RGNZ/MGPB

Selection of the safety risk analysis technique most compatible with nature, requirements and resources of mining projects using an integrated Folchi-AHP method

Rudarsko-geološko-naftni zbornik
(The Mining-Geology-Petroleum Engineering Bulletin)
UDC: 622.8, 331.4
DOI: 10.17794/rgn.2022.3.4

Original scientific paper

Arman Hazrathosseini[1]

[1]*Department of Mining and Metallurgical Engineering, Amirkabir University of Technology, Hafez 424, Tehran, 15875-4413 Iran, ORCID 0000-0002-1615-6697*

Abstract

There are numerous safety risk analysis techniques. Moreover, no ideal method exists for all companies; hence, the selection of the method most congruous with nature of the intended project, as well as the needs and resources of a mining company is of particular significance. To address the issue, a mathematical model has been developed with the aid of the Folchi-AHP method, whereby safety experts can opt for the best technique after multiplying an impacting factors matrix by a correlation matrix. The former is created by the safety team in the decision-making time, and includes 15 evaluation criteria, while the latter is comprised of the relative weight of each criterion to each technique. To find these weights, 22 methods were compared to each other in terms of 15 criteria by 10 safety experts using the analytic hierarchy process (AHP). To ease computations, an Excel program was developed and investigated in four mining projects.

Keywords:

risk analysis technique; evaluation criterion; AHP method; Folchi method; mining project

1. Introduction

In an estimation by the International Labour Organization (ILO), 2.3 million out of 340 million occupational incidents occurred annually worldwide end in fatalities, i.e. there are 6000 deaths on a daily basis (**ILO, 2021**). Previous records indicate that various industries' employees are all exposed to work-related accidents in a different way (**Dudarev et al., 2013**). Owing to its unique working conditions, mining is counted among the most life-threatening professions in the world; therefore, adopting the appropriate precluding measures is imperative (**Mijalkovski et al., 2020, Tripathy and Ala, 2018**). Safety has become a weighty issue within the mining industry, and so has its improvement for the authorities (**Bagherpour et al., 2015**). The Statistical Center of Iran reports 1775 mining accidents, 46 casualties and a fatality rate of 4.3 in 10000 workers in 2019 (**SCI, 2021**), while the fatality rate in a country such as the United States is 1.22, i.e. almost one third (**MSHA, 2021**), setting alarm bells off about safety in the mining sector.

In ISO 8402, safety is defined as a situation, in which the probability of damages to individuals or property has been contained up to an acceptable extent (**ISO 8402, 1994**). To put it differently, safety is a set of conditions to minimize the danger caused by an accident. The word accident signifies some difficulties in its prediction and prevention; hence, we deal with uncertainty or risk. The risk of a project is an incident posing negative or positive impacts on the project's main goals, including time, cost and quality if it takes place (**Larson and Gray, 2015**). The science of identification, assessment, control and response to risks in a project's lifetime is referred to as risk management, the centerpiece of which is risk analysis including hazard identification and risk assessment (**Aven, 2015**). Among dozens of miscellaneous risks in a project, work-related safety and health hazards are of great importance, deserving careful attention (**ISO 31000, 2009**).

Safety risk analysis determines systematically not only what hazards exist in a worksite, but it also estimates their occurrence and severity. Some techniques are adopted for hazard identification, and others for risk assessment. Of course, a number of methods demonstrate both capabilities. Furthermore, they are categorized into two general groups as quantitative and qualitative, and three subclasses of determinative, probabilistic and hybrid methods (**Tixier et al., 2002**). On this account, these techniques are varied in terms of approach and application scope, numbering above 100 (**Ericson, 2015**). For instance, **Saat** (**2009**) investigated 150 risk analysis methods for a construction site in Turkey. On the grounds of their high number, and various outputs, steps and functions, taking an accurate and effective approach for the selection of the best technique is necessary since the output of analysis changes with the meth-

Corresponding author: Arman Hazrathosseini
e-mail address: Arman.hh@aut.ac.ir

od taken (**Gul and Guneri, 2017, Guneri et al., 2015**). Risk analysis should be predicated on the behavior of a system, and it must be compatible with the complexity of the system itself (**Foussard and Denis-Remis, 2014, Rasmussen, 1997**). The selection of the proper and efficient techniques in risk analysis and assessment is one of the most effective ways to diminish different accidents in mines (**Siahuei et al., 2021**). With all that being said, it begs the question as to how to choose the best technique with this vast diversity?

A plethora of studies have been conducted on safety analysis in different sectors and industries using only one particular technique, whereas articles considering the comparison of these techniques pale in number. **AK** (**2020**) drew a distinction among the analytic hierarchy process (AHP), Fine Kenny, failure mode and effects analysis (FMEA), process hazard analysis (PHA) and the Matrix Method in terms of five criteria in the construction sector, laying emphasis on the merging of multiple criteria decision making methods into conventional risk analysis techniques. Another comparison was made by **Koçak** (**2019**) in which four techniques including FMEA, Bowtie Analysis, Job Safety Analysis and the Matrix Method were evaluated by seven criteria in a coal mine using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and the second technique was recognized as the most appropriate one. **Shahba et al.** (**2016**) prioritized environmental risk analysis techniques by adoption of the same approach, and FMEA turned out to be the most capable method with regard to six criteria. **Guneri et al.** (**2015**) compared three techniques with respect to four criteria by resorting to FAHP in a Turkish company, hallmarking FMEA as the most suitable method. Risk analysis techniques in the construction industry were reviewed and discussed by **Sharma and Goyal** (**2015**) suggesting the application of fuzzy logic for more precision in results. In another study, **Chemweno et al.** (**2015**) took an analytic network process (ANP) approach to propose a methodology for the selection of a technique among FMEA, fault tree analysis (FTA) and Bayesian Networks based on eight decision criteria in an asset maintenance decision-making domain. **Mohamadfam et al.** (**2015**) compared the two methods of management oversight and risk tree (MORT) and Tripod-Beta with respect to seven criteria using AHP in order to identify the root causes of fatal excavation accidents in the construction industry, and finally the latter was found to be superior. **Foussard and Denis-Remis** (**2014**) made a comparison among three widely-used risk assessment techniques (PHA, FMEA and Hazard and Operability Analysis (HAZOP)) within the energy sector in terms of symptoms and perspectives. They invited experts to combine these three methods in order to cover all perspectives in the triangulation of definition (functional, genetic and ontological) and avoid confusion before selecting a method in risk workshops. **Moraru et al.** (**2014**) scrutinized 19 risk assessment tools by four factors (quantitative results, uncertainty, complexity and resources) influencing the efficiency of safety management process in industrial work environments. **Kiran et al.** (**2013**) took a number of information security risk models into consideration according to multiple criteria after going through two selection iterations. **KarimiAzari et al.** (**2011**) took advantage of the fuzzy TOPSIS method to select an appropriate project risk assessment method in the construction industry based on four criteria. **Pinto et al.** (**2011**) introduced the most common occupational risk analysis methods in industry, proposing the use of fuzzy sets theory to overcome their limitations. **Marhavilas et al.** (**2011**) compared eighteen methods of risk analysis techniques in work environments with respect to twenty one criteria, but failed to provide a model for choosing the best method. **Popović and Vasić** (**2008**) first drew a differentiation between hazard analysis types and techniques, and then evaluated twenty two risk techniques from the perspective of eight attributes. Another study was devoted to mere review of the relative strengths and shortcomings of forty hazard identification techniques (**Glossop et al., 2000**).

