A Framework for Construction-related Risks by integrating the Fuzzy Grey Comprehensive Evaluation Method (FGCE)

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Received: 13 June 2024 | Revised: 3 July 2024 | Accepted: 11 July 2024

 DOI: https://doi.org/10.48084/etasr.8129

ABSTRACT

There are five basic phases for construction projects: planning, design, tendering, construction and maintenance. The risks of each phase have an impact on time, cost, and quality. In this paper, the tendering phase of the residential complex project was investigated as a case study, and the creation of a fuzzy and grey correlation analysis model was examined using a fuzzy theory and a grey correlation theory to dispel the professional judgment around the project phase. Creating a comparison and a reference matrix based on grey theory and/by examining factors and their impact on duration, cost, and quality separately, gives the construction investors a scientific, direct, flexible, and adaptable technique to assess project risks. The described method categorized the tendering phase risk based on the three project determinants: duration, cost, and quality. The correlation degree is greater than 0.5, hence construction project duration risk is almost nonexistent. The project investor must also investigate risk assumption, reduction, diversion, and evasion tactics to handle cost and quality risks, which are between 0.2 and 0.5. This suggests that tender phase issues do not affect project length but do affect cost and quality, requiring attention and action.

Keywords-grey correlation theory; risk assessment; fuzzy set theory; construction projects

I. INTRODUCTION

The construction industry in Iraq has emerged as a major economic and social force, contributing greatly to the country's progress as both the quantity and scale of construction projects continue to rise. The building projects also entail more complicated impact considerations. The most discussed theoretical and practical issue, nonetheless, was the construction project risk assessment and risk management [1-4], which laid forth a plan to fix Iraq's problems using project risk assessment theory as a foundation. Authors in [5-7] proposed a complete system for evaluating projects' risks that incorporates fuzzy logic, grey theory, and data development analysis. The use of this evaluation method, however, remains unknown. So, to address this knowledge void, this research presents a holistic model that incorporates fuzzy logic and grey relational theory to evaluate building projects. The most common form of fuzzy number in fuzzy theory is the triangle fuzzy number (TFN) because of its size comparison and all-encompassing operating rule [8, 9]. This study incorporates TFNs into the selection of redevelopment schemes through the deployment of the grey correlation approach. Fuzzy indexes are converted into TFNs to calculate the grey correlation coefficient, as fuzzy language already exists in the index used to evaluate brownfield redevelopment. This research then employs the TFN operation and sorting procedure to derive the final fuzzy correlation coefficient by combining the TFN formula with the grey correlation coefficient. A thorough evaluation model is established to select the appropriate scheme comparing the solutions provided by each scheme's fuzzy correlation coefficient. Several researchers have proposed grey correlation to choose the best scheme for a certain situation. A lot of people have employed it to figure out how different parts of a system interact with each other [9]. Given the possibility to convert the qualitative description into numerical values, this method is even more helpful in selecting optimum schemes. Consequently, calculating grey correlations provides a means of determining qualitative indicators. However, this situation makes it challenging for qualitative indicators to comply with fuzzy characteristics [10, 11]. To solve the ratio of relative distance of two fuzzy numbers and identify the determined value of the correlation coefficient, researchers from the fields of engineering and management sciences introduced fuzzy theory into grey correlation analysis and converted the calculation of the grey correlation coefficient [12, 13]. Considering this, this paper analyzes five project phases, which are considered to have a significant impact on the construction project's risks, assessing their impact on duration, cost, and quality.

II. RESEARCH METHOLOGY

The methodology steps are summarized below:

- Initially, a basic phase of the construction project was identified with six factors across the tendering phase. The model was implemented at the Shanashel Baghdad Residential Complex. The impact of the factors for the tendering phase on the determinants of the three projects, namely the duration, cost, and quality, has been studied and the steps of this model can be restored at each phase of the other basic project's stages.
- A questionnaire on risk impact with a five point linguistic rating scale was distributed to experts to identify the influence of each risk on cost, duration, quality. After that, the risk factor was assessed by six of the experts using linguistic evaluation would be converted into TFN triangular fuzzy numbers. After getting TFN values, it would be converted into crisp values.
- The crisp values of TFN were used to build the comparative matrix for the bidding stage, then a reference matrix was created, which indicates to optimal numbers in TFN scale.
- The grey correlation ratio was figured out.
- The degree of grey correlation was assessed.
- The degrees of correlation were ranked and analyzed.

