Development and implementation of network based underground mines safety, rescue and aided rescue system

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Abstract. In this article, we describe safety issues connected with mining industry which continues its rapid development and is regarded as one of the major source of energy in many countries. A series of fatal emergencies primarily due to gaseous hazards has made it vital to develop a robust General Emergency Management System which is technically advance and maintainable. It should contain the following units bound by a network: voice communication, tracking of the personnel, mine atmosphere monitoring, underground equipment control and monitoring, monitoring of escape, rescue apparatus, aided rescue equipment and navigation support during escape. Further, we discuss maintenance, care and application of Self-Contained Self-Rescuer systems on the example of the model SHS-30 developed by the Corporation Roshimazschita (Tambov, Russia).

1. Introduction
Mining Industry has been growing at a tremendous speed in the recent years. For such countries as India, where thermal power is the main source of electricity generation, coal mining is a vital industry. As mining industry is growing, mining technologies are progressing at the same speed, but still life safety of miners is one of the biggest concerns. When we compare mining industry with other industries, mining industry with other industries, mining industry with related energy resources industries are associated with higher rates of occupational injuries and fatalities. The workplace in the mine is not fixed as like in other industries, rather it moves and changes with time, so mining is a hazardous profession and considered as a war against unpredictable forces of the nature. As a result, mining industry continues to be associated with high level of accidents, injuries, and illnesses. Major accidents and disasters in Indian mining industry are continuing at some disturbing rate. Therefore, it is the essence of time that the industry should be equipped to identify hazards, assess associated risks and bring those risks to tolerable levels on a continuous basis. Few examples of severe mine accidents across the globe are listed below:

a) Benxihu Colliery Disaster (1942) – China
   \textbf{Fatalities}- 1,549 lives
   \textbf{Reason}- Fatal explosion of the underground coal mine was caused by a mixture of gas and coal dust. The underground fire exploded out of the mine shaft entrance.
Cause of fatalities - Carbon monoxide poisoning due to the closure of the ventilation system was reported to have caused most of the deaths.

b) Laobaidong Colliery Disaster (1960) – China
   Fatalities - 684 people.
   Reason - Methane Explosion

c) Mitsui Miike Coal Mine Disaster (1963) – Japan
   Fatalities - 458 miners died in the accident and 833 were injured.
   Reason - Coal dust explosion about 500 m below the mine’s ground level entrance. The explosion led to a massive blast which collapsed the tunnel roof at multiple locations.
   Cause of fatalities - Most of the deaths were due to carbon monoxide poisoning. Most of the poisoned survivors suffered severe brain damage.

d) Coalbrook Mine Disaster (1960) – South Africa
   Fatalities - 435 people
   Reason – The collapse of about 3 km² of underground mine area caused the disaster. The underground collapse was caused by the disintegration of about 900 underground pillars supporting the tunnel roofs.
   Cause of fatalities – About 1,000 miners were working underground at the time of the collapse. Half of them could survive by escaping via an inclined shaft. Several rescue workers also died getting trapped under the collapsed ground and methane gas.

e) Wankie Colliery Disaster (1972) – Rhodesia (Zimbabwe)
   Fatalities - 426 people.
   Reason- The disaster was caused by multiple explosions in the underground coal mine.
   Cause of fatalities - The explosion turned into a blast which devastated the main shaft. Four men were killed instantly near the surface. More than 400 mine workers were trapped amid the rocks and were poisoned by deadly methane and carbon monoxide fumes. There were also two new explosions on the next day that filled the underground tunnels with clouds of poisonous gas making the rescue attempts impossible.

f) Dhanbad Coal Mine Disasters (1965 and 1975) – India
   a. Dhori Colliery, Dhanbad, Jharkhand
      Fatalities - 375 miners were killed in the disaster.
      Reason- Firedamp and coal dust explosion.
   b. Chasnalla Colliery, Dhanbad, Jharkhand
      Fatalities - 372 people.
      Reason- Coal dust explosion
      Cause of fatalities - The blast that damaged the roof barrier with a huge water body located above it. Most of the deaths occurred because of flooding of the mine.

