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An investigation of mine accident/incident data and implementation of safety management system to minimize the risk in a trackless underground hard rock mine

Investigations of accidents/incidents are very essential prerequisite to enhance the mine safety. In this paper, a comprehensive study of accident/injury data of a trackless underground hard rock mine was performed. The case study outcomes exhibited that the job occupation categories; the miners/helpers, timbermans, tradesmen involved in maintenance jobs and operators' (DSSLM) injuries are frequent and severe. The major causes of their injuries are fall of persons on same level. However, fall-of-loose-rock, caught-in-between, hitting-with-an-object etc. related accidents are also foremost safety problems in the mine studied. Therefore, a systematic approach is needed to evaluate the risk at different operation in case study mine using suitable multivariate statistical tools. In addition, proactive management efforts is also required to improve the characteristics of the hazardous work environment through suitable control measures to enhance the safety in underground hard rock mines.

1.1 Introduction

The mining industry has historically been viewed as a high-risk environment industry. While the industry has seen recent advances in safety, it still remains one of the most high-risk professions worldwide (Mitchell et al., 1998). Accidents in mines are still continuing at some disconcerting rate. The failure of people, equipment or surroundings to behave or react as expected, results in most of the accidents. Identification of different factors responsible for such failure may play an important role in accident mitigation (Paul and Maiti, 2001). Trackless underground hard rock mine is a bit tricky as per as the mine planning and designing are concerned. Necessitate of appropriate ventilation system, proper designing of support system, selective machinery and their safe operating procedures to extract the ore safely. Increased ground pressure and geothermal gradient with increased depth are the major concerns for underground mining industry. In addition to loss of human lives and sufferings, the costs of mine accidents are substantial (Ary, 1989). Further accidents and injuries lead to a downtime of equipment and loss of production, which in turn affects the production and productivity of miners other than the increase in cost of production. Therefore, a systematic approach is mandatory to see the effects of these accidents/incidents as well as the efforts of management to modify the characteristics of the hazardous work environment to enhance the safety in underground metal mines.

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1.2 Background

Hard rock mining refers to various underground and opencast mining techniques used to excavate hard minerals, mainly those containing metals such as ore containing gold, silver, iron, uranium, copper, zinc, nickel, tin and lead, but also involves using the same techniques for excavating ores of gems such as diamonds. For hard rock mines in India, the number of fatalities and serious bodily injuries in 2010 and 2011 were 87, 47 and 51, 76 respectively (DGMS Note, 2014). Mine operations are associated with a series of activities, or unit-operations such as drilling, blasting, mucking (loading and hauling) and ground control or supporting. Specified their prior importance to the mining process, most of the unit-operations are to be carried out in utmost safe environment to ensure the continuous and hassle free production. Further, there are continual changes in mining methods, geological disturbances, newly deployed heavy earth moving machines (HEMM) in confined spaces are causing problems in ensuring adequate ventilation, proper illumination, administering quality supervision and maintaining healthy participation of workers in safety management. Therefore, mine management has to dedicate their concentration primarily on the safety of employees participating in materials loading, hauling, drilling and blasting and update the technologies available to enhance the safety performances. The traditional methods of job specific training, multistage supervision, safety propaganda, accident analysis etc. are found insufficient to meet the goal of zero accident potential (ZAP). Formation of reactive safety management programmes, compliance of statutory requirements and analysing only accidents or injury experience data are also not providing satisfactory level of safety awareness. Development of proactive safety management and recently designed safety analysis systems are prerequisite to identify the occupational health and safety related hazards in respective unit operations. In this paper, such an approach is presented to activate the safety management in the mining system through risk assessment of respective unit operation.

2.1 Description of mine

The accident/injury experience data have been collected from a case study mine of Singhbhum thrust belt. The mine operates six days a week, three shifts per day for the production of ore. The mine has multi-level workings, thickness and depth of the ore body varies from 1.50-16.35 meters and 100-500 meters respectively. The strike direction of the deposit is NW-SE dipping towards NE, general inclination of the formation/mineralized bands is observed to be 29 to 35 degrees from horizontal. The hangwall, footwall and back supports at the mine mainly consist of rock bolts, and occasionally chock mats. The mining method practiced is horizontal cut and fill with post pillar. The mine has both development and stoping sections. Latest technology of trackless mining system have been adopted in this mine with decline as mine entry and ramps for access to stopes. ROM and waste are hauled up to the surface by trackless method using LHD/LPDT combination and subsequently by skip hoisting system through shaft. Transportation of ore and waste rocks are conducted mainly through drift. The various underground equipment used in the mine are drill jumbos, LPDTs, LHDs, service transport vehicles like supply truck, service truck, passenger carrier etc. Inspite of an effective safety management programme in the mine, the case study mine has undergone 131 accidents causing a loss of almost 3340 number of man days from January, 2005 to December, 2015. So, there was serious requirement of proactive safety management to enhance the safety performance.

