Fuzzy MADM-Based Model for Prioritization of Investment Risk in Iran’s Mining Projects

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Abstract Investment in mineral industries always deals with various economic, political, technical, and environmental risks. Not paying enough attention to such risks increases the possibility of investment failure. Accordingly, in this study, the risk criteria for investing in mineral industries and sub-criteria for risk assessment according to the type of industries, including mineral exploration, exploitation, and processing projects, have been identified and prioritized. In this regard, a methodology is presented based on multi-attribute decision-making methods, including Fuzzy Delphi, DEMATEL, and ANP methods to identify and analyze the risk criteria and evaluate sub-criteria. The results indicate that financial and commercial, technical, HSE, infrastructural considerations, geological, political, security, and legal risks are the main risk measures affecting investment in mining projects with different priorities. From the viewpoint of investment risk assessment in mineral processing and exploration projects, technical, financial and commercial, and geological risk criteria are the most significant, respectively. Generally, all risk criteria must be considered to make a reasonable investment in the mining sector, especially those more important.

Keywords Risk prioritization criteria’s · Mining projects Investment · Fuzzy MADM · ANP · DEMATEL

1 Introduction

Mineral resources can accelerate economic growth and boost social development [1, 2]. However, the main obstacle to economic growth in developing countries is insufficient public acceptance to invest in economic activities such as mineral industries. Mines play an essential role in supplying raw materials to industries, and they are counted as the main factors of industrial growth, especially in developing countries. Thus, in case of suitable and efficient investments in this sector, it is possible to obtain appropriate added value in related industries and provide economic prosperity to other sectors present in the value chain.

When it comes to talking about risk assessment in the mining sector, at first glance, it seems that risk should only be analyzed in the human, operational, and environmental aspects [3]. However, the risk assessment should be conducted in these aspects and the investment aspect. Plenty of investments are required in different stages to run a mining project, including geological exploration, development and implementation, and mineral processing. It is undeniable that each stage needs a lot of capital to purchase costly
equipment and types of machinery and construct large buildings and structures [4]. Hence, first of all, investors need to ensure that the level of investment risk in a mining project is acceptable. Starting investing is a major challenge for stakeholders or investors in the mines and mining industries. Internationally, the investment risk becomes more complex when the host country develops [5]. In general, a country hosting domestic or foreign investors must have political stability, economic transactions, basic essential infrastructure, and a reliable legal system. From the point of view of the investor or lending financial institution, the facility’s purpose is not simple to find a plan to provide liquidity but to identify a plan with a reasonable level of risk so that future loans can be repaid [5–7].

The sources of risk in mining projects can be categorized into two main groups: sources of uncertainty and hazards. In many cases, investors rely solely on financial analysis results such as Internal Return Rate (IRR) and Net Present Value (NPV) to evaluate mining projects, which is highly likely to lead to erroneous decision-making due to the ignoring of other essential contributing factors [8, 9]. In this regard, insufficient and inaccurate information and mineral’s price and demand are some of the items leading to the uncertainty. Besides, the project’s location, environment control, geological conditions, and regulatory changes can be considered sources of hazards in a mining project [8]. Consequently, to decide whether the mining project could gain the expected profit or not, we should pay attention to various kinds of risk sources such as environmental issues, geological conditions, production technology, market environment, social conditions, and policies and regulations. Since any variation of such factors can jeopardize the project’s profitability, it is important to consider these influencing factors in the process of investment risk assessment [10]. For instance, sometimes, even though financial analysis indicates that the project is profitable, the development of a mining project may arouse residents’ opposition, leading to the closure of the project.

Regarding this brief introduction, the main purpose of this article is to identify, analyze and prioritize investment risk criteria and sub-criteria. Prioritizing or ranking risk criteria helps investors monitor their risks and reduce losses [11]. As it is shown, Table 1 presents some of the studies conducted on investment risk and their sub-criteria in mining projects throughout the last years. According to studies, the mineral policy of countries in investment risk assessment in mining projects is grounded on the analysis of a set of risk criteria that expose the investment. So far, various criteria and sub-criteria have been proposed to assess the investment risk on mining projects. However, the importance of these risk criteria and sub-criteria and their impact on each other has not been examined. Since each of these criteria has a certain level of influence on the total risk of investment in the mining project, it is vital to consider such influences in the risk assessment procedure to make an accurate decision. In this regard, the weights of criteria and sub-criteria can be used to quantify their influence. Therefore, the more important criteria are, the higher weights it has. If investors neglect such weights in their risk assessment, a profitable project is highly likely to be counted uneconomical and vice versa. Because when the weights of criteria are ignored, low-risk criteria can make inactive high-risk criteria and vice versa. However, when the weights of criteria are considered, each risk criteria contribute to the overall investment risk proportionate to its influence level.

Furthermore, investment risk criteria on mining projects and their sub-criteria are not prioritized proportionate to the types of mining projects, including mineral exploration, exploitation, and processing. Sometimes, a risk criterion is very important in the investment risk assessment in mineral exploration projects, but it is not very important for mineral exploitation projects. Since decision-making is an essential factor in attaining success in any domain, in this paper, the multi-criteria decision-making (MCDM) methods have been used to identify and prioritize investment risk criteria and sub-criteria. It is undeniable that decision-making methods, especially in disciplines involving a wide range of influencing factors and requiring handling vast amounts of information, are extremely difficult [12]. Therefore, to cope with this hardship and assist decision-makers, MCDM methods could be beneficial.

