Analysis of Accidents for Various Types of Mines and Ores in Vidarbha Region

Omprakash Thakare[1], Rakesh Ahirkar[2], M.M. Gupta[3]

[2]*Assistant Professor, Department of Mechanical Engineering, Shri Rawatpura Sarkar University, Raipur, Chhattisgarh, India*

[1]*Research Scholar, Department of Mechanical Engineering, Ramdeobaba College of Engineering, Nagpur, Maharashtra, India*

[3]*Professor, Department of Mechanical Engineering, Shri Ramdeobaba College of Engineering, Nagpur, Maharashtra, India.*

Abstract- **The mining industry inherently carries daily risks. To address these hazards effectively, it is imperative to possess adequate knowledge of managing such situations. Whether operating underground or in opencast mines, every facet of mining involves certain risks. The identification of hazards and subsequent risk analysis has become an integral aspect of ensuring a secure and efficient work environment. However, the rationale behind this practice warrants scrutiny. While encountering numerous risks in our daily lives, our genuine concern often extends to only a few, perhaps one or two. It is essential to scrutinize all potential risks to pre-empt any potential disasters in the future. Instances from the past highlight how disregarding early warning signs resulted in catastrophic events. Therefore, in today's context, possessing comprehensive knowledge is crucial to avert potential losses. Hazard identification and risk analysis entail pinpointing undesirable events leading to hazards, scrutinizing the mechanisms by which these events occur, and typically estimating the potential extent, magnitude, and likelihood of adverse effects. This study represents on the comprehensive study of Risk Analysis methods, Risk Assessment Procedures, and the sequential steps integral to Risk Assessment processes. It explores the spectrum of techniques encompassing Qualitative, Semi-Quantitative, and Quantitative methods of Risk Analysis. Emphasizing hazard identification and mitigation, this report evaluates Hazard and Operability (HAZOP), Fault Tree Analysis, and Event Tree Analysis as prime methods within Risk Assessment.**

Keywords: **Hazard and Operability, Accident Analysis.**

I. INTRODUCTION

For any industry to be successful it should meet not only the production requirements, but also maintain the highest safety standards for all concerned. The industry has to identify the hazards, assess the associated risks and bring the risks to tolerable level on a continuous basis. Mining being a hazardous operation has considerable safety risk to miners. Unsafe conditions and practices in mines lead to a number of accidents and causes loss and injury to human lives, damages the property, interrupt production etc. Risk assessment is a systematic method of identifying and analyzing the hazards associated with an activity and establishing a level of risk for each hazard. The hazards cannot be completely eliminated, and thus there is a need to define and estimate an accident risk level possible to be presented either in quantitative or qualitative way.

Because of the existing hazards of mining as an activity and the complexity of mining machinery and equipment and the associated systems, procedures and methods, it is not possible to be naturally safe. Regardless of how well the machinery or methods are designed, there will always be potential for serious accidents. It is not possible for an external agency to ensure the safety of an organization such as a mining company nor of the machinery or methods it uses. The principal responsibility for the safety of any particular mine and the manner in which it is operated rest with the management of that mine. It is widely accepted within industries in general that the various techniques of risk assessment contribute greatly toward improvements in the safety of complex operations and equipment. In many industries there is legislative requirement for risk assessment to be undertaken of all hazardous equipment, machinery and operations taking account of the procedures used for operation, maintenance, supervision and management.

Hazard identification and risk analysis involves identification of undesirable events that leads to a hazard, the analysis of hazard mechanism by which this undesirable event could occur and usually the estimation of extent, magnitude and likelihood of harmful effects.

There are good reasons for the mining industry to be concerned about risk in mines, in both qualitative and quantitative terms. Inappropriate shift schedules, excessive working hours, increased pollution problems, adverse environment & work conditions and lack of training can increase exposure risk to miners and result in employee fatigue and danger to life of the miners. The resulting severe economic and social consequences include reduced productivity, higher accident and occupational disease rates, absenteeism, resignations and increased workers compensation. On the other hand, there are considerable commercial, financial and industrial relations benefits to be realized from the development and successful implementation of effective risk assessment. The extent to which employees feel overworked has implications in four areas of immediate concern to employers: safety in the workplace; job performance; employee retention; and health-care costs. These can have a significant impact on a mine ‘s performance and on the health and safety of the workforce in a benign work environment.