2.2 Accident analysis

The accident/injury experience data for the mine during 2005-2015 had been collected and trend analysis w.r.t to the number of accident, man-days loss, unit operations, work place and work categories had been conducted (as is shown in Figs.1, 2, 3, 4, 5). A total number of 131 injuries were reported during the 11-year period. Most of the injuries are in the category of reportable injury where reportable injury is defined as the absence from work for at least 3 days. During the 11year period, the year 2005 witnessed more injuries compared to the other years. 22 injuries had been occurred in the year 2005, followed by 19 numbers of injuries in 2006 and 18 each in 2007 and 2008 respectively (Fig.1).

Fig.2 shows the frequency of man-days loss per year. During the last 11 years period, the year 2008 witnessed highest man-days loss counted 1057 with 18 number of accidents. However trend of man-days loss decreased in next two years and touched its low of 99 days in 2010 with 7 number of injuries. It is evident from the trend injuries that, the number of the accidents and associated man-days loss had been increased from 2011 to 2013 and depicted an alarming situation as per the safety management was concerned.

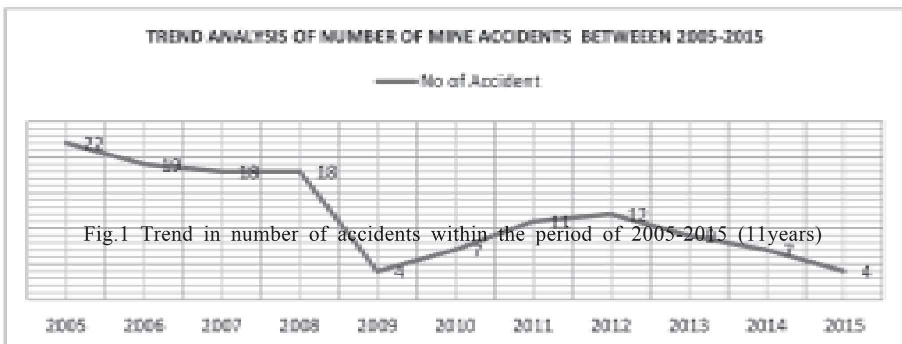

Fig.1 Trend in number of accidents within the period of 2005-2015 (11years)

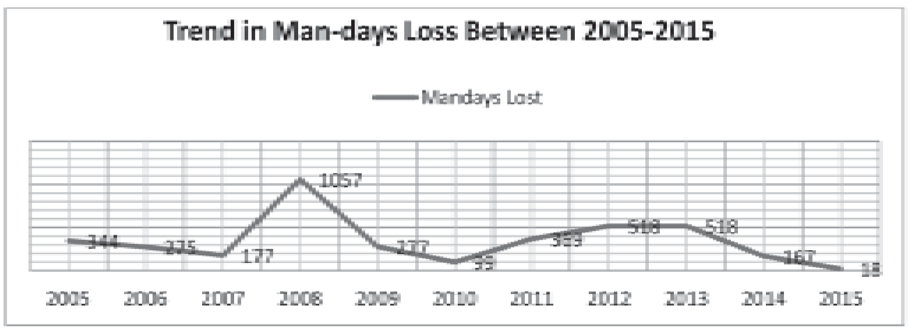

Fig.2 Trend analysis in man-days loss within the period 2005-2015

The distribution of injuries based on occupation/job-title is shown in Fig.3. 45 per cent of the total man-days losses were accounted for mechanical maintenance groups followed by electrical maintenance group (16%). Remaining 39 per cent of the total man-days losses were accounted for the other underground workers like drillers, blasters, support gangs etc. The job of the miner helpers were found more hazardous accounting for 52 per cent of the total man-days loss followed by the tradespersons, drillers and the operators, accounting for 18% and 11% per cent of the total injuries respectively (Fig.4). Fig.5 also shows that during the 11-year period, the

