-RESEARCH PAPER-

International Journal of Mining and Geo-Engineering | IJMGE

IJMGE 58-2 (2024) 229-241 DOI: 10.22059/IJMGE.2024.373443.595157

Hazard identification and process risk assessment at the building stone processing company through combination of EFMEA & William fine methods

Hamid Sarkheil [a, *], Mohammad Talaeian [b], Azadeh Abbaszadeh Gorani [b] and Ali Sadeghy Nejad [a]

[a] *School of Mining Engineering, College of Engineering, University of Tehran, Tehran, Iran.*

[b] *College of Environment, Department of Environment(DOE), Iran.*

Article History:

Received: 03 March 2024.

Revised: 15 April 2024.

Accepted: 07 May 2024.

ABSTRACT

In this research, the levels of safety, health, and environmental risks in a building stone processing company (BSPC) have been identified using the integrated approach of the EFMEA (Environmental Failure Mode and Effects Analysis) and the William Fine method, along with the TOPSIS technique for prioritizing organizational safety layers, examining potential incidents, and enhancing organizational efficiency. To achieve this, data and risk assessment information were first collected and evaluated, and then, with the formation of an expert task force, brainstorming sessions were held to identify and analyze environmental risks in the production process using the EFMEA technique. Additionally, with the assistance of the William Fine method, safety and health risks in the production process were identified and examined. In the next step, the costs of corrective actions were calculated, and the results obtained from the tables of both EFMEA and William Fine techniques were combined, and decisions were made regarding risks with high and very high levels. Subsequently, using TOPSIS, protective layers were prioritized based on two criteria: cost and time. Following the risk assessment using the EFMEA method, four risks were classified as high-risk, nine risks as medium-risk, and two risks as low-risk. Subsequently, employing the William Fine technique, a total of 41 hazards were evaluated across five worksheets. 5% of the hazards were categorized as very high-risk, 19% as high-risk, 27% as medium-risk, and 49% of the evaluated hazards were classified as low-risk. Ultimately, the results obtained from the integration of the William Fine and EFMEA techniques categorized two risks as very high-risk, 12 risks as high-risk, 20 risks as medium-risk, and 22 risks as low-risk. Furthermore, working at heights was selected as one of the risks with high-risk, and protective layers and control measures were proposed and examined. The use of helmets, shoes, harnesses, and the establishment of a safety platform, considering both time and cost criteria, is the first priority for controlling risks in working at heights activity.

Keywords: *Risk assessment, EFMEA, William Fine method, TOPSIS, Building stone processing.*

1. Introduction

Industrial advancements, development programs, and infrastructure projects, despite all the benefits and advantages they bring to humanity, have been the source of many risks, hazards, and notable deficiencies. The risk assessment is a logical method for examining hazards, identifying potential dangers, and their consequences on individuals, materials, equipment, and the environment [1], [2] & [3]. In some cases, environmental health risk assessment is desired [4]. In the risk control process, the first step is identifying risks, predicting, eliminating, or reducing the likelihood of risk occurrence. Raian et al. [5], Taheri et al. [6], and Dodd et al. [7], each mentioned the importance and method of risk control in their articles. Precisely determining the events and consequences resulting from activities in large industries is a challenging task. The direct and indirect costs of these events in heavy industries are substantial. Today, due to the existence of various risk assessment methods, it is possible to identify critical and incident-prone areas before they occur. Measures can be taken to prevent and control incidents. Considering the HSE (Health, Safety, Environment) risk management approach, the identification of safety, health, and environmental hazards, along with the assessment of the likelihood of events and the severity of their consequences, is of paramount importance for protecting the health of employees and preventing environmental pollution [8], [9] & [10]. There are many criteria for identifying accidents caused by work. As Laschi pointed out in a study, identifying the causes, dynamics, and consequences of work accidents in forest operations in a mountainous context [11]. In another study, Rafyieyan et al. investigated the identification and evaluation of the main factors affecting the occurrence of on-site accidents caused by human errors in the construction projects of industrial towns [12]. Finally, the review of the studies of Castrillo [13], Abbasinia [14], Martinez [15], Zhang [16], and Zara [17] shows the importance of identifying accidents caused by work, different criteria, and methods in different sectors of industries. But the most important of them, which is

* Corresponding author. *E-mail address::* sarkheil@ut.ac.ir (H. Sarkheil).

also considered in this research, are the issues related to humans and the environment. A review of the literature and the history of the research, by the method used in this research, shows that many studies have been conducted in the internal and external dimensions in the form of safety, health and, solid risks. There are various methods for investigating and evaluating the potential risks of the activities of a project or development, depending on the required information, each method has a special efficiency in evaluating the activities [18], [19]. Among these methods, we can mention the EFMEA and Fine William, each of which includes advantages and disadvantages depending on the study environment.

Two structured and systematic techniques, the William Fine and EFMEA, are utilized for the risk assessment in identifying potential hazards and estimating the level of risk. These techniques are employed to manage and reduce risk to an acceptable level. In the EFMEA method, after identifying the machinery, location, and activities of the production units' processes, hazards and potential damaging factors are identified. Subsequently, based on the severity of the impact, the likelihood of occurrence, and the potential consequences on the environment, the process of risk assessment and classification is carried out. Accordingly, the priority risk number is calculated by multiplying three characteristics: the severity rank, the likelihood of occurrence, and the extent of environmental contamination.

For example, Petrovskiy and his colleagues conducted a reliability assessment of equipment used in the oil, gas, and petrochemical industries using the failure modes and effects analysis (FMEA) technique based on the fuzzy logic. They demonstrated that the FMEA technique, along with the fuzzy logic, can be one of the best approaches for risk assessment in industries, such as oil, gas, and petrochemicals [20]. G-Ki and his colleagues in an article titled "Risk Analysis with FTA and 4AHP in Tunnel Boring Machine" using the combined method in South Korea in 2015, identified the potential risks that cause unwanted events during tunnel excavation by the tunnel boring machine. The risks identified in this study are divided into four groups, including improper operation of the cutter, interruptions, and locking of machine parts, inappropriate design, and management issues [21]. Semin and her colleagues in an article titled "Risk assessment and its management for environmental pollution in oil refinery using FMEA approach" investigated environmental, safety, and health risks in gas condensate storage tanks in an oil refining company with the FMEA method [22]. Bahadri et al. identified and assessed the risk of Jiroft Dam in the exploitation phase using the EFMEA method. The results of this research showed that in the group of risks related to the physical or chemical environment, soil erosion, and sedimentation, in the biological environment, the risk of impacting the habitat and threatening aquatic life downstream, in the group of health and safety risks, human errors and mistakes, before, after and during exploitation, have been assigned a high level of risk [23] & [24]. Mahdavi et al. conducted an environmental risk assessment of a hydrocracker unit in Abadan oil refinery using the EFMEA analysis and the results showed that 67% of the risks associated with life cycle operations were low and 33% of them were high in severity. In contrast, 75% of the risks associated with control room operators were low and 25% high in severity [25]. The William Fine's method has been used in various industries, so that this method has been employed in assessing the risk of falling from the loading platform in the oil industry, and the results obtained are qualitative and only the levels defined in the method have been used. Thus, in this research, the impact of the evaluators' judgment in the process has been evaluated [26]. Navai et al. evaluated risk using the FINE WILLIAM method by the network analysis and DIMTEL decision-making methods to improve the risk score. The results showed that the method. Dimtel will have a better risk score in the decision network model of risk assessment and then pairwise comparisons using network analysis than using the William Fine method alone [27]. Also, Mirmelaleh et al. in the risk management in the supply chain of Iran's gas industry [28], Farmani et al. in the risk assessment and decision-making strategies of psychological, structural, social and economic factors determining suicide attempts [29] and finally, Helwani and his colleagues used the William Fine's analytical method to identify and evaluate job risks in Iran's hot-rolled steel industry [30]. In another research, Zaim Dar used two techniques of the "William Fine" and "Analysis of failure states and their effects on the environment" to evaluate the health and environmental risks of Khaneh Safali Company. The results show that the control measures given for the risks that are among numerous risks have been managed. It removed a lot and brought many risks under control, transferring most of them to the medium and low areas [31]. Jozi et al. used the EFMEA and William Fine's integrated methods to carry out an environmental risk assessment and management of the Mad iron ore mine located in Khorrambid city, and at the end, solutions were proposed for risk management, including determining operational boundaries, measuring and removing dust, and addressing noise and airplay [32].