Minerals are valuable natural resources. They constitute the vital raw materials for many basic industries and are a major resource for development. The history of mineral extraction in India dates back to the days of the Harappan civilization. The States, which have indicated an increase in the value of mineral production, are Odisha (94.89%), Jharkhand (90.18%) , Karnataka (62.22%), Chhattisgarh (60.88%), Maharashtra (59.30%), Madhya Pradesh (21.92%), Bihar (21.59%), Andhra Pradesh (20.67%), Rajasthan (19.02%), Jammu & Kashmir (UT) (18.02%), Assam (14.45%), Telangana (14.29%), Himachal Pradesh (12.89%), Tamil Nadu (9.52%), Meghalaya (6.80%), Kerala (4.30%), Gujarat (3.88%) and Uttarakhand (2.57%). However, some of the principal mineral producing States revealed decrease in value of mineral production and those include Uttar Pradesh (-24.62%) and Goa (-100 %) availability of the minerals provides a base for the growth and development of the mining sector in India.

Mahakali colliery is located in Chandrapur area of Western Coalfields Limited Maharashtra. It is an underground mine having seam thickness 17.50 m (avg). It is of Degree-I gassiness and the method of working is Board and Pillar method. The total area of lease hold is 1030.62 acres. The depth from the surface is min. 15.5m (3L/8D from south incline no.1) maximum 338 m. For ventilation an axial flow PV-200 (Exhaust) is installed at Airshaft (Old) of 3.65 Mts. diameter to ventilate the mine & Incline No.1, No.2 and Airshaft (New) serves as three intakes.

II. LITRATURE REVIEW

Carpignanoet al. (1998) applied quantitative risk analysis (QRA) for drawing conclusions concerning serious accidental events with the occurrence frequency and the consequences. The QRA approach they selected was based on reservoir analysis and management systems (RAMS) such as Preliminary Hazard Analysis (PHA), Failure Mode Effect and Critical Analysis (FMECA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA) and Cause Consequence Analysis and were able to identify accident initiating events and accidental sequence.to classify these sequences in to frequency categories to determine the related consequences with respect to workers, population and the environments.

Bell and Glade (2003) have done a risk analysis focusing on risk to life. They calculated land slide risk and occurrence of potential damaging events as well as the distribution of the elements at risk and proposed the following approach for risk evaluation: Laulet al. (2006) identified hazards (chemical, electrical, physical, and industrial) and potential initiators that could lead to an accident. Hazard analysis is used to evaluate identified hazards. Hazard analysis is done by “what if check list”, Hazard and Operability (HAZOP) analysis, Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA) and provided methods together with the 8 advantages and disadvantages, for developing a safety document for chemical, non-nuclear facilities.

Wang et al. (2009) applied HAZOP analysis to determine if the operation has potential to give rise to hazardous situation and found the range of hazardous events. They identified the route by which each of the hazardous events could be realized. After HAZOP analysis they introduced MO-HAZOP program which calculates probability of an event which is the product of probabilities of every factor.

Richard Kunda, Josè Frantz and Farhana Karachi (2013), this study was used to determine the prevalence of and ergonomic risk factors associated with WMSIs amongst underground mine workers in Kitwe, Zambia. Methods: A cross-sectional quantitative study was conducted using a sample size of 500 workers. A stratified random sampling method according to mining work activity type was used to obtain the sample. Data was collected by means of a structured questionnaire, and the Statistical Package for Social Sciences (SPSS) was used to analyze data using descriptive and inferential statistical methods. This study revealed significant associations between WMSIs and ergonomic risk factors like working with the back bent and grasping.

Khaula Aisha Batool (2015), there is a dire need for effective identification and response to the OHS issues and problems in order to get maximum productivity which will ultimately support economic growth. Efforts are made to highlight the main issues currently faced by the miners which are concerned with the occupational health and safety of laborers above and below the grounds. Continuous struggle to improve OHS and to respond to changes in the sector is constrained by lack of training, inconsistency in risk management, guidance for junior, small and artisanal miners and poor/ absence of holistic approaches to risk treatment. Some sound remedial and control measures are recommended to minimize the ratio of injuries and reduce the intensity of accidents.

