An Integrated Gray-Fuzzy Cause and Effect Approach to Determine the Most Significant Categories of Project Risks

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Abstract

Identifying critical risks in projects has become a core step in project risk management process; however, the nature of this step can be complex and unstructured, suggesting a benefit in research towards prioritizing project risks on the basis of a cogent method. This paper presents a Gray Decision Making Trial and Evaluation Laboratory (GDEMATEL) method for prioritizing sources of project risk within a multi-criteria decision making (MCDM) framework. The framework categorizes sources of risk via the Project Management Institute’s (PMI) Risk Breakdown Structure (RBS). For this study, project expert judgments and preferences are the source of knowledge about project risk. Uncertainty and variation between expert preferences are controlled by gray theory which converts linguistic preference collection terms into numerical intervals. Since the knowledge and experience of the experts are different, we consider the importance level of expert judgments in terms of triangular fuzzy numbers. Ultimately, a Gray Decision Making Trial and Evaluation Laboratory technique was applied to prioritize the project risks.

Keywords
Gray System Theory, DEMATEL, Project Risk Management, Fuzzy Set Theory

Notations
\(\otimes X\) Gray number
\(\underline{X}\) Lower bound of a gray number
\(\overline{X}\) Upper bound of a gray number
\(Z\) Crisp value of a gray number
\(T\) Total relation matrix
\(D\) Sum of rows of the total relation matrix
\(R\) Sum of columns of the total relation matrix
\(\bar{W}_p\) Fuzzy importance weight of expert \(p\)
\(\bar{a}_{ij}\) Aggregated fuzzy influence value of risk \(i\) on risk \(j\)
\(a_{ij}\) Aggregated crisp influence value of risk \(i\) on risk \(j\)
\(a_{ij}^p\) Influence value of risk \(i\) on risk \(j\) by expert \(p\)

1. Introduction

Risk in projects can be defined as the chance of an event occurring that is likely to have a negative influence on project objectives, measured as a function of likelihood that some event will occur, and the consequence of that event if it does occur [1-4]. Aggregate project risk is simply the collective impact of all individual risks. In order to arrive at a strong and on time delivery of projects, risk management is a crucial practice.

Risk categories provide a structure that enables a thorough process of systematically identifying individual sources of risk at a consistent detail. A Risk Breakdown Structure (RBS) lists categories and sub-categories where risk may arise for a typical project [5]. It also helps a risk manager to manage the risks efficiently and be familiar with sources which are recurring in a typical project. The RBS frequently illustrated in the PMI’s PMBOK Guide is depicted in Figure 1.
The main categories presented in Figure 1 are "Technical", "External", "Organizational" and "Project Management" [5].

- Technical risks are those which appear in relation to applied technology in the project.
- External risks are not in the project managers' authority like inflation rate, environmental factors etc.
- Organizational risks usually come into being when shortage of organizational resources exists.
- Project management risks are connected to managing tasks like estimating, planning, controlling and communication.

A literature review returned no integrated method which includes the fuzzy and gray theory simultaneously in the context of project risks ranking. Moreover researchers have not paid attention sufficiently to project risks categories in a typical project. We considered triangular fuzzy numbers to consider different weights for the experts and then gray numbers in DEMATEL to rank the risk categories of projects, which those fuzzy and gray numbers deal with the uncertainty in the MCDM process. Furthermore, in practice the risks of project are usually dependent and there would be a level of interrelationships between them. Therefore, DEMATEL method is utilized to consider the sophisticated links between risks categories. Gray system theory is also applied owing to better measurement of human’s subjective judgments. As a result, we proposed Gray DEMATEL (GDEMATEL) for this research to prioritize the various types of project risks on the basis of RBS of the 4th PMBOK Guide for construction projects in Iran to reach more cogent assessment and the results would be a helpful tool for risks managers of projects in the construction industry of Iran.

The literature review of the study is represented in Section 2. The research methodology is elaborated in Section 3 and the proposed methodology is utilized to prioritize the risks of the project. The results of applying the proposed model are presented in Section 4. Section 5 presents the conclusion and guidance for prospective studies.

2. Literature Review
The approaches in project risk management have been extensively investigated. In this section a number of researches which are related to risk ranking of projects are reviewed.

