An MCDM Approach for Evaluating Construction-Related Risks using a Combined Fuzzy Grey DEMATEL Method

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ABSTRACT

There is a need for more research into prioritizing project risks based on a sound technique due to the complicated and disorganized character of this stage. The project risk management process typically begins with the identification of critical hazards. This study presents a Grey Fuzzy Decision-Making Trial and Evaluation Laboratory (FGDEMATEL) approach to prioritize potential causes of project risks within Multi-Criteria Decision-Making (MCDM). This framework organizes the numerous risks using the Risk Breakdown Structure (RBS) of the Project Management Institute (PMI). The risk information used in this analysis comes mostly from the views and choices of project experts. Grey theory, which takes language phrases for preference collections and translates them into numerical intervals, is responsible for controlling uncertainty and variance in experts' preferences. As each expert has unique skills and experiences, it evaluates the significance of their opinions using a fuzzy number system that incorporates three dimensions. In the end, the FGDEMATEL approach devised a method to rank various project risks.

Keywords-grey system theory; DEMATEL; project risk management; fuzzy set theory

I. INTRODUCTION

Project risk considers the possibility that something may go wrong and hinder progress toward the project's goals. The risk of a project is the product of two variables: the likelihood that an event will take place and the severity of its potential consequences [1-4]. The total effect of all separate risks in a project is referred to as the aggregate project risk. Risk management is an essential procedure that must be carried out to complete projects successfully and on schedule. A detailed process of systematically determining particular risk sources at a consistent degree of specificity can be accomplished using risk categories as a framework. A Risk Breakdown Structure (RBS) is a document that provides a list of several categories and subcategories within which a typical project may experience risks [5-6]. A risk manager uses it to better manage risks and familiarize himself with elements common to a typical project [7-8]. Figure 1 shows a graphic description of the RBS that appears regularly in the PMI PMBOK Guide.

Many tools and techniques have emerged to help project managers predict and control structural risks during the life of a project. In [9], the possibility of using fuzzy DEMATEL, based on the PMBOK standard, was explored to rate the project risks from most to least significant. In [10], a risk assessment method for construction projects was presented, based on MCDM methodologies such as Grey TOPSIS and COPRAS-G. The ELECTRE method was used in [11] to classify the risks incurred throughout the tunneling process for the Tehran metro project. In [12], the Analytic Network Process (ANP) was presented to manage the interrelationships that exist between risk-related components in multinational construction projects. The ANP method's ranking was used as an input to a decision support tool and depended on it through the bidding phase. In [13], the significance of risk rating in megaprojects was investigated using fuzzy compromise software methods, such as TOPSIS, VIKOR, and LINMAP, and three MADM algorithms, to analyze data in a fuzzy setting. In addition, a new fuzzy VIKOR approach was proposed to help managers better deal with the risks associated with large projects. In [14], high risks in Iran's onshore gas refinery plants were prioritized using fuzzy TOPSIS and fuzzy LINMAP algorithms, with fuzzy LINMAP being more effective. In [15], a formal method was developed for qualitative risk assessment based on a hierarchical risk breakdown structure. An applicable fuzzy MCDM was presented in [16] as a means to identify and simultaneously prioritize project hazards within an EPC project. In [17], a fuzzy MCDM method was used to perform an in-depth risk assessment for a building project in a metropolitan area. Consistent Fuzzy Preference Relations (CFPR) were used to quantify the relative influence of 20 specified risk variables on the success of the project. Additionally, an approach known as Fuzzy Multiple Attributes Direct Rating (FMADR) was used to evaluate the possibility of the occurrence of various risk factors. In [18], the most significant risk factors in a building project were arranged in a hierarchical structure, using a modified logical MCDM with fuzzy logic to choose an efficient risk factor.

This study combined fuzzy logic with the Grey theory. In most cases, the risks associated with a project depend on each other, and there is the possibility of some degree of interaction between them. As a result, the DEMATEL approach was used to investigate the complex interconnections between the various risk categories. Another reason for adopting the Grey system theory is that it makes it easier to assess human opinions. This study proposes the Fuzzy Grey DEMATEL (FGDEMATEL) approach to help risk managers in the Iraqi construction industry prioritize various types of project risks.

