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MRPN Technique for Assessment of Working Risks in Underground Coal Mines

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ABSTRACT

Accidents in underground collieries, under geological and geotechnical uncertainties, cause some irrecoverable consequences for workers. Recognizing and studying the effective factors in the occurrence of such accidents have a very crucial impact on improving worker safety and reducing mining costs. This paper introduces a new and beneficial technique named "modified risk priority number (MRPN)" for recognizing and assessing those risks which may cause working accidents in Iranian underground collieries. The available qualitative data from the mines was quantified using standard tables established for risk assessment. The technique was exemplified using data from mine accidents in Kerman and East-Alborz regions. Roof-fall was found to be the most significant risk factor in the mines that were investigated.

INTRODUCTION

Mining is a particularly hazardous work because of its nature and the work environment (Shahriar and Bakhtavar 2009). Underground collieries are known as the most dangerous environment for mine workers in the mining industry. Most injuries, both fatal and non-fatal, occur due to roof-falls in collieries. There is a large potential for roof-fall occurrences in underground coal mines (Shahriar et al. 2009). Some other in collieries are fires and explosions, dust and gasses, confined working spaces, vibrations, repetitive work, interaction with machinery, and falls and slips. Accidents in underground collieries often impose unpredictable, high expenses on total operational costs in the form of production stoppage and reduction, workers' injuries, and potential liability claims.

Recently, some safety standards with an emphasis on duty of care were established and implemented in the Iranian mining industry. Therefore, the process of risk assessment and management is progressing, especially for underground collieries.

Risks are ranked and classified during a risk assessment which assists managers in evaluating all aspects of control, addressing high risk areas, determining control performances, and modifying methods for controlling as required.

A literature survey was done to assess the risks of the working environment in underground collieries.

Bennet and Passmore (1984) used a logistic regression in order to assess the severity of injuries resulting from working in the US underground collieries during 1975-1981. Schaller and Savidis (1986) introduced a procedure for risk management during mining operations. The research was useful only for some particular mines. Hull et al. (1996) applied a multiple-regression model to evaluate some factors associated with the severity of occupational injuries in New South Wales underground coal mines. Maiti and Bhattacharya (1999) used binary and multinomial logical analysis to assess occupational injury risks in India's underground collieries. A risk assessment-based method was developed by Van Wijk et al. (2002) for utilization in South African collieries. Maiti (2003) improved the risk indices identified in his previous research to be more applicable in Indian underground collieries using a logistic regression analysis. Ko Ko et al. (2004) described a hazard and risk assessment method recorded by the University of Wollongong. The method is applicable for conditions such as natural slopes, embankments and side fill, rock slopes, and soil cuttings. Kniesner and Leeth (2004) used a data set including underground coal mine production, injuries, safety inspections, and other regulatory issues recorded in Mine Safety and Health Administration (MSHA) to create a regulatory approach to workplace safety. Sari et al. (2004) statistically analyzed historical accident records of two underground collieries in Turkey to determine whether mining methods can influence productivity and safety. Duzgun and Einestein (2004) introduced a risk-based method combined with a decision-based analysis methodology for roof-fall risk assessment and management in underground collieries. With this method, probabilities, consequences, and costs of consequences are determined to assess risk. Lind (2005) assessed parameters such as physical coal seam characteristics, mining depth, and conditions for the risk management in underground collieries. Karra (2005) used negative binomial regression to analyze the MSHA database and find mean injury rates. Kentel and Aral (2005) proposed a 2D Fuzzy Monte-Carlo analysis for probabilistic health risk assessment with the possibility of using incomplete information together with expert judgment. In this research, variables in the risk equation of the Monte-Carlo analysis were described as fuzzy numbers instead of random variables. Shahriar et al. (2006) applied a qualitative approach for risk assessment of possible working accidents in underground collieries and a coal washing plant in the Kerman coalfields during 1997-2005. The roof-fall risk index (RFRI) was established and then improved to assess roof-fall risks and hazards in underground mining (Iannacchione et al. 2006; Iannacchione et al. 2007). Coleman and Kerkering (2007) modeled and compared operations risks and lost workdays in underground colliery to those in underground metal/nonmetal mining during 2000 to 2004 using a Beta distribution. Stacey and Gumede (2007) introduced a risk-based method for assessing roof-fall risks in underground stope mining. Shahriar et al. (2009) used a method introduced by Einstein (1997) and then developed by Duzgun and Einestein (2004) to assess and manage roof-fall risks in two main Iranian coal fields. Hosseini and Behraftar (2009) used a risk priority number (RPN) approach together with the method introduced by Duzgun and Einestein (2004) to assess and manage geotechnical risks in the Kerman coalfields. Khademi Hamidi et al. (2010) used a fuzzy-AHP to assess geotechnical risks in tunnels considering geological and geotechnical uncertainties. Behraftar et al. (2010) proposed an RPN method for the assessment of geotechnical roof-fall risks in East Alborz underground collieries. In their research, the probability of event occurrences and their severities were determined for the assessment of risks. Qin (2011) developed a fuzzy parameterized probabilistic analysis method for assessing environmental pollution risks under uncertainties. Two case applications of the method were