In this study, after identifying the activities, equipment, and operations in the production process within the organization under study, hazards in the production process were identified using expert opinions and specialists during brainstorming sessions. Utilizing the EFMEA method, the possibility of environmental events, the severity of the consequences resulting from environmental events, and the extent of pollution were examined, and the priority risk number for environmental risks was calculated. Furthermore, with the assistance of the William Fine method, the possibility of health events and the severity of the consequences resulting from health events were investigated, and the risk number for health hazards and the cost of control measures were calculated.

2. Methodology

The research methodology has been diagrammed sequentially and followed by the execution stages as outlined in Figure 1.

2.1. Data and information gathering

In this section, an attempt is made to collect accessible information sources in the form of descriptive, analytical, qualitative, and quantitative information by reviewing risk assessment documents in similar companies. At this stage, the review of scientific, research, and practical records related to this topic is also done. Furthermore, by examining accidents that have occurred in similar industries, we try to identify risks based on the analysis of the root causes of past accidents, so that a more accurate risk analysis can be conducted with practical evidence.

2.2. Formation of specialized teamwork and conducting brainstorming sessions.

After gathering and categorizing the required data and information, a teamwork consisting of specialists, experts, and domain professionals is formed to conduct brainstorming sessions. These sessions aim to identify and study existing facilities, equipment, activities, and operations, as well as to identify and determine risks arising from the previously identified equipment, activities, and operations. Subsequently, this team designs worksheets for the EFMEA and William Fine techniques to record the obtained data during the brainstorming sessions.

In this stage, for designing the worksheets of each of the techniques, a final summary regarding the form and content of the worksheets will be reached through interviews with experts in the studied industry and the formation of expert meetings.

These worksheets will then be distributed among the teamwork formed to complete them. This group's work in the occupational health risks section includes five specialists with expertise in civil engineering, structures, road and construction, occupational health, industrial safety, and concrete quality control engineering. In the environmental risks section, two environmental specialists replace the occupational health and industrial safety specialists. All occupational health and environmental risks are identified based on the brainstorming method in these specialized teams and are entered into the worksheets. To

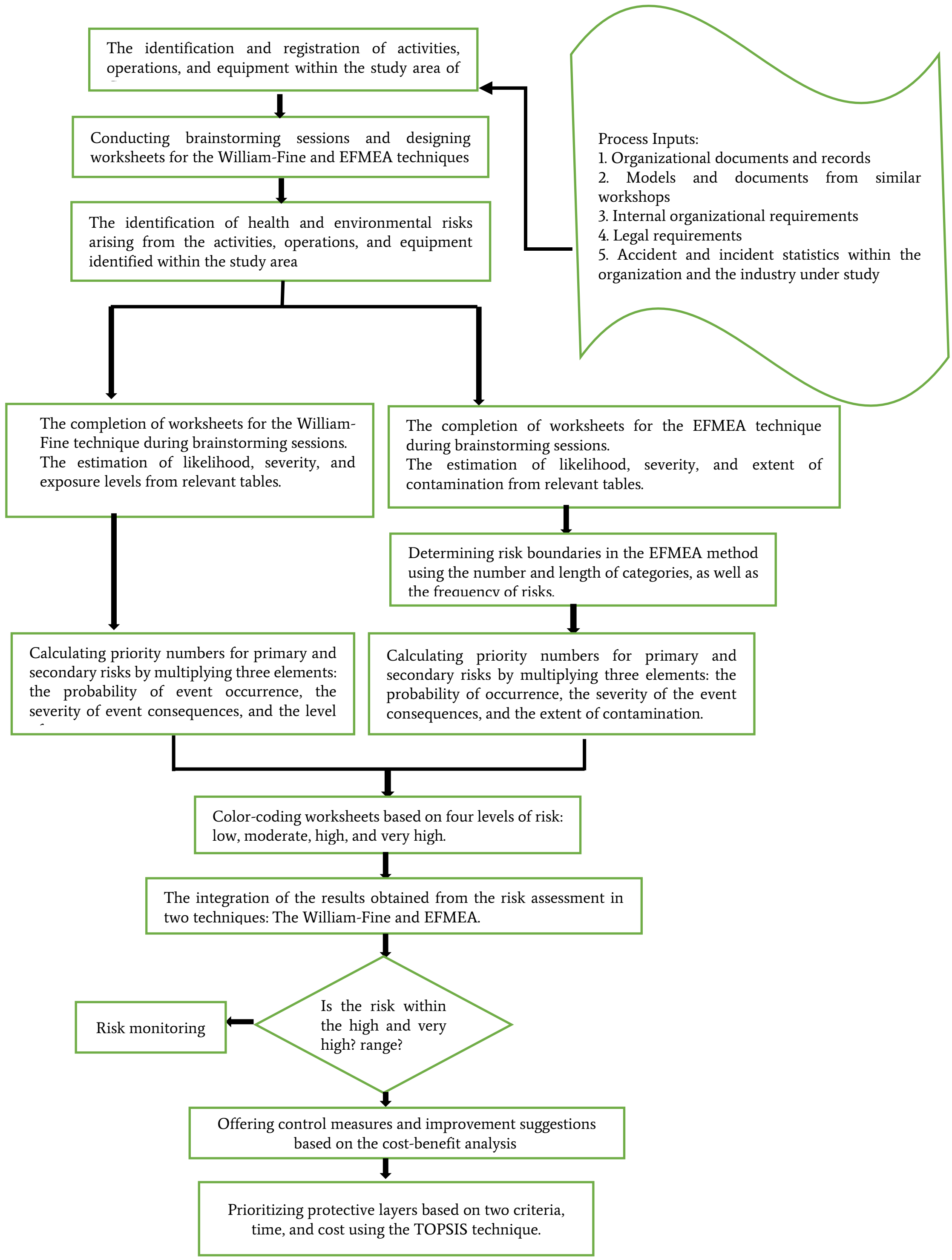

Figure 1. The Research Methodology Implementation.

complete the worksheets, brainstorming sessions are held to identify risks in different sections and score the risk components in each worksheet. Statistical calculations are then used to determine the Risk Priority Number (RPN). Finally, control measures for high and very high risks are presented, and the obtained results are provided as feedback to the management.

2.3. The identification, analysis, and assessment of environmental risks in the production process using the EFMEA technique.

In the initial phase, we identify the factors contributing to environmental pollution and perform a risk assessment using the

EFMEA method. The Environmental Failure Mode and Effects Analysis (EFMEA) techniques are used to identify paths in which components, systems, or processes may experience deficiencies and shortcomings. This allows for the consideration of these deficiencies in the design process and their mitigation to achieve the ultimate goal. This method can be employed to identify failure modes that may affect the overall reliability of the system. This approach involves three main elements: severity, occurrence probability, and extent of pollution. Therefore, each identified risk is examined for these three elements and the results are entered into a predefined table. After entering these elements, the risk number is derived from the product of these three elements. Subsequently, statistical calculations are utilized to determine risk levels based on four categories: low, moderate, high, and very high. Then, tables are displayed again, this time based on color coding to indicate the risk levels. Finally, the levels of risk are compared with each other in the generated graphs, and their frequency percentages are determined. Through this process, we can identify risks of higher importance and plan necessary measures to mitigate them.