Furthermore, the present paper has been arranged as follows. Generally, Fig. 1 illustrates the steps of conducting the research. In Sect. 2, the identified investment risk criteria and their sub-criteria are demonstrated. In Sect. 3, the methodology of analysis and ranking of the recognized risk criteria. Then, in Sect. 4, the obtained results of analyzing and prioritizing the investment risk criteria in mining projects are introduced. Finally, Sect. 5 concludes our findings.

2 Risk Criteria and Sub-criteria Identification

At first, the hierarchy structure of the problem is defined to identify the mining project risks as a goal placed at the top of the hierarchy. Major Risk criteria as criteria and risk sub-criteria as the sub-criteria are placed in downward order of hierarchy structure. An expert team was employed to identify the major and minor risk criteria. This team comprises five individuals familiar with different operations of the mineral value chain, such as mineral exploration, mine exploitation, mineral processing, and mineral industries. They were invited to a meeting in the first stage and became familiar with the research methodology. After
| Researcher(s)         | References | Risk criterion | Risk assessment sub-criteria |
|-----------------------|------------|----------------|-----------------------------|
| Gocht et al.          | [13]       | Market         | Ore prices, demand, and exchange rates |
|                       |            | Technical      | Reserve tonnage, the relation between mine production with the reserve tonnage |
|                       |            | Political      | Environmental regulations, taxation, freedom to trade and exchange, and resource nationalism |
|                       |            | political situation | The nationalism of mineral resources and political stability of the country |
| Simonsen and Perry    | [6]        | Market         | Ore prices, lower product prices, changes in product demand, and changes in product quality |
|                       |            | Environmental and infrastructure | Transport infrastructure as well as environmental impacts (such as air pollution) |
|                       |            | Political      | Environmental, tax, and freedom to buy and sell currency |
| Park and Matunhire    | [14]       | Economic       | ore prices, supply and demand, and exchange rates |
|                       |            | Technical      | Reserve, inconsistency of mine production with the expected amount due to poor management and non-completion of mining operations due to increased costs and engineering issues |
| Wei et al.            | [9]        | Economic       | Net present value |
| Park                  | [15]       | Economic       | Internal rate of return on capital, net present value, and payback period |
|                       |            | Technical      | Geological issues, operational issues, data validity, and production scale |
|                       |            | Marketing      | Standards of Product quality |
|                       |            | Investment climate | Political risk, licenses, infrastructure |
| Wang et al.           | [10]       | Natural condition | Mineral resource investigation, reserve and grade, environment |
|                       |            | Production     | Construction, security |
|                       |            | Market environment | Price, interest rate, exchange rate |
|                       |            | Policy         | Industrial policy, tax policy, environmental protection policy |
| Hashemi               | [5]        | Political      | Nationalization of mineral resources, the political instability of the country, and expropriation of mines and mined assets |
|                       |            | Economic       | Exchange rates, inflation, raw material costs, demand, product prices |
|                       |            | Legal          | Royalty rate, commercial rules, and regulations, and legal culture |
|                       |            | Geology        | Storage rate, ore grade |
|                       |            | Infrastructure | Access to transportation facilities, water resources, telephone lines, and the Internet |
|                       |            | environmental | Environmental Impact Assessment |
| Campisi and Caprioni  | [16]       | Geology        | Ore quality, physical potential, geological assessment methods |
|                       |            | Economic       | Tax debt, stability of tax and economic regime, type of tax |
|                       |            | Environmental | Fixed environmental obligations, type, and severity of regulations |
|                       |            | Operational   | Transfer of ownership, quality of infrastructure, major control by the investor |
|                       |            | Sociocultural | Supporting local stakeholders |
|                       |            | Political      | Consistent Mining Policies, National and Political Stability, Conflicts, Transparency / Corruption, International Agreements, Effective Regulatory Procedures |
| Weizhang Liang et al  | [17]       | Geology        | Geological rating, reserve amount, hydrological conditions, rock mass conditions around the reserve |
|                       |            | Production     | Geological rating, reserve amount, hydrological conditions, rock mass conditions around the reserve |
|                       |            | Environmental | Type of mining method, level of production equipment, mining technology |
|                       |            | Market         | National Industrial Policies, International Environment, National Economy |
|                       |            | Management     | Marketing ability, product price in the market, competitive potential |
| Sobczyk et al         | [7]        | Technical      | Ore transportation supplies, mine production capacity, concentrate transportation supplies, and concentrate quality |
|                       |            | environmental | Local and trans-regional environmental impact assessment |
|                       |            | Geology        | Ore storage quantity and quality |
|                       |            | Political and social | Risk classification of countries |
analysis of different related researches, the criteria were primarily classified, and some of them merged to end up with finalized classification. In this way, the hierarchy structure of major risk on mining projects investment is classified into seven categories. This structure is presented in Fig. 2. In the following, each of the criteria is examined in more detail.