However, the aforementioned studies are encountered with four chief drawbacks: 1) some of them have examined only a limited number of risk analysis techniques, 2) some have not considered an adequate number of evaluation criteria, 3) without introducing the best risk analysis technique, they have only classified the methods according to different criteria, 4) should they have come up with the best technique, their calculations have been predicated on the assumption of constant weights or importance for criteria, while the weight of a criterion is relative to the nature of the intended project as well as the needs and resources of the organization in charge. The high fatality rate in the mining industry on the one hand, and the shortcomings of previous studies on the other hand, emphasize the need for an accurate and effective framework for selecting the most appropriate risk analysis method according to a project's specifications, and the needs and resources of the organization implementing the project. The current study endeavors to fill the research gap by proposing a novel selection methodology explained in the next section.

2. Methodology

A schematic view of the general research procedure is depicted in **Figure 1**. First of all, a number of methods for the identification and assessment of hazards are selected from prevalent methods. Then, by studying previous research studies and relevant standards, an array of criteria for the evaluation of risk analysis techniques are considered. In the next step, a questionnaire will be designed and forwarded to safety experts in an attempt to gather input data for AHP so that a database is established in the output in which methods are classified according to each criterion. The weighted matrix obtained from AHP will provide the arrangements for the implementation of a method

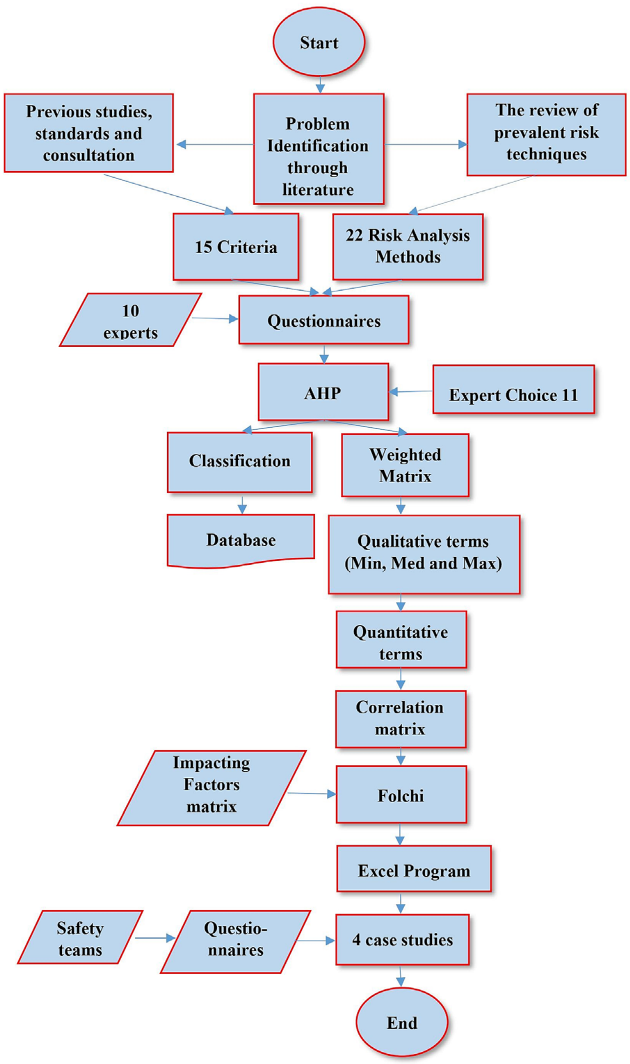


Figure 1: An overview of the research process

called Folchi. For ease of computation, a software will also be developed in the form of an Excel program. Finally, the performance of the proposed model in this research will be put to the test in four mining projects. The plentitude of Multi-Criteria Decision-Making (MCDM) Methods might beg the question as to why AHP and Folchi methods have been taken advantage of in this research, but it is worth mentioning that the conventional AHP method is not only straightforward but also well-known, rendering its application more convenient for both opinion surveyors and participants (experts). Regarding the Folchi method, it provides an opportunity to manipulate and justify the weights of criteria and alternatives according to the needs and resources of a safety team in the time of decision-making.

2.1. Risk Analysis Techniques and Evaluation Criteria

There is a myriad of methods for risk assessment and identifying hazards, of which 22 common methods were selected as follows: Preliminary Hazard Analysis (PHA), Subsystem Hazard Analysis (SSHA), Safety Requirements/Criteria Analysis (SRCA), Operating And Support Hazard Analysis (O&SHA), Health Hazard Assessment (HHA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Failure Modes And Effects Analysis (FMEA), Management Oversight And Risk Tree (MORT), Fault Hazard Analysis (FHA), Functional Hazard Analysis (FuHA), Hazard And Operability Analysis (HAZOP), Structured What If Technique (SWIFT), Energy Trace & Barrier Analysis (ETBA), William Fine Method (Wi-Fi), Job Safety Analysis (JSA), Layer Of Protection Analysis (LOPA), Cause-Consequence Analysis (CCA), Root Cause Analysis (RCA), Change Analysis (CA), Hazard Identification (HAZID), and Hazard Analysis (HAZAN).

According to ISO 31010, in general, the appropriate risk analysis method should have the following characteristics: 1) it should be justifiable and appropriate to the situation or organization under consideration, 2) it should provide results in a form which enhances the understanding of the nature of the risk and how it can be treated, 3) it should be capable of use in a manner that is traceable, repeatable and verifiable (**ISO 31010, 2010**). Once the decision is made to perform a risk assessment, the following factors should be noted: the objectives of the study, the needs of the decision-makers, the potential magnitude of the consequences, the degree of expertise, human and other resources needed, and the availability of information and data. Other criteria can be sought and elicited from previous studies (**AK, 2020, Glossop et al., 2000, KarimiAzari et al., 2011, Kiran et al., 2013, Koçak, 2019, Marhavilas et al., 2011, Mohamadfam et al., 2015, Moraru et al., 2014, Popović and Vasić, 2008, Shahba et al., 2016**). According to these research studies, the factors stated in the ISO standard, and after consultation with some safety experts, 15 criteria were selected to evaluate the risk analysis methods in this study. Each criterion has been defined and accompanied by the justification of its choice in **Table 1**.

