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Risk Assessment in Quarries using Failure Modes and Effects Analysis Method (Case study: West-Azerbaijan Mines)

Akbar Esmailzadeh[1], Sina Shaffiee Haghshenas[2]*, Reza Mikaeil[1], Giuseppe Guido[2], Roohollah Shirani Faradonbeh[3], Roozbeh Abbasi Azghan[1], Amir Jafarpour[4], and Shadi Taghizadeh[1]

1. Mining Engineering Department, Faculty of Environment, Urmia University of Technology, Urmia, Iran
2. Department of Civil Engineering, University of Calabria, Rende, Italy
3. WA School of Mines: Minerals, Energy and Chemical Engineering, Curtin University, Kalgoorlie, WA, Australia
4. Department of Mining and Metallurgical Engineering, Yazd University, Yazd, Iran

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Abstract

Iran is one of the countries with the largest number of quarry mines in the world. Diamond cutting wire is usually used in quarries to cut dimension stone cubes, which is accompanied by hazardous events. Therefore, detecting and investigating the possible quarry risks is crucial to have a safe and sustainable mining operation. In mine exploitation, maintaining the safety of vehicles and increasing the knowledge of personnel regarding safety issues can considerably mitigate the number or radius of effect of hazards. Hence, the incidents and risks in the West-Azerbaijan quarries in Iran are investigated in this work. To do so, a list of the hazards and their descriptions are first prepared. Then the hazard risk rating is conducted using the Failure Modes and Effects Analysis (FMEA) method. The number of priorities is calculated for each incident based on probability, intensity, and risk detection probability. Finally, the main causes of risks in the studies quarries are identified. The results obtained show that the most likely dangers in dimensional stone mines in West Azerbaijan are diamond cutting wire breaking, rock-fall, and car accidents, with the priority numbers of 216, 180, and 135, respectively. These hazards can be mitigated by applying some preservative activities such as timely cutting wire replacement, utilizing an intelligent system for cutting tool control, necessary personal training, and considering some preservative points.

1. Introduction

This paper aims to understand the risks associated with the diamond wire cutting method applied to extract dimensional stones from quarries in Iran. Dimensional stones are all the rocks that are used in the building industry. This includes the rocks that are cut into cubes and the rocks that are used for normal masonry work, decoration, facades, etc. [1-3]. All the existing sedimentary, igneous, and metamorphic rocks are used as dimensional stones. In Iran, dimensional stones are divided into two main groups, granite and limestone. The limestone group includes travertine, marble, and marmarite. Porcelain stone and crystal are also included in the marmarite group. Different methods have been developed for extracting dimensional stones [4-8]. Diamond wire cutting is the most appropriate method among different extraction methods [8-11]. This method is widely used in most dimensional stone quarries [12]. It is of paramount significance to mention that the fractures present in the structure of stone and mine area morphology significantly affect the quality of the produced cubes. According to the importance of fractures, a comprehensive investigation should be conducted regarding the discontinuities that dominate the area [13-17].

The mining industry is considered as one of the most important and fundamental economic sectors in most countries on account of providing the raw materials required for other industries [18]. Besides, running into many uncontrollable parameters throughout the operation period of the

Corresponding author: Sina.shaffieehaghshenas@unical.it (S. Shaffiee Haghshenas).

mines has caused this industry to change into one of the most hazardous and eventful industries [19]. Joy has performed [20] a study on the safety risks management in the Australian mines. He has introduced the development and use of risk evaluation methods as one of the reasons for safety improvement in the Australia's mining industry over the past 15 years. Such systematic methods are based on recognizing the team, evaluating, and controlling the individuals' unacceptable risk, property, environment, and production. He has discussed the risk assessment technique used, while designing equipment and conducting mining operations and the particular set of methods used. The supervisory authorities and mining companies have also approved this paper for the beneficiary of risk, event, and incident assessment management and systematic analytical methods. As a result, risk management seems to be suitable for the work. This issue helps the management team to take into account the critical issues, and may be the only satisfactory and acceptable means of law-based supervision. Haghir-Chehrehghani and Alipour [21] have studied the safety of dimensional stone extraction using diamond wire cut. In this research work, the diamond wire cut is first introduced; then the safety level of the diamond wire cut method utilizing improvement methods is elaborated [21]. Using diamond cutting wire with plastic texture improves the safety to some extent but rubber protectors should be used around the wire cut to be safer. According to credible statistics and information regarding the accidents in the dimensional stone quarries, the event sources are not accessible. Thus this paper emphasized on the necessity of strict control of the supervisory organizations on mining activities and the installation of safety guards.

