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Geotechnical Risks in Underground Coal Mines

[1]K. Shahriar and [2]E. Bakhtavar
[1]Islamic Azad University, South Tehran Branch, Tehran, Iran
[2]Division of Mining Engineering, Urmia University of Technology, Urmia, Iran

Abstract: In this study, a quantitative approach and decision tree were employed in order to assess and manage roof fall risks as only major problem bring about geotechnical issues in Iranian coal mines. For the objectives, risk was assessed due to the determination of likelihoods and cost of consequences (outcomes) by the analysis of assembled roof fall data from 5 different coal regions comprising several underground coal mines in Iran. In addition, the cost of consequences is considered by a relative cost. Then, it was concluded that the annual average accidents in the all investigated mines are high and it is economically admissible to serve the proposed solutions for reducing the accidents.

Key words: Roof fall, accident, relative cost, decision tree, management, mining

INTRODUCTION

Mining is particularly hazardous because of the nature of the work carried out. Averaging among all occupations in mines, underground coal mining activities are the most hazardous with very high risk (Shahriar *et al*., 2006). Surface mining is heeded to be more favourable and dominant than underground mining, particularly in safety, meaning, occupational risk in underground is much higher than in surface mining (Bakhtavar *et al*., 2008). The risk in mining of stone, sand and gravel and other metallic and non-metallic minerals is lower than that for coal. Injuries, fatal or non-fatal, could result from dust and gases, fires, slips, falls, interaction with machinery, confined working spaces, repetitive work, vibrations and so on (Karra, 2005). Accidents and disease have a very high cost to mining industry not only in the direct costs of accidents but also because of the productivity lost which follows an accident and the potential for liability claims. Effective health and safety management begins with its acceptance as an integral part of everything an organization does (Shahriar *et al*., 2006). The nature of injury data is not continuous but discrete and count based. An appropriate model for discrete injury data covering several commodities and work locations is needed. In the area of modelling of injuries and assessment of related risks (especially, Roof Fall (RF)s as geotechnical risks) in mining, a literature search revealed the following:

Multiple regression was used for evaluating factors associated with occupational injury severity in New South Wales underground coal mining industry (Hull *et al*., 1996). For count based injury data, when the counts are large (>10), a normal distribution can be assumed and multiple regression can be used. With over dispersed and annually collected injury data, multiple regression models may not work due to problems such as autocorrelation. A risk and decision analysis methodology was applied to landslide risk assessment (Einstein, 1997).

Risk of occupational injuries among Indian underground coal workers through multinomial logic analysis was assessed (Maiti and Bhattacharya, 1999). Risk indices for these workers were developed employing various personnel and workplace independent variables using logistic regression analysis (Maiti, 2003).

A research was done by using assembled data from the Mine Safety and Health Administration (MSHA) on underground coal mine production, injuries and safety inspections and other regulatory activities to estimate an econometrically sophisticated regression model of the connection between mine inspections and mine safety outcomes (Kniesner and Leeth, 2004).

Kerkering and McWilliams (1981) were assessed indices of mine safety data such as the hazard rate, safety, risk and mean time between accidents from the US mine accident data for a 9.5 year period during 1975-1984. Both fatal and non-fatal injuries combined for one mine operation were analyzed using the Poisson distribution model (Karra, 2005). Here, the focus was on underground bituminous coal only and the logistic regression model is used for modelling a dichotomous dependent variable.

Underlining both fatal and non-fatal injuries caused by working accidents during the years of 1997-2005 at the mines and coal washing plant of Kerman coal region in Iran, a risk assessment and statistical analysis was done (Shahriar *et al*., 2006).

Corresponding Author: E. Bakhtavar, Division of Mining Engineering, Urmia University of Technology, Urmia, Iran

A method was to use a beta distribution to model the losses and to compare underground coal mining to underground metal/nonmetal mining from 2000 to 2004. The first objective of the study examined the distributions and summary statistics of all injuries and the second objective addressed the problem of comparing safety program performance in mines for situations where denominator data were lacking (Coleman and Kerkering, 2007).

Through a research related to RFs taken place in underground stope mining, a risk approach was introduced that will allow designs to be carried out that are compatible with the acceptable risk defined by the mining company management. The implementation of this approach would overcome the ethical shortcomings of the support design practices (Stacey and Gumede, 2007).

In coal working face because of the importance of RF problem, usually to determine safety degree number of RFs and sudden rock droppings from the roof (even if there is happened no injuries due to the occurrences) takes into account.