According to the guidelines outlined in ISO 31000, the EFMEA technique must be conducted with precision through the following stages, in sequence:

- Stage One: Defining the scope and objectives of the study.
- Stage Two: The formation of a team comprised of industry experts and holding meetings.
- Stage Three: The comprehensive description of the system and process in a manner that all members are familiar with the processes and components. Additionally, this team must thoroughly understand the functions of various elements within the studied system and have complete mastery from all angles.
- Stage Four: Each of the above-mentioned executions must be collected and examined against the possibility of study failure, with the following items:
    1. How does failure or flaw occur in the system and its components?
    2. What mechanisms or factors lead to potential failures and flaws in the system?
    3. If failure occurs in any of the system components, what effects does it have?
    4. Does the created flaw in the system lead to environmental, safety, or health consequences?
    5. How can flaws in the system be identified before they occur?
- Stage Five: The identification of weaknesses in the system design.
- Stage Six: Designing the EFMEA worksheets and entering the information obtained from the above stages into these worksheets. In this stage, the relevant worksheets are prepared based on the description of activities and prominent environmental aspects, including the consequences of failures and their impact on the environment, as well as the extent of pollution. These worksheets are provided to the experts, and all the above information is entered into these tables (Table 1 and Table 2). Now, in a brainstorming session, discussions and exchanges of ideas regarding the identification of risks, their consequences, and impacts, along with their aspects, should take place. The outcomes of these sessions are then incorporated into the pre-designed worksheets. An example of such a worksheet is provided in the Table 1.
- Stage Seven: Scoring and calculating the Risk Priority Number (RPN) in EFMEA Technique. In the EFMEA technique, environmental risks are entered into the worksheets based on three components: the severity of consequences resulting from the event, the likelihood of the event occurring, and the extent of pollution. The initial and secondary risk priority numbers (RPNs) are calculated using the following relationship.

RPN= O×S ×R

In which S is Intensity, O is the Possibility of Occurrence, and R is Contamination Range.

The environmental risks and their prominent aspects have been prepared for assessment by the relevant group, and Tables 1 to 3 in the appendix are employed for scoring the risk components and calculating the risk priority number.

- Stage Eight: The determination of confidence limits and risk levels.

Following the scoring process, the initial and secondary risk priority numbers are entered into the worksheets, and statistical calculations are employed to determine the risk boundaries. By utilizing the dataset and the highest and lowest risk priority numbers, risk levels are identified for subsequent applications.

Based on this, three risk levels, namely Low, Medium, and High, are determined, which can serve as outputs recognized in the EFMEA method. Management decisions regarding acceptance or rejection of the identified risks are then made accordingly.

Table 1. The FMEA Data Recording Worksheet.

Environmental hazard identification worksheet using EFMEA method											
Date:						Revision number:				Worksheet number:	
Study phase: Product production phase						Study area: Building Stone Processing company					
Secondary Risk Assessment						Primary Risk Assessment					
Risk Priority Number (RPN)	Contamination Range (CR)	Intensity (S)	Possibility of occurrence (O)	Control measures	Risk Priority Number (RPN)	Contamination Range (CR)	Intensity (S)	Possibility of occurrence (O)	Potential damage (consequence)	Potential failure mode (environmental aspects)	Risk description

Eq 1: Formula for calculating the average of obtained risks ($\bar{X}$) [32].

$$\bar{X} = \frac{1}{N}\sum_{i=1}^{N} Xi = \frac{x_1+x_2+\cdots+x_N}{N} \quad (1)$$

Eq 2: Formula for calculating the standard deviation (σ) of obtained risks [32].

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i-\bar{X})^2} \quad (2)$$

In this method, the risk priority number obtained from Equation 1 serves as a measure of confidence or risk index. Subsequently, using Equations 3 and 4, the lower and upper limits of the risk are determined.

Eq 3: The formula for calculating the lower limit of risk [32].

$$< \left(\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i-\bar{X})^2}\right) - \left(\bar{X} = \frac{1}{N}\sum_{i=1}^{N} Xi = \frac{x_1+x_2+\cdots+x_N}{N}\right) \quad (3)$$

Equation 4: The formula for calculating the upper limit of risk [32].

$$\left(\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i-\bar{X})^2}\right) + \left(\bar{X} = \frac{1}{N}\sum_{i=1}^{N} Xi = \frac{x_1+x_2+\cdots+x_N}{N}\right) < \text{upper bound of risk} \quad (4)$$

And risks between these two values (x_i) are considered as medium risk levels [32].

$$\left(\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i-\bar{X})^2}\right) - \left(\bar{X} = \frac{1}{N}\sum_{i=1}^{N} Xi = \frac{x_1+x_2+\cdots+x_N}{N}\right) < \text{ Medium risk level} < \left(\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i-\bar{X})^2}\right) + \left(\bar{X} = \frac{1}{N}\sum_{i=1}^{N} Xi = \frac{x_1+x_2+\cdots+x_N}{N}\right)$$

Table 3 provides the range of risks determined in the EFMEA method. This table is prepared based on the statistical calculations of the evaluated risks.

After the preparation of the table ranking the scope of environmental pollution and ranking the feasibility of recycling in the EFMEA technique, the complete table 4 is finalized, and the determined risk ranges are highlighted in color.

- Stage Nine: The presentation of control measures to eliminate or reduce potential failure modes.
- Stage Ten: The recalculation of the risk priority number resulting from the elimination or reduction of failure modes (the secondary risk assessment).

2.4. The identification, analysis, and examination of safety and health hazards in the production process using the William Fine method.

After completing the EFMEA tables, we proceed to assess the risk of human exposure to hazards resulting from the activities that employees encounter using the William Fine technique. For this purpose, we first list the activities that affect the health of employees and enter them into a pre-designed table. Once the activities table is ready, we place all activities in the William Fine tables and examine the hazards arising from these activities based on three items: the severity, probability, and level of exposure. In the William Fine method, safety and health risks are assessed based on three components: the severity of the consequences of an event, the likelihood of the event occurring, and the level of exposure. Initial and secondary risk priority numbers are calculated using the following formula. Equation 5: The formula for calculating the number of primary and secondary risk priorities in the William Fine technique:

$$RPN = O \times S \times E$$

In which E is the exposure rate.

The safety and health risks along with their resulting consequences have been prepared by the relevant working group, and Tables 4 to 6 in the appendix are utilized for scoring the risk components. Then, we prioritize the risks based on these three items and rank the risk levels using the William Fine method through color-coded categorization according to the tables of acceptable, conditional acceptance, and unacceptable limits. Similar to the EFMEA method, in this approach, brainstorming sessions are conducted for scoring the probability, severity, and exposure level components, and the risk number is calculated by multiplying these three components. After scoring, the initial and secondary risk priority numbers are entered into the worksheets, and statistical calculations are utilized to determine the risk boundaries (Table 11). By the dataset and the highest and lowest risk priority numbers, risk levels are identified for subsequent applications. Based on this, four risk levels, namely Low, Medium, High, and Very High, are determined, which can serve as outputs recognized in the William Fine method. Management decisions regarding acceptance or rejection of the identified risks are then made accordingly. After determining the number and length of classes and risk levels, we complete the table 3. Then, among the classes, we select the one with the highest frequency. Now, we consider the middle of this classes as the low-risk boundary. Finally, we add the calculated classes' lengths from above to the resulting middle to obtain the boundaries of risk priorities in the other classes.

Table 2. A sample worksheet for recording information in the William Fine's technique.