Ersoy [22] has studied the role of safety measures in mitigating accidents in marble mines located in Iscehisar. Several risks accompany the extraction of natural rocks and marble; it is considered as one of the most complex industrial activities. Currently, considerable progress has been made in the reduction of the activities that are susceptible and related to accidents as a result of the measures taken by safety analysis. Safety at work is essential because it plays a vital role in increasing the personal life levels. To this end, studies were carried out on the accidents of 10 marble mines situated in the Afyonkarahisar Iscehisar, known as the oldest marble mine existing in Anatolia, to assess the work safety. In the next step, safety indices and mining risks were computed using a hierarchical analysis method to weigh the accident risk and safety level. A negative exponential relation with the coefficient of determination of $R^2 = 0.8116$ was detected between the accident index and safety index. Bogoly and Fuzesi [23] have compared the deterministic and probabilistic slope stability analyses of a quarry. They collected the data required for the research work, and the calculations were concerned with the plane, wedge, and circular failures; for that, RocPlane, SWedge, and Slide programs were used. They also examined the factor of safety (FoS) obtained from the deterministic calculations, and compared it with the different results of the probabilistic approach. Moreover, the optimization of the slope design was also conducted with both techniques to realize which analysis shows a more economical solution. It was concluded that the slope design (slope angle, number of benches, location of the benches) was more flexible with the probabilistic analyses considering different acceptance criteria. Also the results revealed the advantages and disadvantages of the application of probabilistic calculations.

From the prior studies, it can be inferred that risk assessment in mining projects is of paramount significance, directly affecting the projects' safety and efficiency. However, the methodology/strategy that should be followed for risk analysis still needs improvement. The researchers can better understand the risk analysis and classification by evaluating the probability of events and their corresponding damages and calculating the risk priority value using mathematical relations. This issue can lead to mitigating measures aligned with risk management to decrease the risks. Hence, this study aims to investigate and manage the risks in the dimensional stone quarries of the West-Azerbaijan Province, Iran, operating with the diamond wire cut method. For this purpose, the associated former studies and events were first reviewed, and the common risks of the quarries of the West-Azerbaijan Province were classified. Then Failure Modes and Effects Analysis (FMEA) was used to evaluate and sort the risks, and some steps and recommendations to reduce the most common risks were suggested.

2. Study of quarry hazards

The extraction of dimensional stones is one of the most dangerous activities in the mining industry [23]. There are severe risks at every step of extracting such rocks, from cutting them out of the bedrock to loading, moving, and dumping them [24]. According to the reports from the Statistical Centre of Iran, and the technical reports from the safety section of some dimensional stone mines [18], important events at rock mines have been identified.

This paper aims to understand the risks associated with the diamond wire cutting method for extracting dimensional stone mines. In the risk analysis studies of dimensional stone quarries, the critical step is identifying the project risks. Failure of the wire cut, blasting, rock-fall, driving accidents, fall of different vehicles and staff from the bench, electrical shock, and equipment fire due to the technical defects are some risks recognized in this regard [25]. Table 1 represents a summary of the risks considered in this study. By following some rules and methods, the safety risks of these kinds of events can be controlled and lessened. Training, skill, and following safety rules are the most important ways to prevent and mitigate the mining accidents [21].

Table 1. Hazards considered for case studies.

Hazard	Code	Explanation
Diamond cutting wire rupture or hitting workers and cutting tools installation	A	Diamond cutting wire ruptures due to its exhaustion and unsuitable cutting tools installation, which leads to severe injuries or death
Workplaces and working conditions	B	Physical harm to the personnel body caused by intolerable work conditions
Rock-fall, stope fall or trapping between two rock blocks	C	Rock blocks falling or personnel and machines trapping between rock blocks
Car accidents	D	Vehicles crash with each other or with personal
Fall of personnel and vehicles from the bench	E	Dimension stone mines have high benches, which sometimes causes the falling of personnel or vehicles
Electrical shock due to cables rupture	F	Cables tearing and exposure lead to electrical shocking
Equipment fire due to technical defect	G	Machines and equipment fires caused by non-timely technical checking

2.1. Study of West-Azerbaijan province quarry hazards

The history of dimensional stone quarries in the province of West-Azerbaijan was reviewed, and the risks of extracting these stones were identified. Using the statistics from the West-Azerbaijan province's industries, mines, and commerce organization, five high-risk mines were chosen from the province's dimensional stone quarries [19]. The information from these five quarries is shown in Table 2. Also the locations and names of the studied quarries are given in Figure 1. The reported incidents for the studies quarries can also be found in Table 3.

