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# GEOTECHNICAL RISK ASSESSMENT IN KERMAN COAL MINE- CENTRAL IRAN

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*ABSTRACT:* Mine safety in underground coal mines is normally threatened by the likelihood of accident occurrence. The outcome of such occurrences includes and is not limited to loss of machinery and equipment, loss of life, injury, disability, and mine closures. In this study, the Risk Priority Number (RPN) has been determined for the Kerman Coal Mine and the main causes of uncertainty found through the RPN. The implementation of a decision tree and a risk management plan considering the causes of accidents has been proposed. Data covering a complete range of every accident occurred during the time period of 2003-2008 has been analyzed and the accidents have been classified and sorted by RPN. It has been shown that amongst all types of incidents, the risk of roof failure is the most probable risk of all. It is concluded that the probability of an accident occurring every 24 days is 95%. It has been shown through the decision tree that due to the high number of accidents, the cost of investing in preventative measures is significantly less than costs related to accident consequences and therefore, financially justified.

**Key words:** Risk Analysis, Risk Priority Number (RPN), Decision Tree.

## INTRODUCTION

Underground coal mining is one of the most high risk industries and every year, accidents in mining activities cause fatalities, serious injuries and incurring heavy financial losses. Minimizing existing risks and providing a safe working environment not only requires a well planned management of the risks related to various accident types, but also the creation of suitable solutions for them.

In underground coal mines, roof collapse as a geotechnical risk, is amongst the main causes of accident occurrences. The consequences of such failures are worker's disability, death, injury, equipment damage and financial losses. During 2003-2008, in Kerman Coal Mines, 59% of accidents and 30% of fatalities have been caused by roof collapse (HSE section, Mineral Supply and Production Co., 2008).

In this paper, the risk of accident occurrences has been studied and for this purpose quality data has been quantified through statistical analysis involving the decision tree method has been used for assessment and management of risks.

## DEFINITIONS

To avoid any confusion in the interpretation of the terminology used in this paper, the following definitions adopted from literature are presented (Einstein, H.H., 1997 and Duzgun, H.S.B., Einstein, H.H., 2004):

**Uncertainty**: Implies a condition in which not only the probable happenings are not known, but also the probability of known happenings is not clear. In other words, neither the probable happenings nor the probability of their occurrences is clear.

**Danger**: Although the potential of rock fall from the roof exists, the characterization of danger does not include any forecasting.

**Hazard**: Conditions in which the probability of a roof collapse exists in a certain period of time.

**Risk**: Implies a condition in which not only the probable happenings are known but also the probability of known happenings is almost clear. However, which incident may occur is unknown. Therefore,

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making a decision in a high risk environment is much easier than in an uncertain environment. Since the hazard may lead to different consequences depending on the mine environment, risk can be introduced as;

Risk = Hazard × Consequences
In the case of roof fall;
Risk = Probability of roof fall (P) × Consequences or R = P× C
Where R= Risk associated with roof fall, P = probability of roof fall occurrence in a certain period of time (Hazard) and C = Consequences which may include fatalities, injuries, disabilities, equipment breakdown, loss of time, etc.

## CLASSIFYING THE INCIDENTS IN THE KERMAN COAL MINE

The effect of risk is determined through probability and consequences. A probable incident and its consequences have been classified through a ranking of 1 to 10, depending on its degree of probability and the intensity of its consequences. Risk Priority Number (RPN), which varies from 1-100, is then calculated by the multiplication of the two above rankings. RPN is employed in deciding on necessary modifications for avoiding or reducing the potential errors.

Data collected from all types of incidents occurred in Iranian coal mines during the time period of 2003-2008 has lead us to adopt specific classifications suitable for all nationwide underground coal mines. As shown in Tables 1 to 3, this classification ranks the probability of occurrence, intensity of injuries and number of "out of work" days from 1-10. RPNs shown in Table 4 were then calculated from due numbers in Tables 1-3.

As seen in Table 4 being struck by flying debris, being trapped between heavy objects and destruction have the highest RPN. Geotechnical problems (mostly roof failure) are the main cause of these incidents. The total RPN for the 3 main incidents caused by roof collapses is 690 out of 1000. This indicates that this type of risk (roof failure) requires particular attention.