2.2. AHP Method

Analytic hierarchy process is one of the most powerful multi-criteria decision-making techniques introduced in 1971 by Thomas L. Saaty, and was considerably welcomed by the scientific community (**Saaty, 1980**). In this method, a decision-making problem is divided into different levels of a goal, criteria, sub-criteria and alternatives. To build a decision model, at the top level is the goal, in the middle level or levels are the criteria, while the bottom level contains possible alternatives, and thus everything is placed to form a hierarchical structure. Experts are then asked through a questionnaire about the pairwise comparison of criteria with each other, and the comparison of each alternative in terms of each criterion to establish pairwise comparison matrices in which the relative weights of the elements are defined. The degree of consistency can also be calculated and judged as ac-

Table 1: Chosen criteria for comparison of risk analysis techniques in the current research

Code	Criterion	Definition	Justification of choice
C_1	Equipment orientation	Applicability of the method to analyze the hazards associated with equipment	Some methods are more capable for the risk analysis of equipment, machinery and devices (**Marhavilas et al., 2011**)
C_2	Multiple risk orientation	Applicability of the method to analyze multiple tasks in the studied site	Some methods are more capable of evaluating the effect of several tasks on each other (**Marhavilas et al., 2011**)
C_3	Individual risk orientation	Applicability of the method to analyze a single task in the studied site	Some methods are more suitable for a certain task (**Marhavilas et al., 2011**)
C_4	Process orientation	Applicability of the method to analyze risks in process systems	Some methods are more suitable for process-based tasks (**Marhavilas et al., 2011**)
C_5	Time	The relative amount of time required for the analysis	In some projects, time might be a deciding factor (**Glossop et al., 2000, Kiran et al., 2013, Mohamadfam et al., 2015, Popović and Vasić, 2008, Shahba et al., 2016**)
C_6	Cost	The relative cost of the technique	Some methods are expensive to run (**Glossop et al., 2000, KarimiAzari et al., 2011, Mohamadfam et al., 2015, Popović and Vasić, 2008, Shahba et al., 2016**)
C_7	Quantitative results	Risk Analysis is performed qualitatively or quantitatively.	Quantitative methods are generally more desirable (**Glossop et al., 2000, Mohamadfam et al., 2015, Moraru et al., 2014, Popović and Vasić, 2008, Shahba et al., 2016**)
C_8	Complexity	The relative complexity of the technique	Some methods are complex to understand and implement (**KarimiAzari et al., 2011, Kiran et al., 2013, Moraru et al., 2014, Popović and Vasić, 2008**)
C_9	Tools	The technique is standalone or additional tools are necessary	Some methods require more tools (sampling tools, software, etc.), which limits their use (**Mohamadfam et al., 2015, Moraru et al., 2014, Popović and Vasić, 2008**)
C_{10}	Expertise	Relative technical expertise and experience required	Implementing some methods requires a team of experts (**Kiran et al., 2013, Mohamadfam et al., 2015, Popović and Vasić, 2008, Shahba et al., 2016**)
C_{11}	Input data	The level of input data required for the technique	Some methods require general data and some require detailed data. The amount of access to this information affects the choice of method (**Marhavilas et al., 2011, Popović and Vasić, 2008**)
C_{12}	Details	The level of details that can be evaluated by the technique	Some methods cover extensive details (**Kiran et al., 2013, Popović and Vasić, 2008**)
C_{13}	Accuracy	The ability of the method in identifying the maximum number of risks and accuracy of assessment parameters	The more accurate the method is, the more risks are identified (**Marhavilas et al., 2011, Shahba et al., 2016**)
C_{14}	Extent of evaluation	Does the method identify risks or assess them, or both?	Some methods are specifically designed for risk identification, and others for assessment (**Shahba et al., 2016**)
C_{15}	Operational phase	The ability to implement the method in the operational phase	Some methods are suitable for other phases of the project, such as the initial design (**Glossop et al., 2000**)

ceptable or rejected. The allowable range of the inconsistency rate is less than 0.1 (**Saaty, 2001**). After receiving completed questionnaires from each of the experts, it is necessary to combine their individual answers to form a group decision-making matrix. **Aczél and Saaty** (**1983**) demonstrated that the geometric mean method is the best way to integrate judgments in the AHP. To expedite calculations, Expert Choice 11 software (developed by Expert Choice, Inc. in Arlington, Virginia, USA) was utilized.

2.3. Folchi Method

In this study, to select the most appropriate method of risk analysis, the concept of the Folchi method was utilized, which was first introduced by Roberto Folchi to express the environmental effects of an open pit mine in Italy (**Folchi, 2003**). This method consists of three main parts, including impacting factors (IFs), decision components (DCs) and a correlation matrix. The DCs can be ranked after the multiplication of the IFs by the correlation matrix. Here, evaluation criteria and risk analysis techniques are tantamount to IFs and DCs, respectively. To establish the correlation matrix, firstly, the importance or weight of these techniques in relation to the criteria previously determined by experts in the AHP is expressed in qualitative terms, and then will be converted into a quantitative form by performing some calculations as stated by Folchi. The matrix of evaluation criteria is comprised of magnitudes (numerical values) assigned by decision makers (safety experts) according to the needs and resources of the organization and the nature of the given project. From the product of the criteria matrix and the correlation matrix, risk analysis methods are prioritized, and therefore the best method(s) can be identified according to the intended criteria.

In order to prepare the correlation matrix, it is vital to turn the integrated opinions of experts on the importance of risk analysis methods in terms of each criterion into linguistic terms of Min, Med and Max. The elements of pairwise comparison matrices obtained from the AHP are in the form of decimal numbers in the range of 1 to 9. To convert the numbers to qualitative variables, a classification is implemented, so that the range of 1 to 9 is divided into three equal parts; hence, the ranges [1-3.7], [3.7-6.4] and [6.4-9] will be allocated to the terms of Min, Med and Max, respectively. According to Folchi's instructions, the elements of this matrix are quantified by defining the maximum effect, which is twice the medium effect, and the medium effect, which is twice the minimum effect. Then, the sum of these coefficients for each DC equals 10. To put it another way, the values of X, 2X, and 4X replace the Min, Med, and Max linguistic variables, respectively in the correlation matrix already filled with qualitative terms. The sum of these values in each column must be equal to 10. After solving this simple first-degree equation, the value of x is calculated for each column, and therefore the linguistic variables become quantitative elements. Next, the matrix of IFs is multiplied by the correlation matrix to compute the effect of IFs (evaluation criteria) on each DC (risk analysis method) (**Equation 1**). For clarification, suppose that the weight of the criterion 'Time' in the 'PHA' technique is 4.3 located in the second range. Therefore, the term 'Med' is entered in the correlation matrix, and then replaced by 2X. After solving an equation in the column of 'PHA', the value of X is calculated. This way, the element of 2X is obtained. The same goes for other elements.

$$[E]_{1*m} = [F]_{1*n} * [C]_{n*m} \qquad (1)$$

Where:

E – is a (1 × m) matrix in which each element represents the amount of overall impact on each DC,

F – denotes a (1 × n) matrix in which elements represent magnitudes,

C – is an (n × m) correlation matrix. The parameters n and m are the number of IFs and DCs, respectively.

The importance or weights of the alternatives in relation to the criteria can be determined using the AHP method, thereby ranking the risk techniques. However, the Folchi method is applied in this study owing to the fact that there is a remarkable distinction between the AHP and the Folchi method. In the former, one has to run the AHP process for every specific project. To put it differently, new questionnaires must be forwarded to experts every time a risk method selection is required, whereas in the latter, a decision maker can change the impact of the weights already designated by experts in the AHP method by assigning different magnitudes in the IFs matrix. In that manner, the correlation matrix remains unchanged, and only the impacting factors determined by decision makers according to the needs and resources of the intended organization are changed in every project, bringing comfort and speed. Hence, the final rankings by both methods will be the same, but it is a matter of convenience.