In view of the above, a better safety and rescue system with all required apparatus and equipment should be in place in order to bring these incidents to the tolerable level and mitigate risks. Another fact, which can also be depicted from above, is that gaseous hazards are the primary ones. Therefore, we need to have a robust subset of the General Emergency Management System for all mines based on new and advance technologies. All mineworkers must be provided with the capability and resources to facilitate escape from their place of work to a place of safety. Figure 1 represents the elements of an emergency escape from an underground mine [1 - 4].
Emergency Escape System Elements and Considerations
An Emergency Escape System, which can detect or analyse the state of the mining system in advance or in time, should alarm the person as well as the management about the hazard. One of the
major hazards in the coal mine is the gaseous hazard which can create methane explosion, CO toxicity, a fire inside a mine and is the most vulnerable to people and property. Design and technology involved in such system of emergency escape should be effective, capable of detecting hazards in time and should be able to warn the people working underground, managers on the surface and other responsible personnel in time to be able to navigate, escape and be rescued. Several types of technologies and systems are available across the globe but a full-proof complete system is the essence of time and should provide conditions for mine workers to escape or be rescued without any injury or fatality. Such system would be a combination of various systems [5 – 7].

The flow chart at figure1 presents the whole emergency escape system but there are gaps in the system and current research paper is aimed at filling those gaps.

2. Mine Network, Early Warning, Personnel and Rescue, Aided Rescue Tracking and Wireless Communication and Navigation System:

Identification of the Gaps:

a. Still more than 60-65% of underground mines are using primitive technologies of communication i.e. wired mine phones for communication; however, such phones are not available everywhere inside the mine.

b. Early warning devices like Spot Gas Detectors, Fixed Gas Detectors, Tele-Monitoring System, Gas Chromatographs, Tube Bundle System etc. which are currently being used independently are not in the same network.

c. Personnel Tracking Devices are not under use in every mine.

d. One of the biggest challenges is tracking whether Rescue Apparatus or Devices like Self Contained Self Rescuer are in proper condition and worn on the miner’s belts or kept at a safe distance within the reach of miners, can be monitored from the surface of the mine and connected to the network. Further, when under the use, there should be information about the usage period left, which should be shared with the user who can be guided accordingly from the surface.

e. Aided Rescue Apparatus like Refuge Chambers and Changeover Station should be in working condition and personnel should be informed about its state and feasibility of reaching from the surface.

f. Mines should also be equipped with the Manual Navigation System as well as Electronic Wireless Communication Navigation System.

g. The whole system should be in the same network.

Design of the System:

a. Creation of Mine Network and Existing System

There is a need for a robust system which is technically advance and maintainable. This system should be capable of putting everything in one network. A system can be created based on a Wi-Fi network (IEEE 802.11 b/g/n standards) which can transmit Voice Commands, Capable of Two-way Voice Communication, Mine Cad Designs, Mine GIS, People, Equipment and Apparatus Tracking, Mine Environment Monitoring, Relevant Data Storage and Analysis. When all the aforementioned aspects are located in one network, risks can be mitigated and calculated in advance, thus, decision making will be faster.

The system should comprise virtual management of underground equipment in real time, track the location of any person in the mine. There should be a single information management infrastructure designed to monitor and control any technological equipment in the mine to provide communication, signalling, monitoring, warning, search and rescue of personnel. It should be used to determine the location of personnel, transport and goods, speed and direction of personnel and transport movement, to alert (with confirmation of delivery to the addressee) and to search for people caught by the accident. It should also provide personnel with mobile communication, transmission of video, audio and telemetry data from technical devices; dynamic control of hazardous and harmful gases and
oxygen in the working area's air and signalling when their values exceed the specified limits. In addition, it should use navigation elements in evacuation and rescue of people from emergency zones according to the emergency plan; operational control of conformity of technological processes to specified parameters. It should also automatically measure the parameters of the mine’s atmosphere; control air dust content; control the settled dust mass; mining equipment management and control the parameters for ensuring work safety; provide automatic gas and fire protection; provide explosion protection in mining areas through proper ventilation and filtration, degassing and installations for monitoring and forecasting these conditions; transfer, processing, analysis, storage and display of information; exchange of information with other systems, guiding people through the navigation system of the mine in order to escape from the mine at the time of emergency [8 - 10]. As discussed, the system should be working at Wi-Fi 802.11 b/g/n/i standards and the network with the help of an optical fibre and Wi-Fi should be created. Data transfer rate in such system would be minimum 1GB/s. It should comprise the following elements:

1) Voice Communication/Messaging/Data:
   a. Android Based Explosion proof phones are available in the market and they can be register in the network like any other smart phone. Video calling, video recording and transferring data are also possible.
   b. Push To Talk Phones: Economical models of phones with the push to talk function are also available. With this phone group calling, texting and one to one calls are possible.

2) Tracking of the Personnel:
   With the help of an active Wi-Fi tag any person can be located. It can be worn upon the helmet, waist, wrist or it can also be incorporated into a cap lamp or a self-contained self-rescuer.

3) Mine Atmosphere Monitoring:
   Mine atmosphere monitoring can be done in various ways and all the data can be transferred to the surface though the network. It is one of important parameters of detection and analysis. Major application of using the environment monitoring system is to assess explicability of the mine gases, toxicity of the mine gases, spontaneous combustion in the mine, asphyxiation in the mine, temperature in the mine and air velocity in the mine. Ways of doing mine atmosphere monitoring include:
   a. Spot Detectors:
      Handheld detectors for detection of gases like methane (CH₄), carbon monoxide (CO), carbon dioxide (CO₂) and oxygen (O₂). Or alternatively, these days sensors are installed in cap lamps of miners and they report the level of gases to the surface. In both cases, alarms can be generated which can be visual as well as be heard in the mining environment. All these devices should be Wi-Fi compatible.
   b. Tele-Monitoring System:
      This system should comprise fixed gas sensors, CH₄, CO₂, CO, and O₂, Temperature Sensor, Humidity Sensor, Air Velocity Sensor and Barometric Pressure Sensors. All the mentioned sensors should be located at strategic locations according to requirement and regulations. It can detect in real-time and transfer data via the network in real time.
   c. Tube-Bundle System:
      This system should comprise a Gas Chromatograph and gas suction pumps which will be on the surface; 30-40 tubes are connected to gas suction pumps so that entry points should be placed in the mines at strategic locations. All these tubes should be connected to moisture trapping kits before entering the Gas Chromatograph such that only gases could enter it. This system is very beneficial in monitoring the level of gases in the goaf or in the sealed area. This system is widely used in almost all Australian Long wall Mines and in fact it is an ideal equipment for Long wall Mines.
      Environment monitoring system should comprise Tele-Monitoring and Tube Bundle System. Further, with the help of this equipment we can easily calculate vulnerability in the mines. We can calculate the trend of gaseous movement and generate data which can help in decision making. With the generated data, various types of Mine Fire Ratios like Grahams Ratio, Hydrocarbon Ratio, Litton’s Ratio, Black Damp Ratio, Young’s Ratio can be calculated. Further we can also generate Coward’s
Triangle and Ellicott’s Extension, and these are great tools of decision making in case of re-opening the mine, depillaring the mine, and detecting active or passive fire in the mine. M/s AGG Life sciences and Safety Solutions has been developed with the software named Eklavya which can help in decision making with the data gathered in the mines by Tube-Bundle System, Gas Chromatograph or Tele-Monitoring System.

4) Underground Equipment Control and Monitoring

a. Proximity Detection:

With proximity detection all the equipment deployed underground can be monitored and their failsafe and accident free operations can be ensured.

b. Belt Control:

Conveyor belts can be monitored regularly. Movement of the motor, its bearing, temperature of bearing, motor and belt can be monitored. Also, regular dispatch of the products can also be monitored. Tension, belt stoppage, belt chute are parameters of the conveyor belt which can be monitored in real-time.

c. Ventilation Control and Monitoring:

With the help of environment monitoring sensors ventilation can be controlled automatically or manually from the surface. Fans can be switched on/off automatically or manually from the surface as required in the mine.

