Mine Communication & Information for Real Time Risk Analysis

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ABSTRACT

Communications in coal mines are poor by general industry standards, and generate significant risks in the lack of information available from underground areas. Mines often employ multiple incompatible systems for communication. This report concludes that there is no technical barrier to the upgrading of coal mine communications to equivalent standards of those used by general commercial and industrial organisations. The greatest needs are for a system that has a common standard, has wide band capacity, and allows for easy connectivity for sub-networks which are customised for specific applications.

Mines are vulnerable in times of emergency, as traditional communications systems may fail. A new emergency communication system LAMPS has the potential to be integrated into a mine communications network, but still retains functionality following a major incident in the mine.

An improved communications system would allow real time risk assessment to be carried out at the mine, and the requirements for monitoring, assessment and decision making have been investigated for some common hazards. These include ventilation issues, strata control and emergency response. This would incorporate the latest technologies in safety management and real time risk assessment, using computer-based assessment, assisted decision making, and virtual reality.

1 INTRODUCTION

Improving safety continues to be a priority for mine operators. Regulators now expect all mines to have safety management processes in place which identify all hazards, develop and implement operational procedures to ensure that each hazard is effectively managed.

Mining is a dynamic operation, with a continuous stream of timely information needed to monitor trends which indicate a change in risk status. This is producing increasing larger data outputs with matching increases in demand for mine communication systems. Mine operators are also expecting to have access to all the information they would like in real time, increasing the demand for communications bandwidth. Equipment manufacturers have responded by providing monitoring and communication equipment to suite their individual applications. This has resulted in multiple communications systems operating in most mines. [1]. New technologies can make a significant contribution to mine safety, particularly in risk management, by improving the monitoring and communication capabilities available to mine operators. This paper looks at the present status of mine communications and information for risk analysis, analyses what may be possible in the future.

2 COMMUNICATION IN MINES

Improved mine communications can assist in safety management in mines. In addition to communication technology developments, other new technologies which can contribute include: new sensors to collect information not currently available, communication interface modules, computer assisted decision making methods, visualisation of mine data, risk assessment and safety management procedures.

2.1 The status of mine communications

Many systems are used for communications in mines and it is common for a number of systems to be installed in parallel as illustrated in Figure 1. These communications technologies include fixed wire telephones, leaky feeder, cellular radio, low frequency through infrastructure, magnetic induction through rock (PED) and optical fibre.