2.4. Questionnaires

The first step in the AHP is to establish a hierarchical structure in which an overview of the goal, criteria, and alternatives is graphically illustrated (see **Figure 2**). The goal of the AHP in this study is the classification of 22 risk analysis methods with respect to 15 criteria. The next step is the design of survey questionnaires. Here, instead of pair comparisons of criteria and alternatives, another approach will be taken into consideration in order to reduce the number of enquiries. That is to say, firstly, the grades of 1 to 9 are allocated by experts to the least and the most important criterion in that order. Then, other criteria are graded based on these two criteria. The same goes for the grading of the alternatives. Finally, one can calculate the preference of criterion i over criterion j by means of dividing the grade of i by the grade of j so as to achieve the pairwise comparison matrices required to run the AHP. For taking the influence of the personal characteristics of experts in the survey (the qualification level (B.Sc, M.Sc or PhD), discipline, and job experience) into account, experts are asked to compare the importance of these three factors at the beginning of the questionnaire. Then, the opinions of participants will be combined according to the weight obtained for each expert to be used in the formation of the final pairwise comparison matrices.

The structure of the questionnaire was designed so that the hierarchical structure was presented along with the tables related to the definition of criteria and alternatives at the beginning. Following this, experts were requested to complete their personal information before determining the importance of those three factors. The next step is the main part of the survey, in which the experts compare criteria and alternatives with each other. This questionnaire contains 350 enquiries and was sent to 10 experts in the field of health, safety and environment in Iran.

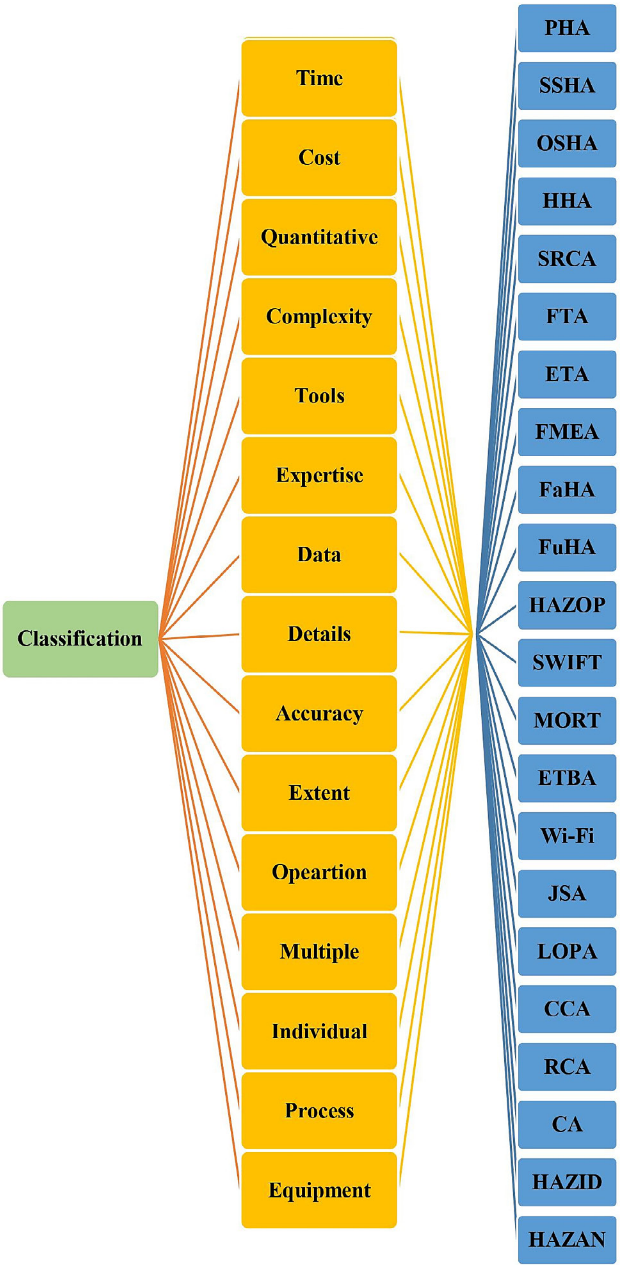


Figure 2: The hierarchical structure in the AHP

3. Results and discussion

This section consists of the risk techniques classification, the selection of the most appropriate technique, and the Excel program.

3.1. Classification of Risk Analysis Methods

It took experts nearly two weeks to fill out the questionnaires. The number of experts with bachelor's and master's degrees was 6 and 4, respectively. The discipline of industrial safety engineering had the highest frequency among participants. The average job experience was found to be 8.5 years. Experts considered the importance of job experience more than discipline, and the discipline more than the qualification level. Then, the influence of each expert was calculated and, their opinions were integrated using the method of geometric mean. In the next step, these combined grades were divided among each other to create elements of paired comparison matrices as input data for the Expert Choice software.

At the output of the software, risk analysis methods were classified according to various criteria, and a database was established to raise decision makers' awareness about the attributes of risk analysis techniques (see **Table 2**). It should be noted that the inconsistency rate in the software was turned out to be 0.035, indicating the accuracy and reliability of judgments. Sensitivity analyses made it apparent that these methods showed the highest fluctuations to the criterion of "Quantitative", and the least fluctuations to "Accuracy" and " Extent of evaluation". However, the main purpose of the current research is to create a framework for selecting the most appropriate risk analysis method according to the nature of the project, the needs and resources of the organization, which will be discussed in the next section.

3.2. Selection of the Most Appropriate Technique

In the previous section, 22 risk analysis methods were compared and classified in terms of 15 diverse criteria. However, in this study, the main purpose of implementing the AHP was to collect and integrate the opinions of experts to form a correlation matrix needed in the Folchi method. The numerical opinions of experts were replaced by linguistic variables, and then quantified by equaling the sum of each column to 10, as previously explained. The final correlation matrix is shown in **Table 3**. The criteria matrix is formed by a safety team in the studied project in the time of decision-making, with experts assigning a magnitude between 1 and 9 to each of the 15 evaluation criteria. The magnitudes of 1 and 9 convey the idea that a criterion is barely and highly important in the perspective of the safety experts, respectively. Then, a score is calculated for each risk analysis method by multiplying the criteria matrix by the correlation matrix using **Equation 1**. The method receiving the highest score is the most consistent method with the nature of a project, the needs and resources of the company conducting the project.

3.3. The Excel Program

In order to facilitate the computations of selecting the most appropriate risk analysis method by the Folchi method, a program was written in the Excel 2016 software (developed by Microsoft, Washington, USA), the overview of which is shown in **Figure 3**. The program file contains two worksheets. The first one contains tables explaining the criteria, risk analysis methods, and definitions of magnitudes ranging from 1 to 9. The sec-

