MINE SAFETY ANALYSIS WITH A SPECIAL FOCUS ON ACCIDENTS DUE TO EXPLOSIVES

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***Abstract:** The analysis of the standard of safety in mines and the rates of accidents in recent times is a factor to highlight. With the increased need of economic development of the mining industry, the safety of the employed population cannot be at stake and thus needs to be thrown light on. This paper mainly will give the comparison of Indian Mining industry with that of the International Scenario. Furthermore, Mine Safety and the Accidents related to it has also been discussed with a special focus on the accidents due to explosives and blasting system.*

***Keywords:** Accidents, Blasting System, Explosives, Mine Safety.*

I. INTRODUCTION TO INTERNATIONAL SCENARIO

In Figure 1, a summary is given of the ten biggest mining companies in terms of number of employees. Most of them are multinationals, and some of them are global. These mining giants all have well-developed websites, so information about their size, ambitions and activities is easily accessible. They are committed to environmental sustainability, social responsibility, and the protection of the health and wellbeing of their employees. Most of them adhere to “safety first”, and some of them mention ‘zero accidents’ as an objective. However, there are also reports from other sources, like Wikipedia and Human Rights Watch, about controversies due to removal of local populations from their land, or toxic waste from mining processes that causes contamination of soil, groundwater and surface water. Every now and then the international media report about spectacular accidents or other events in mining.

Name, ownership & headquarter	Production	Operations in	Number of employees
Vale; public, Brazilian multinational; HQ: Rio de Janeiro	Nickel, iron ore, iron ore pellets, manganese ore, ferroalloys, aluminium, fertilisers, copper, coal & others	South America, Africa, Asia, Australia	200,000
Shenhuan Group; Chinese, state-owned company; HQ: Beijing	Coal	China + investments in Asia & Australia	172,000 (2011)
Aluminium Corporation of China; public, state-backed holding company; HQ: Beijing	Alumina, primary aluminium	China + 9% stake in Rio Tinto (iron, Australia) + investments in Peru	108,000 (2008)
Anglo American; public, British multinational; HQ: London	Copper, diamonds, iron ore, coal, platinum	Africa, Asia, Australia, Europe, North & South America	100,000 (2011)
BHP Billiton; public, Anglo-Australian multinational HQ: Melbourne & London	Iron ore, diamonds, coal, manganese, gold, aluminium& other	Africa, Asia, Australia, South & North America, Europe	41,000 + 65,000 contractors (2011)
Glencore; Public Swiss multinational; merger with Xstrata announced (2012); HQ: Baar	Metals & minerals, energy products, agricultural products	Europe, North, Central & South America, Asia, Australia, Africa & the Middle East	61,000 + Xstrata 39,000 (2011-12)
Norilsk Nickel; public Russian mining & smelting company; HQ: Moscow	Nickel, palladium, copper, platinum, gold, cobalt, selenium & others	Russia, Europe, Africa, Australia	79,000 (2011)

Fig 1: Biggest Mining Companies and the number of employees

Safety and health

Working conditions: The traditional picture of the working conditions in mining and quarrying is that the work is physically demanding and dangerous due to heavy and awkward loads, unstable underground structures, heavy tools and equipment, great accident risks, exposure to toxic dusts and chemicals, heat and cold. The mining work often takes place underground with bad lightening, high up in the mountains or in remote areas where schools, health care and other social services are scarce or non-existent as well as family- and community support. This may be the situation in artisanal and small-scale mining in China, India, Indonesia, Brazil, Ecuador, Congo (DRC), for example, but does not reflect the working conditions in most big mining companies today.

Statistics: Our knowledge about the working conditions and safety and health in mining is dependent on available data. Reference is often given to national registers of accidents and disease. In India, the national accident records have been meticulously maintained since 1901, and therefore allow for long-term evaluation of the safety work in formal mining. Comparisons between countries are often made in relation to fatal occupational accidents, as the statistics in these cases are supposed to be more reliable than other kinds of occupational safety statistics. Such data is presented in all the articles. Injuries are underreported in many countries and injury rates cannot be calculated due to lack of information concerning working hours. Occupational diseases are generally underrepresented in statistics because of deficient diagnosis and lack of acknowledgement of their relation to working conditions. In Ecuador, only one case of silicosis has been recognized during 50 years. Where reliable national statistics exist, mining is generally the sector having the highest, or among the 2-3 highest, rates of occupational fatal accidents and notified occupational diseases.

