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Risk assessment of longwall mining due to coal face failure

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Preliminary communication

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Abstract

Face failure is a typical phenomenon in longwall coal mines that can have a wide range of consequences. Face failure, which includes wall spall and roof collapse occurrences, is a hazardous virus that, if not managed, spreads fast across all stages of coal mining and has the potential to disable the mine. Based on this research, face failure may have a detrimental influence on technical, environmental, community, safety, and economic concerns, and its negative effects will leave an unfavourable legacy for the future. As a result, these impacts can be mitigated by effective management and risk management approaches. The quantitative and qualitative face failure risk model provided in this study has a considerable potential as a suitable tool for decision makers to analyse failure risk. Face failure-related high-risk variables can be discovered using this approach, which also makes comparing various mines easier from a face failure aspect. For validation, the model was evaluated in the Parvadeh, Negin and Pabedana coal mines. The study's findings revealed that Parvadeh's face failure risk factor was 5058, indicating a high risk in this mine due to mechanized mining. Furthermore, the scores of the Negin and Pabedana mines were computed as 3019 and 3165, respectively, indicating that they were in the moderate risk category owing to traditional mining.

Keywords:
risk assessment; risk matrix; face failure; longwall coal mines

1. Introduction

Face spalling and roof fall phenomena have been recognized as a major concern limiting longwall face stability in deep and thick coal seams in recent years (**Kong et al., 2019; Kong et al., 2017; Suorineni et al., 2014; Peng and Chiang, 1984**). Coal wall spalling and roof fall in underground longwall coal faces which is called face failure in here are common phenomena in longwall coal mining that may endanger the safety of production and the financial success of a mining project. The consequences of wall spalling depend on the thickness and depth of the coal seam, so that with an increase in thickness and depth, the severity of the consequence will be more significant. Moreover, a roof collapse is strongly affected by mining depth and roof quality, so that with an increase in depth and a decrease in roof quality, the number of wall collapses increases. In longwall mining, a coal wall spalling event causes the unsupported area in front of the powered support to expand, forcing the exposed roof area or top coal to collapse. Increasing the depth of wall spalling expands the unsupported surface of roof, which will lead to a roof collapse and consequently an out-of-seam dilution (OSD). Waste rock (below cutoff grade) caused by OSD is exceedingly costly to mine, haul, and treat. Roof waste rock is mined, hauled, processed, and replaced with a unity of marketable mineral from plant production capacity as a consequence of OSD owing to a face failure occurrence (**Chugh et al., 2004; 2005**). On the other hand, in extreme cases, a large volume of coal face suddenly collapses to stope, and the resulting rock throw can threaten the miners' lives and cause serious damage to maintenance and technical services facilities. In addition to the above, coal wall spall and roof fall affect the speed of face advance and mining operations and generally threaten the safe extraction of longwall face. Some researchers have conducted studies on the occurrence mechanism and control methods of coal wall spalling and roof fall in order to successfully control and prevent these failures. Analytical and empirical research, numerical techniques, and physical model construction are the three types of these study. Analytical approaches based on engineering concepts and mathematical relationships can be used to characterize coal wall spalling as a function of effective factors (**Yong et al., 2011; Kong et al., 2019; Jiachen et al., 2007; Guo et al., 2019**). **Hao and Zhang (2005)** used a probability analysis approach to construct a coal wall slip-surface mechanical model

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which investigated the connections between coal wall spalling probability and frictional coefficient, distribution, cohesiveness, and fracture surface orientation. In a study about deflection features of the coal wall using the pressure bar theory **Xiwen et al. (2008)** discovered that the upper and middle portions of the coal wall of faces are easy to occur sliceside and suggested that improving the guard plate's efficiency, increasing the support's resistance, and moving the support in time can reduce the occurrence of large slices in coal faces. Coal wall spalling, according to **Jin et al. (2011)**, is influenced by the mechanical characteristics and geometry of the coal seam, as well as the magnitude and route of external forces acting on the coal wall. **Yuan et al. (2011; 2012)** investigated the microscopic process and macro demonstration of wall spalling on thick coal seams of longwall faces using damage growth mechanics and the "wedge" stability theory. **Qingsheng et al. (2015)** established an elastic mechanics model to determine the stress applied to the face wall based on the torque equilibrium of the coal wall, roof strata and powered support, as well as to evaluate the influence of mining height, fracture location of the main roof, support resistance, protective pressure on the coal wall deformation. The displacement approach was also used to calculate the stress and deformation distributions of the coal wall in this investigation.

Numerous studies have examined the prediction and control of roof fall and the parameters affecting it in underground coal mining. **Molinda et al. (2000)** categorized the roof into the status from dangerous to safe by evaluating the relationship between the recorded data of mine roof fall and coal mine roof rating (CMRR) and indicated that the CMRR is the appropriate index for the roof fall prediction. **Deb (2003)** utilized fuzzy logic techniques to analyze the roof falling in coal mines. **Ghasemi et al. (2012)** developed a semi-quantity technique for the evaluation of roof fall risk by identifying the effective parameters on roof falls such as geological, design, and operational factors and then explaining the role of each parameter. **Razania et al. (2013)** provided a prediction system of roof falls using the fuzzy inference system. The CMRR, depth of rock cover, height of mining or coal thickness, intersection diagonals span and primary roof support were selected as effective parameters and the roof falling of prediction model were compared by field measurements. **Aghababaei et al. (2020)** also evaluated the roof fall risk and determined the damaged zone using by the rock engineering systems and the recorded roof fall in the Tabas coal mine.