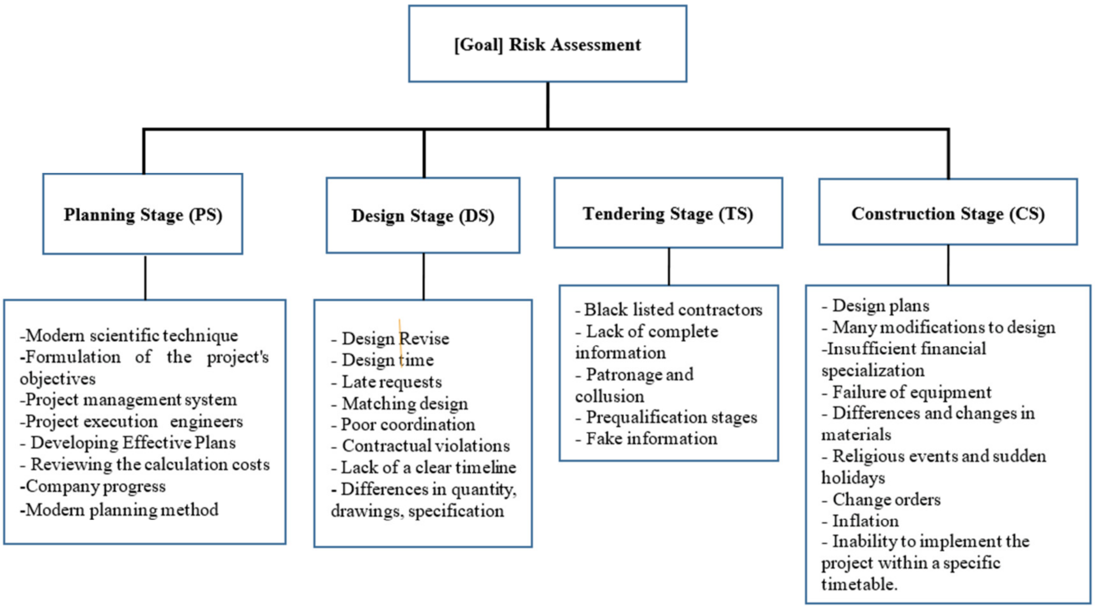

Fig. 1. Risk Breakdown Structure (RBS)

II. RESEARCH METHODOLOGY

The steps of the proposed method are summarized as:

- Identify structural risks that occurred in specific finished construction projects across all stages of their lifecycle by assessing periodic updates on projects from 2019-2022, in addition to consulting with industry experts.
- Distribute a questionnaire on risks occurring at each stage with a five-point linguistic rating scale to identify the influence of each risk on the others.
- Determine the fuzzy weights of the expert's importance based on his self-evaluation of his level of expertise in terms of his knowledge and experience.
- Apply the FGDEMATEL method to these risks.

III. RISK RATING

A. Establishing an Expert Group

This team consists of specialists and experts with specific expertise and experience in project management to identify the primary kinds of project risks, considering the RBS, as described in the fourth edition of the PMBOK Guide.

B. Determine the Fuzzy Weights of Experts

Each expert p has a fuzzy established weight of importance $\tilde{W}p$ (experts' relative significance weight) based on his self-evaluation of his level of expertise in terms of knowledge and experience. A 5-point scale questionnaire, shown in Table I, was used to determine the relative significance weights ($\tilde{W}p$) of the experts using a self-assessing method [16], based on their previous experience and understanding of working on projects.

TABLE I. EXPERTS' RELATIVE SIGNIFICANCE WEIGHT ($\tilde{W}P$) [16]

Lingual variables	Fuzzy number
Very Small (VS)	(0, 0.1, 0.3)
Small (L)	(0.1, 0.3, 0.5)
Moderate (M)	(0.3, 0.5, 0.7)
Large (L)	(0.5, 0.7, 0.9)
Very Large (VL)	(0.7, 0.9, 1)

C. Representation of Grey Numbers

The evaluation criteria were established, and a Grey linguistic scale was constructed to represent more accurately the uncertainties of human assessments. The use of a 5-point scale for the questionnaire allows for calculating both the linguistic scale and the related Grey values. To measure the interrelations between risks using a 5-point linguistic classification system that reflects the influence of any risk on the others, a questionnaire was distributed to the experts, in addition to a matrix containing linguistic scores. In place of linguistic information, a Grey-scale linguistic representation employs Grey values to change the effect scores of lingual data in the initial relation matrix to produce a matrix with Grey numbers. The influence scores of linguistic information in the initial relation matrix are replaced by the Grey values, as shown in Table II [16, 19].