Accidents: Every year, thousands of miners die in accidents and many more get injured, especially in the processes of coal mining and hard rock mining. The accidents may be caused by gas or dust explosions, gas intoxications, improper use of explosives, electrical burn, fires, collapsing of mine structures, rock falls from roofs and side walls, flooding, workers stumbling/slipping/falling, or errors from malfunctioning or improperly used mining equipment.

Coal mining in China is of special interest, as it employs 5 million miners. Since the establishment of the People´s Republic of China in 1949, more than 250,000 Chinese coal miners have died in mining accidents. This compares with figures for the UK where over 100,000 miners were killed since records were first kept in 1850. The UK industry never reached even 10% of the size of the present Chinese coal industry. In terms of fatal accident rates, up until the 1940s the UK had a higher rate than China has today.

Many miners are also employed in coal mining in India – 370,000. From the national records it can be seen that coal mining for many years, up to the 1980s, has had a higher rate of fatal accidents than non-coal mining. In later years, the fatal accident rate has been about the same for coal mining and non-coal mining. In general, there has been a constant decline in fatal accident rates in all mining from 1901 to 2010 due to changing technology, mechanization and growth of a safety culture. However, during the last decades there has been an increasing trend in the rates of fatalities in non-coal mines. Deeper mines and mining under more difficult geotechnical conditions may have been important factors for this increase. Furthermore, the increasing number of small mines, which do not take adequate safety measures, may also be an important contributor.

While in many countries the fatal accident rate in mining has been reduced during the last decades, mining is still ranked high amongst the formal economy sectors for leading fatality rates. The informal mining (artisanal, illegal and/or small-scale mining) is not represented in the national records. Generally, it is estimated that the working conditions in informal mining are worse than in the formal mining sector: heavy manual work, no facilities for safety and health, etc.

II. DETAILED STUDY ABOUT INDIAN SCENARIO OF MINING INDUSTRY

The safety scenario

The right to safe working environment in mines has been recognized for more than 100 years in India. Over the years, the legislation has been updated and newer provisions have been incorporated to ensure safe and healthy working conditions in mines.

The incidence of accidents is an important indicator of the status of safety in mines. The accident records in mines have been meticulously maintained over the years since the enactment of Indian Mines Act, 1901. They are available in the library of DGMS.

In Figure 2, the ten-yearly average of fatal accidents, fatalities and fatality rates for both coal and non-coal mines are shown for the period from 1901 to 2010.

From the table it is observed that during this long period there has been a constant decline in fatal accident rates in both coal as well as non-coal mining. This has been due to changing technology, mechanization and growth of a safety culture. It is also likely that the fatal accident rates may have been substantially influenced due to acquisition by government of large mining companies in the non-coal sector as public sector undertakings and nationalization of coal mines in 1974. During the last decades, however, there is an increasing trend in the rates of fatal accidents and fatalities in non-coal mines. Deeper mines and mining under more difficult geotechnical conditions may have been important factors for this increase. Furthermore, increasing number of small mines which do not take adequate safety measures may also be an important contributor. A further reduction of the accident and fatality rates require improvements in technology and safety culture. The fatal accidents in the illegal mines are investigated by the police, and not by DGMS. It is very difficult to get reliable statistics, though it may be estimated that the number of fatal accidents and fatalities in such mines are small.

Year	Number of fatal accidents	Number of persons killed	Fatal acc rate/1,000 persons employed	Death rate per 1,000 persons employed
Coal mines				
1901-1910	74	92	0.77	0.94
1911-1920	138	176	0.94	1.29
1921-1930	174	219	0.99	1.24
1931-1940	172	228	0.98	1.33
1941-1950	236	273	0.87	1.01
1951-1960	222	295	0.61	0.82
1961-1970	202	260	0.48	0.62
1971-1980	187	264	0.46	0.55
1981-1990	162	185	0.30	0.34
1991-2000	140	170	0.27	0.33
2001-2010	186	107	0.21	0.27
Non-coal mines				
1901-1910	16	23	0.52	0.76
1911-1920	29	37	0.57	0.73
1921-1930	42	50	0.54	0.66
1931-1940	35	43	0.41	0.51
1941-1950	26	31	0.24	0.29
1951-1960	64	81	0.27	0.34
1961-1970	72	85	0.28	0.33
1971-1980	66	74	0.27	0.30
1981-1990	65	73	0.27	0.31
1991-2000	65	77	0.31	0.36
2001-1010	55	65	0.34	0.40

Fig 2: Number of fatal accidents and persons killed in mining in India; ten-yearly averages, 1901-2010.