Saira Sherin, Zahid Ur Rehman, Sajjad Hussain, Noor Muhammad, Talat Bilal (2020
Main causes of accidents in mines are fall of roof, improper ventilation system, gases, fires and mine explosions. Beside these hazards, violation of rules and regulations for mine workers are common, which also cause accidents. This paper is focused on issues associated with the health and safety of workers and the collected data were analyzed with SPSS computer statistics software. The data analyses indicated that the lack of education and violation of safety laws cause accidents in mines. Results show that problems that were rated higher by more than 60% of workers included slide and fall, dust, roof fall and explosive related hazards. In survey more than 50% of the workers admitted the existence of gases, fire and low height mines are common hazards in their workplace.

Hammad Tariq Janjua, and Stergios D. Zarko Giannis (2021), Occupational accidents and illnesses arise due to the activities mentioned above because the working circumstances are not optimal. The decision-matrix risk-assessment (DMRA) approach, in which incidents are evaluated according to their severity and probability, improve working conditions, including public health and environment protection. To assess the risks and to select which actions should continue in the same manner, we highlighted hazards that need control measures.

Ashish Kumar Dasha, R. M. Bhattacharjee, P. S. Paula and Malay Tikaderb (2015), a large number of mobile mining equipment such as haul trucks, dumpers, tractors, tankers are used for different operation and such operations contribute significantly in causation of fatal and serious accidents. In this study, 33 years ‘fatal accident data from Indian coal mines were analyzed from 1980. The rate of fatal accident shows a significant reduction from 1980 to 2000 but it becomes almost flat for the last 13 years since 2000. Though all the accidents were investigated and recommendation were made for preventing recurrence, there is no further reduction in the rate in last 13 years which reflects the gaps in our investigation procedure or recommendation or implementation. An effort has been made in this paper to highlight the major gaps in the existing investigating procedure and thereby making useful recommendations to ensure effective control measures in place to reduce the risk to an acceptable level.

MenglongWu1 (2022), Statistical analysis of non-coal underground mine accidents from 2000 to 2022, revealing the characteristics of non-coal underground mine accidents and 5 risk types were identified, including cage fall accident, powered haulage accident, fire accident, mine water inrush accident, and roof fall and rib spalling accident. A multi-hazard risk analysis and assessment framework for non-coal underground mines based on the inherent risk of the system, the vulnerability of the disaster-bearing body and the adaptability of the disaster-bearing area is proposed. The multi-hazard inherent risks in non-coal underground mines are comprehensively identified and evaluated in five aspects, including hazardous equipment and facilities, hazardous materials, hazardous processes, hazardous operations and hazardous places, and the characterization and unifed measurement of multi-hazard risk is realized by combining the vulnerability index of disaster-bearing body and the adaptability index of disaster-bearing area.

Elham Rahimi Pedram Roghanchi (2021). A retrospective study on accident analysis of the United States mines for 36 years was achieved Using statistical analysis on the MSHA's accident databases between 1983 and 2018. A regression model of generalized estimation equation (GEE) was used for unbalanced panel data that provided 95,812 observations for 19,924 mine-ID-year in aggregate, coal, metal, and nonmetal mines. The contributions of various parameters, including mine type, injured body part, days lost, age, and experience on the rate of accidents and injuries were investigated across the commodity types. The results showed coal miners in the East region are at a higher risk of an accident. The results of regression analysis show that mine-tenured workers have a vital role in accident frequencies. Analysis of the injured body part on the injury rate indicates that the upper body injuries are the most significant among all mine types. Also, the fatality rate is significant in aggregate and coal mines in comparison with metal and nonmetal mine.