III. MODEL DEVELOPMENT FOR FUZZY AND GREY COMPREHENSIVE EVALUATION

A. Applying Fuzzy Theory

1) Transformation of Assessment Language into Triangular Fuzzy Numbers

The method of converting assessment language into fuzzy numbers is crucial for measuring the evaluation of professionals' subjective judgment using fuzzy theory. Most people utilize triangular, irregular trapezoidal, and normal fuzzy numbers. This paper deploys triangular fuzzy numbers to express professional judgement. Specialist judgments are translated through quantitative language evaluation to triangle fuzzy numbers utilizing the characteristic function: triangle fuzzy number A= (a, b, c) [14].

$$A(x)=\frac{1}{2(1+U)}a+\frac{(U+2UV+V)}{2(1+U)(1+V)}b+\frac{1}{2(1+V)}c \quad (1)$$

In (1) $U=\frac{b}{a}$,$V=\frac{b}{c}$ and a, b, c represent triangular fuzzy numbers in TFN= (a, b, c) also A(x) represents the crisp value of TFN. The matrix is then obtained from real numbers representing the influence for each risk factor in each stage.

B. Applying the Grey Correlation and the Fuzzy Theory

1) Building a Matrix for Comparison

Assume that n represents evaluation indexes, denoted as x_1, x_2, x_3, …, x_n, making up the project evaluation, and that the jth evaluation index is represented by x_j. Given that m influences factors' impact on each evaluation index, it can describe the jth evaluation index as $x_i(t)=\{x_j(1), x_j(2), x_j(3),\ldots, x_j(n)\}$, representing the specialists' evaluation of the jth index, while its clear number can be obtained by (2). The method discussed earlier can be used to build a comparative matrix $x_j(t)$ in (2), which displays n evaluation indices.

$$x_j(t)=\begin{Bmatrix} x_1\\ x_2\\ x_3\\ .\\ .\\ x_n \end{Bmatrix}=\begin{Bmatrix} x_1(1) & x_1(2) & x_1(3) \ldots\ldots x_1(m)\\ x_2(1) & x_2(2) & x_2(3) \ldots\ldots x_2(m)\\ x_3(1) & x_3(2) & x_3(3) \ldots\ldots x_3(m)\\ & & .\\ & & .\\ x_n(1) & x_n(2) & x_n(3) \ldots\ldots x_n(m) \end{Bmatrix} \quad (2)$$

2) Creating a Reference for Comparison

The reference matrix $x_0(t)$ uses the best possible value as its starting point. According to [16], it can be an optimal value for a 5-point scale depending on its range. If it is between 0 to 1, then the reference matrix value is 1 and if the scale is between 0 to 10, then its value is 10, as shown in (3):

$$x_0(t)=\begin{Bmatrix} 10 & 10 & 10 \ldots\ldots 10\\ 10 & 10 & 10 \ldots\ldots 10\\ & & .\\ & & .\\ 10 & 10 & 10 \ldots\ldots 10 \end{Bmatrix} \quad (3)$$

3) Figuring out the Grey Correlation Ratio

To determine the level of correlation between the reference evaluation and the actual evaluation, the gray correlation theory is deployed according to [16]:

$$\zeta(x_0(t),x_j(t))=\frac{\min_j \min_t |x_0(t)-x_j(t)| \zeta \max_j \max_t |x_0(t)-x_j(t)|}{|x_0(t)-x_j(t)| \zeta \max_j \max_t |x_0(t)-x_j(t)|} \quad (4)$$

Usually ζ is the ratio of resolution taken as 0.5 and it must belong to (0, 1).

4) Assessing the Degree of Grey Correlation

The effect of each influence factor on each assessment metric is unique. Thus, let us pretend that a certain influencing element has a weight λt in an evaluation index and $\gamma (x_0, x_j)$ is the grey correlation degree of the jth risk evaluation index. Then, the reference evaluation result can be calculated by [17]:

$$\gamma (x_0, x_j)=\sum_{t=1}^{m} \lambda t\{\zeta (x_0(t),x_j(t))\} \quad (5)$$

In (5), $\sum_{t=1}^{m} \lambda t=1$ and this weight index is found for each stage and for each factor by using the AHP method.

5) Rank and Analyze the Degrees of Correlation

A higher correlation degree indicates a closer relationship with the reference evaluation result and greater risk, whereas a lower correlation degree indicates lower risk. When $\gamma \geq 0.5$, the index is of low-risk and nearly does not affect construction project completion. If the index is ($0.2 \leq \gamma < 0.5$), it may indicate possible risks or other issues that require attention. An index $\gamma \leq 0.2$ indicates considerable risk, prompting investors to reevaluate their investment [18].

IV. CASE STUDY

The model was applied to the tendering phase of the Shanasheel Baghdad residential complex project and six experts were called in to assess the risk of the tendering phase on the basis of the methodology mentioned above. The model was implemented for the purpose of assessing the risks of the residential project by identifying and finding the impact of risk factors on the project's main outputs, namely the duration, cost and quality.

