Risk Assessment Approach using Qualitative Risk Analysis in Underground Mines

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Abstract: There are always some dangers associated with mining operations, techniques, and procedures. Despite the introduction of advanced underground mining methods, every year in India, mine accidents result in a large amount of economic loss as well as the loss of lives. Risk assessment is carried out to identify undesirable events that could lead to a hazard, as well as to examine the hazard mechanism by which this undesirable event might occur, as well as to provide an estimate of the amount, range, and likelihood of adverse consequences: It is widely recognized in the industry that various risk assessment approaches contribute significantly to increased safety in complicated operations, techniques, and equipment. A mining industry that appears to be successful must base its operations on safety and long-term sustainability. In order to increase safety, the mining industry should maintain a good risk management plan. The risk assessment method aids mine management in determining the control measures to be used to reduce the hazards detected in the mine.

***Keywords* –** Hazard, risk, likelihood, consequence, risk analysis, risk assessment, underground mining, control measures

1. INTRODUCTION

Risk assessment is all about the assessment of risks involved and preventive measures proposed to be taken. A factor or situation that has the potential to induce human injury or disease, property damage, environmental damage, or all three is known as a hazard. A hazard's risk is defined by the likelihood that it will cause an unpredictable occurrence and the consequences of such an event. The following equation may be used to express this relationship:

$$\text{Risk} = \text{likelihood} \times \text{consequences.}$$

Risk assessment entails identifying undesirable events that lead to a hazard, analyzing the hazard mechanism by which this undesirable event could occur, and, in most cases, estimating the scope, magnitude, and possibility of detrimental impacts. It Detects and assesses hazards, as well as the event sequences that lead to hazards and the risk of hazardous occurrences. Risk assessment is carried out to identify undesirable events that could lead to a hazard, as well as to examine the hazard mechanism by which this undesirable event might occur, as well as to provide an estimate of the amount, range, and likelihood of adverse consequences: It is widely recognized in the industry that various risk assessment approaches contribute significantly to increased safety in complicated operations and equipment to avoid accidents arising out of such risks. There is an urgent need to be aware of the risks of an accident before steps can be taken to prevent it from happening. It may not always be possible to say that a workplace task will lead to an accident. Due to this reason, risk assessments are carried out. Risk assessment consists of mainly two parameters, such as hazard and risk. Where a hazard is anything that is going to happen and that may have the chance to cause harm. Risk is the likelihood that a person may be harmed or suffer an adverse health consequence as a result of being exposed to danger.
Five steps of risk assessment are as follows :

Step 1: identify the hazards

Identification of hazards can be made by Common hazard identification techniques:

Informal approach- checklists, what-if analysis, historical records of accidents

Formal approach- failure mode effect analysis, event tree analysis, fault tree analysis.

Step 2: determine who may be affected and how they might be damaged

The list includes the effect of hazards fatal &serious hazards, medical or hospitalized, permanent disability, first aid hazards.

Step 3: Evaluate the risk level by risk rating.

Choosing an appropriate risk analysis methodology ranging from qualitative, simple qualitative procedures to advanced quantitative methods. Because each technique has its purpose, strengths, and shortcomings, it is recommended that you apply different hazard analysis techniques based on specific

Step 4: Implement precautionary measures proposed

to keep track of any important results. These results will contain the dangers, how they may damage individuals, and the control mechanisms you have put in place. It is worth noting that only businesses with five or more employees are required to record the results of a risk assessment.

Step 5: Review assessment and update if necessary

Go back to the risk assessment again and see if there have been any substantial changes since the last one. There may be a residual risk since the previous evaluation.