Table 2: Classification of risk analysis methods with regard to criteria

Criterion / Rank	Time	Cost	Quantitative results	Complexity	Tools	Expertise	Data	Details	Accuracy	Extent	Operational	Multiple	Individual	Process	Equipment
1	HHA	JSA	Wi-Fi	JSA	JSA	SWIFT	SWIFT	FTA	HAZOP	FMEA	FMEA	HAZID	JSA	HAZOP	FMEA
2	PHA	Wi-Fi	FMEA	RCA	FMEA	CA	PHA	FMEA	Wi-Fi	SSHA	JSA	RCA	SRCA	SRCA	HAZID
3	SWIFT	RCA	FTA	SWIFT	RCA	JSA	OSHA	HAZOP	JSA	JSA	HAZID	SRCA	RCA	CCA	LOPA
4	HAZAN	HAZAN	HAZAN	HAZID	CCA	RCA	HAZID	Wi-Fi	FTA	ETBA	RCA	HAZAN	CCA	RCA	HAZAN
5	HAZID	OSHA	HAZID	HHA	Wi-Fi	FMEA	CA	HAZID	FMEA	LOPA	HAZAN	SSHA	SSHA	SSHA	CCA
6	OSHA	HHA	SRCA	FMEA	MORT	PHA	HAZAN	ETBA	SRCA	FTA	CA	FaHA	HAZAN	FTA	RCA
7	JSA	PHA	ETA	PHA	FTA	HAZID	JSA	HAZAN	ETBA	FuHA	Wi-Fi	Wi-Fi	FTA	OSHA	SSHA
8	RCA	FuHA	LOPA	CA	SWIFT	OSHA	FaHA	CCA	LOPA	OSHA	CCA	FMEA	ETA	SWIFT	ETA
9	CA	CA	HHA	HAZAN	PHA	HAZAN	FMEA	ETA	CCA	Wi-Fi	SRCA	PHA	FMEA	PHA	SRCA
10	FaHA	SRCA	ETBA	FuHA	ETA	ETA	SSHA	FaHA	HAZID	HAZAN	LOPA	FTA	PHA	MORT	JSA
11	CCA	FMEA	OSHA	CCA	CA	CCA	HHA	FuHA	SSHA	HHA	SWIFT	MORT	HHA	ETA	PHA
12	SSHA	CCA	HAZOP	Wi-Fi	HAZID	SSHA	SRCA	MORT	RCA	SRCA	FuHA	JSA	FaHA	Wi-Fi	FTA
13	FuHA	HAZID	PHA	SSHA	HAZAN	FaHA	FuHA	JSA	CA	HAZOP	OSHA	ETA	LOPA	FMEA	FaHA
14	MORT	SSHA	SSHA	SRCA	SRCA	Wi-Fi	RCA	RCA	HAZAN	CCA	ETBA	SWIFT	HAZID	HAZID	Wi-Fi
15	Wi-Fi	ETA	FuHA	ETA	FaHA	HHA	MORT	CA	HHA	HAZID	MORT	CA	FuHA	HAZAN	HAZOP
16	SRCA	FaHA	MORT	MORT	OSHA	FuHA	CCA	LOPA	FaHA	RCA	FaHA	LOPA	Wi-Fi	FaHA	OSHA
17	FMEA	SWIFT	JSA	OSHA	HHA	MORT	ETA	SRCA	ETA	PHA	HAZOP	CCA	CA	LOPA	MORT
18	ETBA	MORT	FaHA	FaHA	SSHA	SRCA	Wi-Fi	OSHA	MORT	FaHA	ETA	HHA	OSHA	CA	HHA
19	FTA	FTA	CA	FTA	FuHA	FTA	FTA	SSHA	PHA	SWIFT	SSHA	FuHA	HAZOP	FuHA	ETBA
20	ETA	ETBA	CCA	ETBA	LOPA	LOPA	LOPA	PHA	OSHA	CA	HHA	ETBA	SWIFT	ETBA	CA
21	LOPA	LOPA	RCA	LOPA	ETBA	ETBA	ETBA	HHA	FuHA	ETA	FTA	HAZOP	ETBA	JSA	FuHA
22	HAZOP	HAZOP	SWIFT	HAZOP	HAZOP	HAZOP	HAZOP	SWIFT	SWIFT	MORT	PHA	OSHA	MORT	HHA	SWIFT

ond worksheet consists of three main parts: the correlation matrix, the criteria matrix and an answer section. After entering the magnitudes of the evaluation criteria in the relevant section, the final scores of the risk analysis methods are calculated automatically, and the top 5 methods are marked in green. At the same time, a bar chart of methods' rankings is drawn according to resultant scores.

The program's user manual includes the following steps: 1) the perusing of tables related to the description of criteria, risk analysis methods and magnitudes in the first worksheet in the Excel file, 2) holding workshops by the safety team to contemplate and determine the magnitude of evaluation criteria according to the nature of the given project, needs and resources of the organization, 3) entering the magnitudes in the relevant section in the second worksheet, 4) observation of the risk analysis methods' rankings in a bar chart, 5) and review and making the final decision about the top 5 methods proposed by the program.

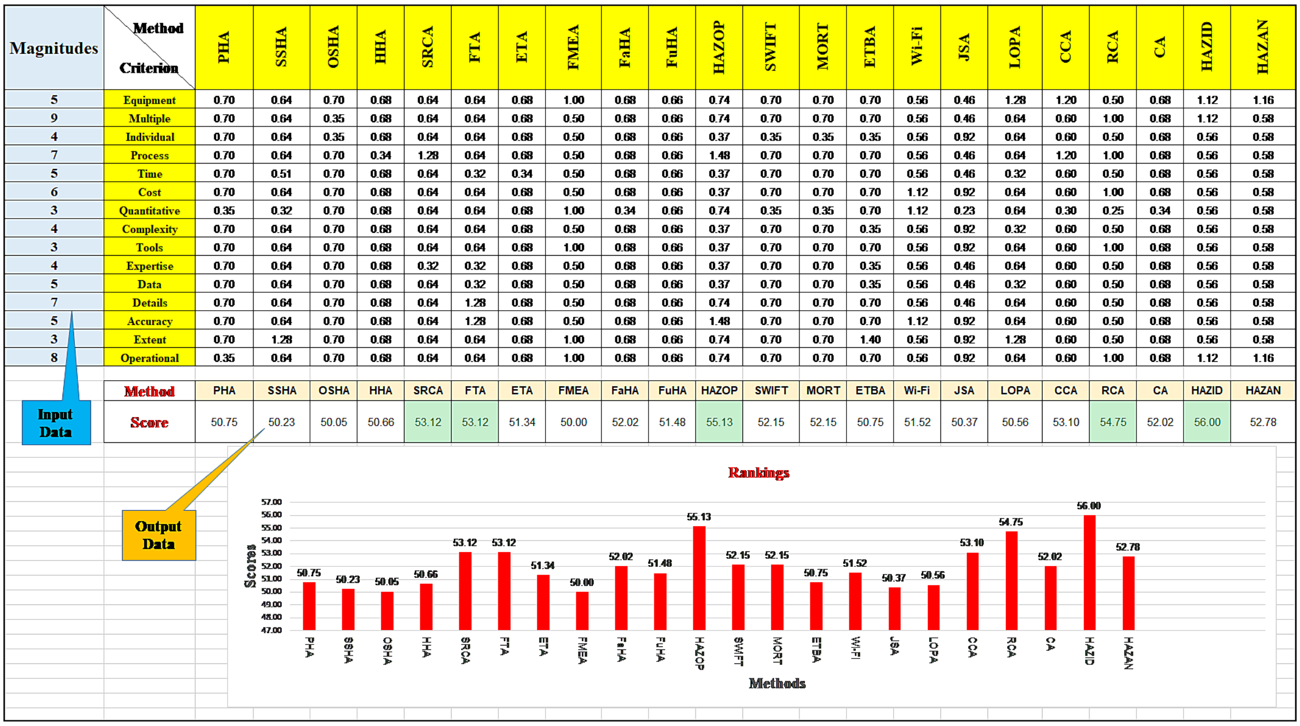
3.4. Case Studies

The proposed model was applied to four mining projects (two stone quarries, a metal mine and a coal mine) to evaluate its performance. To this end, a questionnaire was designed and sent to each mine's safety team, in which they were asked to first identify the topic of the risk analysis project they were working on. In the next step, they were requested to determine which of the 22 risk analysis methods considered in this study is more appropriate for their project based on their experience and knowledge. Finally, at the end of the questionnaire, they assigned a magnitude between 1 and 9 to each of the fifteen evaluation criteria as the input data to the Excel program. Having been run by the author of the present research, the program indicated the most appropriate risk analysis methods for each project in the output.

