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HUMAN FACTOR ANALYSIS ON MINING ACCIDENTS

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ABSTRACT

The objective of this thesis is to employ modern analytical methodologies to conduct a thorough study of incidents. It also helps to identify the main human elements that contribute to major mining accidents in India. The main goals of this study are to determine the significance of human factors in mining accidents, investigate these factors, and integrate different models and methods for comprehensive factor analysis. It evaluates the impact of human decisions and actions, and gain a comprehensive understanding of the intricate relationships involved in these incidents. The Analytical Hierarchy Process (AHP), Fault Tree Analysis (FTA), Human Factors Analysis and Classification System (HFACS), and Bow Tie Risk Management were all used in the investigation.

Keywords: Mining accidents, safety culture, Analytical Hierarchy Process (AHP), Human Factors Analysis and Classification System (HFACS), Bow-Tie Risk Management, Fault Tree Analysis (FTA).

I. Introduction

The world's mining sector is an essential part of modern society as it produces the raw materials that are required by a wide range of industries. Sectors including electronics, energy production, building, and manufacturing. Mining has an existence which runs back thousands of years. Mining operations cover a vast range of activities carried out over a wide range of geographical regions and climates. It also covers every geological formation and deposit i.e. from the extraction of coal and metals to the manufacture of minerals and gemstones.

Mining Accidents: Nature and Impact

Mining catastrophes have long-lasting effects on economies, ecosystems, and people that cut beyond time and location. It is also the reason for immediate casualty toll and destruction of property. In addition to the terrible loss of human life, mining accidents can cause long-term environmental deterioration.

The importance of researching on mining accidents will give us the broad view on cause and remedy for any accident that occur during mining activities. Protection of human life, Preservation of environmental integrity, and Safeguarding economic viability are some of the reasons which will emphasize the importance of the necessity for careful study, analysis, and approaches to understand the cause of accidents and preventing the adverse consequences of mining accidents.

A multidisciplinary strategy which integrates ideas from psychology, ergonomics, sociology, organizational behaviour, and safety research is necessary for understanding the significance of human factors in mining accidents. Investigators can find reasons for mistakes, violations, and risky behaviour that takes place in an accident. Behavioural and cognitive mechanisms that underpin human performance in mining environments are studied by the researchers to find opportunities for treatment and improvement.

2. Chas Nala Colliery Disaster

Accident summary:

At the Bihar coal mine Chas Nala 375 coal miners perished on December 26, 1975. It turned out to be the deadliest mining accident in Indian history. The disaster happened suddenly when a 120 square foot hole formed by the fall of an 80-foot coal seam roof.

The miners below were trapped when seven million gallons of water per minute to rush into the mine from a nearby mine that was flooded due to the rupture.

A flood of water from abandoned incline workings in the same seam, which had been submerged in water since 1949. It flooded the Chas Nala mine which was built with two horizons, one at 172 meters and the other at 291 meters below the surface.

After being used for multiple inclines results in accumulation of water in these ancient workings had over time. An enormous flood of water resulted from the collapse of a coal block at Horizon No.1, this horizon connects the old and new workings.

Unfortunately, those who were trapped inside the mine had no hope of surviving due to the adverse conditions present there. Dewatering the mine and getting to the accident scene took twenty-three days. Although the precise number of casualties was never confirmed, the official toll came to approximately 375.

Analytic Hierarchy Process (AHP) on the incident

Applying the Analytic Hierarchy Process (AHP) method to prioritize risk factors, decision-making criteria, and intervention options relevant to safety management within the context of this accident.

- **Establishing Criteria:**

For AHP analysis criteria are establish that are relevant to safety management in mining accidents.

Based on the information provided, following criteria are identified:

- **Design and Construction Failures**
- **Maintenance and Monitoring Failures**
- **Operational Failures**
- **Environmental Factors**
- **Emergency Response Failures**

Compare each criterion against the others and assign values based on their relative importance. The ratings for the criteria and the performance of each alternative relative to these criteria based on the information provided about the mining accident are determined by the expert judgments from professors and professionals in the sector of mining.

Expert opinions can be obtained by having participants compare the relative merits of alternatives of certain criteria in pairwise comparisons as shown in table 1.

Table 1: Normalised Matrix based on the rating

To normalize the matrix, divide each element by the sum of its column as shown in table 2.

CRITERIA	Design and Construction	Maintenance and Monitoring	Operational	Environmental	Emergency Response
Design and Construction	1	3	5	7	9
Maintenance and Monitoring	1/3	1	3	5	7
Operational	1/5	1/3	1	3	5
Environmental	1/7	1/5	1/3	1	3
Emergency Response	1/9	1/7	1/5	1/3	1

- Design & Construction: 1 + 1/3 + 1/5 + 1/7 + 1/9 = 1 + 0.333 + 0.2 + 0.143 + 0.111 = 1.787
- Maintenance & Monitoring:+ 1 + 1/3 + 1/5 + 1/7 = 3 + 1 + 0.333 + 0.2 + 0.143 = 4.676
- Operational: 5 + 3 + 1 + 1/3 + 1/5 = 5 + 3 + 1 + 0.333 + 0.2 = 9.533
- Environmental: 7 + 5 + 3 + 1 + 1/3 = 7 + 5 + 3 + 1 + 0.333 = 16.333
- Emergency Response: 9 + 7 + 5 + 3 + 1 = 9 + 7 + 5 + 3 + 1 = 2