Numerical methods among the mentioned methods are highly regarded by researchers due to the fact that it allows them to study the effect of several parameters simultaneously on wall spalling and roof fall by performing an accurate solution (**Yong et al., 2011; Ning, 2009; Wang et al., 2015; Bai et al., 2014; Yao et al., 2017; Song et al., 2017; Bai and Tu, 2020**). **Fang et al. (2009)** investigated the effect of bolts in preventing soft coal wall spalling by evaluating the stability of a weak area in a coal wall and specifying the optimal mining height to maintain its stability. Using elastoplastic mechanics theory, **Niu et al. (2010)** examined the stress condition of the coal rib wall and discovered that the mining height and internal friction angle had the most effect on coal wall spalling. **Zhang et al. (2018)** developed a numerical approach to examine the longwall retreat mining influence on the stress concentrations on the headgate pillar and moreover debated on the risks and reasons of roof falls phenomenon in the longwall main entry, and strategies of mitigation for roof spall risks. **Behera et al. (2020)** used the FLAC3D program to solve the major research gap between face failure and spalling, as well as the associated rock mechanics parameters and quantification. They also evaluated the effect of mining on the coal wall spalling characteristics by using definition of the spalling zones.

Physical modelling is usually less popular with researchers since it is time-consuming, costly and isn't to the real scale. **Yang et al. (2019)** assessed the mechanism of wall spalling from the perspective of support–roof strata interaction using by developing a physical model and theoretical coal-shield support deflection model and stated that most face wall spall phenomenon in longwall mining are observed during support-yielding events.

Most studies highlighted the significance of studying face failure occurrences for underground mining operations, but they only looked at safety, economics, and technology, not environmental, health, or other aspects. The effects of face failure on underground longwall mines are examined in this research, as well as the significant risks related with wall spalling and roof fall events. The study also proposed a classification system for estimating face failure risk that mine operators and regulators can utilize to reduce the negative effects of both wall spalling and roof fall.

2. Major face failure risks

Overall, face failure has a substantial impact on mining projects at various stages. To determine the influence of face failure event on the ultimate product cost, it is necessary to assess its effects at various mining stages. Face failure's negative effects are not restricted to the face and underground spaces; pollution and societal problems induced by wall spall and roof fall contribute to a broader spectrum of negative effects.

The following checklist comprises elements that investigate the consequences of face failure based on significant research and experience gained in mines around Iran. It should be noted that this categorization is designed to serve as a guide and is not intended to cover all of the difficulties that may arise at any mine site. Because of the industry's dynamic and diversified nature, new difficulties will arise from time to time. The primary

Table 1: Environment-related risk classification (R_E)

Major Risk	Sub-matter	Particular occurrence
Air	Gas	Methane emission
		Other gas emission (such as SiO_2, NO_2, CO, CO_2, H_2S, SO_2, NO, H_2).
		Oxygen drop
	Dust	Extraction of coal
		Tailing
		Crushing and grinding
		Stockpiles
		Loading and hauling of coal
Land	Soil	Tailing and waste dump
		Deposition of contaminated windblown coal dust
		Erosion potential
		Subsidence
	Landscape	Stockpiles
		Deforestation and plant extinction
		Tailing and waste dump
		Underground excavations
	Flora	Contamination of soil
		Air pollution
		Water pollution
		Destruction of vegetation
	Fauna	Food pollution
		Water pollution
		Air pollution
		Contamination of soil
		Destruction of forests and plants
		Noise pollution
	Subsidence	Subsidence due to caving method
		Subsidence due to excavation
		Vibration due to equipment activity (crushing, picking, etc.)
		Land subsidence due to water withdrawal
	Noise pollution	Technical services (compressor house, Ventilation house, power generation, etc.)
		Excavation equipment
		Transportation system
		Processing system
		Drilling and blasting
Water	Surface water	Effluent
		Acidity (Existence of metal minerals such as pyrite in coal)
	Underground water	Contamination from coal extraction
		Acidification due to pyrite existing
		Drawdown

risks are classified as environmental, technological, social, safety, economic, and health hazards, and are further classified as main risk, sub-issue, and particular occurrences.

2.1. *Environmental risks*

Despite the fact that mining operations are a major source of air pollution, face failure occurrences can compound the problem by releasing particles into the air, which subsequently settle to the ground. The limited underground space disperses the airborne dust to different parts of the mine with the help of ventilation operations which causes the distribution of pollution with lower concentrations in the mine. Airborne dust particles can be released as a result of picking or blasting, hauling, crushing, processing, waste and ore dumping site,

Table 2: Economic-related risk classification (R_{Ec})