TABLE II. REPRESENTATION OF GRAY NUMBERS AND LINGUISTIC SCORES [16, 19]

lingual expression	Impact score	Grey number
No influence	0	[0, 0]
lower influence	1	[0,0.25]
Moderate influence	2	[0.25, 0.5]
large influence	3	[0.5, 0.75]
Very large influence	4	[0.75,1]

D. Convert Gray Numbers to Crisp Values

Using (1)-(5) a matrix with crisp values was created. Grey aggregation methods are required to arrive at a clear number. This study employed a modified version of the de-fuzzification approach known as Conversion of Fuzzy data into Crisp Scores (CFCS) to eliminate fuzziness [20-21]. The Grey number for an expert *p*, who will assess the effect that a risk *i* has on a risk *j*, is denoted by the sign $\otimes X_{ij}^{p}$. The higher and lesser Grey values of the Grey number $\otimes X_{ij}^{p}$ are identified by the notations $\otimes \overline{X_{ij}^{p}}$ and $\otimes \underline{X}_{ij}^{p}$ as: $\otimes X_{ij}^{p} = [\otimes \underline{X}_{ij}^{p}, \otimes \overline{X_{ij}^{p}}]$. The modified CFCS method consists of three stages:

- Normalization:

$$\tilde{\underline{X}}_{ij}^{p} = \left(\underline{X}_{ij}^{p} - min_j \underline{X}_{ij}^{p}\right) / \Delta_{min}^{max} \quad (1)$$

$$\tilde{\overline{X_{ij}^{p}}} = \left(\overline{X_{ij}^{p}} - min_j \overline{X_{ij}^{p}}\right) / \Delta_{min}^{max} \quad (2)$$

$$\Delta_{min}^{max} = max_j \overline{X_{ij}^{p}} - min_j \underline{X}_{ij}^{p} \quad (3)$$

- The total normalized crisp value is calculated by:

$$Y_{ij}^{p} = \frac{\left(\underline{x}_{ij}^{p}\left(1-\tilde{\underline{x}}_{ij}^{p}\right)+\left(\tilde{\overline{x_{ij}^{p}}} \times \tilde{\overline{x_{ij}^{p}}}\right)\right)}{\left(1-\tilde{\underline{x}}_{ij}^{p} + \tilde{\overline{x_{ij}^{p}}}\right)} \quad (4)$$

- Determine crisp value:

$$Z_{ij}^{p} = min_j \underline{X}_{ij}^{p} + Y_{ij}^{p} \quad \Delta_{min}^{max} \quad (5)$$

E. Determine the Aggregated Opinion of the Experts

Equation (6) is used to acquire the aggregated opinion of the *n* experts to evaluate the influence that risk *i* has on risk *j*. This is because each expert possesses his own unique fuzzy importance weight. $\tilde{a}_{ij}$ is the aggregated fuzzy value of the influence that risk *i* has on risk *j*, and $\tilde{W}p$ is the fuzzy important weight that expert *p* assigns to the influence. The calculation of (6) needs the implementation of the basic laws of fuzzy functioning in the ending. Equation (7) is used to obtain an explicit evaluation of $\tilde{a}_{ij}$, which is depicted by $\tilde{a}_{ij}(a_1, a_2, a_3)$, and Z_{ij}^{p} describes the crisp value of risk *i* on risk *j* measured by expert *p*.

$$\tilde{a}_{ij} = \frac{\sum_{p=1}^{n} \tilde{W}p \, z_{ij}^{p}}{\sum_{p=1}^{n} \tilde{W}p} \quad (6)$$

$$a_{ij} = \frac{(a_1 + a_2 + a_3)}{3} \quad (7)$$

F. Applying the DEMATEL Approach

The method's steps are outlined in [22-23].

- The direct relationship matrix has to be created. A pairwise analysis of criteria performed by an expert team generates the A(*n*×*n*) matrix, where each entry in the matrix a_{ij} reflects the influence value of factor *i* on factor *j*. The influence of *i* on *j* is reflected in how a change in one criterion (factor) *i* can affect another factor *j*.
- Normalization of the direct-relation matrix using:

$$X = k \times A \quad (8)$$

$$k = \frac{1}{max \sum_{j=1}^{n} aij}, \quad 1 \le i \le n \quad (9)$$

- The following equation should provide the whole relation matrix, where *I* is the identity matrix,

$$T = (I - X) - 1 \quad (10)$$

- The system produces a causal diagram. When applied to matrix T, the following equations determine the sum of rows (D) and the sum of columns (R). A factor's D value is the extent to which it affects other variables. The value of the factor's R indicates the effect it has on other variables [24].

$$T = [t_{ij}]_{n\times n} \quad i, j = 1,2, \dots, n \quad (11)$$

$$R = [\sum_{i=1}^{n} tij]_{1\times n} = [t_{.j}]_{1\times n} \quad (12)$$

$$D = [\sum_{j=1}^{n} tij]_{1\times n} = [t_{i.}]_{1\times n} \quad (13)$$

- On the horizontal axis, D+R denotes the weight given to each criterion. D-R stands for relation in mathematics. The condition belongs to the group of causes if and only if (D-R) > 0. If (D-R) is less than zero, then the parameter belongs to the effect group. The success or failure of the entire system depends on the actions of the cause factors. In addition, more focus needs to be given to cause group criteria. Factors in the effect group are unsuitable and likely to be easily influenced by others, making them a significant success element [25].