Table 2: Normalized pairwise comparison matrix:

CRITERIA	Design and Construction	Maintenance and Monitoring	Operational	Environmental	Emergency Response
Design and Construction	1 / 1.787 = 0.560	3 / 4.676 = 0.641	5 / 9.533 = 0.524	7 / 16.333 = 0.429	9 / 25 = 0.360
Maintenance and Monitoring	0.333 / 1.787 = 0.186	1 / 4.676 = 0.214	3 / 9.533 = 0.315	5 / 16.333 = 0.306	7 / 25 = 0.280
Operational	0.200 / 1.787 = 0.112	0.333 / 4.676 = 0.071	1 / 9.533 = 0.105	3 / 16.333 = 0.184	5 / 25 = 0.200
Environmental	0.143 / 1.787 = 0.080	0.200 / 4.676 = 0.043	0.333 / 9.533 = 0.035	1 / 16.333 = 0.061	3 / 25 = 0.120
Emergency Response	0.111 / 1.787 = 0.062	0.143/ 4.676 = 0.031	0.200 / 9.533 = 0.021	0.333 / 16.333 = 0.020	1 / 25 = 0.040

Calculate the priority weights

To find the priority vector, average each row of the normalized matrix as shown in table 3:

- Design & Construction: (0.560 + 0.641 + 0.524 + 0.429 + 0.360) / 5 = 2.514 / 5 = 0.503
- Maintenance & Monitoring: (0.186 + 0.214 + 0.315 + 0.306 + 0.280) / 5 = 1.301 / 5 = 0.260
- Operational: (0.112 + 0.071 + 0.105 + 0.184 + 0.200) / 5 = 0.672 / 5 = 0.134
- Environmental: (0.080 + 0.043 + 0.035 + 0.061 + 0.120) / 5 = 0.339 / 5 = 0.068
- Emergency Response: (0.062 + 0.031 + 0.021 + 0.020 + 0.040) / 5 = 0.174 / 5 = 0.035

Table 3: Criteria weights

	Criteria Weights
Design and Construction	0.503
Maintenance and Monitoring	0.260
Operational	0.134
Environmental	0.068
Emergency Response	0.035

Calculate the weighted sum vector

Table 3.6: Multiplying criteria weights with the normalized matrix

Criteria Weights	0.503	0.260	0.134	0.068	0.035
CRITERIA	**Design and Construction**	**Maintenance and Monitoring**	**Operational**	**Environmental**	**Emergency Response**
Design and Construction	1*0.503 = 0.503	3*0.260 = 0.78	5*0.134 = 0.67	7*0.068 = 0.476	9*0.035 = 0.315
Maintenance and Monitoring	0.33*0.503 = 0.165	1*0.260 = 0.78	3*0.134 = 0.402	5*0.068 = 0.34	7*0.035 = 0.245
Operational	0.2*0.503 = 0.1	0.33*0.260 = 0.085	1*0.134 = 0.134	3*0.068 = 0.204	5*0.035 = 0.175

Environmental	0.14*0.503 = 0.07	0.2*0260 = 0.052	0.33*0.134 = 0.044	1*0.068 =0.068	3*0.035 =0.105
Emergency Response	0.11*0.503 = 0.055	0.14*0.260 = 0.036	0.2*0.134 = 0.026	0.33*0.068 = 0.0224	1*0.035 = 0.035

The criteria weights are multiplied with the normalized matrix to obtain weighted sum value as shown in Table 4 and table 5.

Table 4: The weighted sum value

CRITERIA	Design and Construction	Maintenance and Monitoring	Operational	Environmental	Emergency Response	weighted sum value
Design and Construction	0.503	0.78	0.67	0.476	0.315	2.744
Maintenance and Monitoring	0.165	0.78	0.402	0.34	0.245	1.414
Operational	0.1	0.085	0.134	0.204	0.175	0.701
Environmental	0.07	0.052	0.044	0.068	0.105	0.342
Emergency Response	0.055	0.036	0.026	0.0224	0.035	0.178

Table 5: Ratio of weighted sum value and criteria weights

CRITERIA	λ = weighted sum value/ Criteria Weights
Design and Construction	5.456
Maintenance and Monitoring	5.446
Operational	5.232
Environmental	5.029
Emergency Response	5.086

Ratio of weighted sum value and Criteria Weights is shown in table 3.8. The average of these values gives λ_{max}:

λ_{max}= (5.456+5.446+5.232+5.029+5.086)/5 = 5.25

Compute the consistency index (CI)

The Consistency Index (CI) is calculated using the formula:

$CI=(\lambda_{max}-n)/(n-1)$

For our 5 criteria (n = 5):

CI = (5.25−5)/(5−1) = 0.25/4 = **0.0625**

The Consistency Ratio (CR) is calculated using the formula:

CR=CI/RI

The Random Consistency Index (RI) for n = 5 is 1.12:

CR= 0.0625/1.12 = **0.0558**

Since the CR is less than 0.1, our pairwise comparison matrix is consistent.

Design and construction failures: This option has the highest overall score that suggest that the Chasnala mining disaster is primarily the result of design and construction errors. Future tragedies of a similar nature might be avoided by addressing these errors through improved engineering procedures. This procedures include frequent design reviews and adherence to safety standards.

