Hazard identification and safety risk assessment in mining industry

The concern for mine safety continues as, regardless of significant measures taken by Directorate General of Mines Safety, Dhanbad to reduce the mining fatalities, the number of accidents remains high. Hazard identification and risk assessment is the process by which mine management identify hazards present in mines, analyses the risks and assess the risks associated with the hazards in order to determine and implement controls to maintain risk to an acceptable level. The aim of the paper is to identify and evaluate mine hazards and risks using different risk assessment techniques like Failure Mode and Effect Analysis(FMEA) and Workplace Risk Assessment and Control (WRAC) in order to improve mine safety.

1. Introduction

Hazards in mines are inherent in nature and are also produced due to its complex operations, machinery used and the workforce employed. The current safety practices implemented in Indian mines have reached there saturation point and became unproductive. As a result the accidents are recurring every year in underground coal mines. Fig.1 shows that the fatality rate in coal mines have decreased gradually from 1970 to 1990's and from 1991 to 2015, the fatality rate remained almost constant (DGMS, 2016). To reduce the fatality rates and to achieve zero accident goal, implementation of risk assessment process is requisite in mines.

Risk assessment process is the keystone of any productive risk management system. As shown in Fig.2, the risk management model consists of seven sequential steps that enable systematic identification of hazards to implementation of risk controls, communication and monitoring for control effectiveness. Risk assessment is the overall process identifying hazards, assessing their associated risks and estimate the level of risk for each hazard either in qualitative or quantitative way. Hazard identification is the systematic identification of sources of potential injury. Risk analysis helps in developing an understanding of the risks associated with the identified hazards. Evaluating the

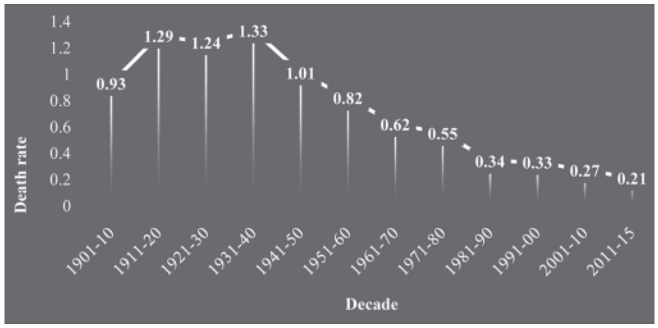

Fig.1 Trend in fatality rate per 1000 persons employed in coal mines

analysed risks helps to determine that if the risks related to the identified hazards are either high or medium or low level.

In the year 2002, DGMS has recommended to apply safety management systems in all mines and issued guidelines for implementing Safety Management Systems (DGMS, 2002). DGMS has also requested to undertake the formal risk assessment process in all the mines with the help of the above guidelines (DGMS, 2011). DGMS (2014a) has campaigned to use 'Risk Calculator' in the risk evaluation stage of risk management process. DGMS has recommended to use Take 5 (Personal Risk Assessment) process to ensure that all the work activities are given a final check to identify and control any potential hazards that may have not already

Fig.2 Risk management process model (ISO 31000:2009)

Dr. D. P. Tripathy, Professor, Department of Mining Engineering, National Institute of Technology, Odisha, 769 008, India. E-mail: debi_tripathy@yahoo.co.in

been addressed prior to commencement of activities (DGMS, 2014b). To clear the confusion at grass root level about implementation strategy of Safety Management Plan, DGMS (2016b) has issued an integrated approach for development of Safety Management Plan for coal and metal mines, as a sequel to DGMS (Tech) (S&T) Circular 13 of 2002. This paper attempts to identify and evaluate risks in a mine using FMEA and WRAC technique.

2. Risk assessment in the mining Industry

The risk assessment process in the risk management plan has three steps. They are hazard identification, analyse risk and evaluate risks.

2.1 Hazard identification

The aim of the hazard identification step is to identify all the possible hazards which pose risk in the mine. Hazard identification is most important step in risk assessment process as when a hazard is not identified, it cannot be actively managed. There are many ways to identify hazards in the mines. Common hazard identification techniques are:

- Previous accident reports
- Inspection reports
- Safety audits
- Checklists
- Work process evaluation
- Safety statistics
- Take 5
- Brainstorming

The best way to identify hazards is to divide the mine workplace based on its activities (loading, drilling, blasting, etc.); equipment (conveyors, trucks, etc.); geographical areas (workshop, pit, compound, etc.).