Risk identification worksheet according to William Fine's method														
Revision number:			**Done date:**				**Worksheet number: 00**					**Activity description:**		
Study phase: Product Production Phase							**Study area: Building Stone Processing company**							
References and implementation methods used:..														
Secondary Risk Assessment						**Primary Risk Assessment**								
risk level (RL)	Risk Number (RN)	Exposure rate (E)	Intensity (S)	possibility of occurrence (O)	**Control measures**	risk level (RL)	Risk Number (RN)	Exposure rate (E)	Intensity (S)	**Possibility of occurrence (O)**	**consequence**	**Event**	**threats**	**Hazard**

Table 3. The acceptable limits, conditional acceptance, and unacceptable levels of risk.

Risk level	Aspect level	Necessary actions	rank
High (H)	obvious	Immediate corrections are required to control the risk or we need to stop the activity of the unit under investigation. This group of aspects will be reviewed in the environment committee meetings and micro goals or corrective and preventive measures and related control will be defined and recorded in the form.	Risk ratings higher than 59/98
Medium (M)	On the verge of becoming evident	It is an emergency situation and either solutions or improvements should be considered as soon as possible, or there is a need for monitoring to ensure the establishment and maintenance of existing controls.	Risk ratings between 20.56 and 59.98
Low (L)	inconspicuous	The potential dangerous factor does not need continuous control and will be monitored annually.	Risk ratings below 20.56

Table 4. Sample EFMEA Data Recording Worksheet with the Established Boundaries.

Environmental hazard identification worksheet using EFMEA method													
Date:					**Revision number:**					**Worksheet number:**			
Study phase: Product production phase					**Study area: Building stone processing company**								
Secondary Risk Assessment					**Control measures**	Primary Risk Assessment					**Potential damage (consequence)**	**Potential failure mode (environmental aspects)**	**Risk description**
risk level (RL)	Risk Priority Number (RPN)	Contamination Range (CR)	intensity (S)	possibility of occurrence (O)		**risk level (RL)**	Risk Priority Number (RPN)	Contamination Range (CR)	intensity (S)	possibility of occurrence (O)			

Table 5. Determining the risk range in the William Fine method.

Color and sign	Risk levels	Risk priority limits
L	(Low)	RPN < 676
M	(Medium)	676 ≤ RPN < 1668
H	(High)	1668 ≤ RPN < 2660
VH	(Very High)	2660 ≤ RPN

Now, by comparing the obtained risk score (R) with the data from the risk boundary determination tables, we can propose and present plans for risk mitigation, control actions, and risk management measures.

After calculating the risk and implementing control measures, the secondary risk assessment is conducted, and the obtained information is recorded in the worksheet. Furthermore, to compare the necessary cost for control measures across different risks, we utilize Tables 7 and 8 in the appendix. Control measures are also discussed in these sessions, and the William Fine worksheet is completed. For the assessment of secondary risks, new scores for the aforementioned three components are entered based on the experts' opinions, and the secondary risk number is calculated accordingly.

2.5. The Calculation of Corrective Action Costs in the William Fine Method

After assessing the risk status, the next step is to extract the expenditure incurred for implementing corrective actions and control measures. This involves comparing the secondary risk figure obtained with the initial risk figure, calculating the percentage reduction in risk. Subsequently, utilizing relevant tables, the cost factor and correction factor (Tables 7&8 appendix) are determined, and inserted into the corresponding formula to derive the cost factor. In the final stage, all expenses resulting from corrective actions on risks associated with a particular activity are aggregated and entered into a table. By plotting a graph, the expenditure levels are compared. This process aids in identifying activities requiring significant expenditure for risk reduction, enabling effective planning for them.

2.6. The integration of results from the EFMEA and William Fine Techniques

Since environmental risks are not considered in the William Fine method, they are combined with the safety and health risks obtained from the William Fine method using the outputs of the EFMEA tables. At this stage, the results extracted from the EFMEA and William Fine tables are combined to see how the level of risks changes before and after control measures are implemented. Using the final results, we can make the best decision in this regard.

2.7. The prioritization of protective layers based on two criteria of cost and time using the TOPSIS technique

In the TOPSIS method, m options are evaluated by n criteria, and each problem can be considered as a geometric system consisting of m points in an n-dimensional space.

The steps of this method are outlined below:

Step one in the TOPSIS technique: The decision matrix (D) is normalized using the following formula to make it dimensionless [33]:

$$r_{ij} = \frac{r_{ij}}{\sqrt{\sum_{j=1}^{j} r_{ij}^2}} \qquad j=1, 2, 3\ldots n \qquad i=1, 2, 3\ldots m$$

The resulting matrix is referred to as ND.

Step two in the TOPSIS technique: The normalized weights of the decision matrix are obtained as follows [33]:

$$V = \mathrm{N_D} \times \mathrm{W_{n*n}} \qquad j=1, 2, 3\ldots n \quad i=1, 2, 3\ldots m$$

Where V is the dimensionless weighted matrix and W is a diagonal matrix of the weights obtained for the indicators.

Step three in the TOPSIS technique: The positive (Ai^+) and the negative ideal solutions (Ai^-) are defined as follows [33]:

$$A^{+} = \{(MAX_i V_{ij} \text{ I } j \in J_1), (MIN_i V_{ij} \text{ I } j \in J_2) \text{ I } i=1, 2, 3, \ldots, m\}$$

$$A^{-} = \{(MIN_i V_{ij} \text{ I } j \in J_1), (MAX_i V_{ij} \text{ I } j \in J_2) \text{ I } i=1, 2, 3, \ldots, m\}$$

$$A_i^{+} = \{v_1^{+}, v_2^{+}, \ldots, v_n^{+}\}$$

$$A_i^{-} = \{v_1^{-}, v_2^{-}, \ldots, v_n^{-}\}$$

Step four in the TOPSIS technique: The distance measure based on the Euclidean norm is computed for both the negative ideal solution and the positive option, and similarly for the positive ideal solution and the negative option as follows [33]:

$$d_i^{+} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^{+})^2} \qquad i=1, 2, 3\ldots m$$

$$d_i^{-} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^{-})^2} \qquad i=1, 2, 3\ldots m$$

Step five in the TOPSIS technique: The relative closeness of A_i to the ideal solution is calculated as follows [33]:

$$C_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \qquad (i=1,2, 3\ldots m)$$

Step six in the TOPSIS technique: Based on the comparison obtained for each option, the ranking order is determined.

3. Result & Discussion

3.1. The identification of health risks using the William Fine technique:

In this section, the human encounter with health hazards arising from activities and operations conducted in the processing facilities of building stone is evaluated using the William Fine technique. Therefore, initially, we identify the existing activities and operations.

- Driving inside and outside the workshop premises (driving vehicles carrying raw materials).
- The extraction of raw materials (aggregate, silica, and cement) for product manufacturing.
- Maintenance and repair of equipment and machinery.
- Operations involving the use of chemical substances required in the production unit.
- Conducting administrative and personnel tasks.

After identifying the activities and operations, all of them are placed in the worksheet of the William Fine technique, and the hazards arising from these activities and operations are evaluated based on three items: severity, likelihood, and exposure level. For scoring the possibility, severity, and exposure level components, brainstorming sessions are utilized, and the final scores are entered into the tables by five experts based on the principle of abundance. By multiplying these three components, the risk score is calculated. Control measures are also discussed in these sessions and the relevant column in the William Fine worksheet is completed. For assessing secondary risks, new scores for the aforementioned three components are entered based on experts' opinions, and the secondary risk score is calculated. The results are again entered into the relevant worksheets. Table 6 illustrates one of the five worksheets related to the above-mentioned activities and operations, and the other worksheets are attached in the appendix section.