Maintenance and monitoring failures: The second-highest score emphasizes how important it is to have reliable maintenance and monitoring systems. It is essential to implement routine inspections, real-time monitoring, and immediate remedial measures.

Operational failures: The disaster's major contribution from operational failures is reflected in this score. The probability of such failures can be decreased by guaranteeing adequate worker training. Other measures includes paying attention to operational protocols, and efficient communication during operations.

Environmental factors: Environmental factors certainly had a role in the disaster. Future incidents can be avoided by having a thorough understanding of the environmental context. This includes geological features and water table levels and integrating this knowledge into the planning and operational stages.

Emergency response failures: It have the lowest score but this aspect is nevertheless very important. Response to mining accidents can be enhanced by creating thorough emergency response plans. This response plans includes holding frequent exercises and making sure that emergency equipment is easily accessible and operational.

Human Factors Analysis and Classification System (HFACS) on the incident

The Human Factors Analysis and Classification System (HFACS) is used to determine and examine the human variables that contribute to accidents. Human error is divided into four categories: Unsafe Acts, Preconditions for Unsafe Acts, Unsafe Supervision, and Organizational Influences. A methodical analysis of the human aspects that are involved in the Chas Nala colliery accident by the application of HFACS.

Level 1: Unsafe acts

- **Decision errors:** Poor risk assessment and decision-making on the possibility of water leakage from abandoned workings and the stability of the coal seam roof.
- **Skill-based errors:** Possible operational mistakes made during mining operations that might have led to the collapse.
- **Routine violations:** May involve a pattern of ignoring safety regulations or using shortcuts to speed up mining operations.
- **Exceptional violations:** Sometimes important safety requirements were disregarded due to pressure to fulfil production goals.

Level 2: Preconditions for unsafe acts

- **Physical environment:** The hazardous working environment was caused by the difficult geological conditions. Also, existence of wet abandoned areas boost the adverse working conditions.
- **Technological environment:** There may be some potential shortcomings in structure integrity and water level monitoring systems.
- **Adverse mental states:** The miners' attentiveness and capacity for making decisions may have been affected by stress or exhaustion.
- **Adverse physiological states:** Their performance may have been affected by physical weariness from hard work conditions.
- **Physical/mental limitations:** Restricted access to preparation exercises and advanced safety training.
- **Crew resource management:** Possible Breakdowns in coordination or communication among the mining team
- **Personal readiness:** Insufficient instructions or preparation to deal with emergencies in a timely manner.

Level 3: Unsafe supervision

- **Inadequate supervision:** Inadequate supervision and the execution of safety precautions by personnel in charge. Not making sure that all safety procedures were properly followed.
- **Inappropriate operations:** choices to continue ahead with mining activities in spite of the hazards connected to the wet workings.
- **Failure to correct problems:** It's possible that supervisors ignored noticed problems or previous near-misses that pointed to possible dangers. Insufficient changes after prior safety evaluations or assessments.
- **Supervisory violations**: It's possible that managers intentionally ignored safety violations in order to achieve deadlines or productivity targets.

Level 4: Organizational influences

- **Insufficient allocation of resources:** Inadequate funding for training initiatives, monitoring systems, and safety gear.
- **Budgetary constraints:** It's possible that these requirements may have led to cutting corners on safety measures.
- **Safety culture:** A culture that puts production over safety may have encouraged that resulted in safety procedures.
- **Safety programs:** Inadequate safety measures that failed to sufficiently address the unique risks associated with mining operations.
- **Communication channels:** Inadequate channels of communication inside the company hindered the efficient transmission of vital safety information.

Bowtie diagram of the Chas Nala Colliery Disaster

Figure 1shows the Bow-tie diagram for Chas Colliery Disaster which includes following important terms:

- **Hazard:** Potential collapse and flooding in the mine.
- **Top Event:** The collapse and flooding of the Chas Nala coal mine is the central event.
- **Threats:** Threats includes collapsing the coal seam roof, water building up in abandoned workings, and inadequate safety procedures and risk assessments could have caused the top event.
- **Consequences:** The top event has resulted in worker fatalities, extended mining operations problems, and a negative impact on the mining community.
- **Preventive measures:** strict compliance to safety procedures and laws, regular maintenance and inspections, and thorough risk assessments for abandoned workings.
- **Mitigative controls:** Effective emergency response and rescue plans, sufficient dewatering systems, and staff education are important to lessen the effects.

