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Risk Analysis by Using Failure Mode and Effects Analysis for Safe Mining

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Abstract: ***For any Organization or Industry to be successful, it has to meet the Production requirements and also need to maintain the Health and Safety standards for all concerned and has to identify the hazards, evaluate the related risks and bring them to tolerable level on a continuous basis. As the mining industry is explicitly complex because of the extent and range of the mining operations, due to this large number of hazards that can pose a potential risk to health and safety. To protect the mining personnel and machinery from these hazards, there is need for Risk Analysis for sustainable operation of the projects, Failure mode and effects analysis (FMEA) is a widely used technique to identify the potential failure modes for measuring reliability of a product or a process. In this paper, review of literature on Hazards and Risk Analysis by using FMEA, in mining industry has been discussed.***

Keywords: Risk, Hazard, Risk Analysis, FMEA, Mining.

1. Introduction

Risk is defined as the combination of the likelihood that an accident or injury will occur and its potential severity, Hazard is anything that has the potential to cause harm. Mining has few constant factors and many variables like Environment, mining conditions and human factors; all these factors can impact the risk, it can be eliminated or mitigated by identifying, evaluating, and controlling the hazards. By performing this process on a recurring basis can creates system safety and health [1], [2].

Risk is the probability of an adverse effect occurring as a result of an activity or an event, risk analysis is an essential component of the decision making process for the sustainable operation of the projects. There are different types of risk analysis tools and methodologies available to help enterprises and organizations assess their health and safety risks. The choice of selecting the right tool will depend on the working conditions, the number of personnel, the type of work activities and equipment, the particular features of the workplace and any specific risks. Failure Mode and Effects Analysis (FMEA) was one of the first systematic techniques to eliminate or reduce failures [3], [4], starting with the highest-priority ones it is mainly a qualitative analysis.

2. Literature Review

There are different types of Hazards that can be identified during Surface and Underground mining operations, few major Hazards are Contaminated Air, Dust, Exposure to Heat, Hazardous Material, Radiation, Slipping-Tripping, Working near water, Working Environment, Confined Spaces, Dredging, Explosives, Drilling, Loading, Transporting, Processing(Crushing and Grinding), Tailings, Fall of Roof, Pillar Collapse, Haulage, Ventilation and Illumination etc. [5]-[10]

Risk Assessment is the process to identify the severity of the Hazard and comparing the level of risk against predetermined standards, factors including the level of exposure and the number of persons exposed and the risk of that hazard being realized. There are different methods used to identify the overall risk from basic calculations using high, medium and low categories. Figure 1 shows the Risk Management Process involves various steps like Hazard identification, Risk assessment, and Preparation of detailed action plan and its implementation to monitoring its effectiveness [3].

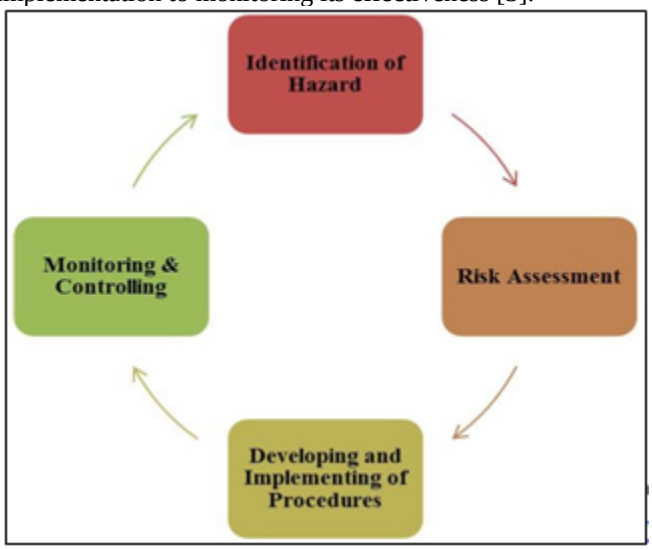

Figure 1: Process for Risk Management [3]

2.1 Types of Hazard Identification and Risk Analysis

- **Baseline Hazard Identification and Risk Analysis** are used to establish a risk profile and prioritize the action plans for issue based risk assessments.
- **Issue based Hazard Identification and Risk Analysis** is used to conduct a detailed assessment study to implement the action plans for the treatment of significant risk.
- **Continuous Hazard Identification and Risk Analysis** is used to identify the Operational health and safety hazards, gather information to feed back to issue-based Hazard Identification, baseline Hazard Identification and Risk Analysis.

2.2 Hierarchy of Control Measures

The hazards that are identified should be dealt in order of priority in one or more of the following hierarchy of controls [5]-[10].

