Variables Affecting Construction Cost Contingency: A Fuzzy Pairwise Methods Analysis

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Abstract

Contingency costs play an important role during the construction phase, as accurately estimating project contingency costs is one of the keys to successful project management. The improper use of contingency costs can lead to various problems. In determining contingency costs, practitioners have traditionally used a highly subjective approach. This study will discuss the weights of variables that influence the magnitude of contingency costs. The risk evaluation carried out focuses on risks related to project construction execution. The use of fuzzy logic with the weight risk analysis method is considered highly appropriate due to the many advantages of fuzzy logic analysis, which can help make risk analysis more objective. The study respondents consist of 12 experts from 6 reviewed construction projects. The analysis reveals that internal variables, such as Safety, Personnel, and Equipment and Material, have a greater impact on contingency costs compared to external variables. Safety ranks highest with a weight of 0.223, followed by Personnel at 0.209 and Equipment and Material at 0.171. External variables, including Natural and Social Variables, have lower weights of 0.101 and 0.073, respectively, indicating their smaller influence compared to internal factors.

Keywords: Risk, variable, weight

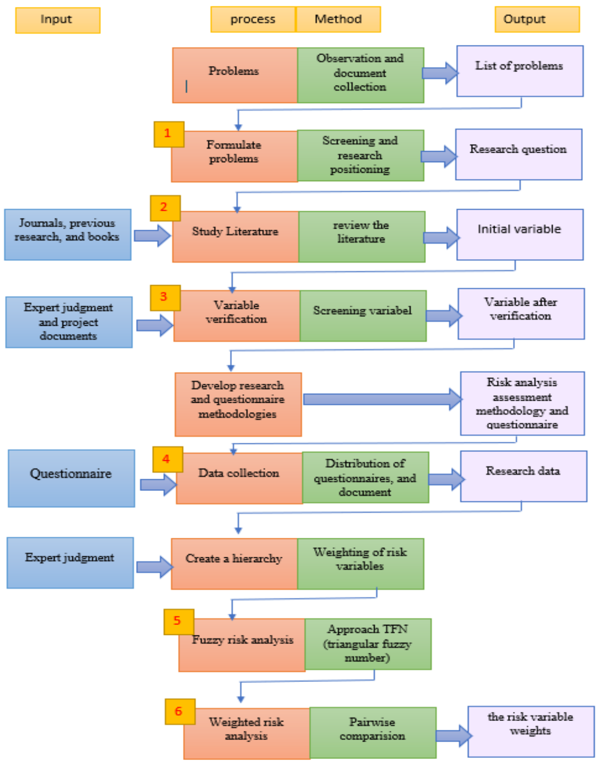
Introduction

A risk management plan plays an increasingly crucial role in the success of every project. An effective plan enables the project to address risks (both threats and opportunities) and provides timely and appropriate responses, thereby reducing losses or enhancing the benefits associated with those risks. The higher the complexity of a project, the greater the level of risk it carries in construction. These risks have a significant impact on the success of a construction project (pegiusa, 2022). Understanding the level of risk in a project indicates that risk responses and risk management plans need to be studied and controlled to redirect or mitigate the impact of those factors. According to Mak and David (2000), contingency costs refer to funds set aside as a reserve to address uncertainties and risks associated with construction projects. This step aims to optimize the use of contingency costs allocated for risk management.

The use of the fuzzy pairwise method in this study aims to minimize subjectivity when assessing project risks. As we know, contingency costs are influenced by the magnitude of risks in construction projects. This research is expected to provide a ranking of the risk variables that impact contingency costs. By identifying the most influential variables, construction practitioners can focus more on these variables during both the mitigation steps and risk management planning.

Methodology

The data collection stages that need to be carried out include identifying risk variables in the implementation of construction work that can be used for risk analysis through a literature review. Next, the risk variables are verified using expert judgment to select those relevant to the project conditions being reviewed. Finally, a questionnaire is developed for risk analysis, utilizing fuzzy probability and weighted risk analysis to determine the percentage of the project risk weight. The weighting analysis of risk variables in the implementation of high-rise building construction is carried out using the fuzzy method and pairwise comparison. The data analysis process begins by constructing a pairwise comparison matrix based on the respondents' questionnaire results, followed by calculating the weight of each variable, conducting a consistency test, and finally applying fuzzy calculations.



Research flow diagram
Source: author's processing (2024)

This study used a questionnaire distributed to 12 experts from 6 reviewed projects. The respondents include project managers, operational directors, technical directors, and chief directors from the companies involved in the research. The method employed involves conducting a literature review to identify initial variables. After identifying the variables, interviews are conducted using expert judgment to determine the relevance of these variables to the project under study. To ensure that the criteria used are appropriate for the conditions of the project under study, it is essential to screen the results of the literature review. This screening was carried out by three experts familiar with field issues: the Operational Director, Technical Director, and Chief Director from a construction company involved in the project. The screening results showed that all risk variables identified in the literature were relevant to the risk evaluation of the project. For instance, external risk variables (natural risks) were deemed relevant by all three experts in the context of the risk evaluation practices for the six reviewed projects, indicating their applicability to risk assessment in high-rise building projects. Subsequently, a questionnaire is developed using the fuzzy pairwise comparison method to determine the weight of influence for each variable.