After reaching a consensus on the scores for three components of likelihood of occurrence, the severity of consequences, and the level of exposure, which were derived from the opinions of five experts, the initial risk scores were obtained and entered into the respective tables. The determination of risk levels was then conducted. Accordingly, in the initial and secondary assessments, risks ranked lower than 676 were considered as low-risk levels, resulting in 20 risks falling within this range. Risks ranked between 676 and 1668 were calculated as moderate-risk levels, with a total of 11 risks falling into this category. Risks ranked between 1668 and 2660 were designated as high-risk levels, comprising eight risks. Finally, risks ranked above 2660 were categorized as very high-risk levels, with two risks identified in this range. The final results are presented in Table 6.

Table 6. The risk identification worksheet using the William Fine Method for extraction and material handling operations.

Revision number: 00	**Completion date: Summer 2018**	**Worksheet number: 01**	**Description of activity/operations : Picking and moving raw materials**
Study phase: Product Production Phase		**Study area: Building Stone Processing company**	
References and enforcement methods used: defensive driving, training, personal protective equipment, description of employee duties, response in emergency situations			

Secondary Risk Assessment					Preventive & Mitigates Measurements	Primary Risk Assessment					Consequences	Events	Threat	Hazard
risk level (RL)	Risk Number (RN)	Exposure rate (E)	Intensity (S)	possibility of occurrence (o)		risk level (RL)	Risk Number (RN)	Exposure rate (E)	Intensity (S)	possibility of occurrence (o)				
L	150	6	5	5	Using a breathing mask, reducing exposure time, avoiding commuting and unnecessary work	H	2500	10	25	10	Respiratory and skin diseases	Creating dust	Low weight of fine dust in raw materials	Spreading dust
L	150	6	5	5	Use of healthy equipment with technical approval, reduction of exposure time, use of personal protective equipment such as protective phones	M	1200	8	15	10	Decrease in the amount and level of hearing (permanent and temporary)	Making disturbing and annoying noise	Wear and tear, lack of repair and maintenance of machinery	Operational machinery and vehicles
L	37.5	3	25	0.5	Providing proper lighting, wearing a light jacket by pedestrians	M	1500	6	50	5	Life injuries and death	Decreased field of view	Adverse weather and conditions (work at night, stormy, rainy and other cases)	
L	75	1	25	3	Training people and operators in connection with identifying the danger zone of machines.	H	2000	4	50	10	Life injuries and death	Equipment hits people		

Table 7. The results of the number of risk levels in the William Fine method in assessing primary and secondary risks.

Secondary risk assessment				Primary risk assessment				The number of risks	worksheet number
VH	H	M	L	VH	H	M	L		
0	0	0	4	0	2	2	0	4	1
0	0	0	24	1	4	7	12	24	2
0	0	0	3	0	0	2	1	3	3
0	0	0	3	0	0	0	3	3	4
0	0	0	7	1	2	0	4	7	5
0	0	0	41	2	8	11	20	41	Total
41				41					

After assessing the risks, it is now time to extract the cost incurred for implementing corrective actions and control measures. To calculate the required cost for control measures, we first compare the secondary risk score obtained with the initial risk score and calculate the percentage reduction in risk. Here, the percentage of risk reduction should be determined based on the difference between two risk priority numbers in the assessment of primary and secondary risks.

Next, we determine the cost factor (the amount required for activity correction) and the correction factor in the William Fine technique, and incorporate them into the cost calculation formula to obtain the cost factor.

At the end of the cost calculation process, all expenses resulting from corrective actions on the risks associated with a particular activity are summed up and entered into Table 8.

In Table 9, the costs for each of five main activities identified in the William Fine method are delineated.

3.2. The Identification of environmental risks using the EFMEA technique

In this section, environmental risks associated with the potential for environmental pollution and resource and energy wastage are identified, Next, the EFMEA method is employed to conduct the risk assessment for them. The EFMEA technique involves three elements: the likelihood of occurrence of an event, the severity of the consequences resulting from the event, and the extent of contamination. Therefore, each identified risk is placed in a predefined table, and for each risk, hazards are identified. Three elements of the likelihood of event occurrence, the severity of consequences, and the extent of contamination are examined, and the results are entered into tables.

By forming a team of experts and specialists consisting of five members, brainstorming sessions were conducted to assign scores ranging from 1 to 5 to each of the aforementioned components. The final score was determined based on the principle of majority agreement among the total opinions of five experts recorded on the worksheet. If three out of five experts provided the same score, that opinion was considered the final consensus of the group. During these sessions, control measures to prevent risks were discussed and examined. The column for control measures was completed afterward, and similar to the previous stage, the secondary risk numbers were determined using the same method and entered into the worksheets. Finally, three components were multiplied together to calculate the risk priority number.

Table 10 is one of five worksheets related to the above-mentioned activities and operations, and the other worksheets are attached in the appendix section.

Then, after determining the initial risk score, the risk levels are identified. In this way, risks with scores lower than 20.56 are considered low-risk levels in both the initial and secondary risk assessments. In the initial risk assessment, two risks fell within this range. Risks with scores between 20.56 and 59.98 were calculated as moderate-risk levels, comprising nine risks. Risks with scores higher than 59.98 are considered high-risk levels, with over four high-risk risks identified in the initial risk assessment. Subsequently, the secondary risk assessment was also conducted, and protective layers were proposed. 14 risks were placed in the low-risk area, and one risk was in the moderate-risk range. This indicates that protective layers and control measures have succeeded in transitioning risks from moderate to low-risk levels.

3.3. The results derived from the combination of the William Fine and EFMEA techniques

The extracted results from the tables of the EFMEA and William Fine techniques were combined to assess the level of risks before and after the implementation of control measures. Ultimately, utilizing the final results, we can make the best decision in this regard. Therefore, cumulative effects are examined, and the results obtained from both the William Fine and EFMEA models are integrated. These combined results are presented in Table 12.

Furthermore, two graphs below compare the frequency of these risk levels before and after the implementation of control measures.

3.4. Prioritizing protective layers using the TOPSIS technique

At this stage, one of the risks with a high level of risk was selected. Among the risks examined, the risk of working at heights was chosen. The proposed protective layers and control measures include:

- The establishment of a safe platform
- Training
- Helmet, shoes, and safety harness
- Rescue ropes
- Periodic inspections

Since prioritization was based on two criteria: cost and time, each of these criteria was assigned weights of 0.6 and 0.4, respectively. Continuing, the TOPSIS decision matrix was formed according to Table 13. Subsequently, the normalized matrix was calculated using the TOPSIS method. The results can be observed in Table 14.

In the next step, the weighted normalized matrix was formed using the criteria weights, which can be observed in Table 15.

Then, the Euclidean distance of each option to the positive and negative ideal solutions was calculated as per Table 16.

Subsequently, the proximity ratio to the ideal option was calculated according to Table 17.

Finally, the obtained weights after normalization were presented in Table 18.

Now, according to Table 19, the ranking was carried out. Respectively, according to expert opinions, using the TOPSIS method, it was concluded that the prioritization of risk control measures in working at heights is as follows: the first priority is given to the use of helmets, shoes, and harnesses, as well as the establishment of a safe platform, considering both time and cost criteria. Subsequently, training and the use of rescue ropes are in the next priorities, and finally, periodic inspections for individuals working at heights can reduce the associated risks of this activity.

4. Conclusion

In this study, an attempt was made to identify and assess safety, health, and environmental hazards arising from a production activity. Therefore, for the identification, assessment, and management of safety health, and environmental risks, a combination of two techniques,

Table8: Estimating the costs incurred from control measures.