Over the years, DGMS has classified the hazards based on the types of occurrences causing the accidents (Xue et al., 2010). The major categories of causes leading to accidents in underground mines are: ground movement; rope haulage; conveyor; explosives; dust, gas and other combustible material; inundation. According to Canadian Centre for Occupational Health and Safety (2016), hazards may be classified as physical, safety, biological, chemical, ergonomic, and psychosocial.

- Physical: pressure, radiation, noise, etc.
- Safety: equipment failures, fall hazards, inappropriate guarding on machines, etc.
- Biological: insects, plants, animals, birds, etc.
- Chemical: depends on the physical, chemical and toxic properties of the chemical.
- Ergonomic: lifting overweight loads, improper seat posture on machines, etc.
- Psychosocial: violence, stress, etc.

In this study, the hazards of ground movement, explosives, dust, gas and other combustible material, and inundation are identified according the above classification.

2.2 Risk analysis

The aim of the risk analysis step is to understand the nature of the risk possessed by the identified hazards. Risk analysis involves the consideration of the source of risk, the consequence and likelihood (Peter, 2010). Many qualitative, quantitative and semi-quantitative techniques are available for risk analysis in mines. FMEA and WRAC are the two common techniques used in mines.

FMEA is a step by step approach for identifying all the possible failures in a design or manufacturing. Failure mode means the mode in which something might fail. Effect analysis means the consequence of those failure (Iannacchione, 2008; Sutrisno and Lee, 2011). FMEA procedure includes listing of components and their failure modes, identifying failure effects and causes, and calculating total risk. WRAC tool is a broad brush risk ranking approach allowing the user to focus on the highest risk (Thompson, 1999;Iannacchione, 2008; Srinivas, 2013). It can be applied in areas of the mine or at particular times of activity. WRAC is most effective when it is scoped with appropriate detail, including clear objectives and the boundaries of the system have been defined (Allanson, 2002). WRAC technique is suitable for identifying multiple failures.

If the risk is mechanical equipment then FMEA is appropriate approach, if the risk is general then the WRAC technique is appropriate. Depending on the purpose of analysis, risk, data availability different risk analysis techniques are applied. The best way to understand risk is by using multiple hazard analysis techniques as each has its own purpose, strengths, and weaknesses. The hazards identified and analysed risks of rope haulage and conveyor using FMEA are present in Tables 1-2 respectively. The hazards identified and analysed risks of ground movement, explosives, dust, gas and other combustible material, and inundation using WRAC are presented in Tables 3-6 respectively.

2.3 Risk evaluation

The aim of the risk evaluation step is to estimate the level of risks and helps to determine the controls to reduce risks. The most common method to estimate risk in mines is by using risk matrices and risk rankings. In risk evaluation, each risk is defined using potential consequence should the hazard occur and likelihood of the occurrence of the each hazard. In terms of safety, consequence is defined as the degree of harm that could be caused to people exposed to the hazard. Likelihood is defined as the chance that the hazard might occur. For a detailed analysis likelihood is replace with exposure and probability as the people present in mines are exposed to the hazards for part of the time (DGMS, 2002).

DGMS (2002) has given risk ranking guidelines for risk

TABLE 1: FMEA OF ROPE HAULAGE

Component	Failure mode	Failure effect
Rope	Breakage of rope	Runaway of tubs
Drawbar	Failure of drawbar	Runaway of tubs
Coupling	Defective coupling	Runaway of tubs
Capel	Defective Capel	Runaway of tubs
Track	Defective laying of track line	Derailment of tubs
Tubs	Improper maintenance of tubs	Derailment of tubs
Tub buffers	Non-provision/ non-functioning	Getting caught between tubs while coupling and uncoupling