### 2.1 Geological Risk (A)

Lack of accurate information and any errors in geological reports can bring about serious risks to the project investor [5]. In geological risk assessment, the classified sub-criteria can be considered due to Table 2 [5–7, 17–19].

### 2.2 Infrastructure Considerations Risk (B)

The existing infrastructure in the mining area is the first issue investors consider, particularly the international ones. The lack of any infrastructure will increase the risk of mining failure. Therefore, sub-criteria are examined according to Table 3 to assess this risk [5–7, 15, 19].

### 2.3 Health, Safety and Environmental Risk (HSE) (C)

The incidence of occupational accidents, non-observance of safety and health principles, Physical, chemical, and biological changes in the region’s environment are important issues related to mining projects. It is not easy...
for investors to assess all aspects of the environmental risk of projects. Facilitators usually receive information about the project’s environmental impact by inquiring from the relevant organization. In addition to the environmental issue, the principles required to standardize the work environment and prevent work-related deaths and various injuries must also be observed by the facility mining project applicant. The HSE risk criteria assessment sub-criteria can be summarized in Table 4 [5–7, 15].

2.4 Technical Risk (D)

The technical risk depends on the technical and technological specifications of the mining project. The sub-criteria listed in Table 5 are used [5–7, 15, 19].

2.5 Political and Security Risks (E)

Political and security risks (such as large changes in governing institutions) are related to government stability, the level of quality, and the efficiency of government handling of affairs [20]. These risks are also among the major concerns of mining investors [5]. Currently, there are classifications in which countries are ranked based on their investment risk. Some investors use this ranking as a criterion for assessing their proposed mining project’s political and security risks [7]. Altogether, the sub-criteria listed in Table 6 can be applied to assess a mining project’s political and security risks [5, 7, 16, 19, 20].

2.6 Legal Risk (F)

Legal risk at the industry level is defined as the risk of changing the regulatory rules governing a particular industry and applying and enforcing these rules [21]. This risk reduces investment attractiveness, illegal economic activity and increases costs [5, 16]. Sometimes, the legislature enacts laws that conflict with the mining law (such as increasing the export duties on a mineral) or changing mining laws and regulations (such as increasing royalty rates). Besides, obtaining the necessary permits for the project is another challenge for the investor [16].

The confusion of economic activists for obtaining licenses and receiving various inquiries, the dispersion of organizations and institutions designated for issuing licenses, and the long time for obtaining licenses are considered important obstacles that cause investors to worry and hesitate to start the economic activity. It should be noted that government support for mining activities and their proper oversight of implementing such activities increase investment appeal. The sub-criteria involved in this type of risk can be presented in Table 7 [16, 19, 20, 22].

2.7 Financial and Commercial Risk (G)

In the concern of mining financing, fluctuations in parameters such as tax rate, exchange rate, government wage rate, inflation, cost of raw materials, demand, and product price upsurge the financial and commercial risk of investment [19, 20, 23, 24]. For example, the dependence of the mining industry on imports of machinery, raw materials, and technical knowledge from abroad makes their financial indicators highly sensitive to exchange rate fluctuations [5]. In mineral supply and demand, investing in a mineral whose per capita consumption is high, its target markets are numerous. It is more competitive than similar products in the market. Certainly, financial risk will have less commercial risk. Another issue is whether the mineral market is competitive, monopolistic, or imported. For instance, investing in a mineral that another producer entirely owns will have greater financial and commercial

Table 3 Sub Criteria’s of Infrastructure Risk Assessment

| Symbol | Infrastructure risk assessment criteria considerations |
|--------|---------------------------------------------------------|
| B1     | Status of project access to water                         |
| B2     | Distance from the project to the power transmission lines |
| B3     | Existence of appropriate transportation infrastructure    |
| B4     | Distance from the project to the main market of the product |
| B5     | Distance between feed consumer and mineral supplier       |
| B6     | Distance from the project to product export bases         |

Table 4 HSE risk assessment sub-criteria

| Symbol | HSE risk assessment sub-criteria                  |
|--------|---------------------------------------------------|
| C1     | Safety and health indicators of personnel and equipment |
| C2     | Environmental dangers of project implementation    |
| C3     | Appropriate mechanism for implementation of HSE considerations |


Likewise, if the production capacity of the mining project is not economically justified, the investor will have doubts. Sometimes the facility applicant does not have the financial credit to receive the capital. Moreover, the financial credit of the owner of the mining project who requests the facility also greatly influences the investor’s decision. As aforementioned, the sub-criteria mentioned in Table 8 are the most important items regarding this risk.