IV. APPLICATION

The proposed method was applied in an Iraqi construction project in Baghdad at the Shanashil residential complex during the project's implementation stages, holder of Investment Permit No. 79A of 2019. The project's location is south of Daura, on the new Daura-Youssafiyah highway, which is 17 km away from the two-floor bridge within the city of Jawhara, Baghdad. It contains 777 residential horizontal units and is divided into 5 residential areas ranging from 160 to 480 m. The four basic stages were adopted, namely Planning, Tender, Design, and Construction phases, during which the construction risks were assessed and diagnosed by seven specialists and experts. The following steps were applied:

- Classifying major risks to the project: PMBOK, fourth edition RBS, as shown in Figure 1.
- Assembled the professional team of experts: The seven members of the team had extensive experience in managing construction projects for Iraqi enterprises that operate on a project basis, and they were asked to fill out the surveys. Table III shows the experts' relative importance weights.
- Establish causal connections: The experts were asked to fill out questionnaires that used the five-point linguistic rating system to investigate the correlation between risks. This scale shows how one risk affects another. Table IV shows the thoughts of the sixth expert.

TABLE III. RELATED SIGNIFICANCE WEIGHT OF EXPERT $(\tilde{W} P)$

Lingual variables	Fuzzy number
Expert 1,2,3	Small (L)
Expert 4	large (H)
Experts 5,7	Moderate (M)
Expert 6	Very large (VH)
Expert 1,2,3	Small (L)

TABLE IV. SIXTH PROFESSIONAL'S ASSESSMENTS OF RELATED RISKS

Phase	Planning	Tendering	Design	Construction
Planning	0	3	2	3
Tendering	2	0	2	2
Design	3	2	0	3
Construction	3	2	3	0

- The language data are switched out for a Grey-scale version. Grey numbers were substituted for the influence scores of language data in the initial relation matrix Table IV, and (1)-(5) were used to obtain the crisp values. Tables V and VI are shown below. Since each expert has his own unique fuzzy importance weight, (6) can be applied with $n = 7$, as in Table VII, to get an averaged view of how the experts feel about the impact of risk i on risk j.

TABLE V. GRAY EQUIVALENTS OF THE 6TH EXPERT'S OPINIONS OF THE INTERRELATIONSHIP BETWEEN RISKS

Phase	Planning	Tendering	Design	Construction
Planning	[0, 0]	[0.5 0.75]	[0.25,0.5]	[0.5, 0.75]
Tendering	[0.25,0.5]	[0, 0]	[0.25,0.5]	[0.25, 0. 5]
Design	[0.5, 0.75]	[0.25,0.5]	[0, 0]	[0.5, 0.75]
Construction	[0.5, 0.75]	[0.25,0 5]	[0.5,0.75]	[0, 0]

TABLE VI. THE 6TH EXPERT'S CRISP ASSESSMENTS OF THE RISKS' INTERDEPENDENCE

Phase	Planning	Tendering	Design	Construction
Planning	0	0.6875	0.3750	0.6875
Tendering	0.4167	0	0.4167	0.4167
Design	0.6875	0.3750	0	0.6875
Construction	0.6875	0.3750	0.6875	0

TABLE VII. THE MEAN FUZZY WEIGHTS OF ALL EXPERTS' OPINIONS IN A MATRIX

Phase	Planning	Tendering	Design	Construction
Planning	0	0.6959	0.6625	0.9063
Tendering	0.7958	0	0.7405	0.7764
Design	0.5492	0.5572	0	0.8465
Construction	0.7586	0.5136	0.8718	0

- Compile a cause-and-effect diagram: For the purposes of DEMATEL, Table VII was used as the direct relation matrix. Tables VIII and IX display the computed total relation matrix alongside the values for D+R and D-R.