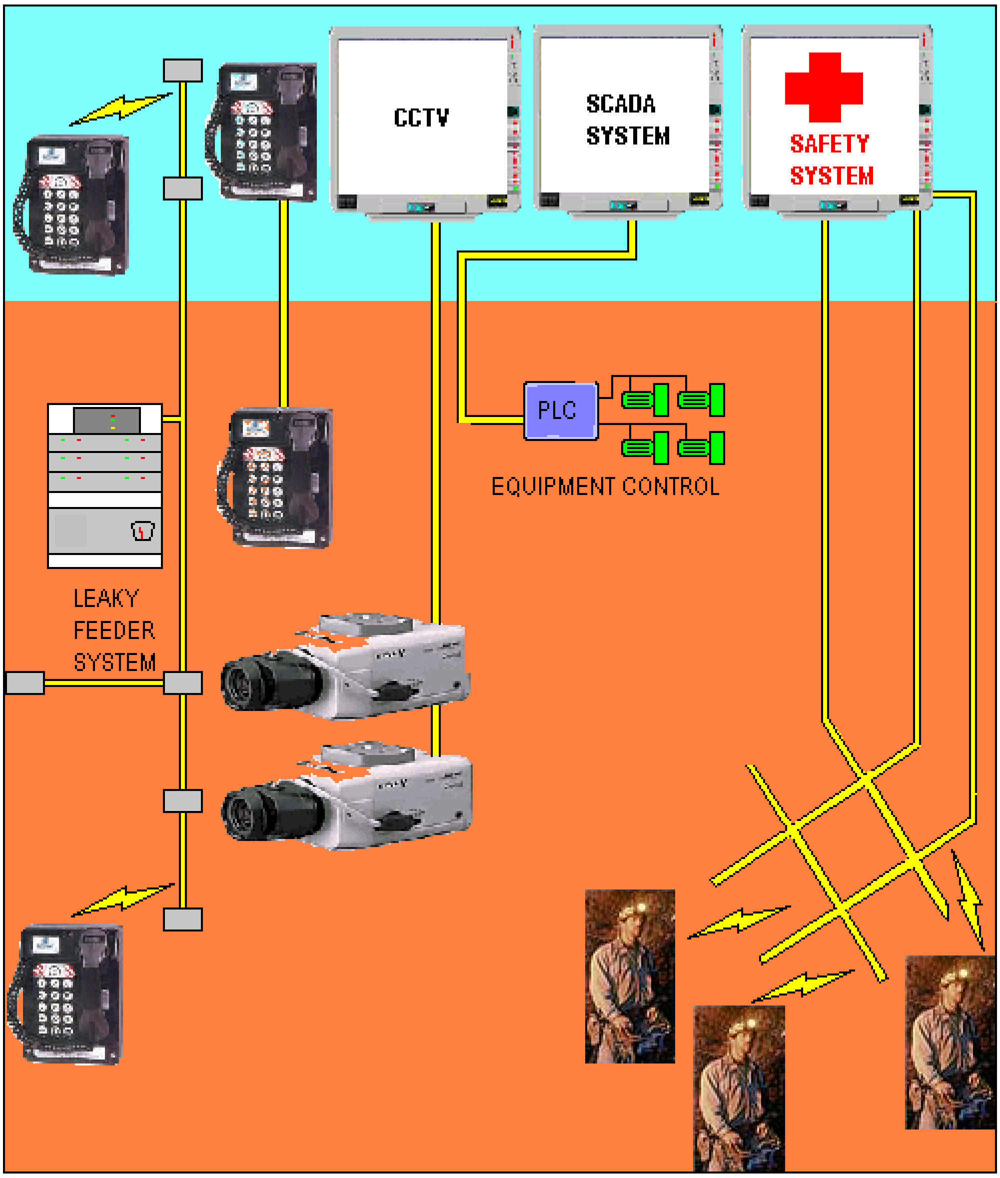

Figure 1: Typical Mine Communications System

Fixed wire telephones are used in most underground mines throughout Australia. Many systems offer direct-dial, PABX and intercom/paging capabilities. Only a few kilometres of leaky feeder cable are installed in coal mines, although they are more widely used in metal mines. Leaky feeder systems provide good voice quality and have been used for video and teleoperation. A personal emergency device (PED) uses a large loop on the surface to propagate signals through the rock to devices carried by underground workers [2]. The low data rate allows for communications equivalent to a messaging system. Optical fibres can support very high data rates between nodes and are used extensively at newer mines such as Moranbah North to communicate with PLC and SCADA systems [1].

Usually some combination of fixed wire, leaky feeder and PED are employed underground. Sometimes fixed wire intercom systems provide two way communications at strategic locations in combination with paging capabilities provided by PED. Elsewhere vehicle drivers may maintain two-way communication whilst in proximity to a leaky feeder cable and rely on PED otherwise. Often, however, there is a reliance on just one or two channels of a leaky feeder system and the bulk of its capacity remains unused.

As well as the different hardware options for transmission technologies, each of these systems uses unique protocols for data transmission. These different formats prevent integration of systems and force duplication of communication infrastructure.

2.2 Emergency communications needs and capabilities

2.1.1 Emergency Communications Requirements

An emergency mine communications system is required to support self escape, aided rescue and mine recovery. Underground staff need to be made aware of safe exit paths for self escape. In the aided rescue phase, the emergency management team need to know where people are trapped in a mine by a physical impediment or injury. Finally, in the mine recovery phase, data about prevailing conditions is desired to minimise risk to workers while attempting to recover the situation. It follows that the emergency communications requirements include sending evacuation messages to underground personnel, personnel location monitoring and mine sensor monitoring. It is desirable that, if the mine power system fails, the communication system should remain active for up to a week and the system should be able to survive a section being lost in a roof fall.

2.1.2 Existing Emergency Communications Systems

Normal mine communications are relied on in times of emergency by many mines. A messaging system specially designed for emergency situations has been developed in Australia, the PED, and almost 10,000 of the units are in use world wide. The PED system [2] allows communication from the surface to personal units underground. It relies on through-the-rock propagation and uses large loop antennas on the surface to communicate messages to underground staff. An underground to surface PED module is under development. The systems mentioned above are reconciled against the five emergency communications requirements in table 1 below. Existing technologies cannot meet all emergency communications requirements. Conventional communication technologies lack survivability as there is a reliance on communication backbones which are susceptible to disruption during emergencies.

