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Risk Assessment in Construction Projects Using the Grey Theory

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Abstract: Construction projects are of a particular nature and are affected by many factors, which exposes them to risks due to the long implementation period and the multiplicity of phases from the project idea phase through the implementation phase to the final delivery of the project, which leads to increased uncertainty and increased likelihood of these risks. This paper examines the risks in construction projects in Libya, and their impact on project objectives. This research identified risks in construction projects based on previous studies and a number of interviews with experts in construction projects, as well as field visits to project sites. On this basis, a questionnaire was prepared to locate and identify the risks that construction projects may face and was distributed to a number of local companies affiliated to the Libyan state operating in the construction sector. After the compilation of the questionnaire, the risks were analyzed qualitatively and quantitatively to determine the impact of each risk and the probability of its occurrence. The results of the study showed that 28% of the risks are certain and high, and 53% of the risks affect the project implementation time to a high degree. The results also showed a strong correlation between the probability of occurrence of the risks. Grey theory was used to weigh and rank the most important risks, and the most important of these was the insufficient manpower, material and equipment criterion.

Keywords: Risks; MCDM; Grey theory; Construction projects; State-owned projects

1. Introduction

Risks in construction contracts have become a feature of construction projects, whether they are known to the parties to such contracts or unforeseeable in advance, especially as these risks often lead to an increase in the cost of projects [1]. A risk is defined as an uncertain condition or event that has a negative or positive impact, if it occurs, on at least one of the project objectives (cost, schedule, quality). Risk management is defined as a systematic process during the life cycle of a project that aims to identify, analyze and then respond to risk in order to achieve an acceptable degree of elimination, control and management [2]. Construction projects are among the most risk-prone, so it was imperative to manage and analyze them in a way that minimized risk.

There are many previous studies on risk management in construction projects. Siraj and Fayek [3] studied the common risk identification tools and techniques, risk classification methods, and common risks for construction projects. Hatefi and Tamošaitienė [4] developed an integrated fuzzy DEMATEL-fuzzy ANP model to evaluate construction projects and their overall risks by considering intertwined relations among risk factors. Gondia et al. [5] used machine learning algorithms in order to facilitate accurate project delay risk analysis and prediction using objective data sources. Chatterjee et al. [6] used a hybrid MCDM technique for risk management in construction projects.

2. Methodology

This study was conducted in two phases. The first phase included distributing a questionnaire to a number of respondents, which was then analyzed for the purpose of identifying the most important risks in construction projects. The second phase is to identify the most important risks using the grey theory.

The use of multi-criteria decision methods has steadily increased in recent years [7, 8]. There are many applications that use these methods, such as the applications in the field of energy [9, 10], transportation [11-13], environment [14-16]. One of the methods used is Grey System Theory, introduced by Deng in the early 1980s, which focuses on solving problems with incomplete information or small samples [17]. Hence, it generates and extracts useful information from the available data. The calculation is created using macros developed with MS Excel software. The steps of the proposed method are as follows:

Step 1: Selecting the set of the most important attributes, describing the alternatives.

Step 2. Determine the attribute weights: Attribute weight W_j can be calculated as follows:

$$\otimes W_j = \frac{1}{K}\left[\otimes W_j^1 + \otimes W_j^2 + \cdots + \otimes W_j^K\right] \tag{1}$$

$$\otimes W_j^K = \left[\underline{W}_j^K, \underline{W}_j^K\right] \tag{2}$$

Step 3. Alternatives evaluated by the decision makers: decision makers use linguistic or verbal variables when evaluating alternatives according to various criteria.