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studied: source pollution in a river system, and groundwater contaminant plume from a waste landfill site.

By reviewing qualitative and quantitative risk assessment approaches in the literature the authors introduced a new qualitative-based technique more applicable for the underground collieries. A modified RPN method was used together with new risk maps. This technique, named modified risk priority number (MRPN), was established according to possible risk sources under geological and geotechnical uncertainties in underground collieries. For more applicability, the ideas of the experts along with the statistics data from a number of Iranian underground collieries were utilized. The technique is simple to use and applicable in all situations where a risk assessment is required in underground colliery under geological and geotechnical uncertainties.

MODIFIED RISK PRIORITY NUMBER (MRPN) TECHNIQUE

Risks can be identified and characterized utilizing a systematic risk assessment approach. As a base for a risk assessment process, all potential hazards must be identified and potential risks must be located throughout the investigated area.

Standard risk is defined in Eq. (1).

$$R = P * C \tag{1}$$

where, R is risk; P is the probability of occurrence; C is consequence.

In mining applications, the probability of occurrence in Eq. (1) can be described as the potential for a mine worker to be injured by a source of risk. The term "consequence" represents the severity of a mining accident which may cause fatal or non-fatal injuries and consequently impose high costs on a mining project.

As stated elsewhere, RPN is defined as a multiplication of "degree of probability," "degree of injury intensity," and "degree of disability" (Hosseini and Behrafrtar 2009; Behraftar et al. 2010).

A more appropriate definition for RPN is presented in this study by Eq. (2).

$$MRPN = D_p * S_c \tag{2}$$

where, MRPN is modified risk priority number; D_p is a degree of probability of occurrence; S_c is a degree of significance of consequence

The degree of significance of consequence is properly defined in Eq. (3).

$$S_c = (Ds)^m * (Dc)^n \tag{3}$$

where, D_s is a degree of severity of injury; m and n are the constants for significance degrees; D_c is a degree of "out of work" times (consequence).

A questionnaire was prepared to collect the opinion of experts regarding significance of degree constants (m and n). Based on this, the authors considered m and n to be 0.9 and 0.85, respectively, in Eq. (3). In the questionnaire, all experts agreed that the term "degree of severity of injury" is more important than the "degree for out of work times". Hence, the most appropriate definition for MRPN is given in Eq. (4).

$$MRPN = D_p * (D_s)^{0.9} * (D_c)^{0.85} \tag{4}$$

A classification was first established which ranks "probability of occurrence," "severity of injury," and "out of work times" from 1 to 10 degrees, as shown in Tables 1 to 3, respectively. Then, all probable risks are categorized on the basis of MRPN as given in Table 4 and schematically, shown in Figure 1. According to Table 4 and Figure 1, a score of 1 for MRPN indicates a negligible risk, represents low defect conditions associated with stable conditions, and implies a very unlikely accident probability. Conversely, an MRPN of 562 implies excessive defective conditions associated with unstable conditions and, therefore,