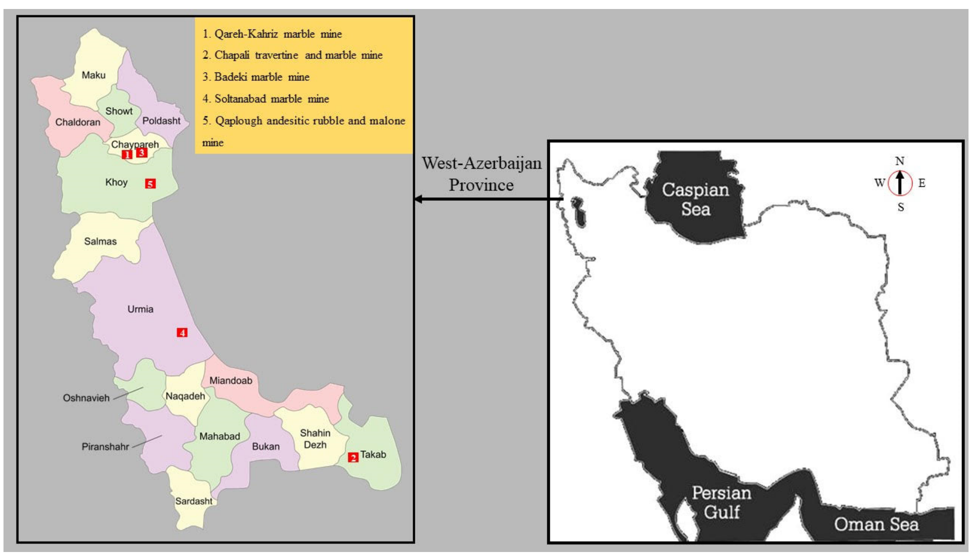

Figure 1. Location of studied quarries.

Table 2. Some data of five case studies in West-Azerbaijan Province in Iran [19].

Case No.	Name of case study	Location	Proven reserve (tons)	Annual extraction (tons)	Extraction method
1	Qareh-Kahriz marble mine	Chaipareh City	120000	15000	Diamond wire cut
2	Chapali travertine and marble mine	25 km away from Takab and 2 km from Chapali Village	640000 (travertine) 14000 (marble)	14000 (travertine) 500 (marble)	Diamond wire cut
3	Badeki marble mine	10 km southwest of Qara-Ziaeddin	535000	19000	Diamond wire cut
4	Soltanabad marble mine	35 km away from Urmia city	333000	13000	Diamond wire cut
5	Qaplough andesitic rubble and malone mine	50 km away from Khoy city in front of Qaplough Village	720000000	5000	Diamond wire cut

Table 3. Reported incidents in quarries [19].

Mine	Date	Type of damage	Code	Explanation
Qareh-Kahriz // Marble (Chaypareh)	2013-05-20	Death	C	Rock falling
Chapali // Travertine and Marble (Chaypareh)	2012-06-14	Death	C	Trapping between two rock blocks
	Unknown date	Injury	D	Vehicles accident
Badeki // Marble (Chaypareh)	Unknown date	Injury	A	Worker sliding due to rain and collision with cutting wire which leads to serious injury
	2013-01-01	Death	A	Cutting wire escaping from the worker's hand, is causing him to lose his balance and fall from the bench in front of the loader.
	2014-02-25	Injury	A	Rupturing the cutting wire and breaking the worker's hand
	2014-10-28	Injury	E	Falling from a bench having 6 meters in height and breaking the worker's hand and foot.
	2016-05-02	Maim	A	Foot cutting of a worker due to rupture of cutting wire
Soltanabad // Marble (Urmia)	2015-03-05	Death	D	Vehicles accident
Qaplough // Andesitic rubble stone (Khoy)	2008-09-10	Injury	D	Vehicles accident
	2010-02-19	Injury	B	Work condition pressure
	2010-07-08	Death	C	Rock falling
	2015-08-31	Death	D	Truck overturning due to either bad weather conditions or driver careless

3. Risk analysis of hazards using FMEA method

One of the most common and effective methods for identifying, manipulating, analyzing, and evaluating risks is the FMEA method. Using this method and identifying the risks and errors, it is possible to prevent incidents in the mining projects. There is an analytical method in risk evaluation that tries to recognize and classify the potential risks in the zone under consideration. FMEA is a technique used for the first time in the US Army [26, 27].