Askari and Shokrizade [1] identified the risks of Build-Operate-Transfer (BOT) projects and then ranked these risks on the basis of their severity and effect on project objectives by Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) and Fuzzy Simple Additive Weighting (FSAW). In the similar research by Ebrahimnejad et al [6], FTOPSIS and Fuzzy Linear Programming Technique for Multidimensional Analysis of Preference (FLINMAP) methods were utilized in order to rank high risks in BOT projects. Khatami Firouzabadi and Vafadar Nikjoo [7] investigated ranking the most significant project risks using fuzzy DEMATEL on the basis of the PMBOK standard. Zavadskas et al proposed risk assessment of construction projects on the basis of MCDM methods include gray TOPSIS and COPRAS-G methods [8]. Yazdani-Chamzini
et al [9] used the ELECTRE technique to rank the risks imposed during tunneling project in Tehran subway project. Bu-Qammar et al [10] proposed analytic network process (ANP) to handle the interrelations between risk related factors in international construction projects. They utilized the ranking of ANP method as an input to a decision support tool which can be used during bidding decisions. Ebrahimnejad et al [11] investigated the significance of risk ranking in mega projects by fuzzy compromise programming methods. They applied three MADM methods include TOPSIS, VIKOR and LINMAP in fuzzy environment and compared these approaches performance. They also developed a new fuzzy VIKOR method to assist managers in handling mega project risks. Ebrahimnejad et al [12] applied fuzzy TOPSIS and fuzzy LINMAP methods to prioritize the high risks in Iranian onshore gas refinery plants. Their results revealed that fuzzy LINMAP performed better than fuzzy TOPSIS. Thuyet et al [13] identified risk factors which influence oil and gas construction projects in Vietnam and proposed risk responses. Wang et al [14] also identified 28 critical risks of a construction project and categorized them into three groups. Tah and Carr [15] represented a hierarchical risk breakdown structure to develop a formal model for qualitative risk assessment. Tavakkoli-Moghaddam et al [16] introduced an applicable fuzzy MCDM to identify and prioritize project risks simultaneously in an EPC project. Kuo and Lu [17] applied a fuzzy MCDM approach to systematically evaluate risk for a metropolitan construction project. They used consistent fuzzy preference relations (CFPR) to measure the relative influence on project performance of 20 identified risk factors included in four risk dimensions. They also utilized fuzzy multiple attributes direct rating (FMADR) approach to analyze the occurrence probability of multiple risk factors. Rezakhani [18] categorized the most important risk factors in a construction project in a hierarchical structure and in order to select an effective risk factor, a modified rational MCDM is developed and fuzzy logic also applied to this model. KarimiAzari et al [19] applied fuzzy TOPSIS method in a risk assessment of an Iranian construction firm. Ebrahimnejad et al [20] identified the important risks in construction industry project and used fuzzy TOPSIS and fuzzy LINMAP methods to evaluate the high risks in the project. Mojahedi et al [21] presented a new methodology to identify and analyze risks concurrently by using multi attribute group decision making (MAGDM). They introduced a new procedure in order to categorize potential risks i.e. potential risks breakdown structure (PRBS). They applied their method in gas refinery plant construction successfully. Wang et al [22] proposed a hybrid AHP-DEA method to evaluate bridge risks of a myriad of bridge structures and according to their evaluation the maintenance priorities of the bridge structures can be determined. Taroun and Yang [23] illustrated the merits and downsides of Dempster-Shafer theory (DST) compared to probability theory (PT), fuzzy sets theory and AHP for handling risk assessment and decision making in construction industry. Finally, Mousavi et al [24] used non-parametric resampling technique, namely, bootstrap, with interval analysis to assess large engineering projects (LEPs) risks. They concluded that their approach outperformed the traditional techniques in terms of accuracy and efficiency.

3. Research Methodology

In this research, we utilized Gray DEMATEL (GDEMATEL) to prioritize project risk categories in Iranian project-based firms in construction industry. The methodology outlined below first introduces the gray system theory to deal with uncertainty in experts’ judgments, followed by the DEMATEL method and the proposed Gray DEMATEL method and application to prioritize the risk of the project. The framework of the proposed method is shown in Figure 2.