### 3 The Proposed Methodology

This section introduces a practical methodology to analyze the recognized investment risk criteria and sub-criteria. The methodology is presented in Fig. 3. As can be seen, at the first step, the identified risk criteria and sub-criteria should be initially screened using the fuzzy Delphi (FD) method. In this stage, based on the expert judgments, those criteria that are not important in the investment risk assessments of three different mining projects will be excluded. Hence, the remaining criteria will be considered the final risk criteria and sub-criteria. The screening process should be conducted separately according to the type of mining projects, including exploitation, exploration, and

| Symbol | Technical risk assessment sub-criteria |
|--------|----------------------------------------|
| D₁     | Qualitative competitiveness is required for the product that can be produced |
| D₂     | Possibility of various uses of mineral consumption in industries |
| D₃     | The level of technology required to implement the plan |
| D₄     | Shelf life of the design |

| Symbol | Political and security risk assessment sub-criteria |
|--------|------------------------------------------------------|
| E₁     | The political stability of the country |
| E₂     | The security stability of mining area |
| E₃     | Consistent protection policies |
| E₄     | The crime index in the region |
| E₅     | Country investment risk rating |
| E₆     | International laws |

| Symbol | Legal and legal risk assessment sub-criteria |
|--------|---------------------------------------------|
| F₁     | Stability of rules and regulations |
| F₂     | Proper implementation of mining laws |
| F₃     | Proper oversight of mining activities by government agencies |
| F₄     | Ease of the process of obtaining the relevant permits |
| F₅     | Ease of obtaining environmental and natural resources permits |
| F₆     | Enjoy special government legal protections |

| Symbol | Financial and commercial risk assessment sub-criteria |
|--------|-------------------------------------------------------|
| G₁     | Financial indicators of project evaluation |
| G₂     | Sensitivity of financial indicators of project evaluation |
| G₃     | Risk of non-fulfillment of financial indicators of project evaluation |
| G₄     | Stability in mineral product demand |
| G₅     | Commercial competitiveness of the product |
| G₆     | Technical and financial credit of the facility applicant |
| G₇     | Multiple target markets (domestic, foreign) for a mineral |
| G₈     | The nature of competitors in the product market |
| G₉     | Influence of project costs from currency fluctuations |
| G₁₀    | The economic justifiability of project production capacity |
| G₁₁    | The type of cost of the granted facility |
| G₁₂    | Duration of repayment of granted facilities |
Yes

Applying Delphi method

Screening of identified risk criteria and sub-criteria according to the type of the mining projects

Determining final risk criteria and final sub-criteria according to the type of mining projects

Applying DEMATEL

Analysis of causal relationships between sub-criteria according to the type of the mining projects

No

Is there a causal relationship?

Estimation of weights using AHP method

Estimation of weights using ANP method

Prioritization of risk criteria and sub-criteria according to the type of the mining projects

Fig. 3 Methodology presented for the prioritization process

processing. Besides, as shown in the second step, since the risk sub-criteria might not be independent of each other, the pattern of causal relationships between the sub-criteria should be recognized using a useful method called DEMATEL (Test and Decision Evaluation Laboratory). It evaluates interdependent relationships among criteria and finds the critical ones through a visual structural model [25].

It is clear that the causal relationships between sub-criteria directly affect the method of weight estimation. Therefore, in the next step, if the results of DEMATEL demonstrate the absence of causal relationships, the Analytic Hierarchy Process (AHP) method could be an appropriate option that can be used. On the other hand, if the results illustrate causal relationships, the Network Analysis Process (ANP) method should be the best choice to estimate the weights of investment risk criteria and their sub-criteria. Similarly, this step should be performed distinctively according to the type of mining project. Finally, the investment risk criteria and sub-criteria will be prioritized using the calculated weights (the weighting process should be done separately according to the type of mining projects). As shown in Table 9, the benefits and drawbacks of these three MCDM methods are illustrated. It is clear that despite all downsides, their advantages completely outweigh their disadvantages, which makes their selection reasonable.

It should be noted that the main design considerations of the methods as mentioned earlier are similar. First of all, since these methods are based on expert judgment, a proper questionnaire should be designed to collect experts’ opinions. In the questionnaire form, the questions should be designed appropriately. Secondly, experts selected for the survey should have sufficient knowledge and experience about the subject. So, they should be selected from relative fields. Another issue that should be considered is the sufficient number of experts. The adequate number of experts can be determined by the general rule of thumb though there is no agreement about the number of experts in a survey. Based on this rule, six to eight experts (and no fewer than four) should participate in the survey. Besides, the opinions of experts should be taken linguistically [26]. The description of the methods mentioned in this paragraph is presented in the following sub-sections.

3.1 Fuzzy Delphi Method

The fuzzy Delphi (FD) method, which is the modified version of the traditional Delphi method, was developed by Kaufman and Gupta [29]. This method seeks to gather expert judgments and achieve group consensus. It should be considered that the limitation of the classical Delphi method that leads to low convergence in retrieving results, loss of important information, and long progress of investigation has been modified in the FD method [30]. So, in this paper, according to the benefits of the FD method, it is used to screen the identified risk criteria and sub-criteria. Throughout the last years, the Fuzzy Delphi technique has been applied in different disciplines, including humanities (e.g., identification of elements of teaching strategy in English skills [31]), management (e.g., identifying sustainable solid waste management barriers [32]), business (e.g., develop global business intelligence [33]), physical science and engineering (e.g., public transport mode choice [34] and recognizing the sustainable maintenance management’s indicators in the Oil industry [35]). The steps of the FD method are explained as follows:

Step 1: Conduct expert judgment and collect the opinion of experts about the importance of sub-criteria using Table 10 [36].