TABLE 2: FMEA OF CONVEYOR BELT

Component	Failure mode	Failure effect
Idlers	Unguarded idlers	Injury to operators
	Material build-up	Reduce belt life and motor life
	No Lubrication	Premature bearing failure
	Sticking idlers	Belt will tensioned unevenly and will prematurely stretch out on one side
Pulleys	Material build-up	Reduce belt life and motor life
	Crooked bearings	Bearing failure and excessive torque on motor
	Improper alignment	Belt will tensioned unevenly and will prematurely stretch out on one side
	No Lubrication	Premature bearing failure
	Loose belt	Belt slippage
Belt	Improper belt tensioning	Belt slippage
	Excessive wear on bottom side of belt	Slippage between belt and drive pulley
	Load too heavy	Belt failure, bearing failure, motor failure
	Dirty underside	Slips and reduces weight carrying capacity
	Damaged idlers	May start fire in belt
	Damaged idlers and pulley	Damage belt (tear, cut of belt, puncture, abrasion,)
Gear box	Gear wheel wear	Drive unit failure
	Gear wheel broke tooth	Drive unit failure
Pull cord and lockout witches	Pull cord and lockout switches not provided	Accident may happen
Screen (at cross under points)	Improper screening	Jamming of chute

TABLE 3: WRAC OF GROUND CONTROL

Hazards	Risks
Physical	
Exposure to excessive noise due to roof/side fall	Temporary or permanent hearing loss may occur
Safety	
Failure to determine the rock mass rating of the district	Systematic support rules will not be framed properly, chance of roof fall
Failure to frame systematic support rules	Improper roof support, chance of roof fall
Failure to provide indicators for strata monitoring	Chance of sudden roof fall, injury to persons
Delay to support freshly exposed roof	Endangering safety of face workers
Failure to provide good quality of cement capsules	Deterioration of roof leads to roof fall
Failure to provide sufficient quantity of support material	Endangering safety of face workers
Failure to provide proper training to support crew	Poor workmanship, injury to support crew
Non vertical alignment ofgalleries in sections	Floor and pillars may get crushed due to uneven distribution of stresses
More height and width of galleries	Unbalanced stress on roof lead to roof fall
Ergonomic	
Manual drilling	Potential danger of injury to driller due to roof/ side fall, chance of injury to driller due improper posture while drilling
Dressing	Weak layers may fall on persons causing injury, chance of injury to persons due to improper posture

TABLE 4: WRAC OF EXPLOSIVES

Hazards	Risks
Physical	
Exposure to excessive noise due to explosion	Temporary or permanent hearing loss may occur
Safety	
Failure to provide proper training to shot firer	Workers may enter blasting zone because of improper signalling, chance of misfire
Drivage of joining gallery from both ends	In adverted entry into blasting area leads to accidents
Failure to maintain reserve stations properly	Chance of pilferage of explosives
Priming of explosives at un-authorized places	Chances of accidental blasting
Carrying out multiple operations at face while charging	More chances of injuries
Improper maintenance of blasting tools and accessories	Chances of accidental blasting
Carrying of explosives and detonator together	Chances of accidental blasting
Presence of energy source near reserve stations	Chances of accidental blasting
Shot firing from source other than exploder	Chance of accidental blasting
Shot firer engaged in work other than blasting	Lack of concentration, chance of misfire
Chemical	
Exposure to high concentrations of respirable dust after explosion	Chance of poisoning due to inhalation of dust which may contain blasting fumes
Ergonomic	
Carrying of heavy load of explosives and detonators	Physical strain

TABLE 5: WRAC OF DUST, GAS AND OTHER COMBUSTIBLE MATERIAL

Hazards	Risks
Physical	
Exposure to ambient environmental factors like high or low air temperatures	Worker may fall ill due to dehydration
Safety	
Failure or delay in sealing off huge area by sectionalisation stoppings	Eruption of inflammable, noxious gases, toxic gases, chances of explosion
Huge coal dust deposition in return airway	Chance of explosion
Leakage from sectionalisation stoppings	Chance of fire and explosion
Presence of subsidence cracks and fissures on surface above development panel	Chance of fire explosion and associated risk injury to person, loss of property
Inadequate gas detecting apparatus/ arrangement	Detection not possible during early stage which may cause explosion
Failure to provide proper training supervisor/ official	Incapable to monitor % of CH_4 in sealed of area as well as in working panels
Gas cutting and welding work near dusty area or any unauthorised area	Chances of explosion, injury to persons
Blasting in gassy seam	Chances of explosion
Contrabands	Chances of explosion, injury to persons
Poor maintenance of flame proof features of electrical machinery	Chances of explosion, injury to persons
Stone dust barrier not provided at panel entry	Chance of explosion
Accumulation of coal dust at working panel and loading points	Chance of fire leads to explosion
Chemical	
Exposure to carbon monoxide and other gas products of combustion	Chance of person falling ill or may lead to death.
Exposure to dust particles	Health related diseases may take place

evaluation, in which risk is evaluated using consequence, probability and exposure. Coal India Limited has modified the risk ranking of DGMS to 5×5 risk matrix and calculating risk using consequence and likelihood (Srinivas, 2012). The DGMS risk ranking scales for consequence, exposure and probability are shown in Table 7a, 7b, 7c. respectively.