3.1 Gray system theory

In gray systems, the word "gray" refers to the information which is partially known and partially unknown, the word "black" is used to represent unknown information and in contrast, "white" for entirely known information. As a result, gray systems are systems with partially known and partially unknown information. The fundamental meaning of being "gray" is having "incomplete information". Gray theory can be applied in various research fields such as gray systems analysis, decision making, modeling and forecasting. Successful applications of gray system have been found in a broad range of human endeavor, including agriculture, industry, energy resources, transportation, etc. In manufacturing, the applications have produced considerable profits. The main contents in gray systems theory are gray numbers, gray elements and gray relations [25].

A gray number, \(\otimes X\), can be defined as an interval with known upper and lower bounds but unknown distribution information for \(X\) [26]. In Equation (1), \(X\) and \(X\) are the lower and upper bounds of \(\otimes X\), respectively.

\[
\otimes X = [\underline{X}, \overline{X}] = \{X' | \underline{X} \leq X' \leq \overline{X}\}
\]

In the following expressions, four basic gray number mathematical operations are shown [25]:

\[
\otimes X_1 + \otimes X_2 = [\underline{X}_1 + \underline{X}_2, \overline{X}_1 + \overline{X}_2]
\]

\[
\otimes X_1 - \otimes X_2 = [\underline{X}_1 - \overline{X}_2, \overline{X}_1 - \underline{X}_2]
\]
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\[ \bigotimes X_1 \times \bigotimes X_2 = \left[ \min(X_1X_2, X_1\overline{X}_2, \overline{X}_1X_2, \overline{X}_1\overline{X}_2) \right] \times \left[ \max(X_1X_2, X_1\overline{X}_2, \overline{X}_1X_2, \overline{X}_1\overline{X}_2) \right] \]  

(4)

\[ \bigotimes X_1 \div \bigotimes X_2 = \left[ \frac{X_1}{X_2} \right] + \left[ \frac{1}{X_2} \right] \]  

(5)

In order to arrive at a crisp number, gray aggregation methods are required. In this study, we use a modification of Converting Fuzzy data into Crisp Scores (CFCS) de-fuzzification method [27] as a de-graying tool [28]. We define \( \bigotimes X^p_{ij} \) as the gray number for an expert \( p \), who will evaluate the influence of risk \( i \) on a risk \( j \). We have \( \overline{X}_{ij}^p \) and \( \underline{X}_{ij}^p \) as the lower and upper gray values of the gray number \( \bigotimes X^p_{ij} \) respectively. That is:

\[ \bigotimes X^p_{ij} = [\underline{X}_{ij}^p, \overline{X}_{ij}^p] \]  

(6)

The modified-CFCS method consists of three steps as explained below:

**Step 1:** Normalization:

\[ \overline{X}_{ij}^p = \frac{X_{ij}^p - \min X_{ij}^p}{\Delta_{\text{max}}} \]  

(7)

\[ \underline{X}_{ij}^p = \frac{\overline{X}_{ij}^p - \min \overline{X}_{ij}^p}{\Delta_{\text{max}}} \]  

(8)

Where:

\[ \Delta_{\text{max}} = \max_j \overline{X}_{ij}^p - \min_j X_{ij}^p \]  

(9)

**Step 2:** calculate total normalized crisp value:

\[ Y_{ij}^p = \left( \frac{\overline{X}_{ij}^p (1 - \underline{X}_{ij}^p) + (\underline{X}_{ij}^p \times \overline{X}_{ij}^p)}{1 - \underline{X}_{ij}^p + \overline{X}_{ij}^p} \right) \]  

(10)

**Step 3:** calculate crisp values

\[ Z_{ij}^p = \min \underline{X}_{ij}^p + Y_{ij}^p \Delta_{\text{max}} \]  

(11)

The Battelle Memorial Institute carried out a DEMATEL method project through its Geneva Research Center. The original DEMATEL was utilized to solve fragmented and antagonistic issues of world societies.