III. ACCIDENT PREVENTION AND MINE SAFETY

From the observations, it has been established that the existing traditional system of administration of Mines Act and subordinate legislation framed there under through inspections, statutory and other investigations into fatal accidents and dangerous occurrences and follow up measures arising out of the traditional approaches to ensure that risk is kept within acceptable levels have reached its limit of effectiveness. Time is now ripe to introduce new initiatives and stress upon areas of high risk in order to bring them down to acceptable risk levels. This can be achieved by introducing the concept of "Risk Assessment" and "Safety Management Plans", the concepts widely accepted and practiced in many countries. An outline of the steps required to be taken to effect necessary changes are given below;

1. Evaluation of organizational structures for effectiveness to achieve set safety objectives.
2. Employee involvement with appropriate training and necessary resources.
3. Change of supervisory role from "doer" to "facilitator".
4. Search for cost-effective new technology.
5. Development of Safety programs based on "Risk Management" principles.

With respect to current needs in health and safety in mining sector, the resources provided by the mining companies and the government organizations in the form of manpower and equipments are inadequate. However, there is increasing awareness among workers, unions, mine managements and the government about level of occupational safety and health and prevention of accidents and occupational diseases in mines. The government has formulated a National Policy on Occupational Safety & Health and the Mines Act is also being amended to address the needs of changing mining scenario. However, more resources would be needed on part of the mining companies and the government to ensure that health and safety is given due priorities in mining sector. The 12th Five year Plan (2012-2017) of Government of India is laying special emphasis on health which will give boost to outlay for health and safety. The present legislation also needs to cover the mining activities in unorganized sector which employs a large number of persons and remains the major area of concern as health and safety provisions are inadequately implemented.

Mine Safety includes the conditions of being safe from the occupational hazards of mining which are listed as follows:

1) Those that cause bodily injury- Mine Accidents
2) Those that are injurious to health- Occupational Diseases

IV. MINE ACCIDENTS

Conventionally, it may be defined as an unexpected event causing loss of life or bodily injury. The Mines Act does not define an accident. Section 23 is titled as "Notice to be given of accidents". It says,

Whenever there occurs in or about a mine:

"An accident causing loss of life or serious bodily injury, or an explosion, spontaneous heating, outbreak fire, inrush of water or gas, premature collapse of any part of the workings, over winding of cages, etc."

A notice has to be given immediately in the prescribed form to the prescribed authorities.

Classification of Accidents

Based upon seriousness:

[1] Fatal: which result in death of one or more persons
[2] Serious: which result in serious bodily injury to one or more persons.
[3] Reportable: which result in reportable injury to one or more persons.
[4] Minor: which result in minor injury to one or more persons.

Mishaps which do not bring about any loss of life or bodily injury are called Dangerous Occurrences.

Based upon number of fatalities:

[1] Disasters: which result in 10 or more deaths
[2] Major Accidents: which result in 4 to 9 deaths

The yardsticks of accident frequency rates and severity rates are universally accepted for comparison of safety performance.

Evaluation of the standard of safety of mines or to compare the safety status of one group with another, or to make international comparisons, it has become a common practice to express accident rates in relation to the exposure to risk. This approach is common to occupational safety experts internationally and it provides a realistic tool for worldwide country comparisons. The usual way is to calculate the death rates and injury rates on the basis of the following:

[1] One million man-hours worked
[2] One lakh man-shifts worked
[3] One thousand persons employed

In India, the figures of man hours worked or man shifts worked are not easily available, and therefore, the frequency rates are calculated on the basis of 1000 persons employed.

V. SAFETY AND ACCIDENTS RELATED TO BLASTING SYSTEMS

The improvement of blasting designs can be a way of reducing accidents vis-à-vis controllable and uncontrollable factors influencing blasting should be given topmost priority.

The undesirable outputs are as follows:

[1] Ground vibrations
[2] Air blast
[3] Back and Side spills
[4] Misfires
[5] Fly rocks

[6] Blasting Fumes

The above causes should be brought down considerably since they singly or in combinations cause accidents from minor to fatal.

The DGMS (Tech.) Circular No. 8 of 1982 lists some of the common unsafe practices in the use of explosives.

[A] Accidents due to human failure
[B] Accidents due to failure of certain type of structures to provide adequate shelter within the danger zone
[C] Accidents occurring beyond the stipulated danger zone
[D] Accidents due to blown through shots, unwanted projections of fly rocks are other peculiar causes of accidents.
[E] Accidents due to projectiles through long boreholes
[F] Accidents due long hours of blasting (DGMS Circular No. 11 of 1961)

VI. ACCIDENTS DUE TO EXPLOSIVES

Storage, Transport, Handling and use of huge quantities of explosives in mines introduce a very serious hazard and carelessness at any stage could lead to a disaster. Below mentioned are some of the legislations which has played its part to guide and safe usage of explosives which has controlled the rate of accidents due to explosives.