Quantitative Risk Analysis:
The assessment of risk can be qualitative or quantitative. The latter requires significant specialist effort, and therefore, the qualitative assessment is often used as the simpler of the two. However, the Quantitative Risk Analysis (QRA) provides significant benefits as it only helps to identify and rank the risk contributors but also assists in setting priorities for directing the risk reduction efforts to achieve an optimal outcome.
The QRA integrates all the individual technical studies of the Safety Assessment and evaluates the risk from operations to personnel. The risk levels calculated are then evaluated against performance standards to ensure ALARP levels are reached.
The main limitation of QRA is the lack of adequate frequency data for initiating events for the MAF (e.g., fire or drilling into a misfired hole) and dependency on human error failure probability, which is not available for the mining industry.
Qualitative analysis can be applied in the following situations:

- As a first step in identifying hazards that require more in-depth study, when this type of analysis is suitable for making judgments, or when numerical data or resources are insufficient for quantitative analysis.
- When statistics and factual information are accessible, they should be used to inform the qualitative analysis.

In this technique, a matrix is created, which describes risk as to the frequency of losses vs. possible magnitudes of losses on qualitative scales. The matrix is used to define policy and risk management choices. Qualitative risk analysis, on the other hand, is overly subjective. As a result, this form of risk analysis is appropriate for simple systems such as single-product safety, basic physical security, and simple procedures.

Table 1: Qualitative risk analysis matrix table

Risk Rank =Likelihood *Consequences	Almost certain	Likely	Possible	Unlikely	Rare
Catastrophic	1	2	4	7	11
Major	3	5	8	12	16
Moderate	6	9	13	17	20
Minor	10	14	18	21	23
Insignificant	15	19	22	24	25

Table 2: Risk Rating

Risk Rating	
High Risk	1-6
Medium Risk	7-15
Low Risk	16-25

Operational risk management is another name for the Risk Matrix Method (ORM). The probability (hazard) dimension is one of the dimensions. It is divided into qualitative categories such as Almost certain, Likely, Possible, Unlikely, and Rare. On the other hand, it is divided into various qualitative categories, including Catastrophic, Major, Moderate, Minor, and Insignificant. If the likelihood and consequence categories are given evidence-based definitions, it is feasible to estimate the risk.

2. LITERATURE SURVEY

Laul et al. (2006) identified possible initiators (chemical, electrical, physical, and industrial) as well as dangers (chemical, electrical, physical, and industrial). To assess identified dangers, hazard analysis is utilized. Hazard analysis for chemical and non-nuclear plants is performed using a "what if check list," Hazard and Operability (HAZZOP) analysis, Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), and provided techniques, along with their benefits and drawbacks.

Jeong et al. (2007) made a qualitative analysis using the Hazard and Operability Method (HAZOP) to identify potential hazards and operability problems in decommissioning operations, and concluded that decommissioning of a nuclear research reactor must be carried out in accordance with its structural and radiological characteristics, and radiation exposure must be kept within the regulatory limits.

Nor et al. (2008) Researchers analyzed and graded the danger associated with loaders and dozers. The dangers of "failure to follow proper maintenance procedures" and "failure of mechanical, electrical, or hydraulic components" were the most serious and frequent for the loaders. They were classified as high risk.

N. Pavan Kumar (2014) FMEA was used to analyze total risk based on estimates in the high, medium, and low categories, according to a publication (Failure Mode and Effect Analysis). Analyzed and rated the seriousness, severity, and impact of failure mode-related risks. Identifying the likelihood of failure as well as the consequences of failure. Finally, using the Risk Priority Number, assign a rating to estimate the risk of failure. RPN=Severity*Occurrence*Detect.

Gonzalez-Delgado et al. (2015), In a journal, stated Factors Associated with Fatal Accidents in Mexican mines: The constant increase in the underground mining industry has led to the use and implementation of new technologies and the use of different substances for the processing and extraction of minerals, which increases the risks in the activities that develop in the mine. The increase in activity increases labor directly or indirectly and is proportional to increased risks, injuries, and even deaths.

C.R. Dominguez (2019) In a journal stated about a study on "The Decision Matrix Risk Assessment" (DMRA) technique, it is a systematic approach for estimating risks which are consisting of measuring and categorizing risk on an informed judgment basis as to both probability and consequences and as to relative importance.

3. METHODOLOGY

This study is based on historical records of incidents, collection of databases on underground mining accidents were obtained from Indian mines ENVIS source and Queensland website. ENVIS database is related to fatalities, serious, and cause of accidents, while database from Queensland website is related to mining operations its risk and risk factors. Studying the risk factors and causes of accidents were compared and compiled.