**Table 1 - Classification of "occurrence probability"**

| Occurrence frequency | Ranking |
|---|---|
| More than once a day | 10 |
| More than once a week | 9 |
| Once a week | 8 |
| More than once a month | 7 |
| Once a month | 6 |
| More than once in 6 months | 5 |
| More than once a year | 4 |
| More than once in 2 years | 3 |
| More than once in 2-5 years | 2 |
| once in more than 5 years | 1 |

**Table 2 - Classification of "injury intensity"**

| Type of injuries | Ranking |
|---|---|
| Death | 10 |
| Amputation | 9 |
| Burns | 8 |
| Bone breakage & dislocations | 7 |
| Internal cuts and bleeding | 6 |
| Electrical shock | 5 |
| Bruising, twisting & strain | 4 |
| Poisoning | 3 |
| Cuts & wounds | 2 |
| Load lifting injuries | 1 |

**Table 3 - Classification of "out of work" times**

| Out of work times | Ranking |
|---|---|
| Permanent | 10 |
| 2-3 years | 9 |
| 1-2 years | 8 |
| 6 - 12months | 7 |
| 3 - 6 months | 6 |
| 1- 3 months | 5 |
| 1 week – 1 month | 4 |
| 1 day – 1 week | 3 |
| 1 shift - 1 day | 2 |
| No out of work time | 1 |

## RISK ESTIMATION

In order to evaluate the risk involved in a roof failure incident, two main components are required. These components are probability/hazard and consequences.

## PROBABILITY OF ACCIDENT OCCURRENCE

There are two methods of estimating the probability of accident occurrence:

1 Observational method

2. Statistical analysis of previous incidents (Einstein, H.H., 1997).

In the first method an experienced miner/engineer can estimate the probability of an accident based on the condition of a mine and certain indicators around the mine. In the second method the probability of accidents can be estimated by analyzing the specifications of previous accidents and their intervals. This method can be more precise provided that information related to the type, date and consequences of the accidents are available.

In this study, because all data pertinent to the previous accidents of Kerman Coal Mine is available, the second method has been used for accident estimation. The number of roof failures in each method (NOF) and time intervals between failures (TBF) from 2003 to 2008 has been analyzed. Statistical outlines of these factors are detailed in Table 5. Considering the nature of the data, proper distribution is selected and using data distribution function their probability is obtained. As the NOF data is distinctive, the Poisson distribution seems to be suitable. The $K^2$ fitting test is performed to evaluate this way of distribution.

**Table 4 – RPN for incidents happened in Kerman Coal Mine during 2003-2008**

| Number | Incident type | Degree of probability | Av. degree of injury intensity | Degree of disability | RPN |
|---|---|---|---|---|---|
| 1 | Being struck by flying debris | 7 | 6 | 9 | 378 |
| 2 | Being trapped between heavy objects | 4 | 5 | 10 | 200 |
| 3 | Destruction | 2 | 7 | 8 | 112 |
| 4 | Falling from a higher surface | 4 | 7 | 7 | 196 |
| 5 | Tripping on a flat surface | 3 | 5 | 7 | 105 |
| 6 | Exposure to electrical circuits | 2 | 5 | 10 | 100 |
| 7 | Gas poisoning | 1 | 10 | 10 | 100 |
| 8 | Explosion | 3 | 6 | 5 | 90 |
| 9 | Colliding with moving objects | 7 | 5 | 1 | 35 |
| 10 | Exposure to severe heat | 2 | 1 | 5 | 10 |

**Table 5 – Statistical outlines of NOF and TBF for Kerman Coal Mine**

| | Range | Minimum | Maximum | Mean | Standard Deviation |
|---|---|---|---|---|---|
| NOF | 10 | 0 | 10 | 6.22 | 3.95 |
| TBF | 101 | 0 | 101 | 8.1 | 10.89 |

Table 6 represents the results of $K^2$ fitting test.