Major Risk	Sub-matter	Particular occurrence
Cost of mining operation	Exploitation	Opening excavation
		Coal mining
		Drilling and blasting
		Depreciation of equipment
		Penalty for OSD increase
		Maintenance
		Purchase cost of equipment
	Transportation	Maintenance
		Depreciation of equipment
		Loss of system capacity
		Purchase cost of equipment
	Processing	Depreciation of equipment
		Maintenance
		Loss of system capacity
		Cost of blending
		Process of dewatering
		Water consumption in mineral processing
		Extreme use of chemical materials in mineral processing
		Mineral processing costs
	Running costs	Energy and fuel
		Staff and miners salaries
		Administrative costs
		Taxes
		Increasing operating costs as mine lifetime is extended
		Royalties
		Insurance
	Reclamation costs	Stope filling
		Opening blinding
		Leveling of ground surface
		Steadying of leveled waste dumps
		Seeding

tailing, as well as face failure event. Since mine-produced dust particles contain silica or metal particles such as pyrites, their release into the environment may result in water and land pollution (**Arasteh and Saeedi, 2016; 2017**). After exhausting the dust of mine return air opening, if the dust particles settle to the surface ground, they may obstruct plant veins, lowering permeability and photosynthesis, and hence have a negative effect on plant growth. Besides, due to the presence of excessive suspended solid particles, heavy metals and water acidity, mining activities have a significant influence on the irrigation, groundwater, rivers, pastures and drinking water. Land pollution can be generated by the settling of polluted particles, mineral fluids carrying contaminated components, or filthy river floods (river pollution caused by mining activities) (**Mukherjee, 2011**).

Noise pollution is also a result of mining activity. Drilling and blasting, mineral and waste extraction by mechanized equipment at the mine site and technical services such as pumps and fans, compressors, crushers and mills and load and haul process in mine are the main sources of noise.

Mining activities may create the aforementioned issues, but in the presence of coal face failure event, the degree of these dangers may be excessive (see **Table 1**).

2.2. Economic risks

A face failure with coal wall spalling and the associated roof fall event leads to an increase in OSD that has an influence on loading and transportation expenses, particularly over long distances, and leads to a loss in transportation system capacity and longevity, as well as an increase in compressed air and power consumption. Due to face failure, there are both qualitative and quantitative losses (OSD) throughout the exploitation stage. When waste materials are combined with ores, the grade of mined vs. in-situ ores are reduced. In extreme cases, when the surrounding strata of coal that causes OSD is weak, the costs of excavation and maintenance in mines rise.

The most significant effect of OSD occurs when the mined waste materials with ores enter processing plants, particularly when the characteristics of coal and waste are relatively near a processing standpoint. The OSD in this situation may result in greater expenses for crushing (primary and secondary), transporting, milling, screening, mineral processing, dewatering, waste dumping, etc. (**Moharana et al., 2004**; **Zarshenas and Saeedi, 2016**). The classification of economic risk is shown in **Table 2**.

2.3. Technical risks

Coal face failure can pose technical challenges for mining engineers at numerous stages of mining, including planning, excavating, drilling and blasting, hauling, and mineral processing. Excessive face failure may stop the extraction operation, so it was necessary to find a solution for restarting operation in the face. To prevent the wall spalling and roof fall, the longwall face should be reinforced using bolts, cables, mesh, timber and chemical stabilization (**Smith, 1992**). Many factors, such as the strength of the coal wall and surrounding strata, existing discontinuities, type of mining, the magnitude of induced stresses, mining depth, mining height, etc. affect the severity of face failure event, with associated OSD phenomenon and should be managed. Furthermore, the physical, mechanical, and chemical characteristics of waste materials mined with coal may differ from or be equivalent to the target coal, posing challeng-

Table 3. Technical risk classification (R_T)

Major Risk	Sub-matter	Particular occurrence
Mining operations	Planning	Mine depth
		Opening type selection
		Technical characteristic of opening (width, height, etc.)
		Mining method selection
		Technical characteristic of mining method
		Underground space stability
		Technical characteristic of coal seams and surrounding strata
	Excavation	Picking
		Extraction equipment
		Rock fragmentation
		Fly rock
		Ground vibration
		Existing fault
		Air vibration
		Maintenance
	Loading	Failure in loading equipment
	Hauling	Failure in hauling equipment
		Traffic designing
		Apportion and dispatching
	Mineral processing	Failure in mineral processing equipment
		Design of mineral processing equipment
		Mineral enrichment process
		Dewatering
	Reclamation	Design, supervision and control of reclamation

es at various phases of mining. If the qualities of the waste and coal differ, the processing plant and equipment of coal extraction are constructed depending on the coal encountered with problems. Technical issues, such as miss load, may develop if the waste characteristics are identical to the coal, such as rock color. **Table 3** is a list of some of these problems.

2.4. Social and community risks

The social repercussions of mining are complicated and sensitive issues. Although mining activities in one location may result in the creation of employment, roads, and infrastructure, an event such as face failure caused by underground longwall coal mining may have a detrimental impact on surrounding communities in addition to the positive consequences. These events can adversely affect peoples' livelihoods, such as shortening the life of miners due to occupational diseases (coal workers' pneumoconiosis (CWP) and …) caused by coal mining, prevent them from accessing clean water and land, and can lead to the loss of crops, livestock products, etc. Reducing the lifespan of workers due to lung diseases as a result of not following safety tips against inhaling respirable coal dust can become a major crisis in the region, so that coal miners may survive only a few years after retirement!