Table 1. Categorization and ranking for probability of occurrence

Level	Failure mode	Description	Probability degree
A	Will occur more than one event in day	It frequently occurs	10
B	Will occur more than one event in week	It occurs several times	9
C	Will occur exactly one event in week	It possibly occurs	8
D	Will occur more than one event in month	It probably occurs	7
E	Will occur exactly one event in month	It occasionally occurs	6
F	Will occur more than one event in each 6 months	It infrequently occurs	5
G	Will occur more than one event in year	It rarely occurs	4
H	Will occur more than one event in each 2 years	It rarely occurs	3
I	Will occur exactly one event during a period of 2 to 5 years	It improbably occurs	2
J	Will occur more than one event in a period of more than 5 years	It impossibly occurs	1

Table 2. Categorization and ranking for severity of injury

Category	Description of injuries	Severity degree
I	Death (fatal injury)	10
II	Amputation	9
III	Electrical shock	8
IV	Burns	7
V	Bone breakage & dislocations	6
VI	Load lifting injuries	5
VII	Internal cuts and bleeding	4
VIII	Bruising, twisting & strain	3
IX	Poisoning	2
X	Cuts & wounds	1

Table 3. Categorization and ranking for "out of work" times

Category	Description of out of work times	Degree
a	Permanent	10
b	2 to 3 years	9
c	1 to 2 years	8
d	6 months to one year	7
e	3 to 6 months	6
f	1 to 3 months	5
g	One week to one month	4
h	One day to one week	3
i	One shift to one day	2
j	Without out of work	1

Table 4. Risk categorization according to modified risk priority number (MRPN)

Risk Category	Modified risk priority number
Full of risk	451 to 562
Extreme	360 to 451
High	287 to 360
Nearly high	214 to 287
Medium to nearly high	159 to 214
Medium	104 to 159
Low to Medium	67 to 104
Low	30 to 67
Negligible	1 to 30

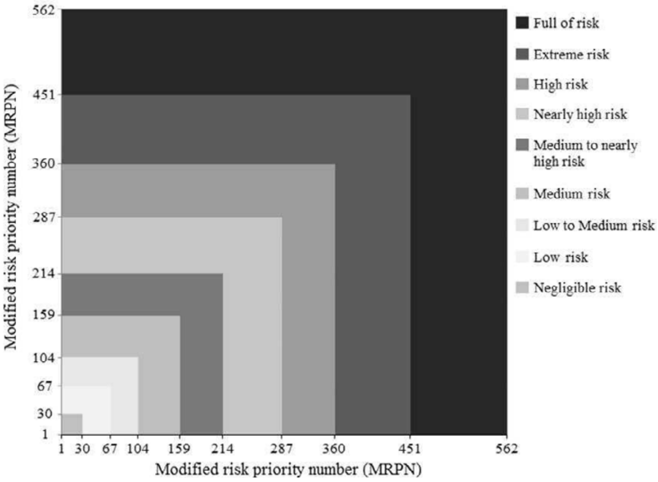

Fig.1. Risk categorization based on modified risk priority number (MRPN)

a high risk for accident probability. Risk is categorized in 9 levels.

An MRPN-based risk assessment map was also made considering the degree of significance of consequence and degree for the probability of occurrence as shown in Figure 2.

RISK ASSESSMENT USING MRPN

Case studies

A number of data sets containing information from incidents which occurred in underground collieries in Kerman and East Alborz during the period 2005-2010 were collected and sorted.

Kerman coal region, located in southeastern Iran, includes five main underground collieries: Pabedana, Babnizoo, Hojdak, Hamkar, and Heshuni. These mines are known as the main area for high coal production.