Step 2: In this step, fuzzy numbers ($\tilde{d}_i$) obtained from the consensus of experts’ judgments are calculated as follows [37–39]:

$$\tilde{d}_i = (a_i, b_i, c_i), i = 1, 2, \ldots, n$$ (1)

$$a_i = \min_k \{\beta_{ik}\}$$ (2)

$$b_i = \sqrt{\prod_{k=1}^{K} \beta_{ik}}$$ (3)
In the above equations, $b_{ik}$ represent the judgment of $k^{th}$ expert about the importance of $i^{th}$ criterion and $K$ is the number of experts. Based on triangular fuzzy numbers (TFNs) logic, experts’ judgments’ maximum and minimum values are regarded as upper and lower bounds, respectively. The geometric mean is considered the median. So, the elements $a_{i}$, $b_{i}$, and $c_{i}$ respectively, refer to the minimum possible value, the most hopeful value, and the maximum possible value. The crisp value of each criterion ($d_{i}$) is calculated as follows [40]:

$$d_{i} = \frac{(a_{i} + 2b_{i} + c_{i})}{4}$$

Step 3: In this step, a threshold value ($s$) should be set to select or reject the criteria. Therefore, any criterion whose $\delta_{i}$ is less than the threshold value should be removed. There is no agreement about how to determine $s$. Generally, its value is determined according to the researchers’ opinions [41].

### 3.2 DEMATEL Method

The DEMATEL method was introduced by Gabus and Fontela [42]. Using the principles of graph theory and matrix theory, this method displays various problems in the form of directional graphs based on the opinion of experts. It examines the relationships between the effectiveness and the impact of criteria on each other. Hence, based on the benefits of DEMATEL (Table 9), it is used to analyze the interrelationships among risk criteria and sub-criteria. The DEMATEL technique has been used in various domains over the last years [25], including health (e.g., healthcare management [43]), humanities (e.g., human error probability evaluation [44]), engineering (e.g., analyze relationships of flyrock causing factors in mines [45] and evaluation of drivers and barriers of electric vehicle [46]), business (e.g., analyze relationships of customer buying decision factors [47] and evaluation of the effect of COVID-19 pandemic on tourism [48]) and so on. In the following, the steps of this method are described [49–52].

Step 1: The degree of the direct impact of each criterion $i$ on each criterion $j$ ($x_{ij}$) is determined by a survey of experts using Table 11.

Step 2: If the number of experts is equal to $K$, the direct correlation matrix $(x)$ is formed employing Eqs. (6) and (7) [51].

$$X = [x_{ij}]_{n \times n}$$

$$X_{ij} = \frac{1}{K} \sum_{k=1}^{K} x_{ij}^{k}, i, j = 1, 2, 3, \ldots, n$$
Step 3: The x matrix is defined by Eqs. (8) and (9), and the normal direct relation matrix (N) is formed [51].

\[ N = X/S \] (8)

\[ S = \max \left( \sum_{j=1}^{n} x_{ij}, \sum_{i=1}^{n} x_{ij} \right) \] (9)

Step 4: The complete correlation matrix (T) is defined as Eq. (10). To calculate this matrix, it is necessary to form an identical matrix (I) [52].

\[ T = N \times (I - N)^{-1} = [t_{ij}]_{n \times n} \] (10)

Step 5: Using Eqs. (11) and (12) the relationships of impact (r) and impact (c), the criteria are calculated as follows [49, 50]:

\[ [r]_{n \times 1} = \left[ \sum_{j=1}^{n} t_{ij} \right]_{n \times 1} \] (11)

\[ [c]_{n \times 1} = \left[ \sum_{i=1}^{n} t_{ij} \right]_{n \times 1} \] (12)

Step 6: A Cartesian coordinate system draws the causal diagram (cause-effect) with the longitudinal axis \((r_i + c_j)\) and transverse axis \((r_i - c_j)\). The value of \((r_i + c_j)\), which is called superiority, is an index that represents the sum affected and taken by criterion i. The value \((r_i - c_j)\) represents the effect that criterion i is shared in the system and is called communication. If the value of \((r_i - c_j)\) is positive, criterion i is the cause and otherwise the effect [53].

Step 7: To map the relationships, only relationships whose values in the T-matrix are greater than the threshold value (average T-matrix values) are considered. As a result, minor relationships are ignored, and only significant relationships are drawn [49, 50].

### 3.3 Network Analysis Process (ANP)

The ANP method proposed by Saaty [54] is a generalized version of the AHP method. In the AHP method, it is assumed that there is no relationship between different factors in levels of decision-making. Nevertheless, some issues cannot be hierarchically structured because there may be connections and dependencies between higher-order and lower-order elements. Consequently, in such cases, the network structure should be used. Thus, the ANP method is used to rank risk criteria and sub-criteria in this paper. The ANP technique has been widely used in various domains during the last years, including engineering (e.g., identification of critical components for the implementation of reliability centered maintenance [55] and risk identification and assessment of oil and gas projects [56]), energy (e.g., evaluation of methods of waste energy recovery from the engine [57] and evaluation of power plants [58]), business and management (e.g., evaluation of smart and sustainable cities [59], performance indicator selection for a supply chain [60] and selection of the optimal tourism site [61]). The steps of the ANP method are as follows [53, 54, 62]:

Step 1: Form a network structure using the relationship map resulting from applying the DEMATEL method [53].