Table 4: Social and community risk classification (R_{sc})

Major Risk	Sub-matter	Particular occurrence
Livelihood	Agriculture	Soil contamination
		Air pollution
		Water pollution
		Loss of agricultural land due to subsidence
	Ranch	Soil contamination
		Air pollution
		Water pollution
		Destruction and pollution of plants and pasturages
	Hunting	Soil contamination
		Air pollution
		Water pollution
		Noise pollution
		Food pollution
	Fishing	Noise pollution
		Water pollution
		Air pollution
	Other jobs associated with Environment	Water pollution
		Air pollution
		Noise pollution
		Destruction of landscape
		Contamination of soil
	Public health	Diseases of the respiratory and nervous system and ergonomic

The intensity of these impacts may be increased by increasing the severity of events during coal mining, e.g. coal wall spalling and roof fall. The categorization of social and community risks are described in **Table 4**.

2.5. Safety and health risks

The failure of the coal face causes higher costs as well as more time and operations to reach all of the minerals accessible in a mine capacity. In more severe cases, shoving the rocks and their collapsing as a result of the face failure can jeopardize the lives of miners. Mining hazards and disasters increase as time and mining operations lengthen. **Table 5** depicts the categorization of safety and health risks.

Table 5: Risk classification of safety and health risks (R_s)

Major Risk	Sub-matter	Particular occurrence
Diseases	Diseases	Diseases (Diseases of the nervous and respiratory system, ergonomic, subcutaneous and skin tissue)
Accidents	Mining	Maim
		Ulcer
		Casualties

3. Risk analysis

Risk management is widely acknowledged as one of the most effective methods for reducing the effects of potentially catastrophic occurrences in mining (**Thompson, 1999**). Mine operators will be able to determine high, medium, and low levels of risk with the use of risk assessment.

The face failure risk model was offered as a tool to help decision-makers in comprehending the effects of wall spalling and roof fall from many perspectives. It employs a straightforward analytical method to enable decision-makers to separate face failure issues into subcomponents and visualize their severe locations. As a result, it makes it easier to manage face failure difficulties. The model can also be used to generate quantitative risk estimations in order to generate a risk factor of face failure (F_{RF}). A comparison of face failure risk parameters from different sites will be especially relevant for larger organizations in determining where the greatest face failure risk will occur. This methodical technique guarantees that crucial mine face failure elements are not neglected (**Laurence, 2006**).

F_{RF} is a quantitative and qualitative evaluation that encompasses the several significant risk components associated with mine face failure. Environmental risks (R_E), economic risks (R_{Ec}), social and community risks (R_S), safety and health risks (R_{SH}), and technical risks (R_T) are the major categories into which these components can be classified. The risk factor of face failure is the aggregate of these individual risks, with the following linear equation expressing the relationship:

$$F_{RF} = \sum \left(R_E + R_{EC} + R_{SC} + R_{SH} + R_T \right)$$

The technique will aid the industry in recognizing, anticipating, avoiding, reducing, and mitigating the risk and potential damaging effects of dilution and achieving the best dilution outcome. Furthermore, each and every factor has been carefully studied.

3.1. Risk quantification

Risk is the possibility or danger of harm, injury, loss, or any other bad event caused by external or internal vulnerabilities that can be prevented by taking proactive measures. In order to discover hazard, risk assessment includes a thorough and rigorous evaluation of any activity, location, or operational system. Such an evaluation will analyze the relationship between the likelihood and potential consequences of actual risks, as well as the present or planned approaches to hazard control.

The product of probability and consequence is defined as risk, i.e.:

$$Risk = Probability \times Consequence$$

Risk matrices are a great tool for assessing face failure hazards because they offer a guidance for risk assessment utilizing repeatable and quantitative matrices, ensuring a uniform approach of risk estimation. This strategy necessitates the formation of a critical team of specialists comprised of mine site staff who are familiar with the facility and its equipment. The group will decide how to handle a situation and define the true risk.

The highest risk levels (i.e. those with the most serious implications and the greatest probability of occurring) in the face failure risk matrix must be addressed or diminished first. In this paradigm, the highest likelihood

Table 6: Face failure risk assessment matrix

Probability	**10 (Almost certain)**	10	20	30	40	50	60	70	80	90	100
	9	9	18	27	36	45	54	63	72	81	90
	8	8	16	24	32	40	48	56	64	72	80
	7	7	14	21	28	35	42	49	56	63	70
	6	6	12	18	24	30	36	42	48	54	60
	5	5	10	15	20	25	30	35	40	45	50
	4	4	8	12	16	20	24	28	32	36	40
	3	3	6	9	12	15	18	21	24	27	30
	2	2	4	6	8	10	12	14	16	18	20
	1 (Rare)	1	2	3	4	5	6	7	8	9	10
		1 (insignificant)	2	3	4	5	6	7	8	9	10 (catastrophic)
	Consequence										

Table 7. a: Face failure risk model utilizes in an Iranian mine- Parvadeh coal mine