[1] The Indian Explosives Act, 1884
[2] The Explosive Rules, 1983
[3] The Coal and Metalliferous Mines Regulations

The common causes of such accidents due to explosives have been discussed below.

VII. ACCIDENTS DUE TO EXPLOSIVES IN SURFACE AND OPENCAST MINES

[1] Projectiles thrown beyond the present danger zone of 300m radius
Remedial Measure: Blasting Pattern should be improved and well designed to reduce the throw. The existing danger zone of 300m should be increased to 500m.

[2] Not posting guards at all points of entry into the danger zone
Remedial Measure: Guards should be posted at every entry points so as to prevent unknowingly entry of persons in the danger zone.

[3] Not taking shelter in spite of being warned
Remedial Measure: Cautiousness of the Blasting In- charge should be there to ensure that all those within the zone of influence have taken proper shelter before initiation of the blasting process.

[4] Not muffling the shots where dwellings are located within the danger zone.
Remedial Measure: In an area where habitats are located within the danger zone, the blast should be muffled in such a manner that fly off fragments cannot project beyond 10m, which can be achieved by controlled blasting techniques.

[5] Structures fail to provide adequate shelter within the danger zone.
Remedial Measure: People within the danger zone should take shelter in substantially built shelters. Other building and shelters like asbestos or tiled roof or wooden structures may not provide adequate strength to withstand the projectile forces.

[6] Firing shot with insufficient length of fuse.
Remedial Measure: The length of fuse should be sufficient to allow the shot firer time to take shelter after lighting the fuse. Plastic Ignitor Cord should be used where large numbers of shots are fired.

[7] Force down explosive cartridges into shot holes.
Remedial Measure: The diameter of shot holes should be large enough to allow adequate clearance of cartridges. If a cartridge gets stuck up due to obstruction or diagonal fall, it should not be forced down the shot hole. The situation should be dealt with as the same manner of a misfired hole.

[8] Accidental blast while handling, transporting, preparing charges, or stemming
Remedial Measure: Precautions and safety measures should be taken down as laid in the Regulations. Blasters and helpers should be trained on a regular basis with courses to revise the procedures.

[9] Inadequate attention to misfired holes and sockets
Remedial Measure: Misfires do pose a high threat in mechanized mines where heavy blasting is done. Before commencing drilling in an area where shots have been fired, thorough survey should take place at all places including remaining butts of old deep holes for unexploded charges that the dill rod may strike.

[10] Blown through shots where pillars formed by underground mining are being extracted by opencast method
Remedial Measure: No shot hole should be drilled in the overburden above underground mines. Every personnel from underground should be withdrawn from all working phases. A parting of at least 3m between the bottom of a shot hole and the coal seam should be left intact.

VIII. ACCIDENTS DUE TO EXPLOSIVES IN UNDERGROUND COAL MINES

[1] Not taking proper shelter
Remedial Measure: After all persons have been withdrawn from the danger zone, an obstacle in the form of a portable horizontal bar should be put across all galleries to the blasting site with a danger notice and those should only be removed by the shot firer after blasting is complete.

a) failure to warn people
b) Persons entering the place of firing after the first round are completed presuming that blasting is over and thus getting killed or injured by the second and subsequent rounds.
c) Flying fragments hitting people after rebounding from the corner or side of a pillar or a tub standing on the truck.
d) Inadequate length of shot firing cable.
e) Not using protective devices where the workings do not offer sufficient protection.

[2] Firing shots at a face without removing persons from other workings within 4.5m; Accidents due to blown- through shots or due to flying fragments released from the other side of the parting or due t roof or side falls caused by vibrations initiated by blasting.
Remedial Measure: Persons should be withdrawn from all workings within 4.5m of the place of firing. The Overman having the hand plan of the districts should caution the Mining Sirdar and Shotfirer in writing when two workings are within 10m of each other. One of the faces should be temporarily discontinued and connection made by advancing along one direction only.

[3] Inspection after shot firing allowing loaders to enter the face area before the place has been inspected and made safe.
Remedial Measure: After the area is free from dust, inspection should be made for misfires or sockets or remnants of explosives. Dressing of the roof and sides should be done where necessary. The entire zone of influence should be inspected and made safe, before the entrance of loaders in the face area.

[4] Blown-out shot igniting gas.
Remedial Measure: Proper stemming should be adhered to in the blasting process. A mixture of 70% fine sand, 30% clay and a small amount of $CaCl_2$ is recommended. Use of water or gel ampoules reduces risk of methane ignition and dust and fumes.