5) Monitoring of Escape, Rescue Apparatus, Aided Rescue Equipment and Navigation Support During Escape:

a. Self-Contained Self-Rescuer (SCSR):

It is used for escape from the mine if the underground mine’s environment is no more respirable. M/s Roshimazschita Corporation is the largest manufacturer of Mining Self Rescuers in Russia and they are saving lives of miners for the last 60 years. These days monitoring of self-rescuers is done manually but with certain technological advancements it can also be put in the network which will inform about the state of the self-rescuer when the belt is worn or kept in Change-over stations. Further, available time of use can also be calculated, and miners can be guided with the balanced time of use. This technology will be further elaborated in this paper.

b. Refuge Chambers:

It is vital for miners in case of poisonous gases eruption or when the mine’s environment becomes irrespirable or unbearable and self-escape is not possible at that point of time. It can generate oxygen chemically and will have its own air-conditioning, lighting, toilet, water, food, first-aid kits etc. It will also contain self-rescuers equivalent to the capacity of occupants of the chamber. Then, miners can take refuge in such chambers and can wait until their rescue is done by the rescuers or self-escape becomes possible. These chambers should also be connected to the network to make it possible to inform about the number of occupants and from there they can also talk to the surface to know about the situation in the mine or about their rescue plan.

c. Change-over Station:

It acts as a storage station for an SCSR, wherein miners should come with exhausted SCSRs and will change their SCSRs for the newer ones. All the brackets with SCSRs in the Change-over Station should be connected to the network and information about the state of SCSRs could be sent to the surface.

d. Escape Navigation System:

All mines have their own rescue and aided-rescue plans. Such navigation system can be developed with the help of GIS and CAD and a sensor with a voice control module can be fitted in the cap-lamp which can guide miners for self-escape on the framework of rescue plans.

All the above systems are available in the market in one or the other form. As discussed in the paragraph d of the identification of gaps section, the major challenges occur with the SCSRs, which is
the most important apparatus in case of self-escape or when rescue is done by the rescue team if the mine environment is irrespirable.

**Monitoring of Self-Contained Self-Rescuer (SCSR):**

A SCSR is an apparatus which is being used by miners in the case of asphyxiation inside the mine and miners must escape from the place or wait for the rescue or stay in the mine until the environment normalizes.

3. **Use, Maintenance, Care and Application of Self-Contained Self-Rescuer; Identification and Analysis of Gaps and Solution**

**Identification of Gaps and Analysis:**

1) The most prevalent SCSR in mining industry is of 30 minutes duration and it needs to be worn on the belt by miners according to the regulatory guidelines across the globe, including India. But in India miners are reluctant to wear SCSRs on their belts. Hence, it is being kept inside the mine at strategic locations, wherein miners can reach them in case of emergency. It is a violation of safety regulations. Hence, this is the primary gap in the system.

2) According to the regulations of the Directorate General of Mines Safety, India (Regulatory Authority of Indian Mines) every year at least one apparatus from each batch of SCSRs needs to be tested for its functional ability in a laboratory. It has got huge cost implication and mining companies as well as suppliers suffer from it. It is the second gap in the system.

3) A SCSR designed for 30 minutes duration might not be applicable to every miner in the mine. It produces Oxygen (O\textsubscript{2}) from potassium superoxide (KO\textsubscript{2}) cartridges (KO\textsubscript{2} cartridges contain not only KO\textsubscript{2}, but a mixture of KO\textsubscript{2} and lithium hydroxide (LiOH) mainly with some other absorbents) and demand of oxygen varies from person to person. Therefore, it may be the case that a person with less weight uses less oxygen produced by the apparatus and apparatus can be used for a longer duration; it may also be possible that at the time of escape miner can escape directly from the mine with long walking distance without changing the SCSR at Change-over Stations. It is the third gap in the system.