Major Risk	Sub-matter	Particular occurrence	Probability	Consequence	Risk	Subtotal	Total Risk
Environment	Air	Methane emission	10	9	90		
		Emission of greenhouse gases	5	5	25		
		Heavy metal emissions	5	5	25		
		Oxygen drop	10	9	90		
		Other gas emission (such as SiO_2, NO_2, CO, CO_2, H_2S, SO_2, NO, H_2)	7	6	42		
		Dust due Extraction of coal	10	8	80		
		Dust due Loading and hauling of coal	10	7	70		
Environment	water	Sedimentation	6	5	30		
		Contamination from coal extraction	7	5	35		
		Effluent	4	5	20		
		Heavy metals salinity	5	7	35		
		Acidification due to pyrite existing	5	5	25		
		Alkalify	5	4	20		
		Wildlife	6	6	36		
		Drawdown	4	4	16		
		Pasture	7	6	42		
		Drinking	4	5	20		
		Contamination (chemical materials)	7	7	49		
		Agriculture	8	6	48		
	Land system	Aquatic ecosystem	5	4	20		
		Contaminated windblown coal dust deposition	10	8	80		
		Tailing and waste dump	5	3	15		
		Subsidence due to caving method	10	6	60		
		Hazardous substance leaks	7	5	35		
		Potential for erosion	8	7	56		
		Forest destruction and plant extinction	8	8	64		
		Creation of more excavation due to exploration	9	6	54		
		Flora	8	8	64		
		Vibration due to equipment activity	7	5	35		
		Fauna	7	4	28		
		Salinity of soil	6	4	24		
		Subsidence due to excavation	9	7	63		
		Land subsidence due to water withdrawal	8	7	56		
	Noise pollution	Technical services (compressor house, Ventilation house, power generation and etc.)	8	8	64		
		Excavation equipment	8	9	72		
		Transportation system	8	8	64		
		Processing	7	7	49		
		Landscape	5	4	20		
		Drilling and blasting	4	3	12		
		Rock burst	3	3	9		
		Loading and unloading of rock	6	5	30		
						1772	
Safety and health	Diseases	Diseases of the nervous and respiratory system, ergonomic, skin and subcutaneous tissue	10	9	90		
	Accidents	Maim	8	9	72		
		Ulcer	9	9	81		
		Casualties	8	8	64		
						307	

Table 7. b: Face failure risk model utilizes in an Iranian mine- Parvadeh coal mine

Major Risk	Sub-matter	Particular occurrence	Probability	Consequence	Risk	Subtotal	Total Risk
Social and community	Livelihood	Water pollution	8	7	56		
		Air pollution	8	6	48		
		Soil contamination	8	5	40		
		Noise pollution	7	6	42		
		Plants and pasturages destruction	8	8	64		
		Loss of agricultural land due to subsidence	9	6	54		
		Destruction of forests	4	6	24		
	Public health	Diseases (Diseases of the respiratory and nervous system, ergonomic, skin and subcutaneous tissue)	10	9	90		
						418	
Economic	Operational costs	Loading	10	8	80		
		Drilling and blasting	5	4	20		
		Depreciation	9	8	72		
		Penalty for grade decrease (due to OSD increase)	10	9	90		
		Purchase of replacement or new machinery	8	6	48		
		Maintenance	9	9	81		
		Capacity reduction	7	5	35		
		Blending cost	7	8	56		
		Extreme use of chemical materials in mineral processing (e.g., activator, collector, and frother)	6	8	48		
		Dewatering process	5	4	20		
		Water consumption in mining and mineral processing	6	5	30		
	Running costs	Staff and miners salaries	8	6	48		
		Energy and fuel	10	6	60		
		Costs of administration	2	2	4		
		Taxes	4	4	16		
		Royalties	7	5	35		
		Increasing operating costs as mine lifetime is extended	7	5	35		
		Insurance	8	7	56		
		Other costs	5	5	25		
	Reclamation costs	Stope filling	9	8	72		
		Leveling of ground surface	6	4	24		
		Opening blinding	9	8	72		
		Steadying of leveled waste dumps	4	4	16		
		Top soiling	3	3	9		
		Seeding	3	2	6		
		Control and supervising on reclamation	6	7	42		
						1100	

or consequence is ascribed to a higher number. In other words, an event with a probability of ten is almost guaranteed to happen; on the other hand, if it has a probability of one, it is highly improbable to happen. If an event has a consequence of 10, the result could be catastrophic, such as a significant environmental problem, substan-

Table 7. c: Face failure risk model utilizes in an Iranian mine- Parvadeh coal mine

Major Risk	Sub-matter	Particular occurrence	Probability	Consequence	Risk	Subtotal	Total Risk
Technical	Mining activities	Mine depth	8	7	56		
		Opening type selection	6	4	24		
		Technical characteristic of opening (width, height and etc.)	6	5	30		
		Mining method selection	8	7	56		
		Technical characteristic of mining method	8	8	64		
		Underground space stability	10	10	100		
		Technical characteristic of coal seams and surrounding strata	10	10	100		
		Picking	10	10	100		
		Extraction equipment	10	10	100		
		Rock fragmentation	9	7	63		
		Fly rock	9	8	72		
		Ground vibration	8	8	64		
		Existing fault	9	10	90		
		Air vibration	7	6	42		
		Maintenance	8	8	64		
		Failure in loading equipment	9	9	81		
		Failure in hauling equipment	9	9	81		
		Traffic designing	8	7	56		
		Apportion and dispatching	8	7	56		
		Failure in mineral processing equipment	8	8	64		
		Design of mineral processing equipment	8	7	56		
		Dewatering	7	6	42		
						1461	
							5058

tial equipment damage, main economic loss, lost community reputation, or other calamities. In the event of the 1st consequence, the effect would be insignificant. **Table 6** illustrates the risk matrix.