III PROBLEM IDENTIFICATON

The mining industry, especially in the Vidarbha region, continues to be fraught with various operational hazards and risks, despite advancements in safety practices and regulatory frameworks. Accidents—ranging from minor injuries to fatalities—persistently occur due to a multitude of factors, including mechanical failures, hazardous geological conditions, and inadequate safety procedures. This has prompted the need for a systematic, region-specific analysis of accident patterns in different types of mines and ore extraction operations. The lack of comprehensive risk assessment and hazard identification methods tailored to the specific working conditions in the Vidarbha region further exacerbates the problem. Therefore, this study addresses the critical need to evaluate and apply effective risk analysis methodologies, such as HAZOP, Fault Tree Analysis, and Event Tree Analysis, to identify, categorize, and mitigate risks in mining activities. The ultimate aim is to improve workplace safety, reduce accident rates, and support proactive safety management strategies in the mining sector of this region.

IV METHODOLOGY

4.1 METHODOLOGIES FOR RISK ANALYSIS

The objective of risk analysis is to produce outputs that can be used to evaluate the nature and distribution of risk and to develop appropriate strategies to manage risk. Events or issues with more significant consequences and likelihood are identified as „higher risk‟ and are selected for higher priority mitigation actions to lower the likelihood of the event happening and reduce the consequences if the event were to occur.

4.1.1. Qualitative methods use descriptive terms to identify and record consequences and likelihoods of the events and resultant risk. Quantitative methods identify likelihoods as frequencies or probabilities. They identify consequences in terms of relative scale (orders of magnitude) or in terms of specific values (for example estimate of cost, number of fatalities or number of individuals lost from a rare species).

For both qualitative and quantitative methods, it is important to invest time in developing appropriate rating scales for likelihood, consequence and resultant risk. The full range of risk situations likely to be encountered within the scope of the exercise should be considered when developing rating scales. Qualitative approaches to risk assessment are the most commonly applied. Qualitative risk assessment methods are quick and relatively easy to use as broad consequences and likelihoods can be identified and they can provide a general understanding of comparative risk between risk events, and the risk matrix can be used to separate risk events into risk classes (ratings). A logical systematic process is usually followed during a qualitative risk assessment to identify the key risk events and to assess the consequences of the events occurring and the likelihood of their occurrence.

Table 4.1 A qualitative method for the classification of Risks

Risk Rank	L1 Almost certain	L2 Likely	L3 Possible	L4 Unlikely	L5 Rare
C1 Catastrophic	1	2	4	7	11
C2 Major	3	5	8	12	16
C3 Moderate	6	9	13	17	20
C4 Minor	10	14	18	21	23
C5 Insignificant	15	19	22	24	25

Qualitative approaches to risk assessment are the most commonly applied. Qualitative risk assessment methods are quick and relatively easy to use as broad consequences and likelihoods can be identified and they can provide a general understanding of comparative risk between risk events, and the risk matrix can be used to separate risk events into risk classes (ratings). A logical systematic process is usually followed during a qualitative risk assessment to identify the key risk events and to assess the consequences of the events occurring and the likelihood of their occurrence.

4.1.2 Semi-quantitative approaches to risk assessment are currently widely used to overcome some of the shortcomings associated with qualitative approaches. Semi-quantitative risk assessments provide a more detailed prioritise ranking of risks than the outcomes of qualitative risk assessments.

Table. 4.2 Example of Semi quantitative method

		1	2	3	4	5
Likliho od level	Descriptor	Insignificant	Minor	Moderate	Major	Catastrophic
5	Almost Certain	5	10	15	20	25
4	Likely	4	8	12	16	20
3	Possible	3	6	9	12	15
2	Unlikely	2	4	6	8	10
1	Rare	1	2	3	4	5

Semi-quantitative risk assessment takes the qualitative approach a step further by attributing values or multipliers to the likelihood and consequence groupings. Semi- quantitative risk assessment methods may involve multiplication of frequency levels with a numerical ranking of consequence. Several combinations of scale are possible.

Table below shows an example of semi-quantitative risk matrix where the likelihoods and consequences have been assigned numbered levels that have been multiplied to generate a numeric description of risk ratings. The values that have been assigned to the likelihoods and consequences are not related to their actual magnitudes but the numeric values that are derived for risk can be grouped to generate the indicated risk ratings. In this example, Extreme risk events have risk ratings greater than 15, High risks are between 10 and 15, and so on.