3.2 DEMATEL method

The Battelle Memorial Institute carried out a DEMATEL method project through its Geneva Research Center. The original DEMATEL was utilized to solve fragmented and antagonistic issues of world societies.
DEMATEL method is built on a foundation of graph theory specifically directed graph known as digraph which enables decision makers to analyze and solve problems by visualization method. These graphs are more helpful than directionless graphs because they can show the directed relationships of sub-systems [29-31]. In order to deal with complex issues, the DEMATEL method was developed between 1972 and 1976. This method puts all factors into two distinct categories called "cause" and "effect" by utilizing impact values between factors. This categorization leads to a more thorough realization of system's components and correspondingly finding solutions to resolve convoluted system’s problems. In DEMATEL, "factors" or "criteria" are defined the same, both are elements that a decision maker is keen on determining the interrelationships between them by constructing a pair-wise relation matrix. Steps of this method are elaborated as following [29-32]:

**Step 1:** The direct relation matrix should be generated. The matrix \( (A_{n \times n}) \) can be achieved by pair-wise comparisons between criteria that is carried out by expert team and each element of this matrix \( (a_{ij}) \) represents the influence value of criterion \( i \) on criterion \( j \). The influence of criterion \( i \) on a criterion \( j \) means how increase/decrease in \( i \) can increase/decrease \( j \).

**Step 2:** The direct relation matrix should be normalized by using Equations (12) and (13):

\[
X = k \times A
\]

\[
k = \frac{1}{\max \sum_{j=1}^{n} a_{ij}}
\]

**Step 3:** The total relation matrix should be produced by Equation (14) in which \( I \) is the identity matrix.

\[
T = X(I - X)^{-1}
\]

**Step 4:** A causal diagram is generated. By applying Equations (15)-(17), sum of rows \( (D) \) and sum of columns \( (R) \) are calculated according to matrix \( T \). \( R \) value of a factor is its influential impact on others. \( R \) value is an impact the factor receives from others [33].

\[
T = \{ t_{ij} \}_{i,j=1}^{n}, i, j = 1, 2, ..., n
\]

\[
R = \sum_{i=1}^{n} t_{ij} = \{ r_{j} \}_{j=1}^{n}
\]

\[
D = \sum_{j=1}^{n} t_{ij} = \{ d_{i} \}_{i=1}^{n}
\]

Where \( (D + R) \) represents the horizontal axis vector which is called "prominence" and indicates the relative importance of each criterion. \((D - R)\) is named "relation". In general, we have:

- If \( (D - R) > 0 \) → the criterion is a member of cause group
- If \( (D - R) < 0 \) → the criterion is a member of effect group

Cause factors have impact on the entire system and their performance can influence on the overall goal. Moreover, criteria in cause group should be paid more attention. Effect factors are tended to be easily impacted by others which causes factors in effect group inappropriate to be a critical success factor [33].

**Step 5:** The inner dependence matrix is attained. In total relation matrix, the sum of each column would be equal to 1 by the normalization method after which the inner dependence matrix can be resulted.

### 3.3 Proposed Modified Gray DEMATEL method

Fuzzy mathematics and gray systems theory differ in many respects such as "methods", "basic sets", "objective" and "requirement" but both these approaches can deal with uncertainty in MCDM successfully [34]. Fuzzy and gray integration applied in the proposed methodology adds benefits to it and takes advantages of the merits of both approaches. Fuzzy relative weights are applied to each expert because it is a powerful tool in MCDM to determine weights and also requirement of fuzzy mathematics is "experience" in comparison with "any distribution" of gray systems. On the other hand, taking advantages of gray systems theory and DEMATEL (i.e. GDEMATEL approach), despite its contribution to the literature, can appropriately capture the imprecision of experts' judgments. This is due to the fact that study's object of gray systems is "poor information uncertainty" compared to "cognitive uncertainty" of fuzzy mathematics. It is not about the priority of fuzzy or gray but it pertains to their points of view "poor information uncertainty" of gray theory or "cognitive uncertainty" of fuzzy theory [25].