**Table 6 – $K^2$ Test results with 95% of confidence for NOF in Kerman Coal Mine**

| | Test | Degree of freedom | Critical amount | Fitting quality |
|---|---|---|---|---|
| NOF | 78.3 | 59 | 79.1 | good |

Therefore, TBF is well represented by exponential distribution. Probability Density Function (PDF) and Probability Mass Function (PMF) are represented by Exponential and Poisson distribution, given by Equations 1 and 2, respectively.

$$f(x) = \frac{1}{\theta} e^{-x/\theta} \qquad 0 \le x < \infty \tag{1}$$

$$p(x) = \frac{e^{-\lambda} \lambda^x}{x!} \qquad x = 0,1,2,.. \tag{2}$$

Where $\theta$ and $\lambda$ are the parameters of exponential and Poisson distributions respectively.

As both Poisson and exponential distributions are single parameter distributions, it is only necessary to estimate the mean values of TBF and NOF (Einstein, H.H., 1997). Assuming that the individual average of the data for TBF and NOF are best estimates of the distribution parameters, $\theta$ and $\lambda$ would equal to average amounts of NOF and TBF respectively.

Therefore, the probability of a roof fall in t days could be obtained from Equation 3 (Einstein, H.H., 1997).

$$P = \int_0^t \frac{1}{\theta} e^{-x/\theta} dx \Rightarrow P = 1 - e^{t/\theta} \qquad (3)$$

## CONSEQUENCES OF ACCIDENTS IN KERMAN COAL MINE

The rates of losses by roof falls have been determined by the safety group of Kerman Coal Mine as follows:

Fatalities; 25%
Injuries; 30%
Equipment damage; 30%
Delay in operations; 15%

As seen in these ratings, 555 of the losses are due to fatalities and injuries. Figure 1 depicts the rate of each type of injury the mine workers suffered as a result of roof failure.

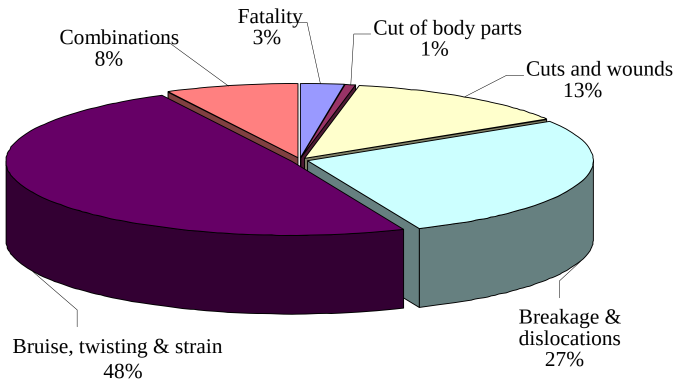


**Figure1 - Rates of various types of injuries due to roof falls in Kerman Coal Mine**

## RISK IN KERMAN COAL MINE

As stated before, risk equals the probability of roof fall multiplied by consequences. On the other hand, the probability of rock fall can be estimated from time intervals of accidents and its distribution (Equation 1). Thus the roof fall risk in t days can be calculated from Equation 4 (Duzgun, H.S.B., Einstein, H.H., 2004).

$$R(t) = C_T (1 - e^{-t/\theta}) \qquad (4)$$

The probability of roof failure can be obtained from Equation 3. Figure 2 depicts the probability of accident occurrence due to roof failures in Kerman Coal Mine. As this figure illustrates, the time intervals between 2 accidents is in 95% probability to be less than 24 days.

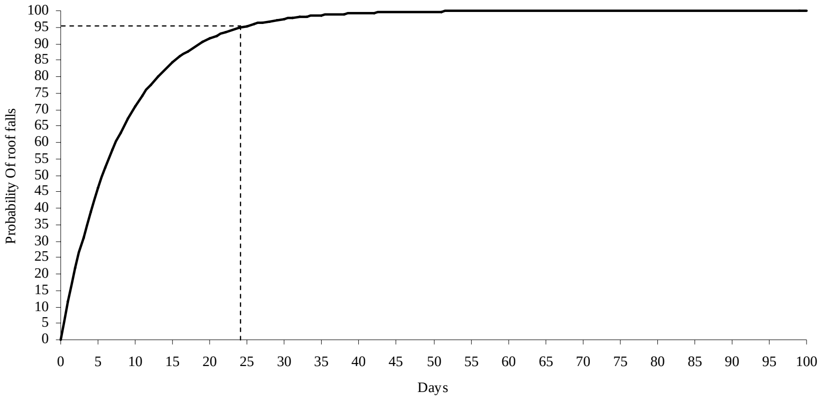


**Figure 2 – The probability of accident occurrence in t days**

## DECISION MAKING ASSESMENT

To propose a solution for the safety problems in the Kerman Coal Mine, the number of accidents from 2003 to 2008 were used as a basis for evaluation. An assessment of the financial justification of risk reduction was also done through the number of accidents and by use of decision tree. Decision tree led us to 2 ways from which we will need to select one. The two options are as follows:

$a_1$; No action required; maintaining the status quo and
$a_2$; reaching a solution in order to reduce/prevent accidents by utilizing experiences from previous occurrences.

As shown in Figure 3 each branch results in two sub branches; one related to the case where failure occurs and the other is for a "no failure" case and therefore bears no consequences. If failure happens, the related sub- branch would be divided into *k* sub-branches where *k* =1, 2, 3 is the number of roof failures. Each roof fall would have its own specific consequences, depending on its circumstance. The cost of losses in $a_1$ main branch depends on the number of falls and their type of consequence would equal $C_1$ and the cost of losses and prevention measures in $a_2$ main branch equals $C_2$. Therefore, *k* denotes the number of roof failures in a year and P (*k*) is the probability of *k* being equal to 1, 2, 3.

Assuming that after the improvement of conditions, $a_2$ branch leads to a Q% saving in total roof fall costs the amounts of $C_1$ and $C_2$ can be calculated from Equations 5 and6, respectively.

$$C_1 = C_T k, \qquad k = 0,1,2,... \tag{5}$$

$$C_2 = (1 - \frac{Q}{100})C_T k + C_a \qquad k = 0,1,2,... \tag{6}$$

Where;
$C_1$ = imposed losses in $a_1$ branch,
K = number of falls,
$C_2$= imposed losses in $a_2$ branch,
$C_T$ = imposed losses due to a single fall, and
$C_a$= cost required for improvement in $a_2$ branch.

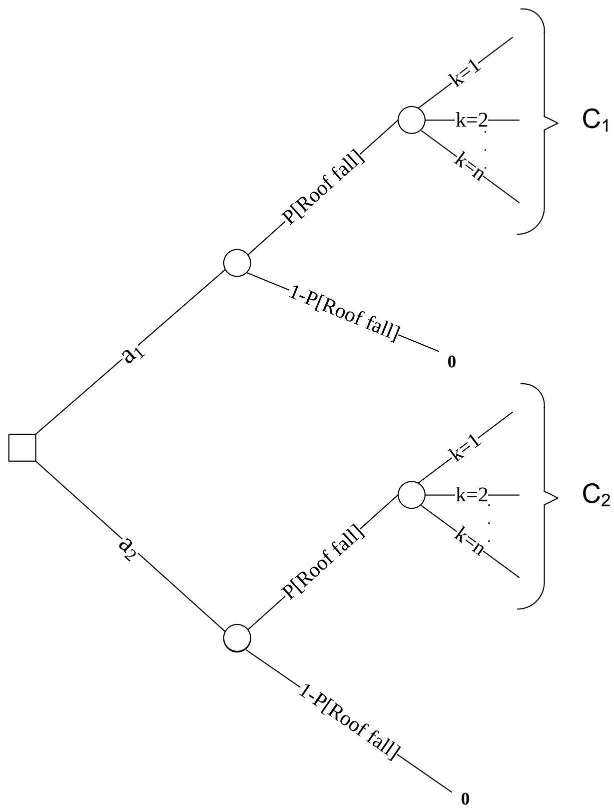


**Figure 3 - Decision tree for accident occurrences in Kerman Coal Mine**

Equation 7 can be employed in order to compare the costs imposed by any branches, through the number of annual accidents.

$$E[a_i] = \sum_{k=0}^{\infty} C_i P(k) \tag{7}$$

Where, P(k) is obtained from Equation 2.