$\otimes G_{ij}^K, (i = 1,2, \dots, m; j = 1,2, \dots, n)$ is the attribute value given by the kth decision maker to any attribute value of the alternative. In grey system this value is shown as, $\otimes G_{ij}^K = \left[\underline{G}_{ij}^K, \overline{G}_{ij}^K\right]$ and computed as:

$$\otimes G_j = \frac{1}{K}\left[\otimes G_j^1 + \otimes G_j^2 + \cdots + \otimes G_j^K\right]$$

Step 4. The construction of Grey Decision Matrix:

$$G = \begin{bmatrix} \otimes G_{11} & \otimes G_{12} & \cdots & \cdots & \otimes G_{1n} \\ \otimes G_{21} & \otimes G_{22} & \cdots & \cdots & \otimes G_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \\ \otimes G_{m1} & \otimes G_{m2} & \cdots & \cdots & \otimes G_{mn} \end{bmatrix} \tag{3}$$

Step 5. The normalization of Decision Matrix:

$$D^* = \begin{bmatrix} \otimes G_{11}^* & \otimes G_{12}^* & \cdots & \cdots & \otimes G_{1n}^* \\ \otimes G_{21}^* & \otimes G_{22}^* & \cdots & \cdots & \otimes G_{2n}^* \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \\ \otimes G_{m1}^* & \otimes G_{m2}^* & \cdots & \cdots & \otimes G_{mn}^* \end{bmatrix} \tag{4}$$

For a benefit attribute $\otimes G_{ij}^*$ is expressed as

$\otimes G_{ij}^* = \left[\frac{\underline{G}_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}}\right]$ where $G_j^{max} = max_{1<i<m}\{\overline{G}_{ij}\}$ and for a cost attribute $\otimes G_{ij}^*$ is expressed as

$\otimes G_{ij}^* = \left[\frac{G_j^{min}}{\overline{G}_{ij}}, \frac{G_j^{min}}{\underline{G}_{ij}}\right]$ where $G_j^{min} = min_{1<i<m}\{\underline{G}_{ij}\}$.

Step 6. Weighted Normalized Grey Decision Matrix normalized D^* matrix is weighted by the $\otimes V_{ij} = \otimes G_{ij}^* X \otimes W_j$.

Process which establishes the weighted normalized grey decision matrix D_W^*.

$$D_W^* = \begin{bmatrix} \otimes V_{11} & \otimes V_{12} & \cdots & \cdots & \otimes V_{1n} \\ \otimes V_{21} & \otimes V_{22} & \cdots & \cdots & \otimes V_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \\ \otimes V_{m1} & \otimes V_{m2} & \cdots & \cdots & \otimes V_{mn} \end{bmatrix} \tag{5}$$

3. The Case Study

The article focuses on the risks that can arise during the implementation of construction projects carried out by state-owned companies. The study population consists of engineers and project managers in Libyan state-owned companies in the city of Misrata, represented by the Organization Development of Administrative Centers, the Organization of Housing and Infrastructure Development in Misrata, and General Construction Company. The study was limited to supervising engineers and project managers who participated in the implementation of state construction projects, i.e. (63) engineers distributed among the three mentioned companies that represent the study population. Table 1 shows the number of questionnaires distributed to each of the mentioned organization.

The sample of the study included engineers, project managers and experts of state-owned companies that carry out subcontracting works, and the total number of engineers in these companies was (150) engineers. The questionnaires were distributed to 63 engineers, and 45 questionnaires were collected from them, and after examination of the questionnaires, 10 of those questionnaires were excluded because the quality required in the response were not met, bringing the number of questionnaires studied to 35. Table 2 shows sample characteristics.

Table 1. Number of questionnaires distributed

Company	Number
Organization Development of Administrative Centers	21
Organization of Housing and Infrastructure Development	21
General Construction Company	21

Table 2. Sample characteristics

Frequency	Expertise
2	Less than 5 years
8	From 5 to less than 10 years
14	From 10 to less than 15 years old
4	From 15 to less than 20 years old
7	More than 20 years
35	**Total**

From Table 2, it can be seen that 71% of the sample has more than 10 years of experience, which gives reliability to the results in the light of their response.

The probability of risks is calculated by Eq. (6).

$$R = P \times I \tag{6}$$

Whereas:

R: The score of risks, which is a value between [1, 0].

P: The probability of the risk occurring and takes a value between [1, 0].

I: The effect of the risk and it has a value between [1, 0].

By reviewing previous studies, reviewing Libyan contracts, conducting field visits to some of the projects and interviewing supervising engineers with experience in construction project management, a preliminary list of the questionnaire containing (32) risks was prepared. The questionnaire was then distributed to experts and project management specialists for feedback. As a result of the feedback received, some changes were made to the questionnaire and the risks were increased to (36) risks. The risks in the questionnaire were then designed from the contractor's perspective and divided to six categories as follows:

Organizational risks: includes all risks resulting from the organizational plans for the implementation of the project.