RFs were founded as only major problem bring about geotechnical risks in Iranian coal mines. In other words, accidents caused by RFs as more conventional geotechnical risk have been usually faced problems of Iranian UCM. These accidents had already have detrimental effects on workers in the form of injury, disability or fatality additionally on related mining companies due to downtimes, stoppages in the mining operations, equipment breakdowns, etc.

In this study, initially RFs risk was assessed and then a decision analysis method, which was previously applied to landslide risk assessment (Einstein, 1997) is used for the management of the risks in Iranian UCM. To assess RF risks determination of likelihoods, related consequences and its cost is required. For the objectives of this study, a collection of statistical data in relation to RFs has been assembled from 5 coal regions, which each one embraces several UCM.

GENERAL DESCRIPTION OF THE COAL REGIONS

The investigated coal regions are Tabas, Kerman, Eastern Alborz, Central Alborz and Western Alborz generally describes as below.

Coal Region of Tabas (CRT) is generally expanded about 30000 km^2 (Fig. 1). Totally, the related geological reserve was estimated approximately 2.5 milliard tones. However, this region includes four major coal areas namely Parvade, Nayband, Mazino and Abdoughi, but considering coal quantity and quality Parvade area is more significant. Mineable reserve of Parvade coal area, which divided into five mines, is nearly 398 million tons.

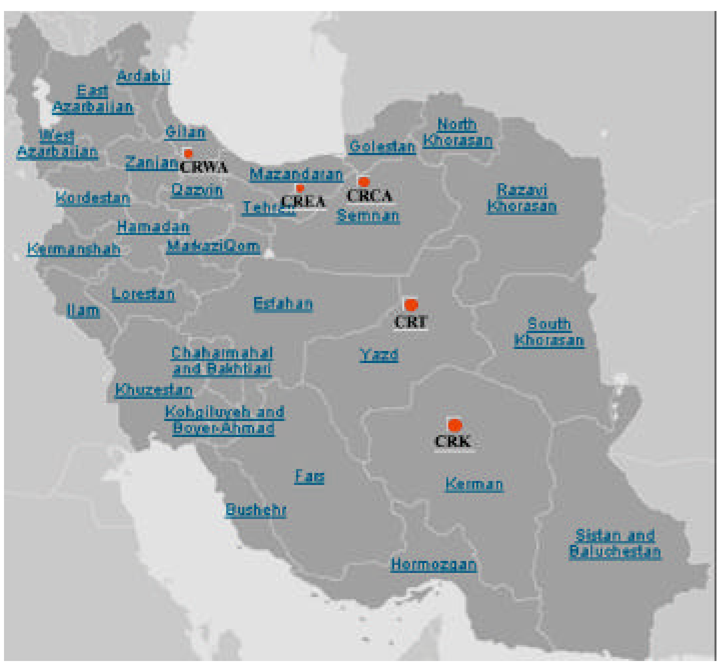

Fig. 1: Location of five studied coal regions

Coal Region of Kerman (CRK) is the most significant center of coal production that located in Southeastern of Iran (Fig. 1). In this region there are various bedding with high expansion and the number of underground active mines. Through the existent UCM take place in the CRK, with emphasizing on importance and production rate, five major mine named Pabedana, Babnizoo, Hojdak, Hamkar and Heshuni are taken into account in this study. Totally, their probable and proven reserves were estimated 202 and 107 million tones, respectively.

The central company of Coal Region of Eastern Alborz (CREA) is located in Shahrood city from Semnan state (Fig. 1). In this region there are two underground mines namely, Tazare and Oulang that their total proven and probable reserves were estimated 101 and 18 million tones, respectively.

As it shown in Fig. 1, the central company of Coal Region of Central Alborz (CRCA) is located near Zirab city from Mazandaran state. This company comprises six UCM so-called Karmozde 1, Karmozde 2, Karsang, Kiyasar, Goliran and Kordabad. Up to now, total proven and probable reserves in the CRCA were appraised 139 and 497 million tones, respectively.

The central company of Coal Region of Western Alborz (CRWA) is near Sangrood village located in 25 km from Loshan city of Gilan state (Fig. 1). Name of mines take place in the CRWA are Sangrood, Central-block and North-block. Total proven and probable reserves in the CRWA were assessed 0.5 and 3 million tones, respectively.

Statistical analysis: Prevalently, in order to recognize the agents more cause to take place events and identify their reasons as well as obviate them, a statistical analysis and assessment of the events is essential.