Many studies have been conducted recently that utilizes gray theory in decision making process, Including: gray TOPSIS [8, 35], COPRAS-G [8], gray DEMATEL [36-39] and new gray theory approach [40]. The Gray DEMATEL method has been used in several studies (e.g. [36-39]) but we modified this method slightly and proposed the steps which are more applicable in project risk prioritizing process. In section 3.3.1, the main steps in Gray DEMATEL method are presented and in section 3.3.2 it is shown that how the method is applied to the case of Iranian project-based firms in construction industry.
3.3.1 Method
Each expert \( p \) uses a five-point linguistic rating scale (Table 2) to determine the influence of risk \( i \) on a risk \( j \) (i.e. \( a_{ij}^p \)) which reveals the extent to which risk \( i \) can impact on a risk \( j \) and vice versa (i.e. \( a_{ji}^p \)). In fact, each expert determines interrelations between two risks. For example, risks \( i \) and \( j \) can be any of "Technical", "External", "Organizational" and "Project Management" risks. Then, the influence scores are replaced with their gray equivalents (Table 2) and crisp values (i.e. \( Z^p_{ij} \) & \( Z^p_{ji} \)) are obtained utilizing Equations 7-11. The aggregated fuzzy opinions (\( \tilde{a}_{ij} \)) of all experts considering their fuzzy importance weights (i.e. \( \tilde{\mathbf{W}}_p \)) (Tables 1 and 3) are calculated using Equation (18) after which crisp values of \( \tilde{a}_{ij} \) (i.e. \( a_{ij} \)) are calculated by applying Equation (19). After all these calculations, the direct relation matrix of the DEMATEL method (Table 7) is obtained and steps 2 to 5 of the DEMATEL method can be applied. The steps of modified Gray DEMATEL are presented as follows:

**Step 1:** Identifying main project risks categories
The Risk Breakdown Structure (RBS) according to the PMBOK Guide 4th edition is considered (Figure 1).

**Step 2:** Establishing an expert team
This team includes experts with specific knowledge and experience in the realm of managing projects. Each expert \( p \) has a specific fuzzy importance weight (\( \tilde{\mathbf{W}}_p \)) according to their knowledge and experience via self-assessment. The relative importance weights of experts (\( \tilde{\mathbf{W}}_p \)) are obtained by self-assessment on the basis of experts’ knowledge and experience in firms. Table 1 is used (which is a modified version of the table used in [33]) to convert linguistic variables into fuzzy triangular numbers.

<table>
<thead>
<tr>
<th>Linguistic variable for relative importance weight of experts (( \tilde{\mathbf{W}}_p ))</th>
<th>Fuzzy numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low (VL)</td>
<td>(0.0, 1.0, 2.0)</td>
</tr>
<tr>
<td>Low (L)</td>
<td>(0.1, 1.0, 3.0)</td>
</tr>
<tr>
<td>Medium (M)</td>
<td>(0.3, 0.5, 0.7)</td>
</tr>
<tr>
<td>High (H)</td>
<td>(0.5, 0.7, 0.9)</td>
</tr>
<tr>
<td>Very High (VH)</td>
<td>(0.7, 0.9, 1)</td>
</tr>
</tbody>
</table>

**Step 3:** Determining relations
Each expert \( p \) is asked to fill out the questionnaire to assess the interrelationship between risks using a five-point linguistic rating scale (Table 2) which reveals the influence of any risk on the other risk (i.e. \( a_{ij}^p \)) which reveals the extent to which risk \( i \) can impact on a risk \( j \) and vice versa (i.e. \( a_{ji}^p \)). The influence of risk \( i \) on risk \( j \) means how posing a risk \( i \) to the project can increase or decrease a risk \( j \) to it. According to Table 2, five levels of influence or impact are defined: "without impact", "low impact", "medium impact", "high impact" and "very high impact".

<table>
<thead>
<tr>
<th>Linguistic phrase</th>
<th>Influence score</th>
<th>Gray equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Impact</td>
<td>0</td>
<td>[0, 0]</td>
</tr>
<tr>
<td>Low Impact</td>
<td>1</td>
<td>[0.0, 0.25]</td>
</tr>
<tr>
<td>Medium Impact</td>
<td>2</td>
<td>[0.25, 0.5]</td>
</tr>
<tr>
<td>High Impact</td>
<td>3</td>
<td>[0.5, 0.75]</td>
</tr>
<tr>
<td>Very High Impact</td>
<td>4</td>
<td>[0.75, 1]</td>
</tr>
</tbody>
</table>

**Step 4:** Replacing the linguistic information with gray linguistic scale
Gray numbers (Table 2) are used to replace the influence scores of linguistic information in the initial relation matrix and then with the aim of getting crisp values, Equations (7-11) are utilized. As each expert has their specific fuzzy importance weight, in order to obtain the aggregated opinion of the \( n \) experts in evaluation of the influence of risk \( i \) on risk \( j \), the Equation (18) is used.