- **Eliminate:** Elimination of the hazard or the need to perform the hazardous activity all-together.
- **Substitute:** It may not remove all the hazards associated, but substitute for process, equipment, and work method for safer alternative.
- **Isolate:** It can be achieved by redesign, enclose or separate people from the hazard by use of lockout system or use of barriers/distance/time.
- **Administration:** Training, Rules, Procedures or safe systems of work.
- **Personal Protective Equipment:** It includes safe equipment for eye, face, skin, foot, head, fall protection and contingencies such as firefighting equipment.
- **Human Behavior:** Situational awareness and compliance with rules and procedures.

3. Methodology

3.1 Failure Mode and Effects Analysis

FMEA is a Risk Analysis Tool, simple method for grading risk, determines appropriate risk reduction options and creates prioritized ranking of failure modes within a system. Each failure mode will be assessed in three parameters, namely, Severity of Impact, Occurrence of problem and Detection of problem. FMEA is used during the initial stage of the Project to prevent failures. Later it's used for control, before and during on-going operation of the process. Ideally, FMEA begins during the planning stage of project and continues throughout the life of the project execution [5]-[10].

3.2 Process Steps

Start with the Process map
For each step, brainstorm potential failure modes and effects
Determine the potential causes to each failure mode
Determine severity, likelihood of occurrence & detectability
Determine RPN
Identify actions.

System/Project: Subsystem/Problem: Core Team: Prepared by:									FMEA No.: FMEA Date:						
Process Step or Variable or Key Input	Potential Failure Mode	Potential Failure Effects	SEVERITY	Potential Causes	OCCURRENCE	Controls	DETECTION	RPN	Actions Recommended	Responsibility & Target Completion Date	Actions Taken	SEVERITY	OCCURRENCE	DETECTION	RPN

Figure 2: Example of Failure Mode and Effects Analysis Work Sheet

3.3 Potential Failure Mode

It is defined as a component, subsystem, or system could potentially fail to meet the design intent. The potential failure mode can also be the cause of a potential failure mode in a higher level subsystem, or system, or be the effect of one in a lower level component. Each potential failure mode for the particular item and item function should be recorded. The assumption is made that the failure could occur, but may not essentially occur.

3.4 Potential Failure Effects or Consequences

It is defined as the effects of the failure mode on functions, should be based on the evaluations or analyses of the systems responses following failure. It may have physical, biological or health and safety consequences need to clearly mention that it could impact safety or noncompliance to regulations [5]-[10].

3.5 Severity

Severity evaluates the seriousness of the effect of the potential risk occur. Severity score is rated against the impact of the effect caused by the failure mode is shown in Table 1.

Table 1: Severity Criteria for Failure Mode and Effects Analysis [1]

Severity of a Failure		
Effect	**Severity of Effect**	**Rating**
Hazardous	When a Potential Failure mode effects	9- 10
Very	System inoperable with destructive	7-8
Moderate/Low	System inoperable with minor or	5-6
Very	System operable with some	2-4
None	No effect	1

a) Occurrence
Occurrence estimates the frequency that potential risk(s) will occur for a given situation or a system. Probability score is rated against the probability that the effect occurs as a result of a failure mode is shown in Table 2.

b) Detectability:
Detectability is the probability of the failure being detected before the influence of the failure to the process or system being assessed is detected. The detectability score is rated against the ability to detect the effect of the failure mode is shown in Table 3.

Table 2: Occurrence Criteria for Failure Mode and Effects Analysis [1]

Occurrence of a Failure		
Probability of Occurrence	**Failure**	**Rating**
Very High: Failure is almost inevitable	>1 in 2	10
	1 in 3	9
High: Repeated Failures, Process that have often failed	1 in 8	8
	1 in 20	7
Moderate: Occasional Failures, but not in major proportions	1 in 80	6
	1 in 400	5
	1 in 2,000	4
Low: Relatively few Failures, Isolated failures associated with similar processes	1 in 15,000	3
	1 in 150,000	2
Remote: Failure is unlikely	<1 in 1,500,000	1

Table 3: Detectability Criteria for Failure Mode and Effects Analysis [1]

Detection of a Failure		
Detection	*Likelihood of Detection*	*Rating*
Very Remote	Undetected, Very Remote chance to detect a potential cause and subsequent failure mode	9-10
Very Low	Very Low chance to detect a potential cause and subsequent failure mode	7-8
Low	Low chance to detect a potential cause and subsequent failure mode	6
Moderate	Moderate chance to detect a potential cause and subsequent failure mode	5
Moderately High	Moderately High/High chance to detect a potential cause and subsequent failure mode	4
High		3
Very High	Very High chance to detect a potential cause and subsequent failure mode	1-2

c) Risk Priority Number (RPN):
It is the product of the three inputs (Severity, Occurrence and Detect) rating used when assessing risk to identify failure modes [4].