- Three distinct plans will be considered to evaluate the complete assessment model. A specific instance of a scheme is project duration (S1), project cost (S2), and project quality (S3). The main index is the stage of project, and the sub index represents the sub factors of the stage.
- The bidding stage consists of six sub factors, as shown in Table I. Each factor has a certain impact on duration, cost and quality, and will be evaluated for the single phase using the linguistic assessment depicted in Table II. Table III indicates the expert's assessment regarding the impact of each factor on project determinants (S1, S2, S3). The factor is then evaluated six times by six experts using linguistic evaluation, and then converted into TFN triangular fuzzy numbers, as evidenced in Table IV. Table IV is repeated for each of the other sub factors, then the aggregation of each triangular fuzzy number for all sub- factors (Bidding Stage) is found, as shown in Table V.

TABLE I. FACTORS OF BIDDING STAGE

Factors	Abbreviation
Blacklisted competitive bidders (contractors)	B1
Lack of complete information on the bidder, including financial, technical, and equipment information resulting in incorrect selection of bidders	B2
Patronage and Collusion lead to the award of tenders to some of the sponsors (corruption)	B3
Misunderstood the task of working fully by bidders.	B4
Blacklisted competitive bidders (contractors)	B5
Lack of complete information on the bidder, including financial, technical, and equipment information resulting in incorrect selection of bidders	B6

TABLE II. TFN MEMBERSHIP FUNCTION

Language terms	Abbreviation	TFN
Very High	VH	(8,9,10)
High	H	(6,7,8)
Medium	M	(4,5,6)
Low	L	(2,3,4)
Very Low	VL	(0,1,2)

TABLE III. ASSESSMENT OF LANGUAGE USAGE IN EVALUATION (EXPERTS) [BIDDING STAGE]

Sub-factor risk influence	Sub - factor B1	Sub - factor B2	Sub - factor B3	Sub - factor B4	Sub - factor B5	Sub - factor B6
S1	VL	H	H	VH	L	VL
S2	VL	H	M	H	M	L
S3	M	M	L	M	VL	M

TABLE IV. EXPERTS' ASSESSMENT FOR SUB-FACTOR B1 (TFN)

B1	VL	L	M	H	VH
1	(8.5,10,10)	(6.8,8.4,9.3)	(3.7,5.6,7.8)	(1.3,3.3,4.5)	(0,1.2,3.5)
2	(8.7,9,10)	(6.7, 8.4, 9.4)	(3.7, 5.4, 7.5)	(1.3,3.6,4.6)	(0, 1.3, 3.3)
3	(8.7,9,10)	(6.7, 8.6, 9.3)	(3.6, 5.6, 7.7)	(1.3,3.4,4.7)	(0, 1.2, 3.3)
4	(8.6,9,10)	(6.9, 8.5, 9.5)	(3.6, 5.5, 7.7)	(1.3,3.6,4.4)	(0, 1.2, 3.5)
5	(8.5,10,10)	(6.6, 8.6, 9.3)	(3.6, 5.6, 7.4)	(1.5,3.5,4.4)	(0, 1.3, 3.4)
6	(8.7,9,10)	(6.8, 8.5, 9.3)	(3.6, 5.6, 7.8)	(1.2,3.5,4.6)	(0, 1.2, 3.3)
Σ	(8.6,9.3,10)	(6.7,8.5,9.4)	(3.6, 5.6, 7.7)	(1.3,3.5,4.5)	(0, 1.2, 3.4)

TABLE V. THE AGGREGATION OF TRIANGULAR FUZZY NUMBER FOR ALL SUB- FACTORS (BIDDING STAGE)

Factor	VL	L	M	H	VH
B1	(8.6,9.3,10)	(6.8, 8.5, 9.4)	(3.6,5.6, 7.7)	(1.3,3.3,4.5)	(0,1.2,3.4)
B2	(8.4,9.2,10)	(6.75,8.5,9.4)	(3.3,5.7, 7.7)	(1.3,3.5,4.5)	(0, 1.3, 3.5)
B3	(8.4,9.1,10)	(6.4,8.5,9.5)	(3.5,5.6, 7.7)	(1.4,3.3,4.5)	(0, 1.3, 3.5)
B4	(8.8,9.5,10)	(6.8, 8.7, 9.5)	(3.4,5.7, 7.8)	(1.5,3.3,4.7)	(0, 1.5, 3.7)
B5	(8.7,9.4,10)	(6.4,8.5,9.3)	(3.6,5.6, 7.7)	(1.3,3.5,4.5)	(0, 1.2, 3.4)
B6	(8.7,9,10)	(6.6, 8.5, 9.2)	(3.6,5.6, 7.8)	(1.2,3.5,4.6)	(0, 1.2, 3.3)

- Crisp numbers of risk influence factors obtained by applying the equation (1) as shown in Table VI.

