij}), \qquad i = 1,2,\dots,n \qquad j = 1,2,\dots,m,\\
&a_j = \min(a_{ij}),\\
&b_j = \left(\prod_{i=1}^{n} bij\right)^{1/n},\\
&c_j = \max(c_{ij}).
\end{aligned} \tag{1}$$

In the above relations, index i refers to the expert, and index j refers to the decision-making index. Also, the de-fuzzified value of the average fuzzy number is obtained from the following relation.

$$\text{Crisp} = \frac{a + b + c}{3}. \tag{2}$$

IV. Consensus and Completion Phase of Fuzzy Delphi: Consensus refers to the response in which the respondents have reached a general decision about the factors, and the stage after which nothing extraordinary happens in the criteria

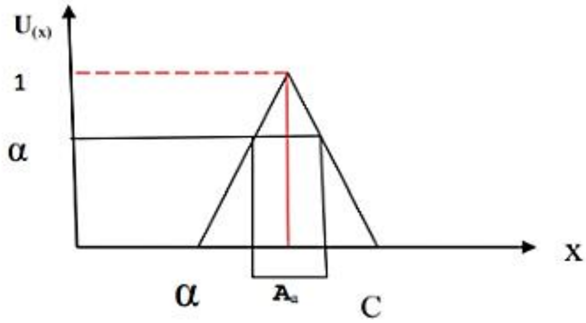

Fig. 1. Schematic diagram of the threshold of the Fuzzy Delphi Method.

2.2 | Fuzzy ANP Method

Data analysis in this study was performed using the Fuzzy ANP method. In the ANP method, preferences between options are determined by pairwise comparisons. The ANP method in a fuzzy environment is a combined and generalized method of the classical ANP method. It is widely used when the complexities of the decision-makers' opinions are considered. In the following sections, the processes related to classical and Fuzzy ANP are fully described. To implement the ANP technique, the first step is to represent the decision problem and goal as a hierarchy of decision elements. This structure usually has one or more clusters.

There are two principles in designing a hierarchical pattern:

I. According to the principle of dependency, each element can only be dependent on one element, and that element can only be directly dependent on one level above it.

II. Based on the principle, expectations: Whenever there is a change in the hierarchical structure, the evaluation process must be carried out anew.

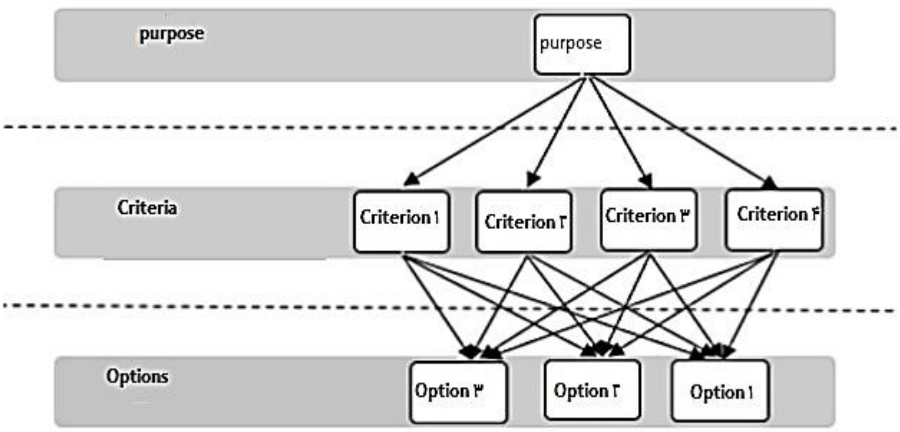

Fig. 2. ANN decision tree model (ANP).

3 | Cluster Two Decision Elements

The main decision-making criteria are placed in the second cluster after the research objective. The main criteria are always present in every problem. These criteria can have non-criteria, and non-criteria may be composed of other sub-criteria, so there is no limit to the decision-making clusters.