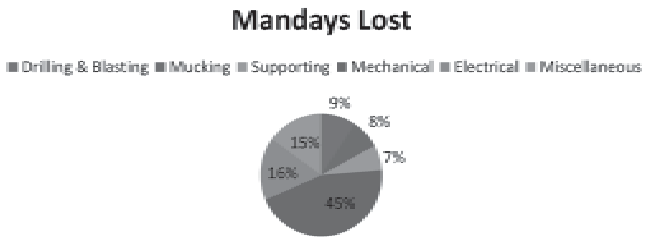

Fig.3 Trend analysis in man-days loss w.r.t mine unit operations for the period 2005-15

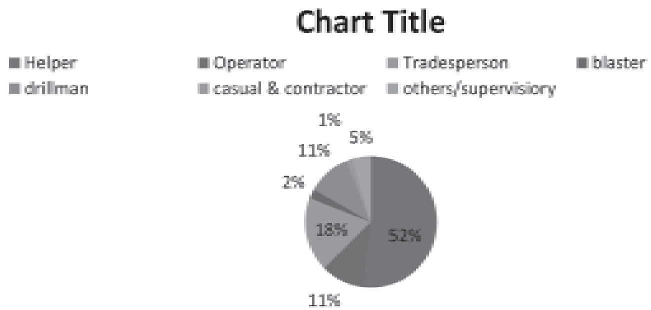

Fig.4 Trend analysis in man-days loss w.r.t workmen categories for the period 2005-2015

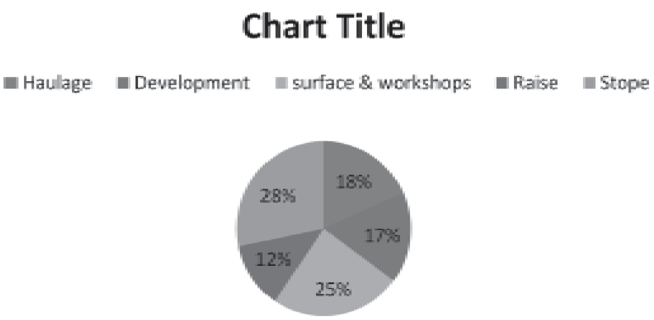

Fig.5 Trend analysis in man-days loss w.r.t work place for the period 2005-2015

28% accidents occurred in underground stopes and 25% of total accidents occurred in surface work shop. Numerous factors such as mining methods, mining height, condition of hangwall and footwall, excessive horizontal stress, size of mine, undulating floor and movement of HEMM contribute to such high rate of injuries to miner's helpers. Care must be taken to improve the working conditions for the surface workshops also. These trend analysis shows that the mine management should take focused safety measures to carry out the mine operation with a down trend accident statistics.

The exhaustive trend analysis of the accident/injury experience data from case study underground mine from year 2005 to 2015 greatly enhances the understanding of accident/ injury occurrences in the mine which is revealed from the study. Of the job occupation categories, the miner helpers' injuries were the most frequent and severe. It is also observed from the study that the man-days loss remain unaltered in 2012 and 2013 irrespective of all control procedures introduced, implemented and practiced by the management. The conventional way of work, experienced based reactive safety management system is found inadequate due to absence of proper hazard identification and risk control technique required for the basic unit operations. Mine management then attempted to devise a proactive risk management system by applying risk assessment as a primary tool and implemented a new safety management system which includes Identification of the hazards allied with activities and sub activities of mine unit operations, formulation of a risk assessment procedure, activation of essential risk control system (in form of OCP) to minimize the number of the accidents and increase the alertness of the mine workers by enhancing the workers participation in safety related work.

3.1 Hazard identification and risk assessment methodology (HIRAM)

The following methodology based on Apex OH&S Manual, 2015 and Procedure (level– II document), 2015 is being used to identify the significant hazards/risks from the identified list of activities/sub-activities in this case-study.