5×5 risk matrix used in Coal India Limited and their consequence and likelihood scales are presented in Tables 8.a, 8.b, 8.c respectively.

Risk evaluation of rope haulage and conveyor belt are

TABLE 6: WRAC OF INUNDATION

Hazards	Risks
Physical	
Exposure to noise in area of pumps	Temporary hearing loss may occur
Safety	
Sudden inrush of water/unconsolidated free flowing materials	Flooding of working area, injury to person and loss of property
Presence of geological disturbance faults, folds, slips etc.	Sudden inrush of water
Presence of surface cracks, fissures, subsidence, pot holes	Flooding of mine
Water entering from old boreholes which are not sealed effectively	Flooding of mine
Unexpected heavy rains and power failure	Flooding of mine
Failure of sumps	Flooding of mine

TABLE 7a: SCALE OF CONSEQUENCE (C)

Consequence (C)	Ranking
Several dead	5
One death	1
Significant chance of fatality	0.3
One permanent disability/serious accident	0.1
Many minor injuries/lost time injuries	0.01
One minor injury	0.001
No time loss injury	0.0001

TABLE 7b: SCALE OF EXPOSURE (E)

Exposure (E)	Ranking
Continuous	10
Frequent (daily happening)	5
Seldom (weekly)	3
Unusual (may be once a month)	2.5
Occasionally (yearly)	2
Very rare (once in 5 years)	1.5
Once in 10 years	0.5
Once in 100 years	0.02
Never in the world in any industry	0.01

TABLE 7c: SCALE OF PROBABILITY (P)

Probability of event (P)	Ranking
May well be expected	10
Quite possible	7
Unusual but possible	3
Only remotely possible	2
Conceivable but unlikely	1
Practically impossible	0.5
Virtually impossible	0.1

TABLE 8a: 5×5 RISK MATRIX

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

Note: Risk Score:

1-6	7-19	20-25
Low	Medium	High

TABLE 8b: SCALE OF CONSEQUENCE (C)

Category	Personal damage criteria
Insignificant (C1)	No treatment
Minor (C2)	First aid treatment
Moderate (C3)	Medical treatment
Major (C4)	Extensive injuries, single fatality
Catastrophic (C5)	Multiple fatality

TABLE 8c: SCALE OF LIKELIHOOD (L)

Category	Safety criteria
Rare (L1)	Occurs once every 1000-10000 years
Unlikely (L2)	Occurs once every 100-1000 years
Possible (L3)	Occurs once every 10-100 years
Likely (L4)	Occurs once every 1-10 years
Almost certain (L5)	High frequency of occurrence, occurs once every year

TABLE 9: FMEA RISK EVALUATION OF ROPE HAULAGE

Failure Mode	C	E	P	C*E*P	Recommendations
Breakage of rope	1	2.5	7	17.5	Rope should be selected properly and maintained regularly, tubs should not be overloaded
Failure of drawbar	1	2	3	6	Only DGMS approved drawbars should be used, periodical inspection and maintenance should be done, worn out and defective pieces should be replaced immediately
Defective coupling	1	1.5	3	4.5	Only DGMS approved couplings should be used, periodical inspection and maintenance should be done, worn out and defective pieces should be replaced immediately
Defective capel	0.1	1.5	1	0.15	Only DGMS approved capel should be used, periodical inspection and maintenance should be done, worn out and defective pieces should be replaced immediately
Defective laying of track line	0.3	2	10	6	Haulage tracks should be maintained regularly and whenever required, track should be inspected daily
Improper maintenance of tubs	0.01	2	7	0.14	Tubs should be maintained regularly
Non-provision/ non-functioning	1	0.5	3	1.5	Tub buffers should be maintained properly, tub spacer should be used while coupling and uncoupling