[5] Crack in shot holes connecting to a pocket of gas which may ignite or explode.
Remedial Measure: Before charging, every shot hole must be checked for cracks. In case of crack detection, a plug of stemming should be placed at the back of every shot hole before charging.

[6] Blasting off-the-solid (BOS) without observing all precautions
Remedial Measure: BOS should not be done without proper explosives and delay detonators. Negligence may result in accidents due to ignitions of gas or due to roof and side falls induced by high levels of ground vibrations.

[7] Accidents in handling, and transport of explosives or due to pilferage of explosives.
Remedial Measure: Regulations regarding the same must be followed. Additionally, shot firers and their helpers must not wear synthetic clothes and non-conducting shoes whilst on duty. These generate static charges with very high voltages which can lead to firing of detonators with dangerous results.

The following figure 3, shows the DGMS classification of accidents caused by explosives:

0500	Explosive
0551	Solid blasting - projectiles
0552	Deep hole blasting - projectiles
0553	Secondary blasting projectiles
0554	Other projectiles
0555	Misfires/sockets - while drilling into
0556	Misfires/sockets- other than drilling into
0557	Delayed ignition
0558	Blow through shots
0559	Other

Fig 3: Codes by DGMS classifying Accidents Due to Explosives

According to CMR 170/ MMR 164,
The major causes of the accidents in underground mines related to explosives and their blasting may be broadly presented as below:

- **[1]** Blown through shots and hit by projectiles from the opposite faces
- **[2]** Direct hit by projectiles on the front side of the face
- **[3]** Drilling into misfired shots
- **[4]** Miscellaneous causes other than above

IX. SHORT CASE STUDIES

1) Premature detonation of explosives due to high temperature in the shot hole
Saunda 'D' West Colliery (OPENCAST)
Owner: Central Coalfields Limited
Hazaribagh District, Bihar
Date: 18th September, 1984
Fatalities: 6 killed.
Conclusions were made that the overburden in which the shot hole was being charged had been heated up to a high temperature due to the fire in the seam being worked as well as the goaved out seam about 6m below and due to the high temperature, the nitroglycerine-based explosive in the hole along with the detonating fuse exploded prematurely causing detonation of 3 lots of explosives stacked near the blast holes.

2) Deaths caused by blasting fumes
Surda Copper Mines
Owner: Hindustan Copper Limited
Singhbhum Copper Belt, Bihar
Date: 4th April, 1984
Fatalities: 5 killed.

This accident occurred in No. 10 level slope which was worked by the "post-pillar" method. Investigations under simulated conditions concluded that immediately after blasting, the concentration of nitrous oxides in the atmosphere near the offending door exceeded 100 ppm. It was the exposure to such high concentration of oxides of nitrogen which led to the death of five persons.

X. CONCLUSIONS

[1] India has a unique blend of big and small, manual and mechanized, opencast and underground mines with average employment of about one million persons per day and an annual turnover of over 40 Billion US dollars and contributing to about 2.5% of GDP. The rapidly changing scenario of mining industry in India has introduced newer hazards and safety concerns at workplace posing new challenges.

[2] The accident scenario and safety experience in Indian mines for more than 100 years show that both fatal accidents and fatalities have come down over the years. However, the death rate per 1000 persons employed in mines has been hovering around 0.30 in coal mines and in non-coal sector after steady decline for some period, the trends of fatal accidents have been again on the rise during 80s and 90s.

[3] Regarding accidents due to explosives the following precautions should be always be followed:

- **[A]** Blasting shall be done with detonating fuse down the hole.
- **[B]** Temperatures down the blast holes should be measured and if it exceeds 80^0C in any hole, such hole should not be charged.
- **[C]** All blast holes shall be kept filled with water.
- **[D]** Detonating Fuse shall not be laid on hot ground without taking suitable precautions which will prevent it from coming in contact with hot strata.
- **[E]** The charging and firing the holes in any one round shall be completed expeditiously and in any case within two hours.
- **[F]** Blasting operations shall be carried out under the direct supervision of an Assistant Manager.

The observations indicate that the existing traditional system of administration of occupational safety in mines through inspections, statutory and other investigations have reached its limit of effectiveness. An approach based on a combination of "strategic" and "systems" thinking needs to be devised to prepare the mining industry to achieve better safety and health standards for persons employed in mines. The new thinking must embrace organizational, behavioral and cultural systems in addition to hazard control, analysis to anticipate hazards and engineering solutions to prevent accidents and occupational diseases.

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