Results and Discussion

Pairwise Comparison Matrix

The pairwise comparison matrix is organized based on the elements developed in this study for risk variables. According to Saaty (1994), the initial step in determining the priority ranking of elements is to construct pairwise comparisons. This involves establishing a scale for comparing the levels of importance. The scale of importance comparison table can be found in the figure 1. below:

Intensity of relative importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent judgments	When compromise is needed between two judgments

Figure 1. The scale of the importance comparison table
Source : Saaty (1994)

After obtaining the questionnaire results, they are converted into a pairwise comparison matrix. The steps for analyzing the Fuzzy Pairwise Comparison method based on the expert questionnaire results start by assigning values to the cells in the comparison matrix. If the first variable is considered more important (1), the cell is filled directly with the value indicated in the questionnaire. Conversely, if the second variable is more important (2), the value entered into the cell is 1/n of the questionnaire value. Responses are entered according to the positions of the rows and columns for each risk variable being compared, as shown in the table. Values from the questionnaire are only entered into cells above the diagonal red cells; cells below the diagonal red cells contain values of 1/n from the compared variables. For example: if response no. 1 indicates that Variable 1 or Variable A is considered more important with a weight of 5, then the value 5 is entered in the row for Personnel and the column for Technology Design. If response no. 3 indicates that Variable 2 or Variable B is considered more important with a weight of 8, then the value 1/n = 1/8 = 0.13 is entered in the row for Personnel and the column for Safety.

1.00	5.00	3.00	0.13	6.00	5.00	7.00
0.20	1.00	0.20	0.13	3.00	0.50	3.00
0.33	5.00	1.00	0.20	2.00	3.00	4.00
8.00	8.00	5.00	1.00	9.00	5.00	6.00
0.17	0.33	0.50	0.11	1.00	0.25	0.33
0.20	2.00	0.33	0.20	4.00	1.00	5.00
0.14	0.33	0.25	0.17	3.00	0.20	1.00
10.04	21.67	10.28	1.93	28.00	14.95	26.33

Figure 2. Pairwise comparison matrix
Source: Author (2024)

For all cells below the diagonal cell, fill in with =1/n in the opposite cell. For example, if the cell at the intersection of the Personnel row and Technology Design column contains 5, then the opposite cell below the diagonal red cell (Technology Design row and Personnel column) should be filled with 1/5 = 0.20. This process is repeated for all cells, and the sums for each column are calculated. The next step is to normalize the values to simplify them into decimal numbers ranging from 0 to 1, which indicate the relative impact of each variable. Normalization is done by comparing each value with the total value; this involves dividing each number in a column by the total of that column in the matrix. The weight values are then averaged from the Personnel column (1) to the Social column (1).

0.10	0.23	0.29	0.06	0.21	0.33	0.27	1.50
0.02	0.05	0.02	0.06	0.11	0.03	0.11	0.40
0.03	0.23	0.10	0.10	0.07	0.20	0.15	0.89
0.80	0.37	0.49	0.52	0.32	0.33	0.23	3.05
0.02	0.02	0.05	0.06	0.04	0.02	0.01	0.20
0.02	0.09	0.03	0.10	0.14	0.07	0.19	0.65
0.01	0.02	0.02	0.09	0.11	0.01	0.04	0.30
1.00	1.00	1.00	1.00	1.00	1.00	1.00	7.00

Figure 3. Normalization Matrix Table
Source: Author (2024)

The fuzzification graph below illustrates the membership function ranging from 0 to 1 for each Pairwise scale. For example, if a scale weighs 5, the TFN will be (3, 5, 7). Thus, based on the questionnaire results, comparisons are organized, and the pairwise comparison matrix is converted into a fuzzy comparison matrix by transforming the scale into TFN (triangular fuzzy numbers). Hence, the pairwise comparison matrix is converted using TFN.

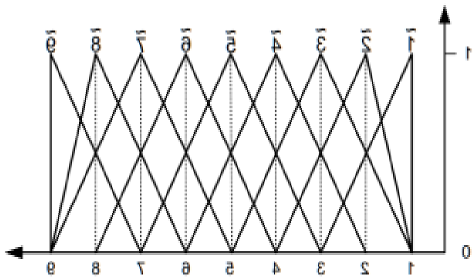


Figure 4. Fuzzification of the scale to TFN
Source : Mawariza (2023)

Integration of Pairwise Results from All Respondents

Finding the geometric mean of the respondents' assessments using the following techniques is required to derive a single final result from the evaluation of the nine respondents:

Where:
combined assessment (aw) = end
ai = the respondent's evaluation
i = Numerous responders

Following the acquisition of aw for every cell, a comparison matrix is created and the priority weight is subsequently looked up. An illustration of the procedure and findings from the average matrix of pairwise comparisons between the risk variables is shown below. The attachment shows the procedure and the pairwise comparison's geometric mean matrix result. Calculating the average pairwise comparison assessment findings between these variables yields the average pairwise comparison matrix assessment between risk variables.