TABLE 10: FMEA RISK EVALUATION OF CONVEYOR BELT

Failure mode	C	E	P	C*E*P	Recommendations
Unguarded idlers	1	3	10	30	All idlers should be provided with guards to protect workers to avoid contact with idlers
Material build-up	0.01	2	10	0.2	Build-up material should be removed regularly
No lubrication	0.001	1.5	7	0.0105	Lubrication should be provided whenever required
Sticking idlers	0.0001	0.5	1	0.00005	Replace or free idlers
Material build-up	0.1	1.5	7	1.05	Build-up material should be removed regularly
Crooked bearings	0.0001	0.5	3	0.00015	Crooked bearings should be replaced, bearings should be maintained periodically
Improper alignment	0.01	0.5	2	0.01	Advance the end of idler to which the belt has shifted in the direction of belt travel, load material towards the belt's centre
No lubrication	0.001	2	7	0.014	Lubrication should be provided whenever required
Loose belt	0.1	1.5	7	1.05	Tighten the belt tension
Improper belt tensioning	0.1	1.5	3	0.45	Tighten the belt tension
Excessive wear on bottom side of belt	0.01	0.5	3	0.015	Lag drive pulley
Load too heavy	0.01	0.02	2	0.0004	Lower load on conveyor belt
Dirty underside	0.1	2	10	2	Maintenance should be done periodically
Damaged idlers	0.3	1.5	3	1.35	Replace damaged idlers, fire extinguisher should be provided
Damaged idlers and pulley	0.3	1.5	3	1.35	Replace damaged idlers and pulleys
Gear wheel wear	0.01	2	7	0.14	Replace gear
Gear wheel broke tooth	0.01	2	3	0.06	Replace gear
Pull cord and lockout switches not provided	1	2.5	3	7.5	Pull cord and lock out switches should be provided as a safety measure
Improper screening	0.01	0.5	3	0.015	Proper screening should be provided

TABLE 11: RISK EVALUATION OF GROUND CONTROL IN WRAC

Risks	L	C	L*C	Recommendations
Temporary or permanent hearing loss may occur	L-3	C-2	8(M)	Personal protective equipment's like ear plugs, noise cancellation headphones should be used.
Systematic support rules will not be framed properly, chance of roof fall	L-1	C-4	10(M)	Rock mass rating should be determined on or before opening of new district
Improper roof support, chance of roof fall	L-1	C-4	10(M)	Systematic support rules should be framed on the basis of rock mass rating
Chance of sudden roof fall, injury to persons	L-2	C-3	9(M)	Load shell, tell-tale, spring type convergence recorder, sliding type convergence recorder, borehole extensometer should be provided
Endangering safety of face workers	L-2	C-3	9(M)	Timely support of freshly exposed roof, maintaining discipline, cultivation of safe practice and strict monitoring
Deterioration of roof leads to roof fall	L-4	C-3	17(M)	Anchorage testing to be done strictly as per statue.
Endangering safety of face workers	L-4	C-3	17(M)	Buffer stock of at least one day consumption should be provided and maintained
Poor workmanship, injury to support crew	L-3	C-3	13(M)	Training and re-training should be provided
Floor and pillars may get crushed due to uneven distribution of stresses	L-3	C-4	18(M)	Verticality of contiguous working to be maintained by proper surveying
Unbalanced stress on roof lead to roof fall	L-3	C-3	13(M)	Height and width are restricted as per DGMS statute
Potential danger of injury to driller due to roof/side fall	L-4	C-4	21(H)	Mechanized drilling by universal drilling machine should be implemented, proper dressing ensured before deployment of drillers for drilling
Weak layers may fall on persons causing injury chance of injury to persons due to improper posture	L-2	C-3	9(M)	Long T-bars should be used while dressing, dressing should be done by standing on the rise side, proper postures should be maintained while dressing