An extensive statistical analysis in regard to general events occurring in the investigated UCM (located in the coal regions of Iran) during a period of 5 years (2003 to 2007) was accomplished.

The results of frequency and severity coefficients are shown in Table 1. In comparison between these two coefficients obtaining from the investigated coal regions and their underground mines, it is evident that the frequency of total events in the CRT is greatest, however the most sever events have been happened in the CREA.

Iranian Mineral Production and Supplying Company (IMPSCO) was presented a classification (as below) emphasizing the kind of occurred events in Iranian underground mines. It is notable that this classification was utilized as the base of established checklist, which was served to assemble the essential RFs data. Generally, in this classification there are only two substances named collapse and caving and sudden dropping of rocks that can be played the role of RF events as most common geotechnical risk in the UCM of Iran:

Table 1: Frequency and severity coefficients of the investigated coal regions during 2003-2007

Coal region	Frequency coefficient	Severity coefficient
CRT	16.80	1.73
CRK	9.75	2.09
CREA	14.00	2.74
CRCA	5.20	0.04
CRWA	7.83	0.15

Table 2: Results of statistical analysis of events regarding their kinds and percentage during 2003-2007

Event	CRT	CRK	CREA	CRCA	CRWA
Collision	37	29	44	19	0
Blasting	0	3	2	0	0
Collapse and caving	5	2	5	43	20
Dropping from a level	9	4	6	9	10
Sudden dropping of rocks	16	57	25	19	50
Stymie between two substances	20	2	6	5	20
Backfall	9	1	8	5	0
Exposure to high heat	1	0	1	0	0
Exposure to electricity	1	1	0	0	0
Suffocation	0	1	3	0	0
Others	1	0	0	0	0

- Collision
- Blasting
- Collapse and caving (is known as a kind of RF)
- Dropping from a level
- Sudden dropping of rocks (is known as a kind of RF)
- Stymie between two substances
- Backfall
- Exposure to high heat
- Exposure to electricity
- Suffocation
- Others

The results obtained due to statistical analysis of the kind of occurred events in respect to their percentage in the coal regions during 2003 to 2007 are shown in Table 2.

Through the statistical analysis of the events shown in Fig. 2, the following results are deduced:

- In the CRT and CREA, the maximum number of events was occurred in form of the collision, as well as the sudden dropping of rocks and the stymie between two substances takes place in the subsequent priorities
- In the CRK and CRWA, the maximum number of events was happened in form of the sudden dropping of rocks, but in the CRCA, the maximum number of events occurred in form of the collapse and caving. However, in the CRCA the sudden dropping of rocks and collision needs to be attended as the subsequent priorities

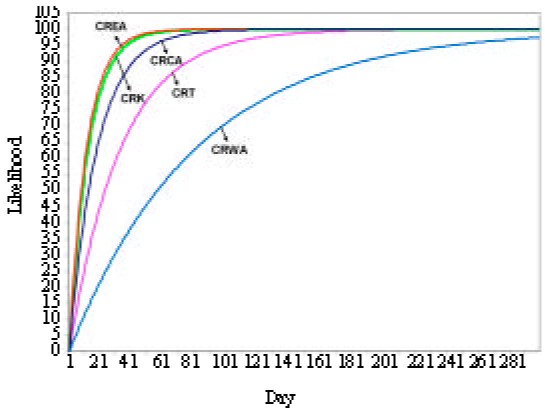

Fig. 2: Graphs of the likelihoods of RF occurrences in the considered coal regions

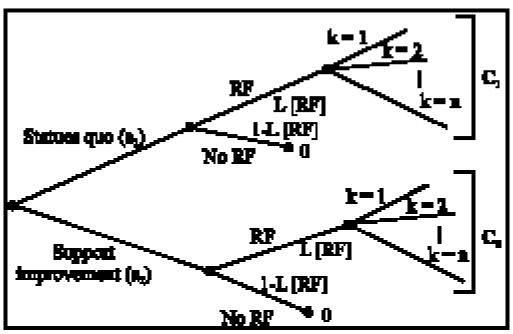

Fig. 3: Decision tree for RF problem

Table 3: Statistical analysis of two kinds of RF events in the coal regions during 2003-2007

Event	CRT	CRK	CREA	CRCA	CRWA
Collapse and caving	5	2	5	43	20
Sudden dropping of rocks	16	57	25	19	50

In Fig. 3, percentages of collapse and caving and sudden dropping of rocks as two kinds of RF event in the studied coal regions of Iran were specified and summarized. According to Table 3, the maximum percentage of collapse and caving has been occurred in the CRCA and the related mines, whereas, sudden dropping of rocks has maximally taken place in the underground mines of the CRK.