TABLE VI. THE TRIANGLE FUZZY NUMBERS AND THEIR CORRESPONDING CLEAR NUMBERS FOR SUB-FACTORS (BIDDING STAGE)

Experts 'assessment	VL	L	M	H	VH
B1	9.3	8.4	5.8	3.4	1.2
B2	9.5	8.2	5.7	3.5	1.3
B3	9.4	8.4	5.7	3.4	1.4
B4	9.5	8.5	5.9	3.4	1.5
B5	9.7	8.3	5.8	3.5	1.3
B6	9.3	8.4	5.8	3.4	1.2

- Tables V and VI provide the data which were used to build the comparative matrix for the bidding stage, as observed in (6), then a reference matrix which indicates the optimal numbers in TFN scale that are between (0-10) was created. The reference matrix is demonstrated in (7):

$$x_j(t)=\begin{Bmatrix} 9.3 & 3.5 & 3.4 & 1.5 & 8.3 & 9.3 \\ 9.3 & 3.5 & 5.7 & 3.4 & 5.8 & 8.4 \\ 5.8 & 5.7 & 8.4 & 5.9 & 9.7 & 5.8 \end{Bmatrix} \quad (6)$$

$$x_0(t)=\begin{Bmatrix} 10 & 10 & 10 & 10 & 10 & 10 \\ 10 & 10 & 10 & 10 & 10 & 10 \\ 10 & 10 & 10 & 10 & 10 & 10 \end{Bmatrix} \quad (7)$$

- For each assessment index, the degree of correlation between the actual and reference evaluation results is determined at ζ =0.5 using (4).

$$\zeta(x_0(t),x_j(t)) =$$

$$\begin{Bmatrix} 0.24 & 0.48 & 0.48 & 0.71 & 0.27 & 0.24 \\ 0.24 & 0.48 & 0.35 & 0.48 & 0.35 & 0.35 \\ 0.35 & 0.48 & 0.26 & 0.34 & 0.24 & 0.26 \end{Bmatrix} \quad (8)$$

- The weight of each risk influence element λt in each risk index is evaluated by utilizing AHP analysis, and the correlation degree γ (x_0, x_i) for each evaluation index is calculated employing (5), as indicated in Table VII.

TABLE VII. THE CORRELATION DEGREE AMONG ALL EVALUATION INDICTORS (BIDDING STAGE)

Risk evaluation index	The correlation degree
Duration	0.55
Cost	0.45
Quality	0.36

V. RESULTS AND DISSCUSSION

In an attempt to create a thorough model for assessing construction project risks, this paper uses TFNs to translate qualitative indexes into quantitative data, combining fuzzy theory with the grey correlation analysis method. Deploying TFN's sorting method and mathematical operations, this study evaluates the six bidding stage criteria for their effect on the project determinates (time, cost, and quality). It addresses the problem of treating qualitative values as fixed values by providing an alternative way. Applying the proposed method to various real-life scenarios is more convenient. To handle fuzzy data more effectively, this approach is consistent and has a sequence of processes. The most common difficulty in construction projects is that of developing a plan that may benefit all stakeholders in evaluating risks. Table VII shows that the risk order is duration, cost, and quality. The duration risk is almost nonexistent in connection to the construction project because the correlation degree is higher than 0.5. In addition, as both cost and quality risks fall within the range of 0.2 to 0.5, the project investor needs to conduct more studies to manage these risks using strategies, such as risk assumption, reduction, diversion, or evasion. This means that the factors of the tender phase do not have a significant impact on the duration of the project, and that they have a clear impact on cost and quality requiring attention and appropriate action.

VI. CONCLUSION

By shifting experts' opinions from quantitative language evaluation to qualitative data evaluation, a model based on fuzzy and grey correlation analysis can be deployed to assess construction project risks. This approach not only allows experts' initiative to shine through, but it also significantly improves the evaluation's objectivity. Investors in construction projects gain a fresh viewpoint and a tool to make the best choice, and the evaluation's reliability and accuracy are boosted. A convenient and thorough assessment of building sites was provided by this all-inclusive evaluation index. To effectively handle risk assessment, policymakers were benefited from utilizing established indices and methodologies. In case policymakers wish to improve urban infrastructure while simultaneously increasing economic growth, this article will show them how to accomplish this in a sustainable way.

Possible future study could involve applying a comprehensive evaluation model to various developing economies to identify risks in the remaining phases of the construction projects. Construction, public-private partnership, and urban infrastructure projects are just a few examples of the many types of projects that can benefit from the current study.

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