East Alborz coal region, located in northeastern Iran, is the second

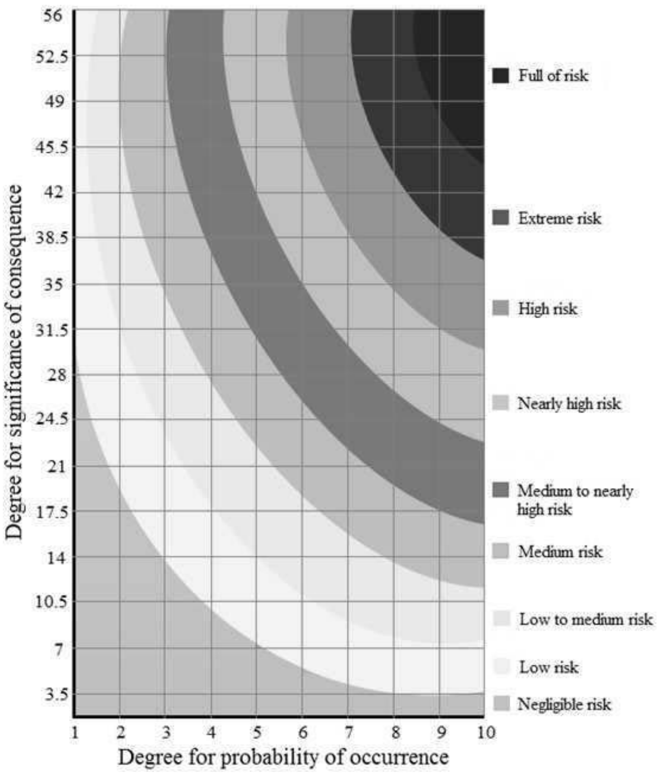

Fig.2. Risk assessment map based on modified risk priority number (MRPN)

case investigated. Tazare and Oulang are the most important underground collieries in this region.

RESULTS AND DISCUSSION

The collected data indicated that the main causes of accidents occurring in the investigated mines are being struck by flying debris, being trapped between heavy objects, tripping on a flat surface, falling from a higher surface, exposure to electrical circuits, destruction, gas poisoning, explosion, colliding with moving objects, and exposure to severe heat (as given in Tables 5 and 6). The statistics for probability of occurrence associated with these accidents are given in Figures 3 and 4 for the Kerman and East-Alborz regions, respectively.

The data collected from all types of incidents has led to the establishment of specific risk assessment classifications suitable for all underground collieries. As shown in Tables 1 to 3, this classification ranks the probability of occurrence, the severity of injuries, and number of "out-of-work" days from 1-10. MRPNs are then calculated employing Eq. (4). Finally, the risks for each type of accident in both regions are assessed using Table 4 and Figure 1. The results obtained for the investigated regions are summarized in Tables 5 and 6. The parameters given in Tables 5 and 6 are presented in Eqs. (2) and (3).

The risk assessment process showed that the maximum MRPN in the Kerman region, about 195, was assigned to "being struck by flying debris," and that implise a "Medium to nearly high risk". However, in the East Alborz region, the maximum value was determined to be 154 for "gas poisoning," which implies a "Medium risk."

It was suggested that incidents to which a "low to medium risk"

Table 5. Risk assessment results for Kerman Coal Mines using MRPN

No.	Accident (source of risk) type	D_P	D_S	D_C	MRPN	Risk category
1	Being struck by flying debris	6	6	9	195	Medium to nearly high
2	Being trapped between heavy objects	4	5	10	121	Medium
3	Falling from a higher surface	3	7	7	90	Low to medium
4	Tripping on a flat surface	4	5	7	89	Low to medium
5	Destruction	2	7	8	67	Low to medium
6	Exposure to electrical circuits	2	5	10	60	Low
7	Gas poisoning	1	10	10	56	Low
8	Explosion	2	6	5	39	Low
9	Colliding with moving objects	6	5	1	26	Negligible
10	Exposure to severe heat	2	1	5	8	Negligible

Table 6. Risk assessment results for East-Alborz Coal Mines using MRPN

No	Accident (source of risk) type	D_P	D_S	D_C	MRPN	Risk category
1	Gas poisoning	3	10	9	154	Medium
2	Being trapped between heavy objects	4	5	10	121	Medium
3	Being struck by flying debris	5	4	9	113	Medium
4	Destruction	3	7	8	101	Low to medium
5	Falling from a higher surface	4	5	7	89	Low to medium
6	Tripping on a flat surface	4	4	7	73	Low to medium
7	Explosion	2	3	10	38	Low
8	Exposure to electrical circuits	1	5	10	30	Low
9	Colliding with moving objects	6	4	1	21	Negligible
10	Exposure to severe heat	2	2	5	15	Negligible