Step 2: In this step, similar to the AHP method, matrices of pairwise comparison of criteria are formed based on experts’ opinions. The nine-hour scale presented in Table 12 can be used to obtain comments. The effect of each element on the other element is specified by the special vector method as follows [54]:

\[ AW = \lambda_{\max} W \] (13)

In the above relation, A is the pairwise comparison matrix of the criteria, W is the eigenvector (weights), and \(\lambda_{\max}\) is the maximum eigenvalue.

Step 3: In this step, the internal priority vectors (i.e., \(W_s\)) calculated in the previous step) are inserted into the appropriate columns of a matrix. Accordingly, a primary

### Table 11 Five-degree range of DEMATEL method (Liu et al. 2020)

| Value | Very low | Low | High | Very high |
|-------|----------|-----|------|----------|
| 0     | 1        | 2   | 3    | 4        |

### Table 12 Scoring scale in ANP method [62]

| Row | Preferences          | Quantity |
|-----|----------------------|----------|
| 1   | Equal importance     | 1        |
| 2   | Somewhat more important | 3       |
| 3   | Medium importance    | 5        |
| 4   | Much more important  | 7        |
| 5   | Absolutely more important | 9       |
| 6   | Preferences between the above values | 2, 4, 6, 8 |

### Table 13 Number of experts by field of activity

| Activity                  | Number of participating experts |
|---------------------------|---------------------------------|
| Mine exploitation         | 19                              |
| Mineral exploration       | 6                               |
| Mineral processing        | 6                               |
### Table 14 Determining the final sub-criteria appropriate to the type of mining project

| Symbol | $d_i$ appropriate for the type of mineral design | Final sub-criteria |
|--------|---------------------------------------------|-------------------|
|        | Exploitation | Exploration | Mineral processing | Exploitation | Exploration | Mineral processing |
| A1     | 3.25         | 4.03        | 3.60                |              |              |                 |
| A2     | 3.34         | 4.49        | 3.43                | *            | *            | *                |
| A3     | 4.12         | 3.96        | 2.69                | *            | *            | *                |
| A4     | 3.16         | 4.03        | 3.25                |              |              |                 |
| A5     | 4.53         | 3.98        | 3.90                | *            | *            | *                |
| A6     | 3.40         | 3.05        | 3.40                |              |              |                 |
| B1     | 3.51         | 2.20        | 4.30                | *            | *            | *                |
| B2     | 3.56         | 2.32        | 4.21                | *            | *            | *                |
| B3     | 3.45         | 2.53        | 4.30                | *            | *            | *                |
| B4     | 3.42         | 3.01        | 4.05                | *            | *            | *                |
| B5     | 3.38         | 2.39        | 3.65                | *            | *            | *                |
| B6     | 3.69         | 2.87        | 4.30                | *            | *            | *                |
| B7     | 3.50         | 2.17        | 3.41                | *            | *            | *                |
| C1     | 3.36         | 3.00        | 3.80                | *            | *            | *                |
| C2     | 3.34         | 3.22        | 3.48                | *            | *            | *                |
| C3     | 3.35         | 2.61        | 3.71                | *            | *            | *                |
| D1     | 4.18         | 3.01        | 4.21                | *            | *            | *                |
| D2     | 3.99         | 2.94        | 3.87                | *            | *            | *                |
| D3     | 3.35         | 2.87        | 3.40                | *            | *            | *                |
| D4     | 3.45         | 2.97        | 4.13                | *            | *            | *                |
| E1     | 3.53         | 2.25        | 3.80                | *            | *            | *                |
| E2     | 3.71         | 3.78        | 3.48                | *            | *            | *                |
| E3     | 3.74         | 2.83        | 3.71                | *            | *            | *                |
| E4     | 2.75         | 3.43        | 2.56                |              | *            | *                |
| E5     | 2.88         | 2.79        | 2.88                |              | *            | *                |
| E6     | 3.34         | 2.87        | 3.80                | *            | *            | *                |
| E7     | 3.39         | 3.35        | 4.13                | *            | *            | *                |
| F1     | 4.09         | 2.88        | 3.89                | *            | *            | *                |
| F2     | 4.01         | 3.38        | 3.80                | *            | *            | *                |
| F3     | 3.53         | 3.35        | 3.43                | *            | *            | *                |
| F4     | 3.36         | 3.34        | 4.13                | *            | *            | *                |
| F5     | 3.35         | 2.95        | 4.05                | *            | *            | *                |
| F6     | 3.68         | 3.34        | 3.43                | *            | *            | *                |
| G1     | 4.10         | 2.25        | 3.34                | *            | *            | *                |
| G2     | 3.92         | 2.10        | 3.46                | *            | *            | *                |
| G3     | 3.36         | 2.25        | 3.49                | *            | *            | *                |
| G4     | 3.83         | 2.49        | 3.67                | *            | *            | *                |
| G5     | 3.77         | 2.47        | 4.05                | *            | *            | *                |
| G6     | 3.73         | 3.71        | 3.34                | *            | *            | *                |
| G7     | 3.73         | 3.43        | 4.40                | *            | *            | *                |
| G8     | 3.28         | 2.87        | 2.66                | *            | *            | *                |
| G9     | 4.12         | 2.81        | 3.38                | *            | *            | *                |
| G10    | 4.53         | 2.73        | 3.90                | *            | *            | *                |
| G11    | 4.15         | 3.05        | 3.52                | *            | *            | *                |
| G12    | 4.12         | 3.05        | 4.40                | *            | *            | *                |
super-matrix is obtained, each part of which represents the relationship between two clusters in a system [53].