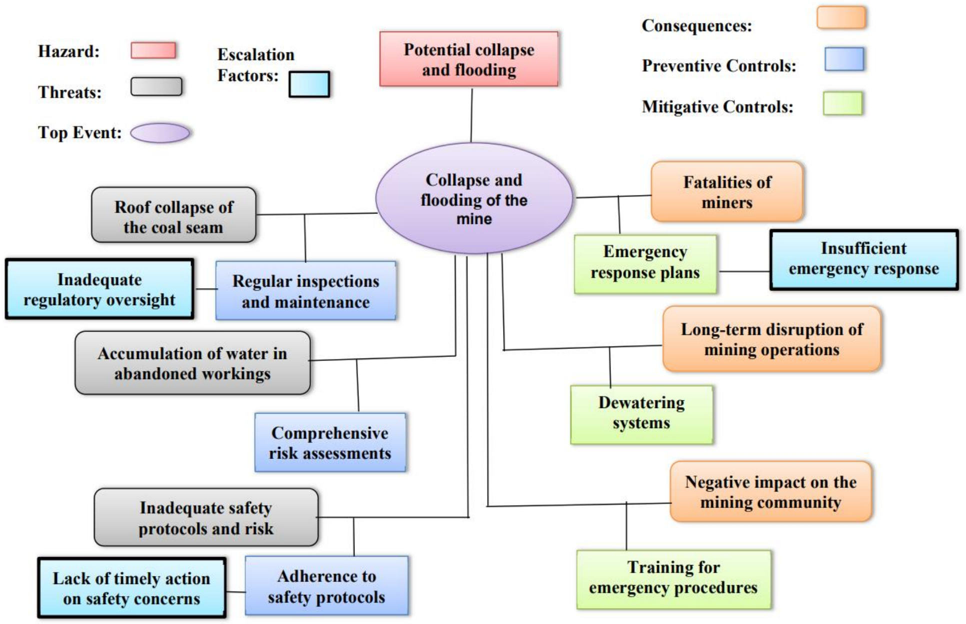

Fig 1 Bowtie diagram of the Chas Nala Colliery Disaster

Fault Tree Analysis (FTA) of the Chas Nala Colliery Disaster

Figure 2 shows the Fault tree analysis for Chas Colliery Disaster which includes following important terms:

- **Top event:** This is represented by a rectangular shape with the label " Collapse and Flooding Leading to Fatalities".
- **Intermediate events (IE):** These are represented by rectangular shape with the label "Collapse of coal seam roof, inrush of water, and failure of emergency response".
- **Basic events (BE):** These are represented by circular shapes and the label "Weak geological structure, historical workings not documented, lack of monitoring, poor emergency planning, blasting operations, outdated technology, minor seismic activity, poor design, over-extraction of coal, and inadequate maintenance".

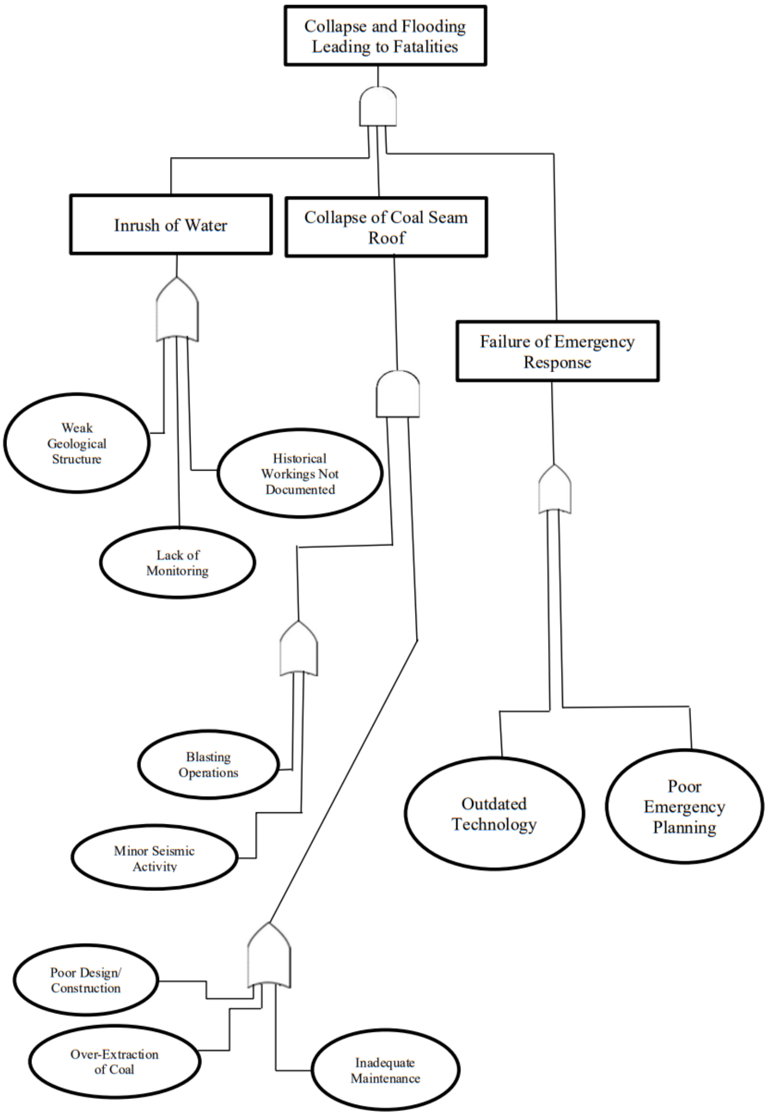

Fig 2 Fault Tree Analysis (FTA) of the Chas Nala Colliery Disaster

3.Ruchayan Village Coal Mine Incident

Accident summary:

On January 25, a tragic accident occurred at a rat-hole coal mine in Ruchayan village, Wokha district resulted in the deaths of six workers and injuries to four others. The workers inside the mine were employing rock breakers around 1:00 PM when this incident occured. There appeared to be a suspected short circuit that resulted in a fire and subsequent explosion.
Two of the mine's co-owners have been arrested and law enforcement has moved quickly to lodge a personal

case. The incident highlights how important it is to implement strict safety regulations and conduct routine equipment inspections in order prevent similar disasters in the future.