4.1.3 Quantitative risk assessment is increasingly applied in the mining and minerals industry due to business requirements to support financial decisions, evenly compare financial risks with environmental and social risks, and to demonstrate transparency, consistency and logic of approach. However quantitative risk approaches often are not intuitive and require some up- front learning investment by decision makers. Quantitative risk assessment is used across the full range of risk applications from deriving preliminary first-pass separation of risk events to much more comprehensive assessments. The comprehensive assessments can derive detailed risk profiles for priority ranking, estimates of the costs that may be incurred due to risk events, input to financial models and a basis for cost- benefit analysis. Quantitative risk assessment follows basic risk assessment approach to its full extent by attributing absolute values to likelihood and consequences. Estimates of likelihood are made in terms of event frequency or probability of occurrence of the risk event.

Estimates of consequence can be made using any consistent measure selected according to the nature of the application. The risk quotient is used to differentiate on a comparative basis between the risk's events using a consistent measure of risk and to identify those events that pose the most risk. Where consequences are expressed in financial terms, the risk quotient is equivalent to the commonly used term, 'expected cost' or 'expected value'.

Table. 4.3 Overall Accident Statistics in 2022 and 2021 in CIL

Sl. No.	Parameters	2022	2021
1	Number of fatal accidents	17	29
2	Number of fatalities	19	30
3	Number of serious Accidents	60	73
4	Number of serious injuries	66	80
5	5Fatality Rate per Mte. of coal production	0.03	0.05
6	Fatality Rate per 3 lakhs manshift deployed	0.10	0.16
7	Serious injury Rate per Mte. of coal production	0.11	0.11
8	Serious injury Rate per 3 lakhs man-shift deployed	0.38	0.3

Table. 4.5 Year wise production in Manganese mine

Year	2022-23	2021-22	2020-21	2019-20	2018-19	2017-18	2016-17	2015-16
Production Manganese ore (MT	1302217	1231264	1143570	1277444	1301191	1201113	1004845	1032275

Table.4.6 Year wise production in Coal mine

Year	2022-23	2021-22	2020-21	2019-20	2018-19	2017-18	2016-17	2015-16	2014-15	2013-14
Production Coal ore	703.22	622.63	596.22	602.13	606. 89	567.37	554.14	538.75	494.23	462.41

Table. 4.7 Comparative Accidents Statistics of coal mines of 5 yearly Average since 1975

Time Frame	Avg. Fatal Accident		Av. Serious Accidents		Av. Fatality Rate		Av. Seroius Injury Rate	
	Accident	Fatalities	Accident	Injuries	Per Mill.te	Per 3 lac Manshift	Per Mill.Te	Per 3 lac Manshift
1975-79	175	196	1224	1278	2.18	0.44	14.24	2.89
1980-84	122	143	1018	1065	1.29	0.30	9.75	2.26
1985-89	133	150	550	571	0.98	0.30	3.70	1.15
1990-94	120	145	525	558	0.694	0.30	2.70	1.19
1995-99	98	124	481	513	0.50	0.29	2.06	1.14
2000-04	68	82	499	526	0.28	0.22	1.80	1.47
2005-09	60	80	328	339	0.22	0.25	0.92	1.04
2010-14	56	62	219	228	0.138	0.23	0.49	0.80
2015-19	33	43	107	112	0.08	0.18	0.19	0.47
2020	29	30	73	80	0.05	0.14	0.13	0.37
2021	27	29	57	61	0.05	0.10	0.10	0.20
2022	17	19	60	66	0.03	0.08	0.10	0.30

From the table 4.5, this table shows annual production figures of manganese ore (in metric tons) from 2015–2023. Key insights: A general upward trend in production over the years Indicates increased demand or improved extraction capacity. Can be cross-analyzed with accident statistics to determine whether increased output correlates with higher risk levels.

From the table 4.6, this table shows the steady increase in coal production, peaking in 2022–23 highlights the critical role of coal in energy production and industrial use for correlating productivity with safety measures and accident frequency.