Spatial risks: These are risks that relate to the project site.

Technical risks: These include risks related to human resources, machines and consultancies offices.

Political and security risks: These are risks resulting from a change in policy and the surrounding security situation.

Financial risks: These are risks related to financial aspects and their own obstacles.

Legal risks: These are risks resulting from breach of contracts and local laws.

The data was analyzed using Excel 2019 to compile a list of risks faced by the contractors in the implementation of the projects and to determine the probability of their occurrence and their impact on the project objectives. Table 3 shows the probability of occurrence of risks in projects implemented by companies. Table 4 shows the score of risk.

It can be seen in Table 4 that the probability of occurrence of the risk's ranges from very high and high to very low. By analyzing the results of the questionnaire, it was found that 17 risks have a high and confirmed probability of occurrence, 4 have a medium probability, and Figure 1 shows their percentages. According to the figure, the probability of a confirmed and high risk is 28% and 17%, respectively.

To find out which risks affect the main project objectives (cost, quality and schedule), a table was prepared showing the degree to which each risk affects these objectives. Table 5 shows the impact of the risks on the main project objectives.

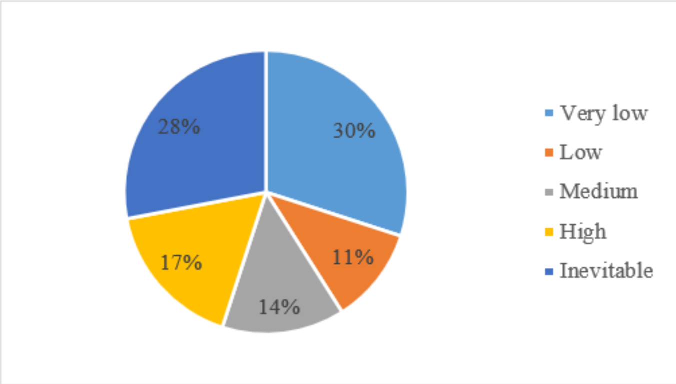

Figure 1. Risk score probability percentages

Table 3. Probability of risk occurrence

Code	Risk	Very low (%)	Low (%)	Medium (%)	High (%)	Very high (%)
R 1	Delays and technical problems with subcontractors	23	31	29	6	11
R 2	Poor coordination and communication between owner and contractor	29	20	17	17	17
R 3	Late arrival of official letters in the workplace	34	40	9	11	6
R 4	Non-compliance with contractual conditions by the owner	40	23	11	11	15
R 5	Delay in the start of the project	23	23	14	26	14
R 6	Delay in approval of executive plans by advisory body	17	11	23	26	23
R 7	Changes in management	17	32	14	14	23
R 8	Delay in handing over the site to the contractor due to lack of site preparation.	26	20	23	17	14
R 9	Lack of space to dump waste	51	17	17	9	6
R 10	Adverse weather conditions	34	31	14	14	7
R 11	The nature of the land and soil differs from those mentioned in the specifications in the contract	46	31	5	11	7
R 12	Lack of space on site, difficulty moving equipment and lack of space for processing materials.	20	26	37	11	6
R 13	Difficulty in accessing the site (too far, congestion)	29	17	26	14	14
R 14	Lack of availability of site service network plans (such as electrical, telephone, water, etc.)	9	11	26	31	23
R 15	Differences between implementation and required specifications due to misunderstanding of schematics and specifications.	23	26	14	29	8
R 16	Insufficient manpower, materials and equipment	12	14	17	17	40
R 17	Fluctuation in machine and labor productivity rates	9	29	17	31	14
R 18	Modification of the technique used in the implementation	31	20	20	6	23
R 19	Late completion of design or design change	11	20	11	17	41
R 20	Non-conformity of the plans (structural, architectural) with the contractual documents.	20	17	11	20	32
R 21	Disputes during the implementation of the project between the stakeholders	20	11	29	26	14
R 22	Inaccurate scheduling of the project	17	9	17	31	26
R 23	Weakness of consulting offices	11	3	23	31	32
R 24	Delay in payment of statements according to the contract	11	14	11	14	50
R 25	Deterioration of safety conditions in the project	9	14	11	31	35
R26	Late arrival of materials	9	14	34	23	20
R 27	Unstable conditions due to political issues	14	14	11	17	44
R 28	Damage to parts of the project due to security events	14	11	11	40	24
R 29	Pressure from parties who do not have a major interest in the project	34	11	14	29	12
R 30	Insufficient financial allocations to carry out the work	3	14	9	29	45
R 31	Delay in completion of partitions due to the contractor's lack of financial liquidity (lack of control over cash flow).	11	9	14	31	35
R 32	Inflation and price fluctuations during the project implementation period	6	6	11	34	43
R 33	Bribery and corruption	29	11	17	20	23
R 34	Crimes committed on the project site	54	31	9	6	0
R 35	Legal disputes on the project site	14	17	29	26	14
R 36	Difficulty in obtaining licenses and work permits	31	17	29	17	6