Cost Estimation			Secondary risk assessment		Primary risk assessment		Hazards	Activity / Operation
Cost (J)	Correction Degree (CD)	Cost Factor (CF)	Risk Level (SRL)	number of secondary risks (PRN)	risk level (PRL)	Primary Risk Number (PRN)		
416	2	3	L	150	H	2500	Spreading dust	Picking and handling of raw materials
200	2	3	L	150	M	1200	Operational machinery and vehicles	
250	2	3	L	38	M	1500		
333	2	3	L	75	H	2000		
250	1	3	L	8	M	750	Rotating machines	Repair and maintenance of equipment and machinery
333	2	3	L	23	H	2000	Cutting welding	
350	2	3	L	150	H	2000	Fuel storage, filling fuel tanks and refueling	
۲۵۰	1	3	L	8	M	750		
150	2	3	L	75	M	900		
50	2	3	L	36	M	500		
18	2	4	L	27	L	125		
18	2	4	L	27	L	125		
333	2	3	L	135	H	2000	Work at height	
150	2	3	L	60	M	900		
75	2	3	L	23	L	450		
333	2	3	L	180	H	2000		
18	2	4	L	10	L	150		
1000	2	3	L	150	VH	6000		
50	2	3	L	18	L	300	Electrician	Repair and maintenance of equipment and machinery
25	3	4	L	90	L	300		
38	2	4	L	18	L	300		
50	2	3	L	30	L	300	Work with hand tools	
50	2	3	L	30	L	300		
30	2	3	L	30	L	180		
187	2	4	L	150	M	1500	Loading operations	
45	2	2	L	30	L	180		
375	2	2	L	150	M	1500		
375	2	2	L	150	M	1500		
45	1	3	L	3	L	135	Work at height	Working with chemicals
125	2	4	L	135	M	1000	Work in the vicinity of materials	
125	2	4	L	135	M	1000	Construction and operation	
50	1	150	L	2	L	150	Carrying out administrative and human resources affairs	Carrying out administrative and human resources affairs
50	1	150	L	2	L	150		
50	1	150	L	2	L	150		
666	2	3	L	300	VH	4000	Driving	Driving
6	2	4	L	8	L	45		
25	2	3	L	25	L	150		
666	1	3	L	25	H	2000		
100	1	3	L	8	L	300		
25	2	3	L	8	L	150		
333	2	3	L	100	H	2000		

Table 9. The costs of implementing control measures for the identified activities and operations.

Cost	Activity / Operations	Row	Cost	Activity/ Operations	Row
150	Personnel and administrative affairs	4	1033	Picking and moving raw materials	1
1821	Driving inside and outside the workshop area	5	4170	Maintenance of equipment and machinery	2
			295	Work with chemicals	3

Table 10. The risk identification worksheet using the EFMEA method.

Date: Summer 2018						Revision number: 00						Worksheet number: 01	
Study phase: Product production phase						Study area: Building Stone Processing company							
Secondary risk assessment						Primary risk assessment							
risk level (RL)	Risk Priority Number (RPN)	extent of contamination (T)	intensity (S)	possibility of occurrence (o)	Preventive & Mitigated Measurements	risk level (RL)	Risk Priority Number (RPN)	extent of contamination (T)	intensity (S)	possibility of occurrence (o)	Consequences	Failure Modes	Hazards Description
L	6	2	1	3	The necessity of using equipment, machines and cars of high quality and without defects Planning to repair and maintain equipment, machinery and cars Planning for inspection of equipment, machines and cars Not using sound insulation around machines with high noise pollution Measurement of noise pollution of equipment for the purpose of future corrective measures	M	30	3	2	5	Temporary and permanent deafness	Using equipment, machines and cars *	Noise

Table 11. The risk boundaries in the EFMEA technique for primary and secondary risk assessments.

Secondary risk assessment			Primary risk assessment		
high risk	Moderate risk	low risk	high risk	Moderate risk	low risk
0	1	14	4	9	2

Table 12. The combined results of primary and secondary risk evaluations in the William Fine and EFMEA techniques.

Secondary risk	Primary risk assessment	Risk levels	Row
55	22	Low	1
1	20	Medium	2
0	12	High	3
0	2	Very High	4

Failure Mode and Effects Analysis (FMEA) and William Fine technique, was employed. Environmental risks were assessed using the FMEA method, while safety and health hazards were evaluated using the William Fine technique, so that the number of risk levels in the William Fine method for initial and secondary risk assessments and approximate risk boundaries in the EFMEA technique for initial and secondary risk assessments are presented in Tables 20 and 21, respectively.

Thus, in the primary and secondary risk assessments, risks with a score lower than 20.56 were considered as a low-risk level, with two risks falling within this range in the initial risk assessment. Risks ranked between 20.56 and 59.98 were categorized as moderate risks, with nine risks falling within this range. Risks ranked higher than 59.98 were identified as a high-risk level, with over four high-risk instances in the initial risk assessment. Subsequently, a secondary risk assessment was conducted, and protective layers were proposed. 14 risks were identified in the low-risk zone, while only one risk was found in the moderate-risk range. This demonstrates that the protective layers and control measures have successfully mitigated risks from the moderate to high-risk zones

* that are worn out and damaged Equipment and machinery that are worn out and damaged. Lack of proper inspection of equipment and machinery. Lack of repair and maintenance of equipment, machines, and cars. Not using sound insulation around machines with high noise pollution. Failure to estimate the level of noise pollution from equipment and machinery.

to the low-risk zone. Based on the obtained results, there are 41 health risks and 15 environmental risks. Therefore, it can be inferred that the identified number of health risks for the studied unit is approximately three times higher than the number of environmental risks. Furthermore, it can be concluded that implementing control measures and protective layers for risks arising from equipment maintenance and repair operations incurs the highest cost allocation (Table 22).

Table13. The TOPSIS decision matrix.

Weight of selection criteria (cost and time)	0.4	0.6
Protection layer or control solution	C1	C2
Create a safe platform	9.00	8.00
Education	8.00	7.00
lifeline	6.00	7.00
Helmet, shoes and safety belt	9.00	9.00
Periodic examinations	6.00	5.00

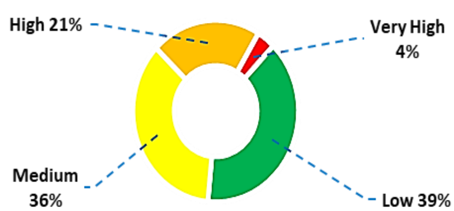

Figure 2. The statistical chart depicting the number of risks identified in the initial risk assessment resulting from the integration of the combined techniques of the Failure Mode and Effects Analysis (FMEA) and William Fine.

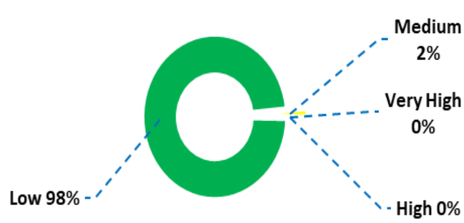

Figure 3. The Statistical chart illustrating the number of risks identified in the secondary risk assessment resulting from the integration of the combined techniques of the William Fine and EFMEA.

Table14. The normalized matrix.

0.4	0.6
C1	C2
0.52	0.49
0.46	0.43
0.35	0.43
0.52	0.55
0.35	0.31

Table15. The weighted normalized matrix.

0.4	0.6
C1	C2
0.21	0.29
0.19	0.26
0.14	0.26
0.21	0.33
0.14	0.18

Table16. Calculating the Euclidean distance of each option to the positive and negative ideal solutions.

D+	D-
0.036808301	0.132367313
0.077444128	0.089014761
0.102109494	0.076572786
0.001431022	0.164815128
0.16299064	0.003397631

Table17. The proximity ratio to the ideal option.

Score
0.782425494
0.534755228
0.428541578
0.991392148
0.020419895

Table18. The final weights for protective layers and control measures.

Index	Normal Score
Create a safe platform	0.283740979
Education	0.193925138
lifeline	0.155407522
Helmet, shoes and safety belt	0.359521233
Periodic examinations	0.007405128

Table 19. The ranking of protective layers and control measures.