3.1. FMEA method steps

Figure 2 depicts the FMEA method process, and the analysis of its effects.

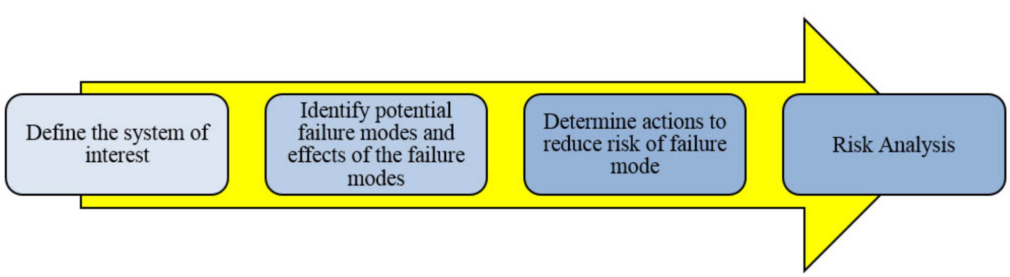

Figure 2. Failure modes and effects analysis method steps.

In general, the FMEA method steps are as follows:

3.1.1. Identify components and associated functions

The first step of FMEA is to identify all the components to be evaluated. This issue is concerned with defining the system under consideration, and the definition typically incorporates a breakdown of the system into blocks, block functions, and the interface between them. At the beginning of a program, there is not usually a good definition of the system, so the analyst has to come up with one using documents like trade study reports, drawings, development plans and specifications, etc.

3.1.2. Potential failure modes or hazards detection

All the environmental risks, equipment, materials, humans, etc. that threaten safety should be considered. Moreover, each risk should be analyzed case by case [28-30].

3.1.3. Identify effects of failure modes

Effects of each risk are consequences that endanger the project and its function. The risk effects include fire, venom, break, joint damages, etc. [31, 32].

3.1.4. Hazard reasons determination

A proper understanding of the studied area can help recognize the risk causes. The most compelling data in this regard includes the technical, environmental, and ergonomic information [32].

3.1.5. Identify controls

Control processes are checked to have a better evaluation of risks. For instance, standards, activities sheets, and the working area rules and requirements are checked as the control processes [33, 34].

3.1.6. Determine severity of failure mode

The risk severity is only considered for its "effect". A decrease in the risk severity is only possible via modifying the process and the way to perform the activities. Table 4 indicates the evaluation criteria of the risk severity.

Table 4. Definitions of safety level [35-37].

Rating	Risk severity	Meaning
1	No safety effect	It is not necessary to carry out the follow-up steps
2	Very minor	With minimum disturbance, the system is used.
3	Minor	The system is operational but with some performance decrease.
4	Very low	With severe performance reduction, the system is still operational.
5	Low	Without causing any damage, the system is rendered inoperable.
6	Moderate	With minor damage, the system is rendered inoperable.
7	High	Damaged equipment has rendered the system inoperable.
8	Very high	Without compromising safety, the system becomes unusable due to destructive failure.
9	Hazardous with warning	When a probable failure mode disrupts safe system functioning with notice, it receives a very high severity rating.
10	Hazardous without warning	When a probable failure mode disrupts safe system functioning without notice, it receives a very high severity rating.

3.1.7. Determine probability of occurrence

The occurrence probability describes the frequency of a potential cause or mechanism of risk. The number of events may be reduced only by removing or decreasing the causes or mechanisms of each risk. In other words, the chance of failure or the expected number of failures during the item's useful life is the probability of occurrence [38]. The occurrence probability is measured on a 1 to 10 basis. It is so helpful to study the former documents and records. Studying the control processes, standards, requirements, work rules, and application method is significant for achieving this number [39, 40]. If the statistical data is correct, the probability of each event occurring can be calculated using numbers between 1 and 10 from Table 5.

Table 5. Failure mode occurrence probability [41].