RISK ASSESSMENT AND DECISION ANALYSIS

Risk assessment is a systematic examination of any activity, location or work process to identify risks to system success, understand the likelihood and potential consequences (outcomes), the threat to success or hazards and review the current or planned approach to controlling the risk, adding new potential controls where required. Because of the uncertainties associated with the inherent variability of the RF phenomenon, it is not possible to predict certainly the RF occurrences. Since, in a risk assessment process, first it is essential to determine and ascertain the RFs likelihood. This means that, to quantify the uncertainties, likelihoods must be estimated. Identification and ascertaining of the related consequences (outcomes) is the second step in the risk assessment process. Here, RF risk introduces as a function of both likelihood and consequences (Eq. 1).

$$R_{RF} = L_{RF} \times Con \quad (1)$$

Where:
R_{RF} = Roof fall Risk
L_{RF} = Likelihood of occurrence of a RF during a certain period of time
Con = The consequences if the RF occurs

Estimation of RF likelihoods: The RF likelihood can be estimated by utilizing statistical analysis of the assembled data. But, it is usually difficult to supply adequate data for appraisement of likelihood. In these cases, miners, experts and engineers experiences can be used effectively. In other words, an experienced miner or engineer by looking at the roof and the feeling about the RFs depending on some indicators can make a decision.

In this research, through sufficient and adequate assembled data regarding RFs occurred in the UCM of Iran, the likelihoods are assessed. In this manner, two major variables named Time Intervals between the RFs (TIRF) and Number of RFs in each Month (NRFM) during 2003 to 2007 are analyzed and statistically processed for the investigated mines. The results acquiring from statistical analysis of TIRF and NRFM variables for the coal regions and their underground mines are shown in Table 4 and 5, respectively.

In order to evaluate the likelihoods of RF incidents, implementation of the most fitness statistical distributions to NRFM and TIRF is required. Generally, accidents tend to follow a Poisson distribution. In other words, the nature of NRFM data fittingly considers Poisson distribution. On the other hand, when NRFM fits to Poisson distribution then for TIRF the Exponential distribution may suitably interest.

Also, in order to achieve the proper distribution, chi-square goodness could perform as a fit test for available data.

The likelihood (probability) density function of a Poisson distribution and the likelihood mass function of an exponential distribution are given in Eq. 2 and 3, respectively.

Table 4: Summary results of statistical analysis of the NRFM during 2003-2007

Coal region	SD	Mean	Minimum	Maximum
CRT	1.167	0.85	0	5
CRK	3.950	3.48	0	10
CREA	1.400	2.67	0	6
CRCA	1.085	0.67	0	3
CRWA	0.590	0.35	0	2

Table 5: Summary results of statistical analysis of the TIRF (days) during 2003-2007

Coal region	SD	Mean	Minimum	Maximum
CRT	49.47	32.66	0	264
CRK	10.89	8.1	0	101
CREA	27.86	18.73	0	208
CRCA	23.39	17.75	0	77
CRWA	109.8	80.71	0	295

Table 6: Statistical analysis of NRFM in the coal regions during 2003-2007

NRFM	CRT	CRK	CREA	CRCA	CRWA
0	0.49	0.11	0.13	0.67	0.70
1	0.27	0.19	0.20	0.11	0.25
2	0.16	0.11	0.19	0.11	0.05
3	0.04	0.13	0.19	0.11	0
4	0.04	0.11	0.15	0	0
5	0	0.11	0.06	0	0
6	0	0.13	0.04	0	0
7	0	0.02	0.02	0	0
8	0	0.06	0.02	0	0
9	0	0.04	0.02	0	0

$$P(i) = \frac{e^{-\lambda} \times \lambda^{i}}{i!} \qquad i = 0,1,2 \tag{2}$$

$$F(i) = \frac{1}{\theta} \times e^{-i/\theta} \qquad i = 0,1,2 \tag{3}$$

Where:
λ = Mean of NRFM
θ = Mean of TIRF

The achieved results of NRFM with respect to relative frequency due to the statistical data analysis of the coal regions are shown in Table 6.