Table 4. Degree of risk

Risks	Risk description	Degree of Risk
R 1	Delays and technical problems with subcontractors	Low
R 2	Poor coordination and communication between owner and contractor	Very low
R 3	Late arrival of official letters in the workplace	Low
R 4	Non-compliance with contractual conditions by the owner	Very low
R 5	Delay in the start of the project	High
R 6	Delay in approval of executive plans by advisory body	High
R 7	Changes in management	Low
R 8	Delay in handing over the site to the contractor due to lack of site preparation.	Very low
R 9	Lack of space to dump waste	Very low
R 10	Adverse weather conditions	Very low
R 11	The nature of the land and soil differs from those mentioned in the specifications in the contract	Very low
R 12	Lack of space on site, difficulty moving equipment and lack of space for processing materials.	Medium
R 13	Difficulty in accessing the site (too far, congestion)	Very low
R 14	Lack of availability of site service network plans (such as electrical, telephone, water, etc.)	High
R 15	Differences between implementation and required specifications due to misunderstanding of schematics and specifications.	High
R 16	Insufficient manpower, materials and equipment	Inevitable
R 17	Fluctuation in machine and labor productivity rates	High
R 18	Modification of the technique used in the implementation	Very low
R 19	Late completion of design or design change	Inevitable
R 20	Non-conformity of the plans (structural, architectural) with the contractual documents.	Inevitable
R 21	Disputes during the implementation of the project between the stakeholders	Medium
R 22	Inaccurate scheduling of the project	High
R 23	Weakness of consulting offices	Inevitable
R 24	Delay in payment of statements according to the contract	Inevitable
R 25	Deterioration of safety conditions in the project	Inevitable
R26	Late arrival of materials	Medium
R 27	Unstable conditions due to political issues	Inevitable
R 28	Damage to parts of the project due to security events	High
R 29	Pressure from parties who do not have a major interest in the project	Very low
R 30	Insufficient financial allocations to carry out the work	Inevitable
R 31	Delay in completion of partitions due to the contractor's lack of financial liquidity (lack of control over cash flow).	Inevitable
R 32	Inflation and price fluctuations during the project implementation period	Inevitable
R 33	Bribery and corruption	Very low
R 34	Crimes committed on the project site	Very low
R 35	Legal disputes on the project site	Medium
R 36	Difficulty in obtaining licenses and work permits	Very low

Table 5. List of risks selected

Ci	Risk description	Degree of Risk
C1	Insufficient manpower, materials and equipment	Inevitable
C2	Late completion of design or design change	Inevitable
C3	Non-conformity of the plans (structural, architectural) with the contractual documents.	Inevitable
C4	Weakness of consulting offices	Inevitable
C5	Delay in payment of statements according to the contract	Inevitable
C6	Deterioration of safety conditions in the project	Inevitable
C7	Unstable conditions due to political issues	Inevitable
C8	Insufficient financial allocations to carry out the work	Inevitable
C9	Delay in completion of partitions due to the contractor's lack of financial liquidity (lack of control over cash flow).	Inevitable
C10	Inflation and price fluctuations during the project implementation period	Inevitable