Rating	Hazard likelihood of occurrence	Meaning	Range of likelihood of occurrence
1	Remote	So unlikely failure	lesser than 1.5 in 10^6
2	Very low	Relatively few failures	1 in 1.5×10^5
3	Very low	Few failures	1 in 1.5×10^4
4	Moderate	-	1 in 2000
5	Moderate	-	1 in 400
6	Moderate	Occasional failures	1 in 80
7	High	-	1 in 20
8	High	Repeated failures	1 in 8
9	Very high	-	1 in 3
10	Very high	Failure is very likely to occur	≥ 1 in 2

3.1.8. Determine effectiveness of current controls in failure detection

The probability of detection evaluates the capability for recognizing the cause/mechanism of the risk occurrence. In other words, the probability of detection is the capability of recognizing the risk before its occurrence [42]. Studies on the control processes of standards, requirements, and work rules and their application method are very important for achieving this number (Table 6) [35].

Table 6. Failure detection ranking.

Item No.	Likelihood of detection	Rank meaning	Rank
1	Very high	Potential design weaknesses will almost certainly be detected	1, 2
2	High	There is a good chance of detecting potential design weakness	3, 4
3	Moderate	There is a possibility of detecting potential design weakness	5, 6
4	Low	Potential design weakness is unlikely to be detected	7, 8
5	Very low	Potential design weakness probably will not be detected	9
6	Detectability absolutely uncertain	Potential design weaknesses cannot be detected	10

3.1.9. Calculate risk priority number (RPN)

A RPN is a function of the three parameters including risk intensity (S), probability of occurrence (P), and probability of detection (D). RPN can be calculated using the following equation [43, 44]:

$$RPN = S \times P \times D \quad (1)$$

After computing the risk priority number for the events with high risks, a workgroup should be carried out to decrease this number through corrective actions. RPN may not play a significant part in deciding what action should be taken in response to failure modes. However, it will help show the threshold values that should be used to identify the locations with the highest concentration. In other words, the highest priority should be given to a failure mode with a high RPN number in the analysis and corrective action plans. It should be noted that a higher RPN is much riskier than a lower one. A higher RPN value, in other words, indicates a higher risk. In this case, it is essential to note that RPN is not a perfect way to show risk because the number of assignments is subjective and does not go on forever [45, 46]. The risks are classified by the risk priority number in the corrective measure's steps. Then based on the FMEA system, one limit is called the Risk Priority Number (RPN) [47-49].

For instance, the limit for the safety level of 90% is achieved as below. Altogether, attention should be given to the RPN risks higher than 100 that require correction. Corrective measures should also be considered for the risks with a minimum of 10 numbers [50]. The risk intensity value is taken from Table 3, the probability of risk detection is taken from Table 6, and the probability of occurrence is selected based on the current information to calculate RPN. In this paper, the collected data indicates the occurrence of 13 events in the rock quarries of the West-Azerbaijan Province including four events related to the failure or collision of the diamond wire cut (R1), one event related to the workload (R2), three events related to rock-fall (R3), four events related to driving accidents (R4), and one event related to the fall of staffs or types of machinery (R5). For instance, the probability of occurrence for the driving events and the workload is 0.3 and 0.07, respectively. The number 3 is considered for 0.3, and one is considered for 0.07 (Table 7).

Table 7. Results of FMEA analysis.

Incident	Severity	Probability of occurrence	Control detection effectiveness rate	Risk priority number
Diamond cutting wire rupture or hitting workers (R1)	8	3	9	216
Mental and physical harm of professional condition (R2)	3	1	4	12
Rock falling, slope sliding, trapping between rock blocks (R3)	10	2	9	180
Vehicle accidents (R4)	9	3	5	135
Workers or equipment falling from the edge of a bench (R5)	6	1	8	48

3.1.10. Determine actions to reduce risk of failure mode

Mining activities constitute a considerable portion of the industry and economy of the country. Thus it is necessary to study and research their risks. Because of this, the main goal of the research work is to find and share a set of ways to lower the risk. After doing studies and getting risk priority numbers (Table 7) for the events using FMEA, it was found that the failure and collision of the diamond wire, the installation of the cutting equipment, rock-fall, and driving accidents with RPNs of 216, 180, and 135 were the most dangerous ones in Table 7. By taking the steps in Table 8, the number of RPNs for the province's dimensional stone quarries would be cut down as much as possible. Table 8 also shows a way to reduce the number of events and the damage they cause, as well as a suggestion for how to do this [16].

Table 8. Reported incidents event in quarries.