The likelihood of having a RF in n days, L, is simply:

$$L = \int_0^n \frac{1}{\theta} \times e^{-x/\theta} dx \Rightarrow L = 1 - e^{-n/\theta} \tag{4}$$

Figure 2 reveals graphs of the likelihoods of RF occurrences in the considered coal regions during 2003 to 2007. It is evident that on the basis of the confidence level of 95%, TIRF in the underground mines of CRT, CRK, CREA, CRCA and CRWA are 98, 36, 33, 53 and 242 days, respectively.

Quantification of consequences: The outcomes of RFs have to be identified and quantified in order to assess risk. The outcomes or consequences may differ depending on the mine environment. For RFs, some of the main characteristics of damage are injury, disability, fatality, equipment breakdown, stoppage in operation, clean up, etc.

Although it is usually impossible to determine the true cost of an accident due to a number of intangibles, the cost of each characteristic referred to previously can be estimated by using the relative cost criterion.

Among the mentioned characteristics above related to RF damages the major issues should be taken into account for the investigated mines are as below:

- Fatality (f)
- Injury (i)
- Equipment breakdown (eb)
- Stoppage in operation (so)

It is remarkable that the cost due to the clean up is ignored and disability has been placed within fatality and injury. In this step, the associated expenses (costs) can be defined. The total cost of a RF (E_t) defines as the sum of the costs of fatality C_f, injury C_i, equipment breakdown C_{eb} and stoppage in operation C_{so}:

$$C_t = C_f + C_i + C_{eb} + C_{so} \tag{5}$$

According to the experts' ideas in this field and the widely study accomplished about percentage of damages (as consequences) due to RFs, it is evident that 20% of C_t is due to the fatality C_f, 40% of C_t belongs to injury C_i, 25% of C_t belongs to the equipment breakdown C_{eb} and finally 15% of C_t is due to stoppage in operation C_{so}. Therefore, if the cost of fatality is Y then:

$$C_f = Y; \quad C_f = 2Y; \quad C_{eb} = 1.25Y; \quad C_{so} = 0.75Y \tag{6}$$

It is notable that the entire relative weights bring in Eq. 6 are assumed for the present study and it will possible to modify them based on the particular experiences of the mining engineers. Having determined the component of total cost of RF, the risk in n days is formulated as:

$$R_{RF} = C_t \times (1 - e^{-n/\theta}) \tag{7}$$

DECISION TREE

The evaluation of risk leads to the following two questions: Is the calculated risk acceptable? If not, what should be done to decrease the risk? The answers to these questions can be determined by a decision analysis approach. Here, the NRFM is estimated and found to have

Poisson distribution. The problem is to decide on whether the present situation, i.e., the mean NRFM is acceptable or if it is required for improving support system to reduce the costs by decreasing the expected NRFM. In other words, the decision has to be made between the two actions namely, do nothing (status quo), denoted by action a_1 and support improvement, which is marked action a_2. The decision tree of the problem is given in Fig. 3. Here, k denotes number of RFs per year, L(k) is the likelihood that k is equal to 0,1,2,... . Assuming that action a_2, that is support improvement, enhances the roof condition leading to a reduction in Ct by Q%, cost functions for a_1 and a_2 can be formulated as follows:

$$C_1 = C_t \times k, \quad k = 0,1,2 \tag{8}$$

$$C_2 = (1 - \frac{Q}{100}) \times C_t \times k + C_m \quad k = 0,1,2 \tag{9}$$

Where:
C_i = Cost function for the action a_i, i = 1,2
k = No. of RFs
C_t = Total cost of a RF
C_m = Cost of support improvement

Then, the expected value (E) of any action can be calculated as:

$$E[a_i] = \sum_{k=0}^{\infty} C_i \times L(k) \tag{10}$$

For action a_1, the expected value is:

$$E[a_2] = C_t \times \lambda \tag{11}$$

Correspondingly, using Eq. 10, the expected value of action a_2 can be calculated as follows:

$$E[a_2] = (1 - \frac{Q}{100}) \times C_t \times \lambda + C_m \tag{12}$$

The basic aim is to choose the branch in the decision tree, which has minimum expected value. The expected value of branches of a_1 and a_2 for the considered mines, each of which has a different value are evaluated (Table 7) together with the chosen action. On the basis of the following assumptions, the relative cost of a_2 branch can be calculated. Note that the assumptions with regard to the situation in Iran are considered and according to nature and characteristics of projects could be possibility changed:

Table 7: Expected values option actions for the coal regions

Coal region	NRFM	$E(a_1)$	$E(a_2)$	Chosen option
CRT	0.85	$10.20C_T$	$5.68C_T$	a_2
CRK	3.48	$41.76C_T$	$18.30C_T$	a_2
CREA	2.67	$32.04C_T$	$14.42C_T$	a_2
CRCA	0.67	$8.04C_T$	$4.82C_T$	a_2
CRWA	0.35	$4.20C_T$	$3.28C_T$	a_2

- Employing a proper educational system and accurate supervision and checking all safety considerations leads to 40% reduction in the total cost of RF after the employment
- Total cost of the educational system employment and suitable supervision on safety aspects is maximally 30% more than the total cost of RF before the employment
- Improving the roof condition and its stability for substance by serving the additional support system or its improvement leads to 20% reduction in the total cost of RF after the improvement
- The required cost for the improvement of roof condition by improving the support system is 30% more than the total cost of RF before the improvement
- Therefore, if the two mentioned procedures would be employed, then they totally lead to 60% reduction in the total cost of RF after their employment. In this regard, the total cost of utilization of the procedures and improving the condition is 60% more than the total cost of RF before the improvement

Finally, the cost function for the action a_2 becomes:

$$C_2 = 0.4\, C_t \times \lambda + 1.6C_t \tag{13}$$

From Table 7 it can easily be seen that related to the investigated coal regions the expected value of a_2 branch considerably is lower than the expected value of a_1 branch. In other word, employment of the suggested procedures (mentioned above) is economically acceptable, because the average number of occurred events per year is great.

CONCLUSION

Roof Fall (RF)s were founded as only major problem bring about geotechnical risks in underground coal mines of Iran. The main detriments due to the RF accidents in the coal region of Iran commonly are in the form of injury, disability, fatality downtimes, equipment breakdowns, stoppages in operations. In the study to assess RF risks first likelihoods were determined and then related consequences based on the relative cost were estimated.

After the risks assessment, for the objective of reducing the high level risks, appropriate actions were taken and the success of such actions were evaluated by using the decision analysis. The achieved results of analysis using decision tree and expected values of the suggested actions indicated that in relation to the all investigated coal regions the expected value of a_2 branch considerably is lower than the expected value of a_1 branch. For this reason, serving the suggested procedures (employing a proper educational system, accurate supervision on safety considerations and support improving) is economically acceptable.

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REFERENCES

Bakhtavar, E., K. Shahriar and K. Oraee, 2008. A model for determining optimal transition depth over from open-pit to underground mining. Proceedings of 5th International Conference on Mass Mining, June 9-11, Lulea, Sweden, pp: 393-400.

Coleman, P.J. and J.C. Kerkering, 2007. Measuring mining safety with injury statistics: Lost workdays as indicators of risk. J. Safety Res., 38: 523-533.

Einstein, H.H., 1997. Landslide Risk-Systematic Approaches to Assessment and Management. In: Landslide Risk Assessment, Cruden, D.M. and R. Fell (Eds.). A.A. Balkema, Rotterdam, ISBN: 9054109149, pp: 25-50.

Hull, B.P., J. Leigh, T.R. Driscoll and J. Mandryk, 1996. Factors associated with occupational injury severity in the New South Wales underground coal mining industry. Safety Sci., 21: 191-204.

Karra, V.K., 2005. Analysis of non-fatal and fatal injury rates for mine operator and contractor employees and the influence of work location. J. Safety Res., 36: 413-421.

Kniesner, T.J. and J.D. Leeth, 2004. Data mining data: MSHA enforcement efforts, underground coal mine safety and new health policy implications. J. Risk Uncertainty, 29: 83-111.

Maiti, J. and A. Bhattacharya, 1999. Evaluation of risk of occupational injuries among underground coal mine workers through multinomial logit analysis. J. Safety Res., 30: 93-101.

Maiti, J., 2003. Technical note: Development of risk indices for underground coal mine workers in India. Trans. Inst. Min. Metall. A, 112: 119-124.

Shahriar, K., E. Bakhtavar and G. Saeedi, 2006. Statistical analysis and risk assessment of working accidents at the Kerman Coal Mines. Proceedings of 15th Turkish Coal Congress, Zonguldak, Turkey, Jun. 7-9, Kozan Offset, Matbaa Cilik San. ve Tic. Ltd. Sti. Ankara, pp: 181-187.

Stacey, T.R. and H. Gumede, 2007. Evaluation of risk of rock fall accidents in gold mine stopes based on measured joint data. J. S. Afr. Inst. Min. Metall., 107: 345-350.