Table 7 depicts the model in action on an Iranian mine. Each occurrence in this scenario has been assigned a level of risk by the author. On a mine site, however, this would be done by a group of key employees.

3.2. Face Failure risk model

A new risk analysis method was suggested that takes into account factors that may be altered by face failure in this section. This proposed method is based on the Thompson risk analysis method (**Thompson, 1999**). **Figure 1** depicts the framework of the risk management process. In a face failure risk assessment program, identifying face failure risks is a critical and complex task. **Tables 1, 2, 3, 4, and 5** show the outcomes of this method.

The F_{RF} was evaluated using a mining face failure questionnaire. Based on the F_{RF}'s potential ratings, face failure risks are divided into five tiers. The range of danger categories varies from minimal to catastrophic. **Table 8** depicts the link between the face failure risk factor and the rate of face failure risk. The extreme risk of face failure is related to the situation where a large size of face failure usually occurs and the face advancement is very difficult. This incident may cause both financial and personal harm to those involved in the working face. When there has been no significant wall spall and roof fall during mining, and the majority of wall spall and roof collapses occur on a local scale, the risk of face failure is minimal. This incident did not result in any personal injuries, but it may lead to out-of-seam dilution, which would raise project costs.

Factors such as irregular geological condition, coal mining height, in-situ and induced stress, equipment of mining, and other critical factors can all have an impact on the outcome of a face failure risk assessment.

3.3. Case studies

Face failure risk questionnaires were issued in the three Iranian mines listed below. Managers and skilled mining employees filled them out. We asked each responder to rank or prioritize the relevance of the key

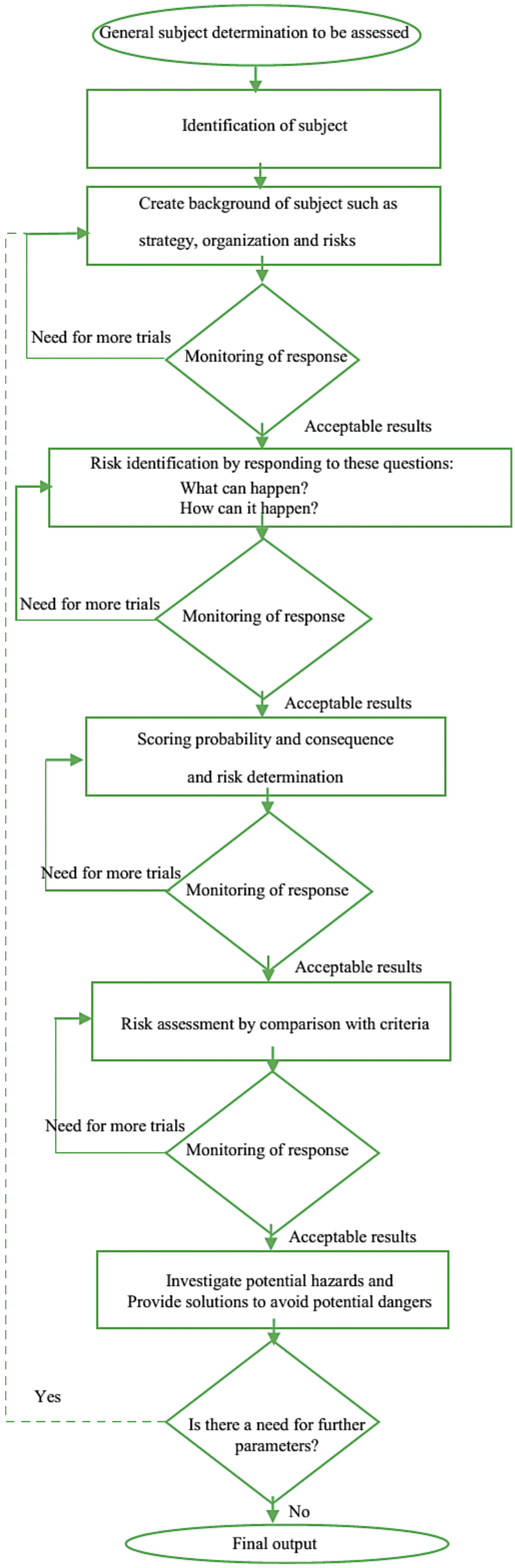

Figure 1: Flowchart of risk management process

Table 8: Risk factor and rating of face failure and its description

Risk factor of face failure	Risk rating of face failure	Description
>8000	Extreme	A large size of a roof fall and wall spall usually occur and the face advancement is very difficult.
6000-8000	Very high	The magnitude of the failure in these areas is rather large. Face failure strongly raise operating cost, cause damage to equipment and reduce productivity. Face's miners are constantly at danger in this situation.
4000-6000	High	The magnitude of the failure in these areas is mostly medium and rarely large. Roof and wall collapses raise operating expenses and reduce productivity. The volume of fallings is reduced when support is installed on time. Negligence in these areas can result in a catastrophic situation.
2000-4000	Moderate	The vast majority of roof fall and wall spall occur on small to moderate sizes. Negligence in these areas might exacerbate the situation.
<2000	Minor	There has been no substantial wall spall and roof fall in these areas. The majority of wall spall and roof collapses occur on a local scale and are scarcely small scale.