3.5.2 Analytic Hierarchy Process (AHP) on the incident

3.4.2.1 Establishing criteria:

- **Safety protocols**
    - **a. Electrical safety**
    - **b. General safety procedures**
- **Mining methods**
- **Worker training**
- **Emergency response**

Expert opinions can be obtained by having participants compare the relative merits of alternatives of certain criteria in pairwise comparisons as shown in table 6.

Table 6: Normalised Matrix based on the rating

CRITERIA	safety Protocols	Mining Methods	Worker Training	Emergency Response
safety Protocols	1	4	5	6
Mining Methods	1/4	1	3	4
Worker Training	1/5	1/3	1	3
Emergency Response	1/6	1/4	1/4	1

Calculate the sum of each column to obtain normalized matrix as shown in table 7:

- Safety Protocols: 1 + 1/4 + 1/5 + 1/6 = 1 + 0.25 + 0.2 + 0.167 = 1.617
- Mining Methods: 4 + 1 + 1/3 + 1/4 = 4 + 1 + 0.333 + 0.25 = 5.583
- Worker Training: 5 + 3 + 1 + 1/3 = 5 + 3 + 1 + 0.333 = 9.333
- Emergency Response: 6 + 4 + 3 + 1 = 6 + 4 + 3 + 1 = 1

Table 7: Normalized pairwise comparison matrix:

CRITERIA	safety Protocols	Mining Methods	Worker Training	Emergency Response
safety Protocols	0.618	0.716	0.536	0.429
Mining Methods	0.154	0.179	0.107	0.286
Worker Training	0.123	0.060	0.107	0.214
Emergency Response	0.103	0.045	0.036	0.071

To find the priority vector, average each row of the normalized matrix and multiply it to normalized matrix to obtain values as shown in table 8:

- Safety Protocols: (0.618 + 0.716 + 0.536 + 0.429) / 4 = 2.299 / 4 = 0.575
- Mining Methods: (0.154 + 0.179 + 0.107 + 0.286) / 4 = 0.726 / 4 = 0.182
- Worker Training: (0.123 + 0.060 + 0.107 + 0.214) / 4 = 0.504 / 4 = 0.126
- Emergency Response: (0.103 + 0.045 + 0.036 + 0.071) / 4 = 0.255 / 4 = 0.064

Weighted Sum Vector:

- Safety Protocols: (1 * 0.575) + (4 * 0.182) + (5 * 0.126) + (6 * 0.064) = 0.575 + 0.728 + 0.630 + 0.384 = 2.317
- Mining Methods: (1/4 * 0.575) + (1 * 0.182) + (3 * 0.126) + (4 * 0.064) = 0.144 + 0.182 + 0.378 + 0.256 = 0.960
- Worker Training: (1/5 * 0.575) + (1/3 * 0.182) + (1 * 0.126) + (3 * 0.064) = 0.115 + 0.061 + 0.126 + 0.192 = 0.494
- Emergency Response: (1/6 * 0.575) + (1/4 * 0.182) + (1/3 * 0.126) + (1 * 0.064) = 0.096 + 0.045 + 0.042 + 0.064 = 0.247

Table 8: Ratio of weighted sum value and Criteria Weights

weighted sum value	Criteria Weights	λ_max
2.317	0.575	4.030
0.960	0.182	5.275
0.494	0.126	3.921
0.247	0.064	3.859

Average λ_{max}: (4.030 + 5.275 + 3.921 + 3.859) / 4 = 4.271

Consistency Index (CI) for Main Criteria

CI = (λ_{max} - n) / (n - 1), where n = 4

CI = (4.271 - 4) / (4 - 1) = 0.271 / 3 = **0.090**

Consistency Ratio (CR) for Main Criteria

Random Index (RI) for n=4 is 0.90 (standard value for RI)

CR = CI / RI = 0.090 / 0.90 = **0.10**

The CR is exactly 0.10, which is acceptable.

Proceeding with sub-criteria under "Safety Protocols."

Expert opinions can be obtained by having participants compare the relative merits of alternatives of certain sub-criteria in pairwise comparisons as shown in table 9.

Table 9: Normalised Matrix based on the rating of sub-criteria

Sub-Criteria	**Electrical Safety**	**General Safety Procedures**
Electrical Safety	1	2
General Safety Procedures	1/2	1

Calculate the sum of each column to obtain normalized matrix as shown in table 10:

Electrical Safety: 1 + 1/2 = 1.5

General Safety Procedures: 2 + 1 = 3

Table 10: Normalized pairwise comparison matrix

Sub-Criteria	Electrical Safety	General Safety Procedures
Electrical Safety	0.667	0.667
General Safety Procedures	0.333	0.333

Average each row of the normalized matrix to get the priority vector:

Electrical Safety: (0.667 + 0.667) / 2 = 0.667

General Safety Procedures: (0.333 + 0.333) / 2 = 0.333

Step 8: Consistency Check for Sub-Criteria

Weighted Sum Vector for Sub-Criteria

Multiply the original pairwise comparison matrix by the priority vector:

Weighted Sum Vector:

Electrical Safety: (1 * 0.667) + (2 * 0.333) = 0.667 + 0.667 = 1.334

General Safety Procedures: (1/2 * 0.667) + (1 * 0.333) = 0.334 + 0.333 = 0.667

λ_{max} for Sub-Criteria

Divide the weighted sum vector by the priority vector:

λ_{max} (Electrical Safety) = 1.334 / 0.667 = 2

λ_{max} (General Safety Procedures) = 0.667 / 0.333 = 2

Average λ_{max}: (2 + 2) / 2 = 2

Consistency Index (CI) for Sub-Criteria

CI = (λ_{max} - n) / (n - 1), where n = 2

CI = (2 - 2) / (2 - 1) = 0 / 1 = **0**

Consistency Ratio (CR) for Sub-Criteria

Random Index (RI) for n=2 is 0 (standard value for RI)

CR and RI have same value that represents perfect consistency.

combine the weights of the main criteria and sub-criteria to get the final weights:

- Safety protocols:
    Electrical safety: 0.575 * 0.667 = 0.384
    General safety procedures: 0.575 * 0.333 = 0.191
- Mining methods: 0.182
- Worker training: 0.126
- Emergency response: 0.064

Electrical safety: This criterion was identified as the most critical factor. The accident was likely caused by a short circuit which is indicated as the high priority. This emphasizes how important electrical safety is in avoiding accidents of this nature. Emphasis should be placed on routine maintenance, electrical system inspections, and the use of safe equipment to avoid future electrical failures.

General safety procedures: The general safety protocols are also very important since they emphasize the requirement of thorough safety precautions. This also includes dedication to SOPs. This is done in order to guarantee the general well-being of workers in dangerous environments.

Mining techniques: The techniques applied in mining operations are essential to ensure security. The relative weight of this criterion indicates that adopting modern and safe mining methods can aid in minimizing risk.

Worker training: Workers must receive sufficient training to handle equipment safely and react to emergencies in a timely manner. The analysis shows that there is a strong demand for improved training courses. Courses must cover cover both regular operations and emergency response.

Emergency response: This criterion is still very important despite having the least weight. Accidents can have a significantly smaller impact when emergency response is efficient. This requires having access to skilled emergency staff, full medical facilities and well-defined emergency protocols.

Human Factors Analysis and Classification System (HFACS) on the incident

HFACS Analysis of the Mining Accident

Level 1: Unsafe acts

- **Skill-based errors:** It has been stated that workers were employing rock breakers within the coal mine. This have caused the fire and explosion that followed. violation to established procedures during mining operations.
- **Decisional mistakes:** Insufficient risk assessment before operating equipment within the mine. Poor decision-making about safety precautions and might have contributed to the accident.

Level 2: Preconditions for unsafe acts

- **Prerequisites at the personal level:** Inadequate experience and training could have caused these kind of errors when using the equipment. fatigue or stress on employees can potentially affect in employees decision-making and focus during the emergency.
- **Prerequisites for supervisor level positions:** Insufficient supervision or observation of labour operations within the mine. Lack of attention to safety rules and procedures.
- **Preconditions at the organizational level:** insufficient new employee orientation and safety training programs. Workers are not being properly informed about safety policies and procedures. Possible shortage of resources to keep workplace safety standards high.

Level 3: Unsafe supervision

- **Insufficient supervisory oversight:** failure to quickly identify and stop dangerous work practices. Neglecting to identify and address equipment-related safety risks.

Level 4: Organizational influences

- **Management of resources:** Inadequate maintenance of electrical systems and supply of safety devices. Not enough money is allocated for employee supervision and training.
- **Climate of the organization:** Potential absence of a culture of safety promoting safety regulations. pressure to give up safety in order to boost productivity.

Bowtie diagram of the Ruchayan Village Coal Mine Incident

Figure 3 shows the Bow-tie diagram for Chas Colliery Disaster which includes following important terms:

- **Hazard:** Potential fire and explosion in the mine.
- **Top event:** The main event is the explosion and fire in the rat-hole coal mine.
- **Threats:** A possible short circuit due to the unfair usage of rock breakers and a lack of regular equipment could have caused the top incident.
- **Consequences:** The top event has resulted in worker fatalities and injuries, a halt to mining activities, and a negative impact on the local community and the families of the affected employees.
- **Preventive Measures:** Adequate training for employees on safe equipment handling, routine maintenance and inspections of electrical equipment, and the installation of fire detection and suppression systems are all steps taken to avoid the hazards.
- **Mitigative Controls:** Effective emergency response is one way to mitigate the effects. Providing first-aid and on-site medical support to injured employees.
- **Escalation Factors:** A lack of resources for emergency response and a delay in acting on safety concerns are additional factors that might decrease the effectiveness of the controls.