\[
\tilde{a}_{ij} = \frac{\sum_{p=1}^{n} \tilde{\mathbf{W}}_p Z^p_{ij}}{\sum_{p=1}^{n} \tilde{\mathbf{W}}_p} \tag{18}
\]

Where \( Z^p_{ij} \) represents crisp value of influence of risk \( i \) on risk \( j \) evaluated by expert \( p \); \( \tilde{a}_{ij} \) is aggregated fuzzy influence value of risk \( i \) on risk \( j \) and \( \tilde{\mathbf{W}}_p \) is the fuzzy importance weight of expert \( p \). Considering this point that in computing Equation (18), rules of fuzzy operations must be applied. Finally, we used Equation (19) to obtain crisp value of \( \tilde{a}_{ij} \) which is shown by \( a_{ij} \). Given \( \tilde{a}_{ij} = (a_1, a_2, a_3) \) then:

\[
a_{ij} = \frac{a_1 + a_2 + a_3}{3} \tag{19}
\]
Step 5: Attaining the causal diagram
The normalized initial direct-relation matrix was generated by using Equations (12) and (13) and the total relation matrix was computed by applying Equation (14). The R and D values are computed using Equations (16) and (17). D value of a factor is its influential impact on others and R value is an impact the factor receives from others [33]. Overall, by mapping the dataset of the \((D + R, D - R)\) the causal diagram can be acquired. This diagram can provide us with precious view into the realization of the entire system.

3.3.2 Application

Step 1: Identifying main project risks categories
The Risk Breakdown Structure (RBS) according to the PMBOK Guide 4th edition is utilized (Figure 1).

Step 2: The expert team was established
This team includes seven specialists with specific knowledge and experience in the realm of managing projects in Iranian project-based firms from construction industry. The questionnaires are filled out by them. The relative importance weights \((\tilde{W}_p)\) of our 7 experts are shown in Table 3.

<table>
<thead>
<tr>
<th>Experts</th>
<th>Importance weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experts 1, 2, 3</td>
<td>Low (L)</td>
</tr>
<tr>
<td>Expert 4</td>
<td>High (H)</td>
</tr>
<tr>
<td>Experts 5, 7</td>
<td>Medium (M)</td>
</tr>
<tr>
<td>Expert 6</td>
<td>Very High (VH)</td>
</tr>
</tbody>
</table>

Step 3: Determining relations
The seven specialists were asked to fill out the questionnaires to assess the interrelationship between risks using a five-point linguistic rating scale (Table 2) which reveals the influence of any risk on the other risk. For instance, Table 4 shows the opinions of the 6th expert.

<table>
<thead>
<tr>
<th>Project Management</th>
<th>Organizational</th>
<th>External</th>
<th>Technical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>External</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Organizational</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Project Management</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Step 4: Replacing the linguistic information with gray linguistic scale
We use gray numbers (Table 2) to replace the influence scores of linguistic information in the initial relation matrix (Table 4) and then with the aim of getting crisp values, Equations (7-11) are utilized. For example, see Tables 5 and 6. As each expert has their specific fuzzy importance weight, in order to obtain the aggregated opinion of our seven experts in evaluation of the influence of risk \(i\) on risk \(j\), the Equation (18) is used in which \(n = 7\) (Table 7).

<table>
<thead>
<tr>
<th>Technical</th>
<th>External</th>
<th>Organizational</th>
<th>Project Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>[0, 0]</td>
<td>[0.25, 0.5]</td>
<td>[0.5, 0.75]</td>
</tr>
<tr>
<td>External</td>
<td>[0.25, 0.5]</td>
<td>[0, 0]</td>
<td>[0.25, 0.5]</td>
</tr>
<tr>
<td>Organizational</td>
<td>[0.5, 0.75]</td>
<td>[0.25, 0.5]</td>
<td>[0, 0]</td>
</tr>
<tr>
<td>Project Management</td>
<td>[0.5, 0.75]</td>
<td>[0.25, 0.5]</td>
<td>[0.5, 0.75]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technical</th>
<th>External</th>
<th>Organizational</th>
<th>Project Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>0</td>
<td>0.3750</td>
<td>0.6875</td>
</tr>
<tr>
<td>External</td>
<td>0.4167</td>
<td>0</td>
<td>0.4167</td>
</tr>
<tr>
<td>Organizational</td>
<td>0.6875</td>
<td>0.3750</td>
<td>0</td>
</tr>
<tr>
<td>Project Management</td>
<td>0.6875</td>
<td>0.3750</td>
<td>0.6875</td>
</tr>
</tbody>
</table>
Step 5: Attaining the causal diagram

Table 7 is considered as the direct relation matrix for DEMATEL calculations. Computed total relation matrix is presented in Table 8 in which \((D + R)\) and \((D - R)\) values are also shown. Overall, by mapping the dataset of the \((D + R, D - R)\) the causal diagram was acquired which is demonstrated in Figure 3.