Failure mode	Actions to reduce risk of failure mode
Diamond cutting wire rupture or hitting workers (R1)	1. Replacing diamond cutting wire with plastic cutting wire 2. Timely and precise control of cutting wire 3. Periodic replacement of cutting wire 4. Intelligent systems applied in equipment set up and control 5. Equipment operators Professional and complete training 6. Safeguards placed in the cutting area
Mental and physical harm of profession condition (R2)	1. Balance creation between worker wages and their life costs 2. Regular wage and insurance payment 3. Meet the workers' adequate work hours and rest time 4. Doing hard work according to mine's standard safety regulations 5. Observance of work safety points 6. Personal training in order to learn how to do right their tasks
Rock falling, stope sliding, trapping between rock blocks (R3)	1. Strong Safeguard installation on the edge of rock-fall prone benches 2. Choice of Correct exploitation direction by applying a complete geological study and scaling 3. Benches floor cleaning 4. Create a heap of sand and gravel in the bench toe 5. Scaling new loos benches to prevent falling rock wedges or blocks
Vehicle accidents (R4)	1. Employment of experienced and careful truck driver 2. Keeping out of vehicles 3. Vehicle traffic complete control in the mine area 4. Observance of road safety regulations 5. Provision of vehicle necessary safety equipment in icy and rainy conditions 6. Observance of work safety regulations and correct traffic management
Workers or equipment falling from the edge of bench (R5)	1. Keeping safety distance out of benches edge 2. Using carrier safety belts 3. Strong safeguard installation on the edge of hazardous benches 4. Workers should be focused on accepted duty and avoid distraction 5. Observance of work safety points

4. Discussion

Quarrying activities must be given greater attention since they are among the most dangerous operations throughout the planning and operation phases. The actions that make up the foundation of risk management include identifying each risk's entire dimensions, being cautious about the effects of risks, and rating risks. When equipped with a comprehensive risk management system, the experts can make sound choices in a shorter period. Therefore, the purpose of this study was to rank the risks of dimensional stone quarries using one of the conventional risk assessment methods. The present study has academic and operational aspects. This study's results showed how the FMEA methodology could be employed to study the mining risks. Furthermore, by ranking the risks in these quarries, a set of preventive measures were suggested, which could be implemented right away in the studied quarries to reduce the risks.

According to Table 7, three risks including diamond cutting wire rupture or hitting workers (R1), rock falling, slope sliding or trapping between rock blocks (R3), and the fall of workers or equipment from the edge of a bench (R5), with risk numbers 216, 180, and 135, respectively, were the most dangerous risks in the quarries. Thus at this step, a set of corrective and curative measures appropriate for each risk level were put forward to reduce the impact of high-risk risks. For instance, for R1 with the highest RPN, suggestions were made to increase safety by replacing metal equipment with plastic. It was also suggested that people who deal with this equipment complete their training and professional courses in order to be able to perform the best performance in the shortest time in the face of the memories caused by these incidents. Similarly, a set of suggestions were made for R3 and R4, the most important of which was to protect the benches with the proper safety measures for R3 and follow the road safety regulations strictly for R4. It should be noted that according to the results from Table 7, although the amount of severity for rock-fall was the highest possible value, this risk took the second rank. This can be associated with the RPN's parameters, which all have approximately the same importance weight.

It is also worth mentioning that when these recommendations are put into action, they should always be accompanied by intensity, accuracy, monitoring, and review throughout the life of the quarries. This ensures that they are implemented correctly and accurately to reduce the risks studied.

Workers or equipment falling from the edge of the bench (R5) and mental and physical harm from professional conditions (R2) obtained RPN values equal to 48 and 12, respectively. As is clear from their RPN values, these risks are less significant than others. Therefore, they were quickly adjusted to an acceptable degree with appropriate corrective action. After consulting with the experts and executive technicians and considering the previous studies, 5 and 6 executive recommendations (see Table 8) were recommended for R5 and R2, respectively, which could help reduce the effects of these risks.

As part of the first steps of making a strategy and plan for extracting quarries, it is also suggested that an effective technical, executive, and safety management system be put in place so that everyone knows what their roles and responsibilities are. Also this issue needs well-informed and thoughtful management. These management systems are best conducted by risk analysis and management.

It is also important to note that the FMEA method can be beneficial for assessing risk but it also has some problems. Firstly, different S, P, and D rating values may result in the same RPN number but the hidden risk implications could be very different. Secondly, this method does not consider the relative importance of O, S, and D concerning each other.