In **Table 4**, the proposed-top-five methods by the program have been compared with the proposed method of

Table 3: The final correlation matrix consisting risk analysis methods and evaluation criteria

Criterion \ Method	PHA	SSHA	OSHA	HHA	SRCA	FTA	ETA	FMEA	FaHA	FuHA	HAZOP	SWIFT	MORT	ETBA	Wi-Fi	JSA	LOPA	CCA	RCA	CA	HAZID	HAZAN
Equipment	0.7	0.64	0.7	0.68	0.64	0.64	0.68	1.00	0.68	0.66	0.74	0.7	0.7	0.7	0.56	0.46	1.28	1.2	0.5	0.68	1.12	1.16
Multiple	0.7	0.64	0.35	0.68	0.64	0.64	0.68	0.50	0.68	0.66	0.74	0.7	0.7	0.7	0.56	0.46	0.64	0.6	1	0.68	1.12	0.58
Individual	0.7	0.64	0.35	0.68	0.64	0.64	0.68	0.50	0.68	0.66	0.37	0.35	0.35	0.35	0.56	0.92	0.64	0.6	0.5	0.68	0.56	0.58
Process	0.7	0.64	0.7	0.34	1.28	0.64	0.68	0.50	0.68	0.66	1.48	0.7	0.7	0.7	0.56	0.46	0.64	1.2	1	0.68	0.56	0.58
Time	0.7	0.64	0.7	0.68	0.64	0.32	0.34	0.50	0.68	0.66	0.37	0.7	0.7	0.7	0.56	0.46	0.32	0.6	0.5	0.68	0.56	0.58
Cost	0.7	0.64	0.7	0.68	0.64	0.64	0.68	0.50	0.68	0.66	0.37	0.7	0.7	0.7	1.12	0.92	0.64	0.6	1	0.68	0.56	0.58
Quantitative results	0.35	0.32	0.7	0.68	0.64	0.64	0.68	1.00	0.34	0.66	0.74	0.35	0.35	0.7	1.12	0.23	0.64	0.3	0.25	0.34	0.56	0.58
Complexity	0.7	0.64	0.7	0.68	0.64	0.64	0.68	0.50	0.68	0.66	0.37	0.7	0.7	0.35	0.56	0.92	0.32	0.6	0.5	0.68	0.56	0.58
Tools	0.7	0.64	0.7	0.68	0.64	0.64	0.68	1.00	0.68	0.66	0.37	0.7	0.7	0.7	0.56	0.92	0.64	0.6	1	0.68	0.56	0.58
Expertise	0.7	0.64	0.7	0.68	0.32	0.32	0.68	0.50	0.68	0.66	0.37	0.7	0.7	0.35	0.56	0.46	0.64	0.6	0.5	0.68	0.56	0.58
Data	0.7	0.64	0.7	0.68	0.64	0.32	0.68	0.50	0.68	0.66	0.37	0.7	0.7	0.35	0.56	0.46	0.32	0.6	0.5	0.68	0.56	0.58
Details	0.7	0.64	0.7	0.68	0.64	1.28	0.68	0.50	0.68	0.66	0.74	0.7	0.7	0.7	0.56	0.46	0.64	0.6	0.5	0.68	0.56	0.58
Accuracy	0.7	0.64	0.7	0.68	0.64	1.28	0.68	0.50	0.68	0.66	1.48	0.7	0.7	0.7	1.12	0.92	0.64	0.6	0.5	0.68	0.56	0.58
Extent	0.7	1.28	0.7	0.68	0.64	0.64	0.68	1.00	0.68	0.66	0.74	0.7	0.7	1.4	0.56	0.92	1.28	0.6	0.5	0.68	0.56	0.58
Operational	0.35	0.64	0.7	0.68	0.64	0.64	0.68	1.00	0.68	0.66	0.74	0.7	0.7	0.7	0.56	0.92	0.64	0.6	1	0.68	1.12	1.16
Total	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10



Magnitudes	Criterion \ Method	PHA	SSHA	OSHA	HHA	SRCA	FTA	ETA	FMEA	FaHA	FuHA	HAZOP	SWIFT	MORT	ETBA	Wi-Fi	JSA	LOPA	CCA	RCA	CA	HAZID	HAZAN
5	Equipment	0.70	0.64	0.70	0.68	0.64	0.64	0.68	1.00	0.68	0.66	0.74	0.70	0.70	0.70	0.56	0.46	1.28	1.20	0.50	0.68	1.12	1.16
9	Multiple	0.70	0.64	0.35	0.68	0.64	0.64	0.68	0.50	0.68	0.66	0.74	0.70	0.70	0.70	0.56	0.46	0.64	0.60	1.00	0.68	1.12	0.58
4	Individual	0.70	0.64	0.35	0.68	0.64	0.64	0.68	0.50	0.68	0.66	0.37	0.35	0.35	0.35	0.56	0.92	0.64	0.60	0.50	0.68	0.56	0.58
7	Process	0.70	0.64	0.70	0.34	1.28	0.64	0.68	0.50	0.68	0.66	1.48	0.70	0.70	0.70	0.56	0.46	0.64	1.20	1.00	0.68	0.56	0.58
5	Time	0.70	0.51	0.70	0.68	0.64	0.32	0.34	0.50	0.68	0.66	0.37	0.70	0.70	0.70	0.56	0.46	0.32	0.60	0.50	0.68	0.56	0.58
6	Cost	0.70	0.64	0.70	0.68	0.64	0.64	0.68	0.50	0.68	0.66	0.37	0.70	0.70	0.70	1.12	0.92	0.64	0.60	1.00	0.68	0.56	0.58
3	Quantitative	0.35	0.32	0.70	0.68	0.64	0.64	0.68	1.00	0.34	0.66	0.74	0.35	0.35	0.70	1.12	0.23	0.64	0.30	0.25	0.34	0.56	0.58
4	Complexity	0.70	0.64	0.70	0.68	0.64	0.64	0.68	0.50	0.68	0.66	0.37	0.70	0.70	0.35	0.56	0.92	0.32	0.60	0.50	0.68	0.56	0.58
3	Tools	0.70	0.64	0.70	0.68	0.64	0.64	0.68	1.00	0.68	0.66	0.37	0.70	0.70	0.70	0.56	0.92	0.64	0.60	1.00	0.68	0.56	0.58
4	Expertise	0.70	0.64	0.70	0.68	0.32	0.32	0.68	0.50	0.68	0.66	0.37	0.70	0.70	0.35	0.56	0.46	0.64	0.60	0.50	0.68	0.56	0.58
5	Data	0.70	0.64	0.70	0.68	0.64	0.32	0.68	0.50	0.68	0.66	0.37	0.70	0.70	0.35	0.56	0.46	0.32	0.60	0.50	0.68	0.56	0.58
7	Details	0.70	0.64	0.70	0.68	0.64	1.28	0.68	0.50	0.68	0.66	0.74	0.70	0.70	0.70	0.56	0.46	0.64	0.60	0.50	0.68	0.56	0.58
5	Accuracy	0.70	0.64	0.70	0.68	0.64	1.28	0.68	0.50	0.68	0.66	1.48	0.70	0.70	0.70	1.12	0.92	0.64	0.60	0.50	0.68	0.56	0.58
3	Extent	0.70	1.28	0.70	0.68	0.64	0.64	0.68	1.00	0.68	0.66	0.74	0.70	0.70	1.40	0.56	0.92	1.28	0.60	0.50	0.68	0.56	0.58
8	Operational	0.35	0.64	0.70	0.68	0.64	0.64	0.68	1.00	0.68	0.66	0.74	0.70	0.70	0.70	0.56	0.92	0.64	0.60	1.00	0.68	1.12	1.16