TABLE 12: RISK EVALUATION OF EXPLOSIVES IN WRAC

Risks	L	C	L*C	Recommendations
Temporary or permanent hearing loss may occur	L-3	C-3	13(M)	Personal protective equipment’s like ear plugs, noise cancellation headphones should be used.
Workers may enter blasting zone because of improper signalling, chance of misfire	L-3	C-3	13(M)	Training, re-training of blasting crew, use of blasting card system
In adverted entry into blasting area leads to accidents	L-4	C-3	17(M)	Strict implementation of blasting card system
Chance of pilferage of explosives	L-2	C-2	5(L)	Maintained reserve station properly
Chances of accidental blasting	L-3	C-3	13(M)	Priming the explosives should be done only at faces
More chances of injuries	L-3	C-3	13(M)	Charging of explosives should be done only when drill machine is removed from face
Chances of accidental blasting	L-2	C-3	9(M)	Timely maintenance of blasting tools
Chances of accidental blasting	L-3	C-3	13(M)	Separate containers for detonators and explosives
Chances of accidental blasting	L-3	C-4	18(M)	Proper citing of reserve station as per statute
Chance of accidental blasting	L-3	C-4	18(M)	Blasting only by approved exploder
Lack of concentration, chance of misfire	L-2	C-2	5(L)	Shot firer not to be overloaded
Chance of poisoning due to inhalation of dust which may contain blasting fumes	L-4	C-3	17(M)	Respirators should be used when exposed to blasting fumes, asbestos, dust, etc.
Physical strain	L-2	C-2	5(L)	Proper breaks should be taken while carrying heavy loads, carrying overload should be avoided

Table 13: Risk evaluation of dust, gas and other combustible material in WRAC

Risks	L	C	L*C	Recommendations
Worker may fall ill due to dehydration	L-1	C-2	3(L)	Proper clothing should be worn, adequate ventilation should be provided in working place.
Eruption of inflammable, noxious gases, toxic gases, chances of explosion	L-3	C-4	18(M)	Erection of sectionalisation stopping should be done, regular monitoring at surface by tele monitoring system and underground monitoring of all sectionalisation stoppings should be done.
Chance of explosion	L-1	C-4	10(M)	Dust should be suppressed adequately by sprinkling of stone dust, return airway should be regularly cleaned
Chance of fire and explosion	L-1	C-4	10(M)	Sectionalisation stoppings should be maintained and monitored regularly, erection of stopping out bye of previous stopping if required and pressure balancing to avoid leakage of stoppings
Chance of fire explosion and associated risk injury to person, loss of property	L-3	C-4	18(M)	Cracks should be filled by dozing, subsidence crack and fissures should be monitored regularly, cracks should be concreted if required
Detection not possible during early stage which may cause explosion	L-2	C-4	14(M)	Sufficient calibrated gas monitoring instruments should be provided, calibration of instruments should be done as per Statue.
Incapable to monitor % of CH_4 in sealed of area as well as in working panels	L-2	C-4	14(M)	Training and re-training of mining supervisors/ officials should be provided
Chances of explosion, injury to persons	L-2	C-3	9(M)	Flash back arrester, sand, water, should be kept near the gas cutting/ welding work place, cutting /welding work shall be started only with prior permission from manager, cutting/welding work should be monitored by supervisor
Chances of explosion	L-3	C-5	22(H)	Check for presence of inflammable gas, P-5 explosive and delay detonators are to be used. Proper drill pattern is shall be adopted, spray water before and after blasting, quality of explosive should be ensured.
Chances of explosion, injury to persons	L-2	C-3	9(M)	Deployment of body searcher, awareness among workers should be brought
Chances of explosion, injury to persons	L-3	C-5	22(H)	Flame proof features should be maintained as per statute.
Chance of explosion	L-4	C-4	21(H)	Stone dust barriers should be provided as per statute.
Chance of fire leads to explosion	L-3	C-3	13(M)	Coal dust should be cleaned regularly, water spraying and stone dusting should be done as per statute
Chance of person falling ill or may lead to death	L-3	C-5	22(H)	Good ventilation must be ensured at all the working places.
Health related diseases may develop	L-5	C-3	20(H)	Dust suppression methods should be followed, dust monitoring should be done periodically, personal protective equipment's like respirators should be used.

done using DGMS risk ranking scales (Tables 7a, 7b, 7c) are shown in Tables 9 and 10 respectively.

Risk evaluation of ground control, explosives, dust, gas and other combustible materials and inundation are done using Coal India Limited 5×5 risk matrix scales (Tables 8a, 8b, 8c) are shown in Tables 11-14.