TABLE VIII. TOTAL RELATION MATRIX

Phase	Planning	Tendering	Design	Construction
Planning	3.3653	3.1148	3.8861	4.1787
Tendering	3.6807	2.9447	3.9599	4.2161
Design	3.1864	2.7664	3.2520	3.7337
Construction	3.4504	2.9406	3.7569	3.7145

TABLE IX. VALUES OF D+R AND D-R

Phase	D-R rank	D-R	D+R rank	D+R
Planning	3	-1.9165	4	26.5679
Tendering	4	-1.9806	2	28.2277
Design	2	0.8621	3	27.7934
Construction	1	3.0350	1	29.7054

Figure 2 shows the acquired causal diagram after mapping the dataset of (D+R, D-R), which displays the ranking and relation between stages as shown above.

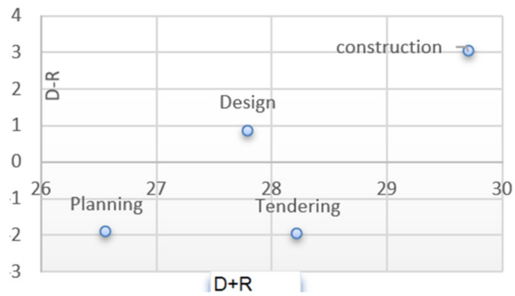

Fig. 2. The causal diagram.

V. FINDINGS AND DISCUSSION

Planning and Tendering risks are classified as part of the effect group in both the causal diagram shown in Figure 2, and the total relation matrices shown in Tables VIII and IX. This is because the D-R scores for these risks are negative and they tend to be easily influenced by other risks. On the contrary, risks associated with Design and Construction are classified as part of the cause group. This is because both categories have positive scores on the D-R value scale, indicating that they are significant risks that have the potential to affect the overall success of the project. Construction, Planning, Tendering, and Design risk values were also examined in the D+R ranking. Construction ranks first in terms of relative importance compared to other hazards. It is necessary to focus on both the D+R and D-R rankings to arrive at a DEMATEL ranking that makes sense. First, the D-R ranking and risks that are part of the cause group are considered. Specifically their D-R values must be positive. Next, the D+R ranking is examined. In this instance, the Construction and Design risks are members of the cause group and rank first and second in importance. However, in the D+R ranking, they are in ranks 1 and 3, respectively. As a cause group is of the utmost significance, and the disparity between the risk values associated with Construction and Design poses a significant challenge. The risks associated with Construction come at the top, followed by the Design concerns. The D-R ranking does not help with the third and fourth positions, because both are effectively in the same group with negative D-R values, and the difference between their respective values within this group is insignificant. Therefore, the Tendering risk is the third important risk category, while the Planning risk is the fourth, according to the D+R ranking. The following is the final order in risk classification: 1. Construction risks, 2. Design risks, 3. Tendering risks, and 4. Planning risks.

VI. CONCLUSION

This study provides useful insights, especially for risk managers. Construction and Design risks, which fall under the umbrella of cause group risks, are extremely important to consider. According to the findings, the technology used in the project should be seen as one of the main sources of risk and should be carefully chosen to reduce the effects of Construction risks. It is also shown that Design risks are substantial and can bring about many drawbacks for effective project accomplishment, such as a lack of a clear timeline and poor coordination, even though these components are outside the purview of the authorization of a project manager but cause a wide scope of issues, and administrators should be attentive to lessen their adverse effects. Due to the numerous complexities of modern projects, companies must be able to prioritize project risks to complete more productive projects.

This study established FGDEMATEL to account for the language ambiguity and uncertainty inherent in human judgment, as well as the interrelationships between the various project risk categories based on the RBS of the PMBOK Guide. Based on the results, managers in Iraqi project-based construction companies need to pay more attention to the Construction risk category than they already do. This is monitored from the Design and Tendering risk categories, as well as the Planning risk category. To obtain more precise and unique results that would be more relevant for specific project types, a future study should be carried out in other industry sectors, such as industrial, IT, and research. The proposed framework allows the user to examine the project at various stages, identify uncertainties, and assess risks associated with specific parties. It also allows the user to add an unlimited number of unpredictable risks to the project and see how they affect time or cost. To explore the most significant stages and provide information on the highest-order risks, this study investigated structural risk assessment while investigating uncertainties and ambiguities utilizing fuzzy logic, combining it with the Grey system and DEMATEL methodology.

The results of this study demonstrate that the proposed framework can be used to predict most risk factors and that, with careful planning, the project can also determine the effect of a risk factor on time and cost. There is still a great problem with risks in construction projects. Knowing the cause-and-effect groups allows us to clearly indicate how controlling one factor in one phase can affect another factor in another phase. This, in turn, helps reduce delay or cost by speculating and knowing the predetermined relationships through the DEMATEL approach, which is how the proposed framework can assess risks and create interrelationships between them.

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