face failure concerns (such as environment, economic, technical, etc.). The main features of the studied mines were as follows:

- Case A: Parvadeh (1) coal mine is situated 85 km south of the town of Tabas, in the province of South Khorasan, Iran. Parvadeh (1) mine consists of several longwall panels where the panels W1 to W3 and E0 to E3 have been extracted and the panel E4 is being mined. The mining method used in the mine is the mechanized longwall mining that utilize the double drum shearer, Powered supports and AFC system. The location of Parvadeh Mine in Iran is shown in **Figure 2**.
- Case B: Negin coal mine is located north of Parvadeh 2 of Tabas coalfield and 87 km south of Tabas which is one of the biggest coalmines in this area. Extraction of coal is confined to the traditional caving longwall mining method where produces about 9% of the Iran's annual coal needs. The location of Negin coal mine have been shown in **Figure 2**.
- Case C: Pabedana coal mine, one of the most significant coal mines in Central-East Iran, is located in

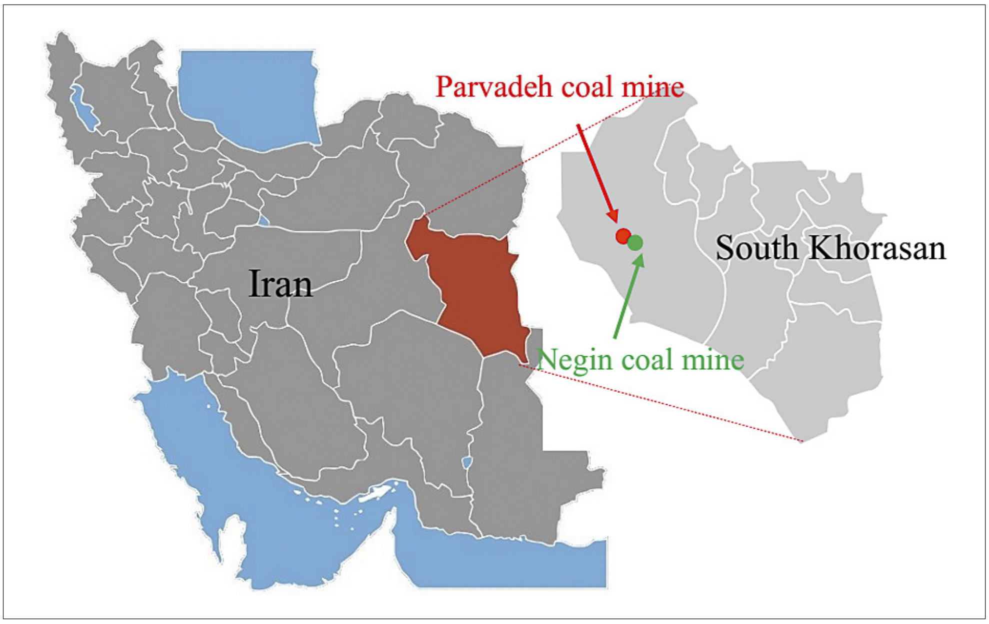

Figure 2: The location of Parvadeh and Negin coal mine in Tabas, Iran.

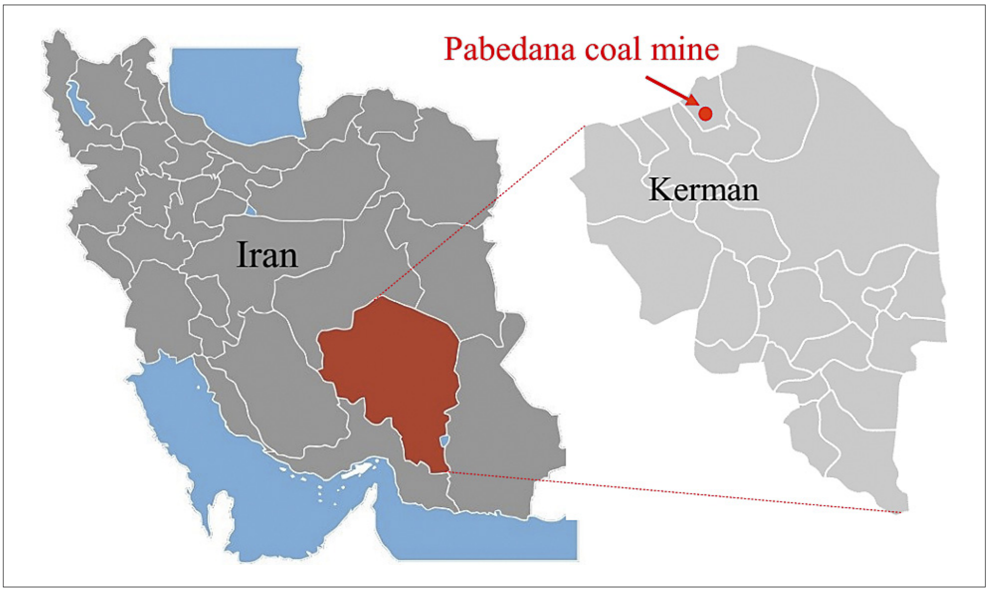

Figure 3: Pabedana coal mine location in Kerman, Iran

Kerman Province and covers an area of 13 km^2. This mine's coal is extracted using traditional longwall methods. The Pabedana coalfield contains a cokable type of coal, and mining began in 1977. **Figure 3** depicts the location of the Pabedana coal mine.