From the table 4.7, this is a historical table summarizing accidents, fatalities, injury rates, and related metrics in coal mining across various 5-year intervals from 1975 to 2022. It includes: Average fatal and serious accidents Fatality and serious injury rates (per million tonnes and per 3 lakh man-shifts)

VI RESULT AND DISCCUSSION

This section analyzes the accident trends, production data, and risk classifications across different mining sectors in the Vidarbha region, with a focus on both coal and manganese mines. The aim is to correlate risk analysis methodologies with actual field outcomes to improve mine safety practices.

6.1 Accident Trends and Risk Reduction

The comparative statistics in Table 4.7 show a significant decline in both fatal and serious accidents in Indian coal mines over the decades:

- Fatal accidents have dropped from an average of 175 (1975-79) to just 17 (2022).
- Serious injuries have reduced from over 1200 annually in the 1970s to just 60-66 cases in 2022.
- Fatality rate per million tonne of coal has decreased from 2.18 to 0.03, while the serious injury rate per 3 lakh man-shifts has also improved substantially.
- This reduction is a positive indicator of improved safety measures, stricter regulations, and more widespread application of structured risk analysis methodologies like HAZOP, FTA, and ETA.

6.2 Correlation Between Production and Accidents

Manganese Mines:

As per Table 4.5, manganese ore production has increased steadily, reaching 1.3 million tonnes in 2022-23 from 1.0 million tonnes in 2016-17. Despite this rise in output, available accident data suggests that serious accidents have not proportionately increased, indicating an improvement in safety management systems.

Coal Mines:

Table 4.6 shows a steady increase in coal production over the past decade, from 462.41 MT (2013-14) to 703.22 MT (2022-23). Despite this growth, accident frequency and severity have declined, proving the effectiveness of modern risk management and safety protocols even under higher operational loads.

VII CONCLUSION

The consistent reduction in accidents, despite increased mining activity, suggests that structured risk management strategies are making a tangible impact on worker safety. However, residual risks remain due to human factors and geological uncertainties. Thus, continuous improvement through risk-informed decision-making, adoption of modern tools, and stronger enforcement of safety norms is imperative to further enhance the safety and sustainability of mining operations in the Vidarbha region.

REFERENCES

[1] Carpignano, A., et al. (1998). *Quantitative Risk Analysis (QRA) based on RAMS methodology*. Safety Science.

[2] Bell, R., & Glade, T. (2003). *Landslide risk analysis concepts, methods and challenges*. Bulletin of Engineering Geology and the Environment, 62, 83–94.

[3] Lau, J., et al. (2006). *Hazard identification and safety analysis in non-nuclear facilities*. Journal of Hazardous Materials.

[4] Wang, Y., et al. (2009). *Application of HAZOP in industrial risk assessment and introduction of MO-HAZOP program*. Process Safety and Environmental Protection.

[5] Kunda, R., Frantz, J., & Karachi, F. (2013). *Prevalence of and ergonomic risk factors associated with work-related musculoskeletal injuries in underground mine workers in Kitwe, Zambia*. Journal of Occupational Health and Safety.

[6] Batool, K. A. (2015). *Occupational Health and Safety Challenges in Mining Sector*. Journal of Occupational Health and Environmental Research.

[7] Sherin, S., Rehman, Z. U., Hussain, S., Muhammad, N., & Bilal, T. (2020). *Causes of*

accidents in mines and analysis using SPSS. International Journal of Safety Research.

[8] Janjua, H. T., & Giannis, S. D. Z. (2021). *Decision-Matrix Risk Assessment (DMRA) in occupational safety improvement*. Safety and Health at Work.

[9] Dasha, A. K., Bhattacharjee, R. M., Paula, P. S., & Tikader, M. (2015). *Fatal accident trends in Indian coal mines over 33 years*. Mining Technology.

[10] Wu, M. (2022). *Statistical Analysis and Multi-Hazard Risk Assessment of Non-Coal Underground Mines (2000–2022)*. Journal of Safety

[11] Pedram Roghanchi, E. R. (2021). *Accident Analysis in U.S. Mines (1983–2018) Using GEE Regression Model*. Mining Engineering Journal.

[12] Coal India Limited (CIL). *Annual Safety Statistics Report* (2021–2022).

[13] Directorate General of Mines Safety (DGMS). *Accident and Fatality Statistics Reports*.