**Step 4:** In this step, the weighted super-matrix is achieved by unifying the initial super-matrix [53].

**Step 5:** In this step, the limit sup matrix is calculated as the weighted super-matrix until all its elements become the same [54]:

$$\lim_{k \to \infty} W^k$$

(14)

4 Results and Discussion

In this section, based on the presented methodology, investment risk criteria in mining projects and their subcriteria are analyzed and prioritized according to the type of mining project. The results are presented below.

4.1 Screening the Criteria and Sub-criteria of Risk

According to the steps of the fuzzy Delphi method, using the criteria and sub-criteria identified in the third section, three questionnaires were developed to obtain expert opinions on the importance of the criteria and sub-criteria identified following the type of mining projects. The number of experts participating in the survey is presented in Table 13 by field of activity. The acquired values of each sub-criterion ($\delta_i$) are featured in Table 13 according to the type of mining projects. To select the final criteria, first of all, the threshold value ($s$) should be set. Since there is no exact method to determine $s$, its value may vary based on the researchers’ opinions [36, 63–66]. Generally, when a 5-point spectrum is being used, the threshold value could be set to 3 (i.e., the average of the spectrum). However, in this study, the value of $s$ is set with more strictness. Therefore, based on the authors’ viewpoints, the threshold value is 3.33. It means if the crisp score of a criterion is less than two-thirds of the maximum score (i.e., 5), the criteria will be rejected. It should be noted, the sub-criteria of the employment rate of the mining project (D5) and the technical competence of the facility applicant (D6) were added to the sub-criteria of technical risk assessment for exploitation and processing design by experts’ opinions (Table 14).

4.2 Cause and Effect Analysis of Criteria for Assessing Risk Criteria

According to the fourth section, a collective judgment of experts was used to determine the causal relationships between the sub-criteria of risk assessment criteria. The characteristics of the experts participating in the survey process are divulged in Table 15.

In the next step, according to the screening results of the sub-criteria, the causal relationships between them were specified due to the type of mining project using the DEMATEL method. Based on the results, the causal relationships between the geological risk criteria assessment sub-criteria for exploitation, processing, and exploration projects are illustrated in Figs. 4 and 5, respectively. As known, the sub-criteria of all risk criteria are interrelated, and the ANP method should be used to determine their weights. For example, as shown in Figure 5, in the issue of mineral exploration projects, the Reliable Exploration Information sub-criterion (A2) has the highest impact, and the potential reserve (A4) sub-criterion has the lowest impact on other sub-criteria. As well, the sub-criteria of reliable basic information (A1), the required quality of raw material (A5), and reliable exploration information (A2) are the cause, and the sub-criteria of proved reserve (A3) and probable reserve (A4) are effects.

The relationships map of the geological risk criteria assessment sub-criteria for mineral exploration projects can be displayed in Figure 6.

4.3 Prioritizing Risk Criteria and Their sub-criteria

According to the steps of the ANP method, the first step is to determine the network structure. Due to the outcomes of the DEMATEL method, the structure of the network of investment risk criteria on exploitation, processing, and exploration projects and their sub-criteria are exposed in Figs. 7 and 8, respectively.
Three questionnaires were prepared regarding the type of mining project, and experts were asked to express their views on the importance of risk criteria and their criteria to form paired comparison matrices. The goal is equivalent to prioritizing risk criteria and their evaluation sub-criteria in this structure. After forming the pairwise comparison

Fig. 4 Causal relationships of risk assessment criteria of mineral exploitation and processing projects (1. Geology, 2. Infrastructure considerations, 3. HSE, 4. Technical, 5. Political and security, 6. Legal and legal, 7. Financial and commercial)
matrices, the final weights of the risk criteria and their evaluation sub-criteria were estimated using Super Decision software based on the type of mining project. The final results are presented in Table 16.

Furthermore, the estimated significance coefficients for the risk criteria and their sub-criteria are depicted in Figs. 9 and 10. From the view of investment risk assessment in processing projects, risk criteria, financial and commercial, technical, infrastructural, and geological considerations are the most significant ones. According to the results obtained from investment risk assessment in mineral exploitation projects, technical, financial, and commercial risk criteria, infrastructure, and geological considerations are the most significant, respectively. Henceforth, special attention should be paid to these criteria in evaluating exploitation plans. Indeed, these criteria in evaluating processing projects should be heeded.

The political and security risk criteria are the least important among other risk criteria from exploitation and processing plans. The geological risk criteria are the most significant from investment risk assessment in exploration projects. Conclusively, these criteria should be considered when evaluating mineral exploration projects. The legal risk criteria are the least important among other risk criteria.