4 | Final Cluster of Decision Options

Decision options are displayed at the lowest level. As mentioned, the goal of the ANP technique is not always to select the best option, and sometimes this technique is used only to rank a set of criteria or sub-criteria, so the target cluster is not present in all ANP studies.

5 | Fuzzy Analytic Hierarchy Process

First step: Drawing a hierarchical tree (Identifying the goal, criteria, and non-criteria) and forming a matrix of paired comparisons, and using an appropriate linguistic spectrum to collect information.

Step1. Calculate the sum of preferences for each element

Each element of the even matrix is denoted by aij. The sum of the elements of each row is calculated.

$$\sum_{j=1}^{n} a_{ij}. \tag{3}$$

Step 2. Normalize the sum of preferences of each element

$$S_i = \sum_{j=1}^{n} a_{ij} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}\right]^{-1}. \tag{4}$$

Step 3. Defuzzify the values

To defuzzify the values, the following formula was used.

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) = \begin{cases} 1 & \text{if } m_2 \geq m_1, \\ 0 & \text{if } l_1 \geq u_2, \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{Otherwise.} \end{cases} \tag{5}$$

6 | Determining Important Components That Affect Increasing Project Quality

In the first stage, 18 factors affecting the quality of the project were presented in the form of a questionnaire and made available to the experts.

Table 1. Factors raised in the questionnaire (1).

Influential Factor	Row
knowledge	1
Competent human resources	2
Meritocracy in Human Resources	3
Understanding and justifying the employer's safety, quality, and accidents	4
Justification of the employer in terms of project quality	5
Employer's justification in terms of project time	6

Table 1. Continued.

Influential Factor	Row
How the project manager works	7
Management of project executive agents	8
Project planning quality	9
Ability to build designs	10
Supervision of project workshop activities	11
Setting realistic requirements	12
Setting realistic requirements	13
Selecting and supervising contractors	14
Communication and cooperation between implementing agents	15
Correct financial management	16
Choosing the best contractor	17
Clarity of project scope	18

After preparation, this questionnaire was provided to 10 experts, and they were asked to mark the importance of each component in the questionnaire using a 5-point Likert scale. After collecting the experts' opinions, the obtained verbal expressions were fuzzy using the triangular fuzzy numbers in *Table 2*.

Table 2. Triangular fuzzy numbers.

Fuzzy Expression	Verbal Expression
(0, 25, 0, 0)	Very little
(0,50,25,0)	Low
(0, 75, 0, 25, 0)	Average
(1, 0, 75, 0, 5)	A lot
(1, 1, 0, 75)	Too much

$$\begin{aligned}
&\tilde{a}_{ij} = (a_{ij}, b_{ij}, c_{ij}), i = 1,2, \dots, n \; j = 1,2, \dots, m,\\
&a_j = \min(a_{ij}),\\
&b_j = \left(\prod_{i=1}^{n} b_{ij}\right)^{1/n},\\
&c_j = \max(c_{ij}),\\
&\text{crisp } = \frac{a+b+c}{3}.
\end{aligned} \quad (6)$$

Table 3. Components identified in the first stage.

Row	Influential Factor
1	Competent human resources
2	Understanding and justifying the employer's safety, quality, and accidents
3	Justification of the employer in terms of project quality
4	Employer's justification in terms of project time
5	How the project manager works
6	Management of project executive agents
7	Project planning quality
8	Ability to build designs
9	Supervision of project workshop activities
10	Management and management commitments
11	Selecting and supervising contractors
12	Communication and cooperation between implementing agents

Table 4. Points obtained in the second stage.

Row	Influential Factor	Score
1	Competent human resources	0.44
2	Understanding and justifying the employer's safety, quality, and accidents	0.43
3	Justification of the employer in terms of project quality	0.71
4	Employer's justification in terms of project time	
5	How the project manager works	0.93
6	Management of project executive agents	0.33
7	Project planning quality	0.88
8	Ability to build designs	0.65
9	Supervision of project workshop activities	0.73
10	Management and management commitments	0.39
11	Selecting and supervising contractors	0.75
12	Communication and cooperation between implementing agents	0.77
13	Correct financial management	0.83
14	Choosing the best contractor	0.93
15	Clarity of project scope	0.46

At this stage, 5 factors from the previous questionnaire that had a score of less than 0.5 were removed, and the final criteria were obtained.