Table 6. The importance of grey number for the weights of the criteria

Importance	Abbreviation	Scale of grey number $\otimes W$
Very Low	VL	[0.0, 0.1]
Low	L	[0.1, 0.3]
Medium Low	ML	[0.3, 0.4]
Medium	M	[0.4, 0.5]
Medium High	MH	[0.5, 0.6]
High	H	[0.6, 0.8]
Very High	VH	[0.8, 1.0]

Table 7. The linguistic assessment of the attributes by experts

Ci	Expert #1	Expert #2	Expert #3	Expert #4	$\otimes W$		Whitening degree
C1	VH	VH	VH	H	0.75	0.95	0.8500
C2	H	VH	H	H	0.65	0.85	0.7500
C3	H	H	VH	VH	0.70	0.90	0.8000
C4	M	H	M	VH	0.55	0.70	0.6250
C5	M	M	VH	H	0.55	0.70	0.6250
C6	VH	VH	H	H	0.70	0.90	0.8000
C7	H	H	H	VH	0.65	0.85	0.7500
C8	H	H	MH	H	0.58	0.75	0.6625
C9	MH	H	H	VH	0.63	0.80	0.7125
C10	H	MH	MH	MH	0.53	0.65	0.5875

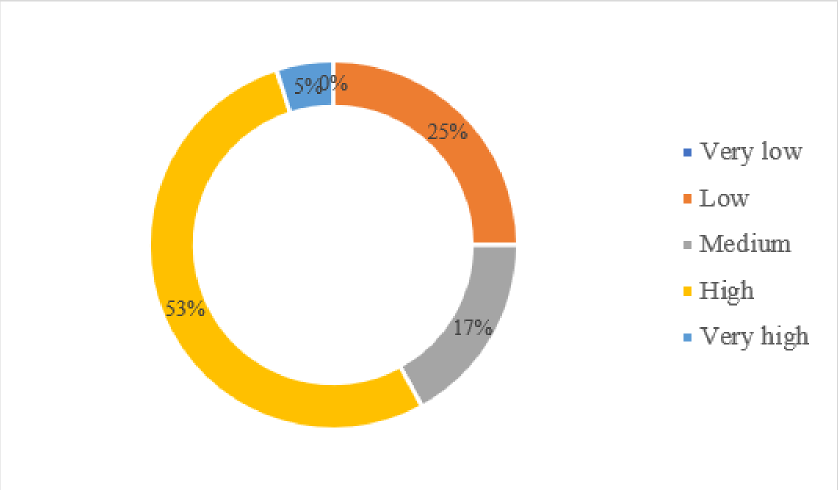

Figure 2. Impact of risks on project execution time

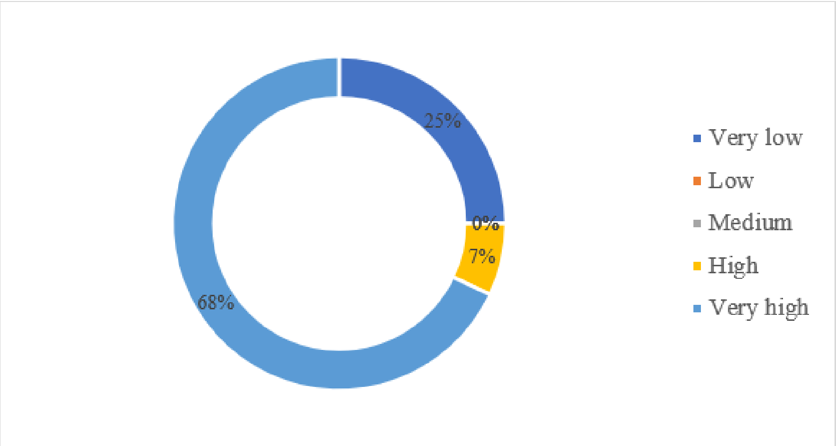

Figure 3. Impact of risks on the quality of project implementation

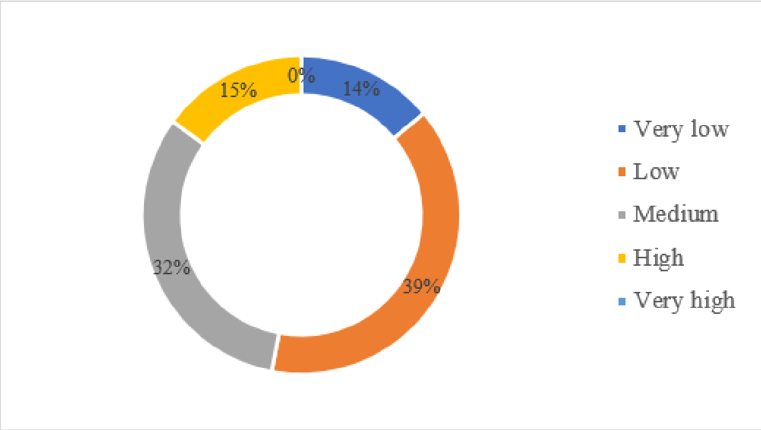

Figure 4. Impact of risks on the cost of project implementation

To determine the percentage of risks that affect the time and severity of the project, graphs were drawn to illustrate the percentage of impact of each risk. Figure 2 shows that the percentage of risks that affect the project implementation time is 53% to a high degree, with 5% to a very high degree. Figure 3 shows the percentage of risks that affect the quality and severity of project implementation. 7% of the risks have a high impact on the quality of the project implementation. Figure 4 shows the risks that affect the cost of the project and its degree of severity. It can be seen that 15% of the risks have a very high impact.

To determine the correlation between the risk occurrence probabilities, a model was prepared in Excel to calculate the Pearson's P coefficient. From the model data, 630 possible correlation relationships were calculated, each with a correlation coefficient. It was found that most of the correlations are positive. The results show the following:

82 very strong correlations were found using the Pearson coefficient greater than 0.75 and constituting 13%.

77 strong correlations were found using the Pearson coefficient greater than 0.5, constituting 12.2%.

41 correlation relationships using the Pearson coefficient were found between 0.3 and 0.5, constituting 6.5%.

The strongest correlations between the risk occurrence probabilities appeared as follows:

Delay in completion of partitions due to lack of financial liquidity provided by the contractor (lack of control over cash flow) R31, inflation and price fluctuations during the project implementation period R32 using the Pearson coefficient P=0.995.