5. Conclusions

Mining operations are among the most dangerous engineering activities, and require appropriate risk analysis to improve the safety and efficiency of the projects. Different events always accompany the mining operations of the dimensional stone quarries. Failure of the wire cut, workload, rock-fall, driving accidents, falls of mining vehicles and staff from the bench, electrical shock, and fire are some of the risks recognized in this regard. This research work aimed to investigate and find the incidents of the dimensional stone quarries and their causes, and recognize the most probable events to perform risk analysis. In this way, the most dangerous things that can happen when extracting dimensional stone are the failure and collision of the diamond wire, the installation of the cutting equipment, a rock-fall, and a car accident. Using the FMEA method, the RPN number of the entire event was computed and classified after taking into account the risk analysis results of several dimensional stone quarries. Then proper solutions were presented to decrease the identified risks. The obtained results indicated that the failure and collision of the diamond wire, installation of the cutting equipment, rock-fall, and driving accidents with RPNs of 216, 180, and 135, respectively, were the most hazardous events related to dimensional stone quarries. Then based on the obtained results, a set of risk mitigation measures and recommendations was defined and proposed based on the priority of each risk. Finally, there was complete agreement between the results and what happened in the studied quarries. This shows that FMEA is a proper technique for risk assessment in mines that engineers can utilize in practice.

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ارزیابی ریسک در معادن با استفاده از روش آنالیز حالت و اثرات شکست (مطالعه موردی: معادن آذربایجان غربی)

اکبر اسماعیل زاده[۱]، سینا شفیعی حق شناس[۲*]، رضا میکائیل[۱]، جوزپه گیدو[۲]، روح الله شیرانی فرادنبه[۳]، روزبه عباسی اذغان[۱]، امیر جعفرپور[۴] و شادی تقی زاده[۱]

۱- دانشکده محیط زیست، گروه مهندسی معدن، دانشگاه صنعتی ارومیه، آذربایجان غربی، ایران
۲- گروه مهندسی عمران، دانشگاه کالابریا، رنده، ایتالیا
۳- دانشکده مهندسی معدن، متالورژی، مواد معدنی، انرژی و مهندسی شیمی، دانشگاه کرتین، کالگورلی، استرالیا
۴- گروه مهندسی معدن و متالورژی، دانشگاه یزد، یزد، ایران

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* نویسنده مسئول مکاتبات: Sina.shaffieehaghshenas@unical.it

چکیده:

ایران یکی از کشورهای دارای بیشترین تعداد معادن سنگ ساختمانی در جهان است. سیم برش الماس معمولاً در معادن برای برش مکعب های سنگ ساختمانی استفاده می شود که با حوادث خطرناکی همراه است. بنابراین، شناسایی و بررسی خطرات احتمالی معدن برای داشتن یک عملیات معدنی ایمن و پایدار بسیار مهم است. در بهره برداری از معدن، حفظ ایمنی وسایل نقلیه و افزایش دانش پرسنل در مورد مسائل ایمنی می تواند به میزان قابل توجهی از تعداد یا شعاع تأثیر خطرات بکاهد. از این رو، حوادث و خطرات موجود در معادن معادن آذربایجان غربی در ایران در این کار بررسی شده است. برای انجام این کار ابتدا فهرستی از خطرات و توضیحات آنها تهیه می شود. سپس رتبه بندی ریسک ها با استفاده از روش تجزیه و تحلیل حالت و اثرات شکست (FMEA) انجام می شود. تعداد اولویت ها برای هر حادثه بر اساس احتمال، شدت و احتمال تشخیص خطر محاسبه می شود. در نهایت، علل اصلی خطرات در معادن مورد مطالعه شناسایی شدند. نتایج به‌دست‌آمده نشان می‌دهد که محتمل‌ترین خطرات موجود در معادن سنگ ساختمانی آذربایجان غربی، شکستن سیم الماس تراش، ریزش سنگ و تصادفات رانندگی به ترتیب با اولویت ۲۱۶، ۱۸۰ و ۱۳۵ است. این خطرات را می توان با اعمال برخی فعالیت های مستمر مانند تعویض به موقع سیم برش، استفاده از سیستم هوشمند کنترل ابزار برش، آموزش شخصی لازم و در نظر گرفتن برخی نکات حفاظتی کاهش داد.

کلمات کلیدی: ایمنی، خطرات، معادن، سنگ ساختمانی، آنالیز حالت و اثرات شکست.