Table 1: Communication Systems Currently in Use – Application to Emergencies

	Send evacuation messages to personnel	Personnel location monitoring	Mine sensor monitoring	Operate for 1 week after mine power failure	Survive cable (* infrastructure) breaks
Fixed wire	Limited use	No	No	Potentially	No
Leaky feeder	Yes	Potentially	Potentially	No	No
Cellular	Potentially	Potentially	No	No	No
Low frequency	Limited use	No	Potentially	No	No *
PED	Yes	Limited use	No	No	No
Optical fibre	No	No	No	No	No
Ideal	Yes	Yes	Yes	Yes	Yes

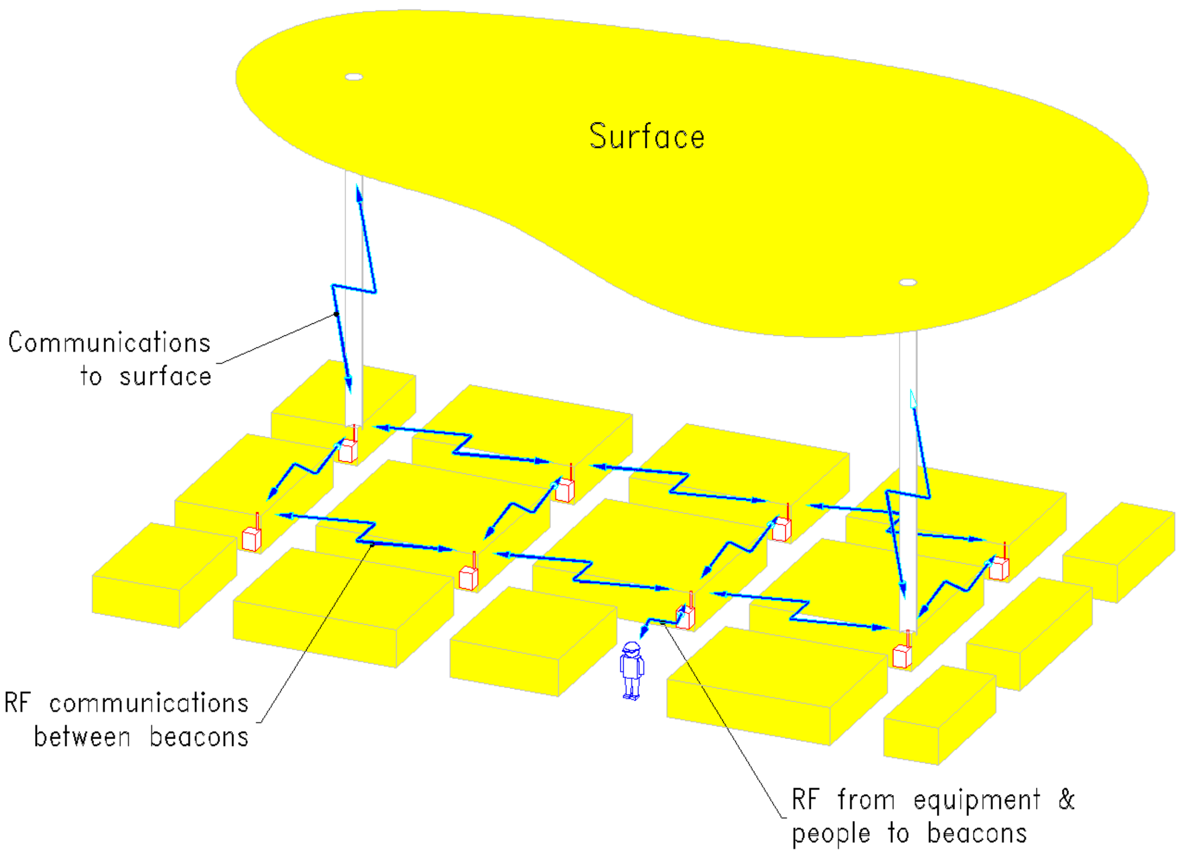

Figure 2: Depiction of an underground LAMPS network

2.3 A new emergency communication system LAMPS (Location and Monitoring for Personal Safety)

The LAMPS system has three types of components: tags (also known as personal transponders), readers (also known as network beacons) and control / monitoring. Tags will be built into cap-lamp battery covers and routinely transmit a unique identification number. A network of readers will provide staff location information and communication through to a control / monitoring facility.