4. Discussion of results

The survey's main goal was to establish a risk categorization or grade for a face failure in coal mines. Another goal of the investigation was to demonstrate the effect of mining wall spall and roof fall on the in Iranian underground coal area.

- Mine A:

The study's findings revealed that the primary wall spalling concerns were technological, environmental, economic, safety and health, and economic difficulties. Air pollution produced by coal dust due to mechanized extraction by shearer, diseases of the respiratory and nervous system, casualties, equipment failure and OSD are the most important factors with a high score. The overall F_{RF} score was 5058, indicating that it was classed as high risk. The utilization of mechanized equipment, high production compared to the traditional method, and poor roof and face are the reasons for this mine's high level of risk.

- Mine B:

The main risk, as indicated by the outcomes, were technological and environmental concerns. The major concerns included technical issues counting underground space stability and existing fault. The F_{RF} score was 3019, indicating a moderate risk level. This risk level is lower than that of the Parvadeh Mine, which could be due to the shallower mining depth and different extraction equipment.

- Mine C:

The mine with a score of 3165 is at a medium risk level where there are the most environmental and technical concerns. This level of risk is higher than that of the Negin Mine, which can be ascribed to the deeper mining depth as well as the larger hydraulic radius.

5. Conclusions

Failure of the face and roof is one of the most critical issues affecting all aspects of coal mining projects. As a result, the consequences of these hazardous occurrences must be addressed throughout mining efforts. In this work, a novel model for estimating face failure risks in longwall coal mines is suggested. According to the findings of this study, the main failure risks include environmental, social, technical, economic, safety, and health hazards. Failure risk was divided into five categories in this approach, ranging from minor to extreme. To demonstrate the model's suitability, failure risk assessments were performed at the Parvadeh, Pabedana, and Negin coal mines, taking into account all of the variables at the mine sites that were caused by wall spall and roof fall. According to the data, the F_{RF} at Parvadeh was 5058, indicating a high failure risk for this mine. Negin's F_{RF} of 3019 revealed a moderate failure risk. Moreover, the 3165 result shows that there are moderate face failure concerns at Pabedana coal mine. However, the mechanization of mining operations can be the cause for the superiority of the risk level in Parvadeh mine compared to the other two mines. Furthermore, technical, environmental and economic concerns had the greatest effect in Parvadeh, while technical, environmental issues received the top grades in Negin and Pabedana mines. Since the suggested technique is robust, it can be highly useful for estimating face failure risks in underground longwall coal mining methods.

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SAŽETAK

Procjena rizika kod širokočelnoga pridobivanja ugljena uslijed sloma radnog čela

Slom čela tipična je pojava u širokočelnim rudnicima ugljena koja može imati širok raspon posljedica. Slom čela, što uključuje pojavu loma u bokovima prostorija i urušavanje krovine, opasna je pojava koja se, ako se ne kontrolira, brzo širi u svim fazama eksploatacije ugljena i ima potencijal da onesposobi rudnik. Ovo istraživanje pokazuje kako slom čela može imati štetan utjecaj na tehničke, ekološke, društvene, sigurnosne i ekonomske aspekte, a njegovi negativni učinci ostavit će nepovoljne posljedice za budućnost. Ovi se utjecaji mogu ublažiti učinkovitim pristupima upravljanja i upravljanja rizikom. Kvantitativni i kvalitativni model rizika od kvara predočen u ovoj studiji ima znatan potencijal kao prikladan alat za donositelje odluka u analizi rizika štete. Pomoću ovoga pristupa mogu se otkriti varijable visokoga rizika povezane s kvarom na čeonim dijelovima, što također olakšava usporedbu rudnika s aspekta sloma na radnom čelu Za validaciju model je evaluiran u rudnicima ugljena Parvadeh, Negin i Pabedana. Nalazi studije otkrili su da je faktor rizika sloma čela Parvadeha bio 5058, što upućuje na visok rizik u ovome rudniku zbog mehaniziranoga rudarenja. Nadalje, rezultati rudnika Negin i Pabedana izračunani su kao 3019 odnosno 3165, što upućuje na to da su oni bili u kategoriji umjerenoga rizika zbog tradicionalnoga rudarenja.

Ključne riječi:
procjena rizika, matrica rizika, slom čela, širokočelni rudnici ugljena

Author's contribution

Hossein Arasteh (PhD Candidate, Mining Engineering) contributed to the methodology formulation of the whole research process and data collection and analysis. **Gholamreza Saeedi** (Associated Professor): participated in the development of research methodology, verification and evaluation of the models, data analysis and completed literature review. **Mohammad Ali Ebrahimi Farsangi** (Associated Professor): regulated the research process and reviewed the final work.