Index Rank	Normal Score
Helmet, shoes, and safety harness	0.359521233
Establishment of a safe platform	0.283740979
Training	0.193925138
Rescue ropes	0.155407522
Periodic inspections	0.007405128

Table 20. The number of risk levels in the William Fine Method for the initial and secondary risk assessments.

Secondary risk assessment				Primary risk assessment			
VH	H	M	L	V H	H	M	L
0	0	0	41	2	8	11	20

Table 21. Approximate risk boundaries in the EFMEA Technique for the initial and secondary risk assessments.

Secondary risk assessment			Primary risk assessment		
H	M	L	H	M	L
0	1	14	4	9	2

Table 22. The costs of implementing control measures for identified activities and operations.

Cost	Activity / Operations	Row
1616	Picking and moving raw materials	1
4170	Maintenance of equipment and machinery	2
295	Work with chemicals	3
150	Personnel and administrative affairs	4
1821	driving inside and outside in workshop area	5

REFERENCES

[1] Saljoughi, M., Ghasemi, S., & Ghiasi, S. (2013). Environmental Risk Assessment of the Zinc Production Plant in Bandar Abbas Using EFMEA Method. Tehran.

[2] Sarkheil, H., Talaeian Eraghi, M. & Vatan Khah, S. (2021) Hazard identification and risk modeling on runway bird strikes at Sardar-e-Jangal International Airport of Iran. Model. Earth Syst. Environ. 7, 2589–2598. https://doi.org/10.1007/s40808-020-01032-0

[3] Sarkheil H (2021) Risk and incident analysis on crucial safety performance indicators and anomalies feedback in south pars gas complex. Results Eng 9:100210. https://doi.org/10.1016/j.rineng.2021.100210

[4] Sarkheil, H., Shirkhani, D., Azimi, Y. et al. (2023) Fuzzy radon hazard index assessment for stochastic environmental health risk evaluation of urban scale building. Stoch Environ Res Risk Assess 37, 3493–3515. https://doi.org/10.1007/s00477-023-02460-x

[5] Raian, S., Siddiqua, T., Abdul Moktadir, Md., Rahman, T (2023), An Empirical Model for Identifying and Controlling Operational and Environmental Risks in Spinning Industry in an Emerging Economy. Computers & Industrial Engineering, 180, 109244. https://doi.org/10.1016/j.cie.2023.109244.

[6] Taheri, M., Amalnick, M. S., Taleizadeh, A. A., Mardan, E. (2023) Investigating the Green Inventory Control Problem Considering Liquidity Risk: Application in the Dairy Industry. Sustainable Cities and Society, 92, 104479. https://doi.org/10.1016/j.scs.2023.104479.

[7] Dodd, T., Guthrie, J., Dumay, J. (2023) Management Controls and Modern Slavery Risks in the Building and Construction Industry: Lessons from an Australian Social Housing Provider. The British Accounting Review, 55 (3), 101098. https://doi.org/10.1016/j.bar.2022.101098.

[8] Sarkheil H, Rahbari Sh (2016) HSE key performance indicators in HSE_MS establishment and sustainability: a case of south pars gas complex. Iran Int J Occup Hyg 8(1):52–60

[9] Sarkheil H, Tahery B, Rayegani B, Ramezani J, Goshtasb H, Jahani A (2020) Evaluating the current status of the national health, safety, and environment management system for integration, harmonization, and standardization of environmental protection. Health Risk Anal 1:18–24. https://doi.org/10.21668/health.risk/2020.1.02.eng

[10] Seyed Ali Jozi, Parwaneh Farrokhi, (2013), Journal Article: "Environmental Risk Management of Kavian Steel Company in Ahvaz Using FMEA Method." Journal of Environmental Management and Planing, No. 4, 1391

[11] Laschi, A., Marchi, E., Foderi, C., Neri, F. (2016) Identifying Causes, Dynamics and Consequences of Work Accidents in Forest Operations in an Alpine Context. Safety Science, 89, 28–35. https://doi.org/10.1016/j.ssci.2016.05.017.

[12] Rafieyan, A., Sarvari, H., Chan, D. W. M. (2022) Identifying and Evaluating the Essential Factors Affecting the Incidence of Site Accidents Caused by Human Errors in Industrial Parks Construction Projects. International Journal of Environmental Research and Public Health, 19 (16), 10209. https://doi.org/10.3390/ijerph191610209.

[13] Carrillo-Castrillo, J. A., Trillo-Cabello, A. F., Rubio-Romero, J. C. (2017) Construction Accidents: Identification of the Main Associations between Causes, Mechanisms and Stages of the Construction Process. International Journal of Occupational Safety and Ergonomics, 23 (2) 240–250. https://doi.org/10.1080/10803548.2016.1245507.

[14] Abbasinia, M., Mohammadfam, I. (2022) Identifying, Evaluating and Prioritizing the Causes of Occupational Accidents in the Construction Industry Using Fuzzy AHP and Fuzzy TOPSIS. Work, 72 (3), 933–940. https://doi.org/10.3233/WOR-210024.

[15] Reyes-Martínez, R. M., Maldonado-Macías, A., Prado-León, L. R. (2012) Human Factors Identification and Classification Related to Accidents'causality on Hand Injuries in the Manufacturing Industry. Work, 41 (Supplement 1), 3155–3163. https://doi.org/10.3233/WOR-2012-0577-3155.

[16] Zhang, W., Zhu, S., Zhang, X., Zhao, T. (2020) Identification of Critical Causes of Construction Accidents in China Using a Model Based on System Thinking and Case Analysis. Safety Science, 121, 606–618. https://doi.org/10.1016/j.ssci.2019.04.038.

[17] Zara, J., Nordin, S. M., Isha, A. S. N. (2023) Influence of Communication Determinants on Safety Commitment in a High-Risk Workplace: A Systematic Literature Review of Four Communication Dimensions. Frontiers in Public Health, 11.

[18] Seyedali, J., Naser, G., & Iraj, M. (2012). "Environmental Risk Assessment and Management of the Polyethylene Unit of Aryasasol Polymer Company Using EFMEA Method." 6(4), 147–159.

[19] Sarkheil H, Tavakoli J, Rezvani S (2015) An innovative neglected invisible hazard identification (NIHI) at workplaces; the case of athletics Hall Boroujen-Iran. Int J Occup Hyg 7:159–166

[20] Petrovskiy, E., Buryukin, F., Bukhtiyarov, V., Savich, I., Gagina, M. (2015) The FMEA-Risk Analysis of Oil and Gas Process Facilities with Hazard Assessment Based on Fuzzy Logic. Modern Applied Science, 9 (5), p25. https://doi.org/10.5539/mas.v9n5p25.

[21] Hyun, K.-C., Min, S.; Choi, H.; Park, J., Lee, I.-M. (2015) Risk Analysis Using Fault-Tree Analysis (FTA) and Analytic Hierarchy Process (AHP) Applicable to Shield TBM Tunnels. Tunnelling and Underground Space Technology, 49. https://doi.org/10.1016/j.tust.2015.04.007.

[22] Semin, A. N., Faminskaya, M. V., Ponkratov, V. V., Mikhayluk, O. N., Shapoval, G. N. Risk Assessment and Its Management for Environmental Pollution in Oil Refinery Using FMEA Approach.

[23] Sarkheil H, Tavakoli J, Rezvani S (2016) Inherent safety process assessment in the initial phase of the chemical design process: the case of acetic acid production process. J Saf Promot Inj Prev 4(1):207–212

[24] Bahadori-Amjaz, F., Soleimani-sardo, M.(2021) Evaluation of the Environmental Risks of Jiroft Dam during the Utilization Phase. Geography and Environmental Planning, 32 (4), 45–64. https://doi.org/10.22108/gep.2021.129846.1446.