Risk analysis, the risk assessment process it includes many techniques, from simple qualitative methods to an advanced quantitative method for risk analyzing and rating. Suppose the severity (consequence) of the loss and the frequency (probability of likelihood) of the event cannot be determined from the historical data. In that case, a qualitative risk assessment can be performed. In this study, qualitative risk assessment was considered to be appropriate. The risk associated with a particular underground activity is ranked based on their likelihood and consequence on the judgment process through the risk matrix.

Based on risk ranking, high, moderate, low-risk actions were taken, and control measures were given.

To achieve the objectives of this paper, authors have studied two sources one from ENVIS Centre on environmental problems of mining in India, and the other from the database of hazards and their risk factors from the Queensland government agency website have been compared, compiled, and studied for their most commonly occurring hazards in underground mining methods and their operations, the applicability of risk assessment and their dealing measures. While in Indian mines, 'likelihood, consequences, exposure' methods have been used. While in Australian mines, hazard identification, risk assessment, and removal of residual risk have been carried out by hierarchy of control based on their risk rank may also use a control development matrix as an aid or checklist to assist in the development of controls. The matrix consists of "control intents": Prevention; Monitoring; and Contingency on one axis and control means on another: consisting of equipment/design or layout, procedures, and competency. This process is also known as the "nine-box model." The team considers and records controls for each box.

4. RESULTS AND DISCUSSION

4.1 Identification of hazard

There are various hazard identification techniques or tools, each of which May be useful in particular circumstances. A historical record of incidents as hazard identification tool an informal approach and fault tree analysis a formal approach. A single technique or combination of techniques can be used, particularly considering the nature of mine.

Significant causes that lead to hazards:

Explosive/Blasting

- Not taking shelter, especially with respect to contiguous working.
- Possibility of blown through shots
- Formation of excessive noxious fumes
- Ignition of coal dust by shot firing
- Personnel injuries from fragments and fly rock
- Unexpected detonation

Machinery (include transport of persons, material, and equipment)

- Maintenance schedule not followed
- Temporarily trailing cables joints
- Bye-passing protective devices
- Unskilled operator
- Moving parts of machines
- Falling from vehicle
- Conveyor fire in the return airway
- Frictional ignition by belt rubbing on coal spillage
- Personnel exposed to high noise levels and doses from drilling equipment, scrapers, loaders, and face conveyors

Improper strata control

- Failure to identify bad roof
- Improper dressing
- Improper supervision
- Poor workmanship
- Non-superimposition of some pillars in contiguous working
- Inadequate support designs
- Poor quality of support material

Inundation

- River overflow above HFL
- Inrush through subsidence cracks
- Waterlogged working underground
- Drowning of underground personnel

Geotechnical & Geo-mechanical

- Highwall/pit wall/stockpiles/berms
- Fall and dislodgement of earth and rock
- Instability of the excavation and adjoining structure
- Floor
- Mine road design and construction
- Objects/structures falling on people
- Fall of things such as components, tools, structures
- Airblast/wind

Electrical

- Electricity (high voltage installation)
- Electrical energies from apparatus such as cables, transformers, switchgear, and connections
- Electrical equipment inspection, testing, and tagging to standards
- Equipment overheating
- Failure of communication system

4.2 Risk rating:

In this technique, accidents based on probability and consequence categories are selected. After that, collecting database to support the rating for the likelihood and consequence of each potential risk, basis a risk matrix has been prepared. The cells are categorized into red, yellow, or green along with rating. Red typically indicates high risk, i.e., an unacceptable risk, yellow indicates moderate risks, and green indicates low risk with no immediate concern.