**SCSR Model:** SHS 30 at figure 2 has the following major parts:

1. Mouth Piece;
2. Heat Exchanger;
3. Corrugated Tube;
4. Oxygen Bonded Chemical Cartridge;
5. Breathing Bag.

The above apparatus contains a nose-clip at the mouth piece and protective goggles.

**Figure 2.** General Overview of SHS 30.

Before going ahead let’s examine the design of a SCSR. Corporation Roshimazschita based out of Tambov, Russia is one of the largest manufacturers of SCSRs for various types of applications including mining. Model SHS-30 (figure 2), which is manufactured by the corporation, is one of the best products available on the market. A SCSR looks simple but it is a complex apparatus and a lot of science is involved into its manufacturing and design. It needs to pass through a lot of rigorous testing
before going into the market. This product goes through various types of approval and certification in the global as well as in the domestic market.

A SCSR is a very critical apparatus and it has got a useful life of five years when used in all shifts and ten years when it is used for one shift or kept on the shelf. Throughout these years, it should be useful and the main criteria are leak tightness of the apparatus and consistency of the chemical inside the canister, which means that it has not started any reaction on its own or with the environment. It may also be noted that at present there is only one method of control, i.e. leak indicator is being placed on the SCSR for visual inspection. In practice, there is no relevant method to check that the chemicals inside the apparatus are leak-proof without opening it.

KO₂ inside the container can react with water or CO₂ and upon reaction it can produce heat or water and reaction with water and CO₂ is exothermic in nature. Let’s see some major reactions of KO₂ with water and CO₂;

1) KO₂+H₂O → 2KOH+3/2O₂+9.4 kcal;
2) 2KO₂+CO₂ → K₂CO₃+3/2O₂+43.1 kcal;
3) 2KOH+CO₂ → K₂CO₃+H₂O+33.7 kcal;
4) KOH+CO₂ → KHCO₃+33.1 kcal;
5) KOH+3/4H₂O → KOH.3/4H₂O+16.57 kcal;
6) KOH+H₂O → KOH.H₂O+20.0 kcal.

As we can see, if the leak tightness of the apparatus is compromised, it can result in decomposition of KO₂ into KOH/K₂CO₃/KHCO₃ and the apparatus can’t be used. A system can be designed with a Contact Type Temperature Sensor, Capacitive Pressure Sensor, Pressure Strain Gauge outside the Rescuer, Capacitive Humidity and a Wi-Fi tag. All these sensors should be connected to a microcontroller logic board in order to simultaneously monitor all these parameters and transmit information on the display. It also needs to be connected to a wireless device and it can transmit the information to the surface wirelessly via the same network of communication discussed earlier in this paper.

Furthermore, movement of a Wi-Fi tag will ensure that the apparatus is worn on the belt by the miner and for monitoring of the chemicals inside the cartridge by the sensors, thus, ensuring the hermiticity and usability of the cartridge, and hence, regular requirement of lab testing and misleading visual inspection can be avoided and safety and usability of the device will be ensured. It is the solution to the problems mentioned in paragraphs 1 and 2 above.

The gap mentioned in the paragraph 3 is also a very critical one. If we refer to the standards EN 137904:2002 and IS 15803:2008, there are mainly three parameters which needs to be monitored when the apparatus goes though lab testing;

1) Concentration of O₂ at inhalation:
   • Inhaled gas should have minimum 21% (by volume) of oxygen concentration
   • A short-term deviation from the minimum level of 17 percent (by volume) and for a period of maximum 2 min at the beginning
2) Concentration of CO₂ at inhalation:
   • Average concentration of CO₂ should be less than 1.5% for the rated duration and should not be more than 3% at any point in time during the use.
3) Breathing Resistance:
   • 35 litres/minute
   • Rated duration of up to 30 min by the sum of inhalations
   • Exhalation resistances should be maximum 16 mbar and individual breathing resistance for inhalation or exhalation should be maximum 10 mbar.
   • For the apparatus with a rated duration of more than 30 min the sum of inhalation and exhalation resistance should not exceed 13 mbar and the maximum individual breathing resistance for inhalation or exhalation should not exceed 7.5 mbar.
   • For apparatus of all rated durations breathing resistance for inhalation as well as for exhalation should not exceed 20 mbar.
4) Temperature:
- Temperature of the inhaled gas should not exceed 55 deg. Celsius.