R24 and R27 (P=0.993).

R16 and R24 (P=0.982).

R24 and R27 (P=0.993).

R2 and R4 (P=0.981).

R25 and R32 (P=0.977).

R25 and R30 (P=0.970).

R16 and R27 (P=0.970).

R2 and R9 (P=0.970).

This confirms the strong correlation between the probabilities of occurrence of risks and the fact that the occurrence of risks leads to other risks.

The Inevitable risks were selected in order to assess their rank. Grey theory was used for this purpose. Four experts were invited to participate in determining the importance of each of these criteria (risks). Each expert was interviewed with the aim of clarifying the goal of the research as well as its methodology. Table 5 shows the evaluation criteria selected. Linguistic variables can be expressed in grey numbers on a scale shown in Table 6.

Table 7 shows the experts' evaluation of each of the criteria (risks) utilized in the study. It also shows the conversion of the linguistic variables into numerical weights, in addition to the whitening degree calculation. The result shows that risk 1 is the most important with a weight of 0.85, followed by risks 6 and 3 with a weight of 0.85.

4. Conclusions

The study focused on the impact of risk probability on the main project objectives of time, cost and quality during the implementation of construction projects. The scope of the study was limited in projects running through public companies, and the subject of the study was limited to supervising engineers and project managers. The results showed that there are many risks that have a high and certain probability of occurring and affecting the main objectives of the project. The results of the study showed that 28% of the risks are certain and high, and that a high percentage of risks affect the schedule and less than in quality. It was found that 53% of the risks affect the project execution time to a high degree, 15% of the risks affect the project cost to a high degree, and 7% of the risks affect the project quality to a high degree. The results showed that there is a direct correlation between the probabilities of occurrence of most risks. In other words, the occurrence of some risks can trigger the occurrence of other risks.

Data Availability

The data supporting our research results are included within the article or supplementary material.

Conflicts of Interest

The authors declare no conflict of interest.

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