5 Conclusion

Mines and mining industries are among the productive sectors in the economy of any country. However, investing in the mining sector is a major challenge for investors. An economic evaluation of the projects performs mainly based
on specific financial indicators such as NPW and ROR. Also, risk assessment is based on sensitivity analysis and changes in financial indicators to price changes. The most important impacts of this research can be considered in identifying and ranking the quantitative and qualitative parameters that affect the failure of mining projects. These
| Symbol | Final weights of risk criteria | Symbol | Final weights of sub-criteria |
|--------|--------------------------------|--------|------------------------------|
|        | Exploitation Rank | Exploitation Grade | Processing Rank | Exploitation Grade | Processing Grade |
| A      | 0.125 4 | 0.459 1 | 0.149 4 | A_1 | – | – | 0.239 10 | – | – |
|        | 0.158 20 | 0.274 8 | 0.367 1 | A_2 | – | – | 0.117 12 | – | – |
|        | 0.297 5 | 0.051 15 | 0.354 2 | A_3 | – | – | 0.055 37 | – | – |
| B      | 0.187 3 | – | – | 0.175 3 | B_1 | 0.065 35 | – | – | 0.089 | 28 |
|        | 0.043 40 | – | – | 0.214 16 | B_2 | 0.066 34 | – | – | 0.196 17 |
|        | 0.251 9 | – | – | 0.196 17 | B_3 | 0.175 16 | – | – | 0.186 18 |
|        | 0.281 6 | – | – | 0.177 19 | B_4 | 0.137 24 | – | – | 0.067 34 |
| C      | 0.052 6 | – | – | 0.079 5 | C_1 | 0.632 1 | – | – | 0.333 4 |
|        | 0.158 21 | – | – | 0.333 5 | C_2 | 0.211 12 | – | – | 0.333 6 |
| D      | 0.278 1 | 0.131 4 | 0.232 2 | D_1 | 0.067 32 | – | – | 0.247 12 |
|        | 0.105 26 | – | – | 0.268 9 | D_2 | 0.150 32 | – | – | 0.268 9 |
|        | 0.175 16 | – | – | 0.186 18 | D_3 | 0.260 8 | – | – | 0.351 3 |
|        | 0.281 6 | – | – | 0.177 19 | D_4 | 0.345 3 | – | – | 0.080 30 |
| E      | 0.037 7 | 0.140 3 | 0.038 7 | E_1 | 0.165 19 | – | – | 0.319 7 |
|        | 0.300 4 | 0.455 4 | 0.218 15 | E_2 | – | – | 0.091 13 | – | – |
|        | 0.209 13 | – | – | 0.167 22 | E_3 | – | – | 0.173 20 |
| F      | 0.054 5 | 0.111 5 | 0.050 6 | F_1 | 0.170 18 | – | – | 0.288 8 |
|        | 0.223 11 | 0.154 11 | 0.100 27 | F_2 | – | – | 0.173 20 |
|        | 0.276 7 | 0.484 3 | 0.044 40 | F_3 | – | – | 0.203 10 |
|        | 0.121 25 | 0.284 7 | 0.253 11 | F_4 | – | – | 0.253 11 |
|        | 0.145 23 | – | – | 0.253 11 | F_5 | – | – | 0.062 36 |
parameters are usually not considered in the economic evaluation of projects and even in the financial risk analysis of projects. Applying these factors to investment decisions can provide sufficient confidence to investors, lenders, financiers, society, and even the workforce for continual and sustainable production and profitability. Therefore, in this paper, investment risk criteria in mining projects and their sub-criteria were identified through field research and prioritized according to the type of mining projects. Also, due to the qualitative measurement of some of the mentioned parameters, fuzzy calculations have been combined and applied with decision-making techniques.

Based on the results, financial, commercial, technical, HSE, infrastructure, geological, political, security, and legal risk assessments are the risk criteria for investing in projects. Furthermore, the types of sub-criteria that can be used to assess these risk criteria were identified. This study presented a methodology based on fuzzy Delphi, DEMATEL, and ANP methods for estimating weights and prioritizing risk criteria and their sub-criteria according to the type of mining project to analyze the identified criteria and sub-criteria. According to the results obtained from investment risk assessment in mineral exploitation projects, technical, financial, and commercial risk criteria, infrastructure, and geological considerations are the most important criteria. The most important financial and commercial, technical, infrastructure, and geological risk criteria are investing risk assessment in mineral processing projects. From the perspective of investment risk assessment in mineral exploration projects, the geological risk factor is essential.

All risk criteria, especially more important ones, should be reflected to make a reasonable investment in the sector. Since investors are dealt with multiple quantitative and qualitative criteria in assessing the investment risk on mining projects, multi-criteria decision-making methods will be beneficial in prioritizing the risk of different mining projects. Since the main investment risk criteria and sub-criteria in mining projects were successfully identified,
screened, and prioritized in this study, the next step of this research would be establishing an investment risk assessment framework, which enables investors to make reasonable decisions. Many methods can be used for this aim, such as the Fuzzy Comprehensive Evaluation (FCE) Method. The FCE method is based on fuzzy mathematics. It allows decision-makers to use quantitative and qualitative criteria and then classify the level of risk. Thus, further research will assess the possibility of using this method to classify the level of investment risk in mining projects.

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