These issues can be addressed by installing a combination of a portable medical capnograph and a spirometer between the mouthpiece and the heat exchanger. It should also be connected to a microcontroller and data should be transferred wirelessly to the surface so that the user can be guided from the surface about using the apparatus and escaping the mine.

Sensors of the SCSR:
1) Temperature Sensor:
   It can be a Resistance Thermal Detector (RTD), also known as a resistance thermometer, which measures the temperature by correlating the resistance of the RTD’s element with the temperature. An RTD consists of a thin film or, for greater accuracy, a wire wrapped around a ceramic or glass core. The most accurate RTDs are made using platinum but lower-cost RTDs can be made from nickel or copper. However, nickel and copper are not so stable or repeatable. Platinum RTDs offer a linear output that is highly accurate (0.1 to 1 °C) from -200 to 600 °C. It should be used to monitor the temperature of chemicals inside the cartridge, and if any increase in the temperature is noticed, an alarming message should be sent to the wearer of the rescuer and simultaneously to the surface through the network. An increase in the temperature of the chemicals is a signal of failure in the SCSR’s hermeticity as they might have started reacting with moisture or CO₂.

2) Capacitive Pressure Sensor:
   Sensors based upon capacitive sensing technique are strain-based sensors. The sensor capacitances are arranged in a push-pull, half-bridge configuration where both capacitors are parameter modulated. A sensing spring within the capacitive pressure sensor is conductive or has conductive surfaces upon it and is positioned between two fired-alumina ceramic or glass-compound capacitor support structures. The capacitor support structures are electrically isolated, where the capacitor plates are screen-printed or vapor-deposited onto the support structures as shown. The push-pull symmetry arrangement results in capacitance of one side of the sensor module increasing and the other decreasing when unbalanced pressures act upon the spring member. It is used to measure the change in the pressure inside the cartridge or the starter.

3) Bonded Strain Gauge:
   A fine resistance wire with the diameter 0.025 mm is bent several times in order to increase the length of the wire so that it permits a uniform distribution of stress. This resistance wire is placed between the two carrier bases (paper, bakelite or teflon) which are cemented to each other. The carrier base protects the gauge from damages. Leads are provided for electrically connected strain gauge, measuring instrument and the microcontroller, which should work in accordance with the Wheatstone bridge method. It shall be used to monitor the impact on the SCSR.

4) Capacitive Humidity Sensor:
   A humidity sensor is a small capacitor consisting of a hygroscopic dielectric material placed between a pair of electrodes. Most capacitive sensors use plastic or polymer as a dielectric material, with a typical dielectric constant ranging from 2 to 15. When no moisture is present in the sensor, both this constants and sensor’s geometry determine the value of capacitance. It is used to determine any moisture content inside the cartridge from the environment or due to reaction of a chemical bed with water.

Conclusion
Mining industry is a very dynamic industry with severe occupational hazards. With revolutionary changes in mining technologies, it is growing faster and serious considerations needs to be given to the miners’ safety in order to mitigate the risks. To bring accidents at tolerance or avoid the in the underground mines, is only possible with the use of modern technology.

A network-based system is the essence of time, wherein all the equipment, people, apparatus deployed underground should be put in the network and real-time monitoring of every parameter, every piece of equipment, apparatus and people deployed underground should be done.
SCSR is one of the major apparatus for the escape of miners, serious and strict measures should be taken make miners wear them on their belts and its use and serviceability should be monitored regularly, and hence, the best way to design a rescuer based on sensor technology with a network monitoring facility.

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