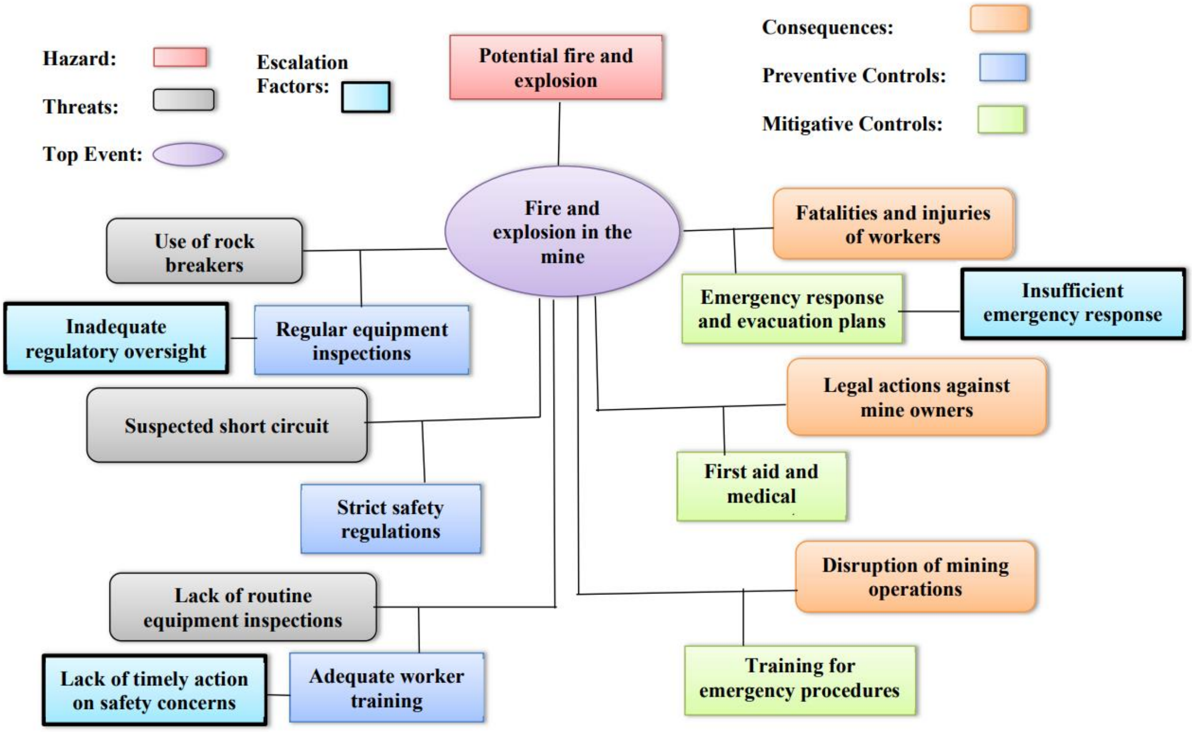

Figure 3: Bowtie diagram of the Ruchayan Village Coal Mine Incident

Fault Tree Analysis (FTA) of the Ruchayan Village Coal Mine Incident

Figure 3.4 shows the Fault tree analysis for Chas Colliery Disaster which includes following important terms:

- **Top event:** This is represented by a rectangular shape with the label " Short circuit".
- **Basic events (BE):** These are represented by circular shapes and the label "Improper use of rock breaker, electrical failures, lack of safety culture, inadequate training, resource deficiencies, and inadequate supervision".