3. Conclusion

Despite the mining fatalities have been reduced gradually over the years through training, regulation and management commitment to safety, the number and severity are still unacceptable. Underground mine accidents require special attention and better prevention efforts.Till date, many high risk prone industries have successfully applied and reduced risks by using various hazard identification and risk assessment techniques suitable for their industry. In this paper FMEA and WRAC techniques are used to identify hazards and evaluate their risk associated with the identified hazards. FMEA technique is used when the hazards are equipment related risks and WRAC technique is used when the hazards are non-equipment related risks. FMEA and WRAC risk assessment techniques applied in mines will help the mine operators and officials to identify low, medium and

TABLE 14: RISK EVALUATION OF INUNDATION IN WRAC

Risks	L	C	L*C	Recommendations
Temporary hearing loss may occur	L-2	C-2	5(L)	Personal protective equipment's like ear plugs, noise cancellation headphones should be used.
Flooding of working area, injury to person and loss of property	L-3	C-5	22(H)	Stoppage of working in case of abnormal seepage of water, advance check borehole, hydro geological survey to be carried on to find out presence of water body
Sudden inrush of water	L-2	C-2	5(L)	Provision of geological disturbances are demarcated in different plans and 15 m barrier is left against such disturbances
Flooding of mine	L-3	C-3	13(M)	Provision of filling surface cracks, fissures, subsidence, pot holes to avoid any inrush of such water to underground
Flooding of mine	L-2	C-2	5(L)	Provision of sealing bore holes, barrier is maintained around the bore hole.
Flooding of mine	L-2	C-2	5(L)	Evacuation of persons from underground
Flooding of mine	L-3	C-5	22(H)	Stoppage of working in case of abnormal seepage of water

high risk levels and will also help to prioritize risks. Both the techniques provide opportunities for reducing risks associated with the underground mine and the safety recommendations for the reduction or prevention of hazards are presented. For improving the safety in mines, it is best to use combination of risk assessment techniques considering their own purpose, advantages and disadvantages.

References

1. Allanson, C. (2002): Strata control in underground coal mines: a risk management perspective. In: Proceedings of Coal 2002: Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, p 135.
2. Canadian Centre for Occupational Health and Safety (2016): Hazard and Risk. Retrieved from https://www.ccohs.ca/oshanswers/hsprograms/hazard_risk.html.
3. DGMS (2002): Safety Management System - A Guideline for Implementation, DGMS (Tech) (S&T) Circular 13 of 2002, Dhanbad, India.
4. DGMS (2011): Provision for Audit and Review of SMS. DGMS (Tech) (S&T) Circular 2 of 2011, Dhanbad, India.
5. DGMS (2014a): Campaign in "Risk Calculator". DGMS (Tech) Circular (MAMID)/01 of 2014, Dhanbad, India.
6. DGMS (2014b): Take 5 (Personal Risk Assessment). DGMS (Tech) Circular (MAMID)/02 of 2014, Dhanbad, India.
7. DGMS (2016a): Standard note 2016. Retrieved from http://dgms.gov.in/pdf/report/STDnote-1.1.2016.pdf.
8. DGMS (2016b): Integrated Approach for Development of SMP for Coal and Metalliferous Mines. DGMS (Tech) (S&T) Circular 5 of 2016, Dhanbad, India.
9. Iannacchione, A., Varley, F. and Brady, T. (2008): The application of major hazard risk assessment to eliminate multiple fatality occurrences in the US minerals industry. Information Circular 9508, National Institute for Occupational Safety and Health (NIOSH), USA.
10. ISO (2009): "Risk Management – Principles and Guidelines." *ISO standard 31000*: 2009.
11. Peter, B. H. (2010): "Risk management: Procedures, Methods and Experiences." Reliability: Theory & Applications 1:79.
12. Srinivas, J. V. (2012): Fundamentals of risk management. Science and Research Division, Coal India Limited, Kolkata, India.
13. Sutrisno, A. and Lee, T. R. (2011): "Service reliability assessment using failure mode and effect analysis (FMEA): survey and opportunity roadmap." *International Journal of Engineering, Science and Technology* 3: 25.
14. Thompson, S. .(1999): Risk assessment for mines. In: Proceedings of Queensland Mining Industry Health and Safety Conference, p 89.
15. Xue, S., Reece, D. and Yarlagadda, S. (2010): "Coal mine health and safety project for report hazard identification and risk management." Report no: EP106662. CSIRO Earth Science and Resource Engineering. Australia.