The fuzzy pairwise comparison matrix for every respondent is provided below. The attached document shows the fuzzy pairwise comparison assessment matrix between the variables of the assessment findings on the questionnaire based on the weighting of the first respondent to the last one. An example of computing the average pairwise comparison between the criteria of all respondents is the average evaluation of risk variables, which may be determined from the nine comparison matrices.

	Personnel			design tech			quipment n material			safety			const. Technology			naturally			social		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
Personnel	1.00	1.00	1.00	1.01	1.66	2.70	0.61	1.22	2.37	0.50	0.83	1.47	0.92	1.91	3.32	1.22	2.62	4.39	1.95	3.95	6.05
design tech	0.37	0.60	0.99	1.00	1.00	1.00	0.27	0.43	0.81	0.33	0.67	1.20	0.70	1.33	2.66	0.48	0.87	1.62	1.35	2.66	4.48
equipment n materials	0.42	0.82	1.65	1.24	2.31	3.74	1.00	1.00	1.00	0.14	0.20	0.33	1.00	2.62	4.64	1.88	4.02	6.01	1.19	2.09	3.63
safety	0.68	1.20	2.01	0.83	1.50	3.02	3.00	5.00	7.00	1.00	1.00	1.00	0.76	1.44	2.62	0.94	1.88	3.20	1.02	2.08	3.71
const. Technology	0.30	0.52	1.09	0.38	0.75	1.43	0.22	0.38	1.00	0.38	0.69	1.31	1.00	1.00	1.00	0.52	0.98	1.85	0.49	1.00	2.10
naturally	0.23	0.38	0.82	0.62	1.15	2.09	0.17	0.25	0.53	0.31	0.53	1.07	0.54	1.03	1.91	1.00	1.00	1.00	0.97	1.99	3.44
social	0.17	0.25	0.51	0.22	0.38	0.74	0.28	0.48	0.84	0.27	0.48	0.98	0.48	1.00	2.04	0.29	0.50	1.03	1.00	1.00	1.00

Figure 5. Matrix of Fuzzy Pairwise Comparisons
Source: Author (2024)

	geometric average		
	r̃		
Personnel	0.94	1.65	2.61
design tech	0.55	0.91	1.52
equipment n materials	0.77	1.35	2.14
safety	1.03	1.75	2.79
const. Technology	0.42	0.72	1.35
naturally	0.45	0.74	1.30
social	0.32	0.53	0.94
total	4.49	7.66	12.66
reserve (pow of-1)	0.22	0.13	0.08
increasing order	0.08	0.13	0.22

Figure 6. Geometric average metrics
Source: Author (2024)

Ranking of variables based on fuzzy pairwise comparison results

The next step is to count the geometric average is calculated based on the following equation:

$$\tilde{r}_i = \left(\prod_{j=1}^{n} d_{ij}\right)^{1/n} , \quad i = 1, 2, \dots\dots, n$$

The next step is to calculate the reserve (pow of-1) with the power of the vector addition and then convert it to a triangular number. After obtaining the reserve result (pow of-1), do the fuzzy weighting of the criteria I (multiply each sum r̃ by the inverse vector. Mi is a non-fuzzy number, so normalization (Ni) is required. This process is also applied to the value of each alternative concerning each criterion, based on the group assessment of all respondents.

	fuzzy weighted			Mi	Ni
	ẇ				
Personnel	0.07	0.216	0.5812	0.3	0.209
design tech	0.04	0.119	0.3381	0.2	0.120
equipment n materials	0.06	0.177	0.4771	0.2	0.171
safety	0.08	0.229	0.6213	0.3	0.223
const. Technology	0.03	0.094	0.2993	0.1	0.102
naturally	0.04	0.096	0.2901	0.1	0.101
social	0.03	0.069	0.2096	0.1	0.073

Figure7. Table of risk variable weights from fuzzy pairwise comparison
Source: Author (2024)

The analysis shows that the ranking of risk variables affecting contingency costs at the primary level is as follows: Safety with a weight of 0.223, followed by Personnel with a weight of 0.209. Next, Equipment and Material weigh 0.171, followed by Technology Design with a weight of 0.120 and Construction Technology with a weight of 0.102. Finally, Natural Variables weigh 0.101, while Social Variables weigh 0.073. The results indicate that external variables, such as Natural Variables and Social Variables, have a smaller influence compared to internal variables.

Conclusion

The results of the analysis in this study conclude that the most influential risk variables affecting contingency costs are Safety, Personnel, and Equipment and Material, with the highest weights. Safety ranks highest with a weight of 0.223, followed by Personnel at 0.209 and Equipment and Material at 0.171. External variables, including Natural and Social Variables, have lower weights of 0.101 and 0.073, respectively, indicating their smaller influence compared to internal factors. The fuzzy logic approach used in the study has proven to be effective in making risk analysis more objective and accurate.

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