	Method	PHA	SSHA	OSHA	HHA	SRCA	FTA	ETA	FMEA	FaHA	FuHA	HAZOP	SWIFT	MORT	ETBA	Wi-Fi	JSA	LOPA	CCA	RCA	CA	HAZID	HAZAN
Input Data	Score	50.75	50.23	50.05	50.66	53.12	53.12	51.34	50.00	52.02	51.48	55.13	52.15	52.15	50.75	51.52	50.37	50.56	53.10	54.75	52.02	56.00	52.78

Figure 3: A general view of the developed Excel program

the safety team. As it is obvious, the decision makers in the Tajrood Marble Quarry, the Kulikosh Marble Quarry, and the Tabas Coal Mine regarded FMEA, Wi-Fi and FTA to be suitable, respectively, while according to the output of the Excel program, the best method for each mine is JSA, HHA and RCA, respectively.

Only the method proposed by the safety team at the Bama Mine Processing Plant was the same as the method proposed by the Excel file on the grounds that the topic of interest in that mine was process-oriented, and since the HAZOP method is known for analyzing process systems, the safety team of this mine managed to

Table 4: The comparison of the method proposed by safety teams in studied mines with methods proposed by the Excel program

Mine	Risk analysis Topic	IFs Matrix [C_1, C_2…C_{15}] created by mining companies	The proposed method by the mining company based on experience	Top five proposed methods by the Excel program
Tajrood Marble Quarry	Safety of workers	[1, 4, 5, 1, 7, 3, 4, 5, 2, 8, 8, 5, 8, 6, 8]	FMEA	JSA Wi-Fi FMEA FTA HHA
Kulikosh Marble Quarry	Respiratory diseases	[1, 3, 1, 1, 8, 6, 5, 7, 2, 3, 4, 1, 3, 4, 1]	Wi-Fi	HHA FMEA FTA JSA Wi-Fi
Bama Lead-Zinc Processing Factory	Milling and flotation equipment hazards	[9, 5, 1, 9, 8, 7, 5, 7, 2, 3, 7, 7, 6, 5, 7]	HAZOP	HAZOP LOPA OSHA SEIFT MORT
Tabas Coal Mine	Explosion in underground tunnels	[5, 9, 4, 7, 5, 6, 3, 4, 3, 4, 5, 7, 5, 3, 8]	FTA	RCA CCA FMEA FTA HAZAN

select the technique properly, whereas in other mines, practitioners failed to opt for the best method fitting the nature of the project, the needs and resources of the mining company. It is noteworthy that the method proposed by the team in the Kulikosh Quarry is the fifth method suggested by the program. This point emphasizes the importance and necessity of applying the proposed model in mining projects. Since the approach adopted here incorporates a considerable number of criteria simulataneously, it enjoys more precision than conventional decision making methods. One cannot prescribe one specific technique to all projects. Dozens of contributory factors should be taken into account, and it will not be implemented unless a systematic approach is taken. Moreover, the Excel program needs only some input data to be run, and it doesn't seem to be a daunting task, but rather a tractable one. Thus, it stands to reason to be admitted that not only is the proposed model beneficial but also applicable.

4. Managerial implications

Having been encompassed with a plethora of miscellaneous risk assessment techniques, safety experts might be inflicted by bafflement upon the technique selection process, thereby failing to engage the appropriate method. Provision of the Excel program by managers will bring benefits to mining companies in terms of financial, accuracy and safety aspects. That is to say, one can take into account multiple factors related to the nature of the given project, and feasible resources of the implementing company, and subsequently choose a more suitable technique. For instance, assume that the time and budget of a company for risk assessment is limited. Then, the user of the computer program enters lower magnitudes for these criteria, and this way time-consuming and expensive methods are faded into insignificance; thus, a more congruous result will be obtained. Managerial implications can be summarized as follows:

- the importance of drawing a distinction between various projects in terms of essence and available resources and needs;
- the requirement of a systematic framework for the selection of the best risk assessment technique;
- a greater level of safety can be realized using the novel approach proposed at a low budget. No particular financial investment is required, except for the trivial cost of the software.

5. Conclusion

Each project or organization has specific characteristics that are different from another project or organization; therefore, choosing the most compatible method with the nature of the project, needs and resources of the organization in the time of decision-making from hundreds of available methods is of paramount importance, as well as an arduous task. To address this bottleneck, a decision-making support model was introduced by combining the AHP and Folchi methods enabling the safety team in mining projects to select the most appropriate method based on the project's specifications and available resources. A user-friendly program was developed in Excel software facilitating the computational process. The suggested model in this research was evaluated in four mining projects, presenting a successful performance. The most significant advantages of this model can be enumerated as reduction in costs, increased speed and accuracy in the process of methodology selection by safety practitioners in mining projects.

Acknowledgement

The author would like to give their appreciation to the managers and engineers in the four mining companies for their sincere collaboration.

6. References

Aczél, J. & Saaty, T. L. (1983). Procedures for synthesizing ratio judgements. Journal of mathematical Psychology, 27, 1, 93-102.

Ak, M. F. (2020). Comparison of Risk Assessment Methods within the Scope of Occupational Safety in the Construction Sector. Avrupa Bilim ve Teknoloji Dergisi, 18, 272-282.

Aven, T. (2015). Risk analysis: assessing uncertainties beyond expected values and probabilities, John Wiley & Sons, 1, 115 p.

Bagherpour, R., Yarahmadi, R. & Khademian, A. (2015). Safety risk assessment of Iran's underground coal mines based on preventive and preparative measures. Human and Ecological Risk Assessment: An International Journal, 21, 8, 2223-2238.

Chemweno, P., Pintelon, L., Van Horenbeek, A. & Muchiri, P. (2015). Development of a risk assessment selection methodology for asset maintenance decision making: An analytic network process (ANP) approach. International Journal of Production Economics, 170, 663-676.

Dudarev, A. A., Karnachev, I. P. & Øyvind Odland, J. (2013). Occupational accidents in Russia and the Russian Arctic. International journal of circumpolar health, 72, 1, 20458.

Ericson, C. A. (2015). Hazard analysis techniques for system safety, John Wiley & Sons, 1, 132 p.

Folchi, R. (2003). Environmental impact statement for mining with explosives: a quantitative method. Proceedings of the annual conference on explosives and blasting technique. ISEE, 285-296.

Foussard, C. & Denis-Remis, C. (2014). Risk assessment: methods on purpose? International Journal of Process Systems Engineering, 2, 4, 337-352.

Glossop, M., Loannides, A. & Gould, J. (2000). Review of hazard identification techniques. Health Saf Lab. Health and Safety Executive, Sheffield, UK, 1, 29 p.

Gul, M. & Guneri, A. F. (2017). Use of FAHP for occupational safety risk assessment: an application in the aluminum extrusion industry, Chapman and Hall/CRC, 1, 249-272.