ESTABLISHMENT OF THE SAFETY MANAGEMENT

1. Risk assessment of hazards of different activities/sub-activities have been worked out by differentiating activities in routine and non-routine activities.
2. To calculate the risk assessment of hazards of any activity, the probability will be worked out based on hazard exposure and frequency. During the risk assessment, severity of hazard must also be taken into consideration. The activities/sub-activities whose associated hazards are having the risk level of 12 and above points would be considered as significant one and the risk would be known as substantial and intolerable.
3. To control the risk level of all these hazards, operational control procedures should be designed and made effective. Hazards associated with the activities bearing the legal requirement would be considered as significant one irrespective of risk score.
4. The risk assessment of hazards pertaining to the working area had been worked out considering the duration of exposure of the employees from 2-6 hrs in a shift in normal condition. The duration of exposure and the frequency of work rated on the basis of time spent in work front and the number of the times of job done in a week.

Based on these guidelines, risk assessment of different hazard would be worked out by rating method as mentioned in the Table 1. Severity of the accident would be classified into three main categories i.e. low, medium and high accordingly it has been rated depending on the risk involve in the accident.

Table 2 reveals the severity of the accident rated on the basis of impact of associated hazards for occupational health and safety of the employees.

TABLE 1 PRIORITIZATION OF SEVERITY

A.	Low (L):	1
B.	Medium (M):	2
C.	High (H):	3

TABLE 2 IMPACT OF ASSOCIATED HAZARDS

Rating	Impact
High (H)	Loss of life or permanent damage to any body organ, disabling injury, Loss of body part or fatality.
Medium (M)	Medical treatment case (MTC) or hospitalization.
Low (L)	First-aid case (FAC)

TABLE 3 PROBABILITY/LIKELIHOOD OF THE ACCIDENT

Probability/Likelihood		Frequency of exposure(Y)		
Duration of Exposure(X)	L	1	2	3
	M	2	4	6
	H	3	6	9

TABLE 4 ESTIMATION OF RISK

Severity (Z)	Risk Level (X*Y*Z)		
Low	1	2	3
	2	4	6
	3	6	9
Medium	2	4	6
	4	8	12
	6	12	18
High	3	6	9
	6	12	18
	9	18	27

Note: However, risk would be divided in five (05) categories i.e. trivial, tolerable, moderate, substantial and in-tolerable based on the risk assessment score.

- If risk score is in between 1 to 3, than risk will be called as trivial.
- If risk score is in between 4 to 7, than risk will be called as tolerable.
- If risk score is in between 8 to 11, than risk will be called as moderate.
- If risk score is in between 12 to 18, than risk will be called as substantial.
- If risk score is more than 19 than risk will be called as intolerable.

The probability/likelihood of the accident rated on the basis of duration of exposure to the hazards and frequency of occurrences for occupational health and safety of the employees as depicted in the Table 3.

Probability/likelihood: (duration of exposure X frequency of exposure)

The final score of risk level associated with any activity would be calculated by multiplying probability score to severity as mentioned in the Table 4.

3.2 ASSESSMENT OF RISK AND CONTROL PROCEDURE FOR LOOSE DRESSING OPERATION

3.2.1 Assessment of risk

Following the above mentioned HIRAM, risk associated with the unit operations of mines (drilling, blasting, loose dressing, mucking, supporting), operation of ventilation fans, dewatering operation, mechanical and electrical maintenance activities etc. were estimated. In this paper, assessment of the risk level for the loose dressing operation immediately after blasting in a mine face is shown in Table 5.

3.2 RISK CONTROL

3.2.1 Operational control procedure

After formulation of risk assessment procedure, management framed and implemented essential risk control system (in form of OCP) to minimize the number of the accidents and associated man-days loss. Operational control procedure (OCP) had been formulated for every task including machine maintenance in surface workshops. Supervisors were provided special training to monitor the OCP related issues. OCP adopted for loose dressing operation in underground mine is stated below as an example.

OCP adopted for “Fall of loose rock”

- The workplace is to be inspected by mining mate before deputing any persons
- Timberman should start the work, standing from a safe site.
- Timberman should advance only after ensuring that the area behind him is safe.
- Persons other than timberman will be allowed only after the timberman declare the place to be safe and the mining mate inspects the workplace.
- Loose dressing by timberman will be done at the freshly exposed area after each round of blasting.
- No person is allowed to go inside the mine without wearing DGMS approved type of helmet.
- Roof and sides of every working area are dressed for loose rock with the help of crow bars or pipe bar.
- The timberman allocated for the loose dressing job are authorized by mine manager and are competent persons.
- The side and back are supported by leaving rock pillars, installing rock bolts and erecting chock mates and wire mesh wherever required.
- Initial and periodical vocational training is imparted to all as per VT Rules 1985.
- Crow bars and pipe bars are made of steel at our workshop as required.
- Rock bolts are installed as per systematic support rule approved by DGMS .
- Rock pillars are left in-situ as per systematic support rule approved by DGMS.