The expected amounts for $a_1$ and $a_2$ branches can eventually be calculated from Equations 8 and 9, respectively (Duzgun, H.S.B., Einstein, H.H., 2004).

$$E[a_1] = C_T \lambda \tag{8}$$

$$E[a_2] = (1 - \frac{Q}{100}) C_T \lambda + C_a \tag{9}$$

Depending on the cause of accidents and the reduction rate in losses, the values of Q and $C_a$ vary on a case by case basis.

Finally, by following the sub-braches and employing related equations, a branch which bears lower costs would be selected.

## DECISION ANALYSIS OF ACCIDENTS IN KERMAN COAL MINE

Figure 4 illustrates a histogram of the number of monthly accidents.

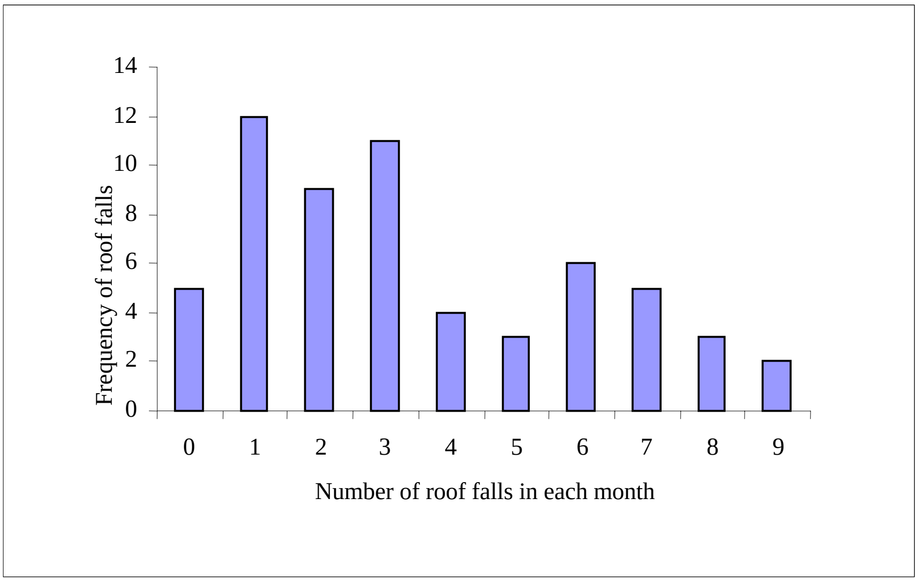


**Figure 4 - Histogram of monthly NOF in Kerman Coal Mine**

The relative costs in $a_2$ branch (i.e. $C_2$) can be calculated with the following assumptions proposed by the safety group of the main company:

1- The adoption of a well planned training program, thorough safety inspections and improving roof conditions will lead to a 40% reduction in losses due to accidents.
2- The costs of training, safety inspections and improving roof conditions is 1.3 times of losses due to doing no action which is represented by $a_1$ branch (i.e. $C_1$).

$C_2$ could then be calculated from the Equation 10.

$$C_2 = 0.6 C_T k + 1.3 C_T \tag{10}$$

The average number of accidents per year can be obtained from monthly accidents and Table 5 using Equation 11 as follows:

$$\begin{matrix} t = 12 \\ \lambda_m = 6.22 \end{matrix} \Rightarrow \lambda_y = t\lambda_m \Rightarrow \lambda_y = 74.64 \tag{11}$$

Using the amounts of $\lambda_y$ obtained by Equation 11in the Kerman Coal Mine, the amounts related to each branch are obtained by Equation 12 as:

$$\begin{aligned} E[a_1] &= C_T \lambda \Rightarrow E[a_1] = 74.64 C_T \\ E[a_2] &= 0.6 C_T \lambda + 1.3 C_T \Rightarrow E[a_2] = 46.08 C_T \end{aligned} \tag{12}$$

As seen in equation 12, the amount related to $a_2$ branch is significantly lower than that of $a_1$ branch. In other words, due to the high number of accidents in the mine, investing in prevention measures is financially justified.

## CONCLUSIONS

This investigation of accidents has lead to the followings conclusions in Kerman Coal Mine:

- 88% of accidents are caused by roof failure.
- The Risk Priority Number (RPN) is relatively high and equates to 690 out of 1000.
- With the current situation it is 95% probable that an accident will happen every 24 days.
- Costs related to prevention measures are considerably less than those of accident consequences.

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