Explosives/blasting:

Hazard type	Likelihood Level	Maximum Consequences	Risk Rating
1.Not taking proper shelter, especially with respect to contiguous working	L1	C5	2
2.Possibility of Blown through shots	L1	C5	2
3.Ignition of coal dust by shot firing	L4	C2	12
4. Formation of excessive noxious fumes	L5	C3	20
5.Personnel injuries from fragments and fly rock	L4	C3	17
6.Unexpected detonation	L5	C2	16

Machinery:

Hazard type	Likelihood Level	Maximum Consequences	Risk Rating
1.Unskilled operators	L2	C1	2
2.Moving parts of the machines	L5	C1	2
3.Personnel exposed to high noise levels and doses from drilling equipment, scrapers, loaders, and face conveyors	L1	C3	6
4.Maintenance schedule not followed	L4	C1	7
5.Temporarily trailing cables joints	L4	C1	7
6.Bye-passing protective devices	L2	C5	19
7.Falling from vehicle	L3	C4	18
8.Conveyor fire in the return airway	L4	C4	21
9.Frictional ignition by belt rubbing on coal spillage	L5	C5	25

Improper strata control:

Hazard type	Likelihood Level	Maximum consequences	Risk rating
1.inadequate support design	L1	C5	1
2.poor quality of support material	L2	C5	2
3.failure to identify bad roof	L5	C5	11
4.improper dressing	L4	C5	7
5.improper supervision	L4	C5	7
6.poor workmanship	L4	C5	7
7.non-superimposition of some pillars in contiguous working	L4	C5	7

Inundation:

Hazard type	Likelihood level	Maximum consequences	Risk rating
1.waterlogged working u/g	L1	C5	1
2.river overflow above HFL	L4	C5	7
3.inrush through subsidence cracks/BH	L4	C5	7
4. Drowning of underground personnel	L3	C1	7

Geotechnical & Geo-mechanical:

Hazard type	Likelihood level	Maximum consequences	Risk rating
1.high wall/pit wall/stockpiles/berms	L3	C1	4
2.fall and dislodgement of earth and rock	L4	C1	7
3.instability of the excavation and adjoining structure	L4	C1	7
4.floor	L4	C3	17
5.mine road design and construction	L4	C3	17
6.objects/structures falling on people	L4	C3	17
7.fall of things such as components, tools, structures	L5	C3	20
8.air blasts/wind	L3	C5	22

Electrical energies:

Hazard type	Likelihood level	Maximum consequences	Risk rating
1.Equipment overheating	L4	C1	7
2.electricity (high voltage installation)	L4	C3	17
3.electrical energy from apparatus such as cables, transformers, switch gears, connections	L3	C4	18
4.electrical equipment inspections, testing, and tagging to standards	L4	C4	21
5. Failure of communication system	L5	C3	20

4.3 Management of risk

The complete elimination of the hazard source; replacement of the hazardous work method/equipment/process; engineering methods, such as putting a barrier between the source and the target; providing training, awareness, safe operating procedures and framing rules; providing personal protective equipment to workers; and safe human behavior are some of the most common methods of control. The hierarchy of controls can be implemented to risks with a high-risk level based on the risk level acquired from the other phases of the risk assessment process with relevant legislation and Standards.

Major case	Risk	Risk Rating	Control measures
Explosives/blasting	Not taking proper shelter, especially with respect to contiguous working.	2	Monitor the efficacy of taking shelter while drilling and blasting
	Possibility of Blown through shots	2	Stop one the approaching faces when within 9m
	Ignition of coal dust by shot firing	12	Operating procedure Blast design Competence Limitation of duration Limitation of the firing pulse
	Formation of excessive noxious fumes	20	Blast design, Check the condition of the explosive before use Competence Initiation method Loading procedure Priming procedure Selection of explosive type
	Personnel injuries from fragments and fly rock	17	Blast design Competence Establish nearby personnel presence Evacuation of nearby personnel Operating procedure Restriction of access
	Unexpected detonation	16	Competence Inspection after firing Misfire procedure Misfire reporting Operating procedure Operator vigilance