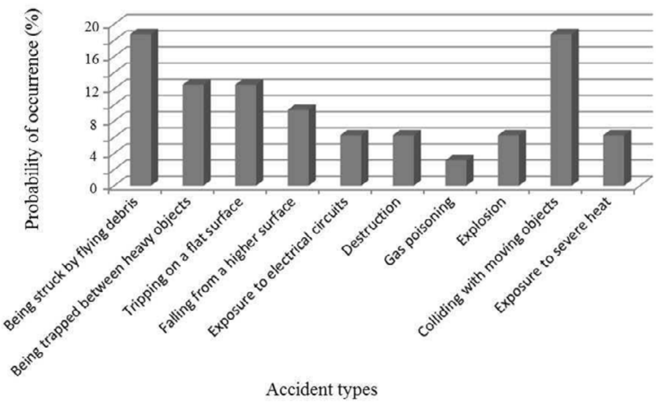

Fig.3. Probability occurrence of the accident in Kerman coal mines

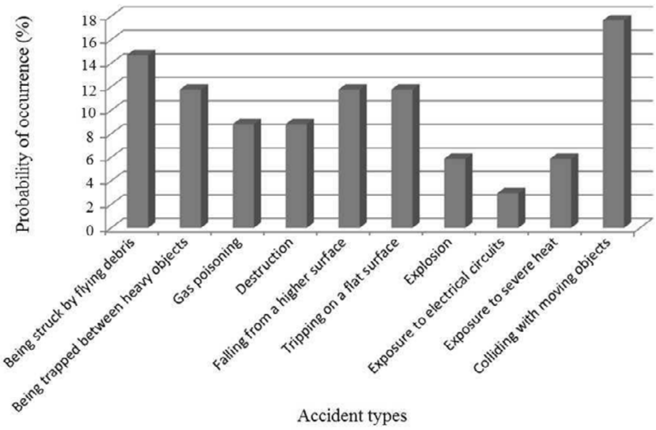

Fig.4. Probability occurrence of the accident in East Alborz Coal Mine

category is ascribed should be taken seriously by management. This indicates that most accidents in both regions require special attention.

Among all the incidents occurring in collieries, only three of them, namely "Being struck by flying debris," "Being trapped between heavy objects," and "destruction" can be categorized as being related to roof-falls. Therefore, the risk for roof-fall was assessed according to an MRPN technique based on the average MRPNs for three types of accidents. For example, the average roof-fall MRPN for the Kerman coal region, taken from Table 5, equals 127.7, indicating a medium risk. This value for East-Alborz region being 111.7 (taken from Table 6) indicates a medium risk. Hence, it is recommended that support systems be improved in the mines having medium risk associated with roof-fall accidents.

Roof-fall occurrence, the most common accident in underground collieries, is uncertain. Therefore, the chance for occurrence of this type of incident should be minimized through accurate engineering and administrative controls. Despite the fact that the roof-fall occurrence is generally considered part of underground colliery activities, its consequences can be problematic, i.e. fatal or non-fatal injuries. The lowest percentage of injuries to mine workers from roof-fall, often result in fatalities, whereas some medical attention is immediately required for all other cases. Although some progress in mine worker safety has been made, further improvement is still possible to reduce injury rates of workers.

CONCLUSIONS

Modified risk priority number (MRPN) is introduced for risk assessment of working accidents in underground collieries. It can be properly applied in all such situations where a degree of safety should be determined. MRPN was assessed by applying data from accidents in Kerman and East Alborz underground collieries. The results showed that roof-fall was the only major risk in the Kerman collieries. In the East Alborz collieries, however, in addition to roof-fall, the risk of gas poisoning was considerable. Among all the incidents occurring in the regions, only "being struck by flying debris," "being trapped between heavy objects," and "destruction" were categorized as being related to roof-falls. Therefore, the risk for roof-fall was assessed based on the average MRPNs for three types of accidents. It was concluded that the average roof-fall MRPN for the Kerman and East Alborz coal regions equal 127.7 and 111.7, respectively, both indicating a medium risk. Accidents to which a "low to medium risk" category is ascribed require special attention. This indicates that most accidents in both regions require special attention. Hence, to reduce risks in the mines, control is needed most; it is recommended that the support systems of these mines be improved.

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