Severity (S) x Occurrence (O) x Detect (D) = RPN

RPN provides guidance for ranking potential failures and identifying the recommended actions for design or process changes to lower Severity or Occurrence. They may be additional controls to improve the Detection, identify and note who is the process owner and responsible for the activities and target completion dates.

4. Results/Discussions

The first step when reviewing for potential mine hazards is to examine the nature of mining at the site and classify the hazard level. This is typically done through a critical area report prepared by a geologist or geotechnical engineer. The type of developments that are allowed depends upon the classification of the hazard. The major hazards that can be identified during Surface and Underground mining operations and their Failures and controls are shown in Table 4. After identifying the Hazards, prioritize the risks, in the next step rank and identify the major hazards which need immediate action [5]-[10].

Advantages of FMEA

- Accepts high degree of complexity
- Uniform quantification of risk can be applied
- Results can be correlated directly with actual risks
- The effect of various methods of mitigation/detection on risk can be modeled easily
- Provides well-documented record of improvements from corrective actions implemented
- Provides information useful in developing test programs and in-line monitoring criteria
- Provides historical information useful in analyzing potential product failures during the manufacturing process
- Provides new ideas for improvements in similar designs or processes [5]-[10]

Table 4: Major Hazards identified in Surface and Underground mining with Failures and Controls [11]

Hazard	Sub-Process	Failures	Controls
Contaminated Air	Smoke and Fume	Blast Fume, Engine Emissions	Design of exhaust outlets, maintenance and monitoring of engines
Dust	Combustible, Respirable dust	Machine generated, Blast	Dust Extraction system, Removal Procedure, Equipment design
Exposure to Heat	Heat Stress, Working near open flame	Excessive Heat from welding, Heat from Weather/Environment	Use of Personal protective equipment, Ventilation, Automation & Mechanized Process
Hazardous Material	Exposure to Hazardous Substances	Disposal, Storage, Transportation, Use of Hazardous Substances	Design of Storage facilities, Regular auditing of Transport procedures, effective communication
Radiation	Exposure to Radiation	Ionizing, Laser, Solar Radiation sources	Isolation, Use of Personal protective equipment
Slipping-Tripping	Slipping-Tripping	Incorrect design of Surfaces where people move or climb, Clothing	Suitable design, Restricted access to area, properly fitting clothing
Working near water	Biological, Electrocution, working near water	Contact with Contaminated water, Electrical Energy	Water Quality Monitoring, Use of Personal Protective Equipment, Earth Leakage

			Protection
Confined Spaces	Working in Confined Spaces	Cramped, Entrapment, Noise Levels	Design, Isolation of equipment, Audiometric Testing
Explosives	Explosion of Chemical, Flammable gas	Excessive Heat	Heat Reduction, Ventilation, Gas installation
Drilling	Equipment Establishment, Operation, Noise	Collapse of Equipment, old machinery	Civil preparation of site, Design and Maintenance
Loading	Loading	Rock falling, Hydraulic system	Use of Personal protective equipment, Maintenance
Transportation	Belt feeder, Road, Rail Transport	Equipment Jams, Brakes fail	Equipment and Brake Maintenance,
Processing	Crushing, Grinding	Blockages, Dust, Noise	Use of Hydraulic machines, Noise isolators
Tailings	Person or Machine Engulfed in Material	Person/Machine Breaks Through Crust, Sinks in or release of Liquefied Material	Keep Person/Machine Out Of Range
Fall of Roof, Pillar	Fall of Roof, Pillar Collapse	Fall of Roof and Pillar Collapse in Coal Mines	Support, Fencing, maintain Safety measures
Haulage	Rope Haulage	Low quality Ropes and Rollers, Safety devices	Regular Maintenance
Ventilation	Air flow, Heat control, Dust	Sluggish Or Poorly Controlled Ventilation, Heat detecting	Heat control procedure, Dust Auditing

5. Conclusion

Risk Analysis is a step-by-step process used to eliminate or mitigate risks before performing a specific task. By using Failure Modes and Effect Analysis, it is easy to identify the Potential failures for measuring reliability of a product or a process, the results based on the RPN will give guidance for ranking the potential failures and it is easy to identify or recommend the necessary actions for design or process changes to lower Severity or Occurrence. The results from an FMEA can be used to prioritize and manage the implementation of risk reduction measures and also in identifying and managing the potential hazards in the work area [5]-[10].

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