Machinery	Unskilled operators	2	Stop machine usage if a skilled person is not present-train more operators.
	Moving parts of the machines	2	Fence moving parts of the machine and do not allow people.
	Personnel exposed to high noise levels and doses from drilling, equipment, scrapers, loaders, and face conveyors	6	Allowable noise levels Equipment design to minimize noise production Hearing protection where necessary Limitation of exposure Noise auditing
	Maintenance schedule not followed	7	Implement, monitor& take corrective action for non-compliance
	Temporarily trailing cables joints	7	Stop doing temporary cables.
	Bye-passing protective devices	19	Stop the machine if the protective device is not functioning.
	Falling from vehicle	18	Competence, machine design, Maintenance(roadway), work procedure
	Conveyor fire in the return airway	21	Automatic shutdown, ch4 monitoring, co monitoring Ventilation control
	Frictional ignition by belt rubbing on coal spillage	25	Design of belt capacity Design of transfer Fire-resistant belting Housekeeping Inspection
Improper strata control	inadequate support design	1	Review support designs and rules and regulations should be followed.
	poor quality of support material	2	Review support materials and rules and regulations should be followed along with corrective steps.
	failure to identify bad roof	11	Effective supervision, survey, and monitoring procedures should be done.
	improper dressing	7	Proper dressing and proper supervision
	improper supervision	7	Adequate supervision along with monitoring procedures
	poor workmanship	7	Training, test & monitoring
	non-superimposition of some pillars in contiguous working	7	Marking such pillars and alert concerned people during extraction

Inundation	waterlogged working u/g	1	Pumping, dams, and inspection
	river overflow above HFL	7	The embankment, float alarm guard, and wireless
	inrush through subsidence cracks/BH	7	Garland drain, crack filling & inspection.
	Drowning of underground personnel	7	Accurate surveying of new workings near old ones, adherence to design, Design of barrier to resist full hydrostatic pressure, register of plans of old workings
Geotechnical & Geo-mechanical	fall and dislodgement of earth and rock	4	adequate design correct civil preparation of the site equipment inspection equipment maintenance proper assembly
	instability of the excavation and adjoining structure	7	adequate temporary support adherence to design avoidance of abutment zones design of extraction sequence speed of extraction
	floor	17	design of supports, installation procedure, maintenance of supports
	mine road design and construction	17	Follow up rules and regulations regarding design and construction.
	objects/structures falling on people	17	operating procedure inspection of roof provision of temporary support if necessary
	fall of things such as components, tools, structures	20	operator competence protective supports on mobile bolters or bolter equipped continuous miners
	air blasts/wind	22	design standards system auditing working alone procedures competent operators
Electrical energies	Equipment overheating	7	duty cycle effective cooling equipment design maintenance overload protection system design thermal protection of consumer devices
	Electricity, electric shock (high voltage installation)	17	competence earth continuity protection (testing of trailing cables) earth leakage protection earthing isolation procedures routine testing technical audits testing procedures for energized equipment

	electrical energy from apparatus such as cables, transformers, switch gears, connections	18	overload protection thermal protection
	Ignition of firedamp or coal dust	21	Use of flameproof and intrinsically safe apparatus.
	Failure of communication system	20	competence in the operation of systems procedure when the system fails provision of alternative/backup systems system auditing system maintenance

Indian mines are not using risk assessment techniques to their full potential, according to a new report. Indian mines are under the control of a few select organizations where money is more important than risk factors, and the production rate is higher than the life of the mine. Risks must be treated in accordance with relevant legislation and Standards of Mine Act 1952, The Mines and Minerals Development and Regulation Act (MMDR) 1957, and all together with the rules and regulations formed under them.

5. CONCLUSION

Risk assessments are crucial because they are a key component of any health and safety management strategy. They aid in raising awareness of hazards and risks. This paper concentrates on the risk assessment approach using qualitative risk analysis in underground mining hazards. The other stages of the risk assessment process, i.e., risk treating, treatment of risk, are carried out to improve safety in mines by implementing control measure plans based on risk level. In this study, historical records of incidents were compiled into subgroups based on sub-risk factors and control. Qualitative risk analysis techniques were used to identify the risk levels of hazards in underground mines. Altogether, hazard events were identified and categorized into six categories of hazard groups: explosive/blasting, machinery, improper strata control, inundation, geotechnical & geo-mechanical, and electrical. The hazard events were further analyzed, and a risk ranking was given based on probability and occurrences. Red indicates unacceptable risk and should be concerned immediately, yellow indicates moderate risk, and green indicates low risk with no immediate concern.

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