TABLE 5 ASSESSMENT OF RISK FOR LOOSE DRESSING OPERATION

Sl. No.	ACTIVITY	SUB ACTIVITY	Kind of Activity: Routine (R)	Kind of Activity: Non-Routine (NR	Hazard	Hazard	RISK ASSESSMENT: Severity	RISK ASSESSMENT: Probability: Exposure Duration 'E'	RISK ASSESSMENT: Probability: Frequency of Exposure 'F'	RISK ASSESSMENT: Risk Level	RISK ASSESSMENT: Type of Risk	Legal requirement: Y	Legal requirement: N	Risk Associated	Present Control Measures	Frequency of monitoring	Whether control is adequate	Whether risk is significant
1	2	3	4	5	6		7	8	9	10	11	12		13	14	15	16	17
1	Loose dressing	Water spraying	R		a	-Fall of loose rock	3	L	H	9	Mo		N	Minor cuts to fatal injuries	Experienced and competent personnel are deployed to avert such situation.	After every blast	Y	N
					b	-Fall of person on same level	2	L	H	6	To		N	Minor injuries	Job specific training is imparted to avert such cases.	Daily	Y	N
					c	-Dust	2	L	H	6	To	Y		Excessive exposure for long durations may lead to Silicosis	Respirator is used.	Monthly	Y	N
					d	-Blasting fumes	1	L	H	3	Tr	Y			Adequate ventilation is provided.	Monthly	Y	N
		Dressing down loose	R		e	-Fall of loose rock	3	M	H	18	Su		N	Minor cuts to fatal injuries	Experienced and competent personnel are deployed to avert such situation.	After every blast	Y	Y
					f	-Fall of person on same level	1	M	H	6	To		N	Minor injuries	Job specific training is imparted to avert such cases.	Daily	Y	Y
					g	-Dust	1	M	H	6	To	Y		Excessive exposure for long durations may lead to Silicosis	Respirator is used.	Monthly	Y	N
					h	-Fumes	1	M	H	6	To	Y			Adequate ventilation is provided.	Monthly	Y	N

- Chock mates and wire mesh of standard design are erected wherever necessary as per standard procedure.
- The roof and sides of all the working area are checked by crowbar.

3.1.2 Workers participation

Management was very thoughtful regarding the participation of workmen in safety management issues to increase the attentiveness of the mine workers concerning the work related hazard. Special committees with experienced workmen were formed to inspect winding system, haulage, stopes, vehicle safety etc. Reports of those committees were decided to discuss in pit safety committee meeting. More over reporting of near-miss accidents were encouraged and reward for such reports had been announced.

4.0 Conclusions

Comprehensive investigations of the identified hazards allied with the mine unit operations have been conducted. An appropriate risk assessment significantly enhances the perceptive of hazards/risk associated with the mine unit operations, which is revealed from the study. Mine management implemented the proactive safety management system and monitored its every action to reduce the unsafe conditions and unsafe acts. As a consequence, the mine perceived a significant decrease in number of accidents as well as in man-days loss in year 2014 and 2015. Table 1 shows the decrease trend of accident numbers from 9 in 2013 to 7 in 2014 and 4 in 2015. According to table 2 mandays loss decreased from 518 days in 2013 to 167 days in 2014 and 18 days only in 2015 which was the lowest ever in case study mine history. Mine management developed and implemented some distinctive safety related programme with particular objectives and targets to ensure safety in mines and accomplish ZAP. Precaution must be taken through providing adequate safety awareness training, judicial task allocation and appropriate propaganda amongst the mineworkers to minimize accidents.

This study reveals that thorough risk assessment of different operation in the case study mine using suitable multivariate statistical tools is required to be done to evaluate the root causes of accident/injury occurrences. In addition, further proactive management efforts is also required to improve the characteristics of the hazardous work environment through suitable control measures to enhance the safety in underground hard rock mines.

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