Table 8: Total relation matrix

<table>
<thead>
<tr>
<th></th>
<th>Technical</th>
<th>External</th>
<th>Organizational</th>
<th>Project Management</th>
<th>(D + R)</th>
<th>(D + R) Rank</th>
<th>(D - R)</th>
<th>(D - R) Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>3.3653</td>
<td>3.1148</td>
<td>3.8861</td>
<td>4.1787</td>
<td>28.2277</td>
<td>2</td>
<td>0.8621</td>
<td>2</td>
</tr>
<tr>
<td>External</td>
<td>3.6807</td>
<td>2.9447</td>
<td>3.9599</td>
<td>4.2161</td>
<td>26.5679</td>
<td>4</td>
<td>3.0350</td>
<td>1</td>
</tr>
<tr>
<td>Organizational</td>
<td>3.1864</td>
<td>2.7664</td>
<td>3.2520</td>
<td>3.7337</td>
<td>27.7934</td>
<td>3</td>
<td>-1.9165</td>
<td>3</td>
</tr>
<tr>
<td>Project Management</td>
<td>3.4504</td>
<td>2.9406</td>
<td>3.7569</td>
<td>3.7145</td>
<td>29.7054</td>
<td>1</td>
<td>-1.9806</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 3: The causal diagram

4. Results

According to the total relation matrix (Table 8) and the causal diagram (Figure 3); "Organizational" and "Project Management" risks are categorized as the "effect group" because the \((D - R)\) scores are negative and they tend to be easily influenced by other risks. In contrast, "Technical" and "External" risks belong to the "cause group" due to this fact that they acquire positive scores in \((D - R)\) values, which means they are crucial risks and are able to influence on the overall achievements of the firm. In the \((D + R)\) ranking we have "Project Management", "Technical", "Organizational" and "External" risks respectively due to their values. It means relative importance of "Project Management" is greatest among other risks. To reach a cogent ranking from DEMATEL, it is highly crucial to pay attention to both \((D + R)\) and \((D - R)\) ranking. At first, \((D - R)\) ranking and risks which belong to cause group (i.e. their \((D - R)\) values are positive) are considered after which \((D + R)\) ranking is considered. Here, "External" and "Technical" risks are members of cause group with ranks 1 and 2; but in \((D + R)\) ranking they stands at ranks 4 and 2 respectively. As cause group is highly important and the difference between \((D-R)\) values of "Technical" and "External" risks is fairly considerable. "External" and "Technical" risks rank first and second levels respectively. For third and fourth positions, \((D - R)\) ranking does not help because both of them are in effect group with negative \((D - R)\) values and the difference between their values in this group is not considerable. Thus, with regard to \((D + R)\) ranking "Project Management" risk is the third and "Organizational" risk is the fourth significant risk category. The final result of ranking is as follows: 1. "External" risk, 2. "Technical" risk, 3. "Project Management" risk, and 4. "Organizational" risk.
5. Conclusions

The results of this study would provide many helpful implications to managers, particularly risk managers. It is obvious that cause group risks must be regarded as highly critical risk categories which are "Technical" and "External" risks. This result indicates that technology which is applied in the project should be considered as one of the crucial sources of risks in projects and must be chosen appropriately in order to lower the effects of "Technical" risks. It is also revealed that "External" risks are very significant and can bring about many obvious that cause group

The outcome of this research indicates that "External" risk is of high significance and must be paid more attention by managers after which the most critical risks categories are "Technical", "Project Management" and "Organizational" respectively in Iranian project-based construction firms. Future research should be conducted in the domain of different industry sectors, including Industrial, IT, research-based and other projects to achieve more exact and exclusive results which would be more useful for the specific types of projects.

References