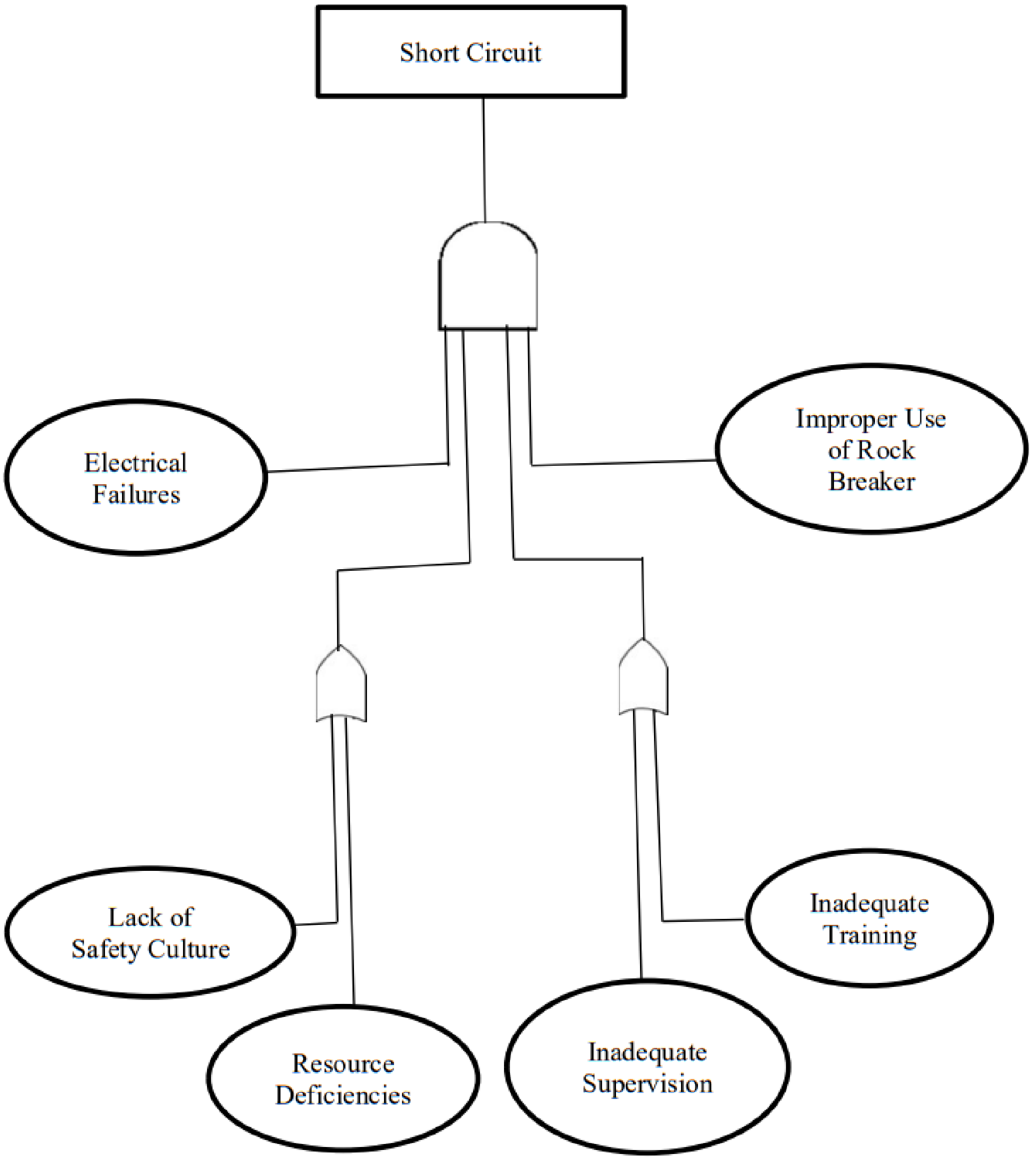

Fig 4 Fault Tree Analysis (FTA) of the Ruchayan Village Coal Mine Incident

CONCLUSIONS

Using a combination of modern analytical techniques such as Bow Tie Risk Management, Analytical Hierarchy Process (AHP), Human Factors Analysis and Classification System (HFACS), and Fault Tree Analysis (FTA). This thesis analyzed the human factors causing significant mining accidents in India. The study aimed to identify important human factors, evaluate the significance of human decisions and actions, and provide a thorough understanding of the complicated interconnections involved in mining accidents. The complex system is approched by looking at a number of incidents, including Chas Nala coal mine disaster and Ruchayan Village Coal Mine Incident.

The results highlight how important it is to have a strong safety culture, competent supervision, thorough training, and strict regulatory control in order to prevent mining accidents and guarantee the safety of workers. The integration of multiple analytical methods ensured a thorough examination of the complex factors involved. This highlights the need for a multifaceted approach to improve safety in mining operations.

By combining several analytical models, a thorough understanding of the variables influencing mining accidents was made possible. Every approach produced different insights:

Analytical Hierarchy Process (AHP): AHP assisted in prioritizing the lack of regular inspections, inadequate support systems, inadequate geological surveys, and inadequate emergency planning, which were among the contributing elements to the accidents. The technique produced a hierarchy of key issues through precisely weighting the components.

Human Factors Analysis and Classification System (HFACS): HFACS identified the human and organizational deficiencies at various levels, from organizational influences to unsafe acts. It highlighted how important it is to deal with structural problems such a weak safety culture, insufficient supervision, and inadequate training.

Fault Trees Analysis (FTA): The FTA offered a thorough analysis of the accident's root causes. It highlights the complex relationships between several contributing components. It emphasized the importance of strong preventive measures and effective hazards response systems.

Bow Tie Risk Management: This approach successfully discovered preventive and mitigation measures as well as the causal pathways leading to accidents. It highlighted the significance of thorough emergency response plans, dependable support systems, and routine geotechnical surveys.

REFRENCES

1 Abad, A., Lioveras, J. and Michelena, A. 2004. Nitrogen fertilization and foliar effects on durum wheat yield and quality and on residual soil nitrate in irrigated Mediterranean conditions. Field Crops Research 87: 257-269.
2 Dash, A. K. 2019. Analysis of accidents due to slope failure in Indian opencast coal mines. Current Science 117(2): 304-308.
3 Dursun, A. E. 2024. Fatal Accident Analysis and Hazard Identification in Turkish Coal-Extracting Industry Using Analytic Hierarchy Process. Mining, Metallurgy & Exploration 41(1): 149-172.
4 Fu, G., Xie, X., Jia, Q., Tong, W., & Ge, Y. 2019. Accidents analysis and prevention of coal and gas outburst: Understanding human errors in accidents. Process Safety and Environmental Protection 122: 157-168.
5 Kumar, P., Gupta, S., & Gunda, Y. R. 2020. Estimation of human error rate in underground coal mines through retrospective analysis of mining accident reports and some error reduction strategies. Safety science 123: 104555.
6 Kumar, R., & Ghosh, A. K. 2014. The accident analysis of mobile mine machinery in Indian opencast coal mines. International Journal of Injury Control and Safety Promotion 21(1):54-60
7 Li, M., Wang, H., Wang, D., Shao, Z., & He, S. 2020. Risk assessment of gas explosion in coal mines based on fuzzy AHP and bayesian network. Process Safety and Environmental Protection 135: 207-218.
8 Liu, R., Cheng, W., Yu, Y., & Xu, Q. 2018. Human factors analysis of major coal mine accidents in China based on the HFACS-CM model and AHP method. International Journal of Industrial Ergonomics 68: 270–279.
9 Maiti, J., Khanzode, V. V., & Ray, P. K. 2009. Severity analysis of Indian coal mine accidents – A retrospective study for 100 years. Safety Science 47: 1033-1042.
10 Matsimbe, J., Ghambi, S., & Samson, A. 2020. Application of the bowtie method in accident analysis: Case of Kaziwiziwi coal mine. Engineering and Technology Quarterly Reviews 3(2)