[25] Mahdavi, A., Varshosaz, K. (2024) Environmental Risk Assessment of a Hydrocracker Unit in Abadan Oil Refinery Using the EFMEA Analysis., 12 (1).

[26] Meghdad Pirsaheb, Ali Akbar Zinatizadeh, Fateme Asadi, Kiomars Sharafi (2015), Assessment and risk, safety, health and environmental management of on shore drilling machines of National Iranian Drilling Company with the method of 'William Fine.' https://www.researchgate.net/publication/304623915

[27] Zahra Navaei Aznaveh, Manocheher Omidari (2016), Article: "Enhanced Safety Risk Assessment Using the William Fine

Method Improved by the ANP-DEMATEL Hybrid Decision Model.",2nd International Conference on Management Industial Engineering, Technical Journal of Engineering and Applied Sciences, Link (accessed 2024-02-23).

[28] Safavi Mirmahalleh, S. R., Mehrmanesh, H., Haghighat Monfared, J. A (2023) Model for Risk Management in the Supply Chain of Iran's Gas Industry. Iranian journal of management sciences, 15 (57), 61–96.

[29] Azam Farmani, Mojtaba Rahimianbougar, Yousef Mohammadi, Hossein Faramarzi, Siamak Khodarahimi, Sajeda Nahaboo, (2023) Determinants of Suicide Attempt: Risk Assessment and Decision Making Strategies, Psychological, Structural, Social and Economic https://journals.sagepub.com/doi/full/10.1177/00302228211003462 (accessed 2024-02-23).

[30] Halvani, G., Ehrampoush, M. H., Ghaneian, M. T., Dehghani, A., Hesami Arani, M. (2017) Applying Job Hazard Analysis and William Fine Methods on Risks Identification and Assessment of Jobs in Hot Rolling Steel, Iran. Journal of Mazandaran University of Medical Sciences, 26 (145), 293–303.

[31] Dar, M. Z., Moghoyi, R., & Abadi, F. R. S. (2017). "Health and Environmental Risk Assessment of the Ceramic House Factory Using Hybrid Methods EFMEA and William Fine." Sixth HSE Conference and Festival.

[32] Joozi, S., & Salimi, S. M. (2021). "Environmental Risk Management of Mad Kan Sar Iron Ore Mine, Khorrambid, Using Hybrid Methods EFMEA and William Fine." Journal of Mineral Resources Engineering

[33] Karbasian, M., Khayambashi, B., Tavakoli, M. (2016) Performance Evaluation of Education System with Human Capital Approach by Data Envelopment Analysis and TOPSIS-with a Case Study. International Journal of Management in Education, 10, 414–432. https://doi.org/10.1504/IJMIE.2016.079367.

[1] Thompson DT (1982) EULDPH: A new technique for making computer-assisted depth estimates from magnetic data. Geophysics 47(1): 31-37

[2] Reid AB, Allsop JM, Granser H, Millett AT, Somerton IW (1990). Magnetic interpretation in three dimensions using Euler deconvolution. Geophysics 55(1): 80-91

[3] Okpoli CC (2019) High resolution magnetic field signatures over Akure and its Environs, southwestern Nigeria. Earth Sci Malays 3(1): 9-17

[4] Hosseini SH, Habibian Dehkordi B, Abedi M, Oskooi B (2021) Implications for a Geothermal Reservoir at Abgarm, Mahallat, Iran: Magnetic and Magnetotelluric Signatures. Natural Resources Research 30(1): 259-272

[5] Ghiasi SM, Hosseini SH, Afshar A, Abedi M (2022) A Novel Magnetic Interpretational Perspective on Charmaleh Iron Deposit Through Improved Edge Detection Techniques and 3D Inversion Approaches. Natural Resources Research, 1-24

[6] Reid AB, Thurston JB (2014) The structural index in gravity and magnetic interpretation: Errors, uses, and abuses. Geophysics 79(4): J61-J66

[7] Reid AB, Ebbing J, Webb SJ (2014) Avoidable Euler errors–the use and abuse of Euler deconvolution applied to potential fields. Geophysical Prospecting 62(5): 1162-1168

[8] Ghanbarifar S, Hosseini SH, Abedi M, Afshar A 2023 A dynamic window-based Euler depth estimator for 2 potential field geophysical data. Bulletin of Geophysics and Oceanography, (Accepted for publication).

[9] AL-Farhan M, Oskooi B, Abedi M, Ebrahim Zadeh Ardestani V, AL-Khalidy A (2022) Implications on oil trapping in the Kifl field of Iraq through geophysical investigations. International Journal of Mining and Geo-Engineering: 56(4), 391-400

[10] AL-Farhan M, Oskooi B, Ebrahim Zadeh Ardestani V, Abedi M, AL-Khalidy A (2019) Magnetic and gravity signatures of the Kifl oil field in Iraq. Journal of Petroleum Science and Engineering: 183, 106397

[11] Abedi M (2022) Cooperative fuzzy-guided focused inversion for unstructured mesh modeling of potential field geophysics, a case study for imaging an oil-trapping structure. Acta Geophysica 70(5): 2077-2098

[12] Fedi M, Florio G, Paoletti V (2015) MHODE: a local-homogeneity theory for improved source-parameter estimation of potential fields. Geophysical Journal International 202(2): 887-900

[13] Barbosa VC, Silva JB, Medeiros WE (1999) Stability analysis and improvement of structural index estimation in Euler deconvolution. Geophysics 64(1): 48-60

[14] Salem A, Ravat D (2003) A combined analytic signal and Euler method (AN-EUL) for automatic interpretation of magnetic data. Geophysics 68(6): 1952-1961

[15] Gerovska D, Araúzo-Bravo MJ (2003) Automatic interpretation of magnetic data based on Euler deconvolution with unprescribed structural index. Computers & Geosciences 29(8): 949-960

[16] Melo FF, Barbosa VC (2018) Correct structural index in Euler deconvolution via base-level estimates. Geophysics 83(6): J87-J98

[17] Aster RC, Borchers B, Thurber C (2018) Parameter estimation and inverse problems. Academic Press, New York, NY.

[18] Chen T. Zhang G (2018) Forward modeling of gravity anomalies based on cell mergence and parallel computing. Computers & Geosciences 120: 1-9

[19] Barbosa VC, Silva JB (2005) Deconvolução de Euler: passado, presente e futuro-um tutorial. Revista Brasileira de Geofísica 23(3): 243-250

[20] Sissakian VK (2013) Geological evolution of the Iraqi Mesopotamia Foredeep, inner platform and near surroundings of the Arabian Plate. Journal of Asian Earth Sciences 72: 152-163

[21] Abdulnaby W (2018) Structural Geology and Neotectonics of Iraq, Northwest Zagros. In book: Tectonic and Structural Framework of the Zagros Fold-Thrust Belt, 10.1016/B978-0-12-815048-1.00004-4.

[22] Sissakian VK, Mohammed BS (2007) Geology of Iraqi Western Desert. Iraqi Bull. Geol. Min. Special Issue: 51-124

[23] Fouad SFA (2010) Tectonic and structural evolution of the Mesopotamia foredeep, Iraq. Iraqi Bulletin of Geology and Mining 6: 41–53

[24] Jassim SZ, Goff JC (2006) Geology of Iraq, Czech Republic, ISBN 80-7028-287-8, pp 341. Prague, 35-52

[25] Al-Banna A (1992) Gravity lineaments, fault trends and depth of the basement rocks in Western Desert. Iraqi J. Sci., 33: 63–79

[26] Hijab BR, Aldabbas MA (2000). Tectonic evolution of Iraq. Iraqi Geological Journal 32: 26-47