Table 5. Score of each of the criteria identified in the second stage.

Row	Influential Factor	Score
1	Justification of the employer in terms of project quality	0.71
2	Employer's justification in terms of project time	
3	How the project manager works	0.93
4	Project planning quality	0.88
5	Ability to build designs	0.65
6	Supervision of project workshop activities	0.73
7	Selecting and supervising contractors	0.75
8	Communication and cooperation between implementing agents	0.77
9	Correct financial management	0.83
10	Choosing the best contractor	0.93

7 | Ranking of Identified Factors Using the FANP Method

After using the Fuzzy Delphi Method to identify the most critical factors affecting the quality of construction projects, in this section, it is necessary to determine the ranking and order of importance of each criterion. For this purpose, the Fuzzy ANP analysis method has been used.

Table 6. Criteria used with the corresponding symbol.

1	Justification of the employer in terms of project quality	C1
2	Employer's justification in terms of project time	C2
3	How the project manager works	C3
4	Project planning quality	C4
5	Ability to build designs	C5
6	Supervision of project workshop activities	C6
7	Selecting and supervising contractors	C7
8	Communication and cooperation between implementing agents	C8
9	Correct financial management	C9
10	Choosing the best contractor	C10

The order of importance of each criterion is as follows:

I. The employer's justification in terms of project time.

II. How the project manager works and the ability to build designs.

III. Quality of project planning.

IV. Communication and cooperation between implementing agents.

V. Proper financial management.

VI. Monitoring project workshop activities.

VII. Selection and supervision of contractors.

VIII. Justification of the employer in terms of project quality.

IX. Choosing the best contractor.

8 | Conclusion

This research aims to identify effective factors in increasing the quality of construction projects. The statistical population of the present study consists of all experts in the construction industry, from whom 10 people were selected and responded to the questionnaires. The data collection tool in the present study was a Fuzzy Delphi questionnaire, the criteria of which were extracted by examining and reviewing past sources. In this stage, 18 criteria were selected, including: knowledge, human resources, meritocracy in human resources, employer's recognition and justification regarding safety quality and accidents, employer's justification in terms of project quality, Client justification in terms of project time, buildability of designs, supervision of project workshop activities, determination of realistic requirements, management and management commitments, Selection and monitoring of contractors, communication and cooperation between implementation factors, proper financial management, selection of the best contractor, and clarity of the project scope were extracted. Using the Fuzzy Delphi method, 5 less critical criteria were eliminated, and in the final questionnaire, 10 criteria were identified, which were ranked using the Fuzzy ANP method. In the Fuzzy ANP analysis, each of the ten criteria identified in the previous stage was provided to 10 experts, and they scored them.

The results of ranking each of the identified factors showed that the order of importance of the criteria is:

I. The employer's justification in terms of project time.

II. How the project manager works and the ability to build designs.

III. Quality of project planning.

IV. Communication and cooperation between implementation factors.

V. Proper financial management.

VI. Supervision of project workshop activities.

VII. Selection and supervision of contractors.

VIII. Justification of the employer in terms of project quality.

IX. Selection of the best contractor.

Acknowledgments

The author thanks the construction industry experts in Tonekabon County for their valuable input.

Funding

This research received no external funding.

Data Availability

Processed data are available from the corresponding author upon reasonable request.

Authors' Contributions

The author undertook all components of the research and manuscript preparation and approved the final manuscript.

Conflict of Interest

The author declares no conflict of interest.

Consent for Publication

The author confirms consent for the publication of this work

Ethics Approval and Consent to Participate

This article does not contain any studies with human participants performed by the author.

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