Guneri, A. F., Gul, M. & Ozgurler, S. (2015). A fuzzy AHP methodology for selection of risk assessment methods in occupational safety. International Journal of Risk Assessment and Management, 18, 3-4, 319-335.

Ilo (2021). World Statistic: The enormous burden of poor working conditions; International Labour Organization, URL: https://www.ilo.org/moscow/areas-of-work/occupational-safety-and-health/WCMS_249278/lang--en/index.htm (Accessed 1st August 2021).

Iso 8402 (1994). Quality Management and Quality Assurance-Vocabulary, International Organization for Standardization, www.iso.org, pages 4-6.

Iso 31000 (2009). Risk Management: Principles and Guidelines., International Organization for Standardization, www.iso.org, page 16.

Iso 31010 (2010). Risk Management–Risk Assessment Techniques International Organization for Standardization, www.iso.org, Page 13.

Karimiazari, A., Mousavi, N., Mousavi, S. F. & Hosseini, S. (2011). Risk assessment model selection in construction industry. Expert Systems with Applications, 38, 8, 9105-9111.

Kiran, K., Mukkamala, S., Katragadda, A. & Reddy, D. (2013). Performance and analysis of risk assessment methodologies in information security. International Journal of Computer Trends and Technology (IJCTT), 4, 10, 3685-3692.

Koçak, D. (2019). Bir Kömür Madeninde İş Sağlığı ve Güvenliği Risk Değerlendirmesi İçin Uygun Yöntem Seçimi (Appropriate method selection for occupational health and safety risk assessment in a coal mine), Master's thesis, Hacettepe University, 93 p, URL: http://www.openaccess.hacettepe.edu.tr:8080/xmlui/bitstream/handle/11655/6553/10236319.pdf?sequence=1 (Accessed 1st August 2021), (In Turkish, There is an English abstract).

Larson, E. W. & Gray, C. F. (2015). A Guide to the Project Management Body of Knowledge: PMBOK (®) Guide, Project Management Institute, 6, 53 p.

Marhavilas, P.-K., Koulouriotis, D. & Gemeni, V. (2011). Risk analysis and assessment methodologies in the work sites: On a review, classification and comparative study of the scientific literature of the period 2000–2009. Journal of Loss Prevention in the Process Industries, 24, 5, 477-523.

Mijalkovski, S., Peltechki, D., Zeqiri, K., Kortnik, J. & Mirakovski, D. (2020). Risk assessment at workplace in underground lead and zinc mine with application of fuzzy TOPSIS method. Journal of the Institute of Electronics and Computer, 2, 1, 121-141.

Mohamadfam, I., Soleimani, E., Ghasemi, F. & Zamanparvar, A. (2015). Comparison of management oversight and risk tree and tripod-beta in excavation accident analysis. Jundishapur journal of health sciences, 7, 1.

Moraru, R. I., Băbuț, G. B. & Cioca, L. I. (2014). Rationale And Criteria Development For Risk Assessment Tool Selection In Work Environments. Environmental Engineering & Management Journal (EEMJ), 13, 6.

Msha (2021). Fatality Reports: Coal Fatalities for 1900 Through 2020 and Metal/Nonmetal Fatalities for 1900 through 2020, Mine Safety and Health Administration, URL: https://www.msha.gov/data-reports/fatality-reports/search (Accessed 1st August 2021).

Pinto, A., Nunes, I. L. & Ribeiro, R. A. (2011). Occupational risk assessment in construction industry–Overview and reflection. Safety science, 49**,** 5**,** 616-624.

Popović, V. & Vasić, B. (2008). Review of hazard analysis methods and their basic characteristics. FME Transactions, 36**,** 4**,** 181-187.

Rasmussen, J. (1997). Risk management in a dynamic society: a modelling problem. Safety science, 27**,** 2-3**,** 183-213.

Saat, M. B. (2009). Implementation of integrated occupational health and safety risk assessment methods, checklist and matrix methods, to a construction site [Unpublished master's thesis]. Gazi University Institute of Science and Technology, Ankara, Turkey, 175 p. (in Turkish, There is an English abstract).

Saaty, T. (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation: McGraw-Hill. New York, 1**,** 78 p.

Saaty, T. (2001). How to Make and Justify Decision: The Analytic Hierarchy Process (AHP), Pittsburgh: RWS Publication. 1**,** 34 p.

Sci (2021). Survey results of Iran's active mines in 2019. Statistical Center of Iran. URL: https://ssicenter.mcls.gov.ir/icm_content/media/digitallibrary/2021/7/book873/873.pdf (Accessed 1st August 2021). 1**,** 15 p.

Shahba, S., Daryabeigi, M., Nourbakhsh, Z. & Ghaleh, S. (2016). Prioritization of risk analysis methods in environmental risk management using TOPSIS, The second conference on environmental science, engineering and technologies, Tehran, Iran, (In Persian-There is no English abstract).

Sharma, S. & Goyal, P. K. (2015). Fuzzy logic: An appropriate technique for effective risk analysis and decision making for construction projects. International Journal of Emerging Technology and Advanced Engineering, 5**,** 12**,** 71-77.

Siahuei, M. R. A., Ataei, M., Rafiee, R. & Sereshki, F. (2021). Assessment and Management of Safety Risks through Hierarchical Analysis in Fuzzy Sets Type 1 and Type 2: A Case Study (Faryab Chromite Underground Mines). Rudarsko-geološko-naftni zbornik (The Mining-Geological-Petroleum Bulletin), 36**,** 3.

Tixier, J., Dusserre, G., Salvi, O. & Gaston, D. (2002). Review of 62 risk analysis methodologies of industrial plants. Journal of Loss Prevention in the process industries, 15**,** 4**,** 291-303.

Tripathy, D. P. & Ala, C. K. (2018). Identification of safety hazards in Indian underground coal mines. Journal of Sustainable Mining, 17**,** 4**,** 175-183.

SAŽETAK

Odabir najkompatibilnije tehnike analize sigurnosnoga rizika u skladu s prirodom, zahtjevima i resursima rudarskih projekata korištenjem integrirane metode Folchi-AHP

Tehnike su analize sigurnosnoga rizika brojne. Štoviše, ne postoji idealna metoda za sve tvrtke, stoga je od posebne važnosti odabir metode koja najviše odgovara prirodi planiranoga projekta, kao i potrebama i resursima rudarske tvrtke. Kako bi se riješio problem, razvijen je matematički model uz pomoć metode Folchi-AHP, pri čemu se stručnjaci za sigurnost mogu odlučiti za najbolju tehniku nakon množenja matrice faktora utjecaja s korelacijskom matricom. Prvu kreira tim za sigurnost u vrijeme donošenja odluke i uključuje 15 kriterija evaluacije, dok se druga sastoji od relativne težine svakoga kriterija za svaku tehniku. Da bi se pronašle te težine, 10 stručnjaka za sigurnost uspoređivalo je 22 metode u okviru 15 kriterija koristeći se analitičkim hijerarhijskim procesom (AHP). Kako bi se olakšali izračuni, razvijen je program u Excelu koji je istražen u četirima rudarskim projektima.

Ključne riječi:
tehnika analize rizika, kriterij vrednovanja, metoda AHP, metoda Folchi, rudarski projekt

Author's contribution

Mr. Hazrathosseini (**M.Sc in Mining engineering**) contributed to the design, implementation of the research and the writing of the manuscript.