A LAMPS network is depicted the Figure 2. Eight readers are shown, which provide communications along multiple, redundant paths within underground tunnels. The figure also depicts a personnel transponder, reporting vital signs data to nearby readers. A separate control and monitoring subsystem at the surface monitors the communications traffic and displays the staff location information. In emergencies, the control and monitoring subsystem serves to communicate escape route information to the individual transponders.

Although the development of LAMPS was motivated by underground coal mine safety, it equally has other personnel/equipment location monitoring applications. The tags perform the same function as other active radio frequency identification systems in that they communicate unique identification numbers to a communications network. Additional readers can be added to the network at any place or time provided their serial numbers and positions are registered in the control and monitoring computer(s).

The LAMPS system offers independence from mine power; tolerates failures in sections of a mine by communicating over redundant pathways; supports self rescue, aided rescue and mine recovery. LAMPS is a status and location monitoring system for personnel and resources within underground mines during normal and emergency conditions. Alarm conditions can be triggered whenever personnel data are not received or regions are unable to sustain communications. During mine emergencies, when there may be a loss of mine power, LAMPS supports emergency response in the following ways. The LAMPS readers are equipped with internal batteries. The readers provide a communications pathway with high redundancy to report the location and status of personnel. An evacuation signal can be communicated to underground staff by flashing the cap-lamps. Finally, LAMPS can be used to relay sensor data for gas and air quality monitoring from appropriate sensors deployed in hazard areas. This information can be accessed from any point in the mine. In addition, the technology can permit the display of the location of personnel and equipment on images of mine maps and layouts. The LAMPS tags are amenable to a variety of sensor monitoring applications. Equipment monitoring could include vibration, temperature, mine gas analysis data and roof loading measurements.

A demonstration of communicating tag data over a leaky feeder system was conducted in September 2000 in the Enterprise mine at Mt Isa. A number of tags were distributed on the floor within proximity to a reader mounted on pipe-work. A commercially available modem served to transmit the tag data to the nearby leaky feeder cable via a quarter wave whip antenna. The time-stamped data was observed on laptop computer connected to another modem having a whip antenna, in a vehicle travelling along the drives in regions where leaky feeder communications were available. These modems are used for convenience and are not necessarily employed in a mine installation. Subsequently the tags were deposited in the back of a vehicle which was driven at nominal speed past the overhead reader. The time-stamped data was successfully observed on a stationary laptop connected to a modem plugged into the leaky feeder system base station, some 2.5 km from the reader.

2.4 Integrated mine communications

There are obvious advantages for users in having communications with a high level of compatibility. The ideal is for information from each area to be seamlessly exchanged with all other devices, no matter where they are in the system. The requirement in mines for a wide variety of data, control, voice, and vision systems will continue to increase, as mines move to higher levels of automation. If these systems continue to proliferate their own unique protocols, the problems for mines in duplication of communications will increase.

2.1.3 The potential of ethernet networks for underground mines

An ethernet (ie TCP-IP) network is a candidate for a universal underground mine communications infrastructure. The network protocols and architectures are well evolved, and have been introduced into metal mines for point to point communications. Components such as hubs, switches and interface cards are available.

This communication system model has high bandwidth backbone, which runs through the underground mine, and also includes surface facilities. A mixture of fibre optic cables, twisted pair and wireless local area networks could provide this facility. Components of the communication system will interface with the backbone through standard ethernet connections, and IS hardware developed, which has been adapted from normal commercial equipment. All of the different functions such as monitoring or voice communication will be carried out with appropriate equipment, but they will be plugged into a common communications carrier as close to source as practicable. Once connected to the network, the data or voice communications can access the communications carrier at any suitable location. The data may well be in a form that requires some specific hardware or software to be able to use it, but it would be available anywhere in the network. As explained elsewhere in this paper, components of the LAMPS system (which includes backup capabilities to survive and operate after emergencies have damaged the normal communications system) would also be connected to the communication carrier, as part of the normal operations of the mine.

The model for a standardised mine using ethernet is described in Figure 3. It illustrates how a number of devices would use a common communications carrier. Illustrated are leaky feeder systems, telephones, equipment and other forms of monitoring.

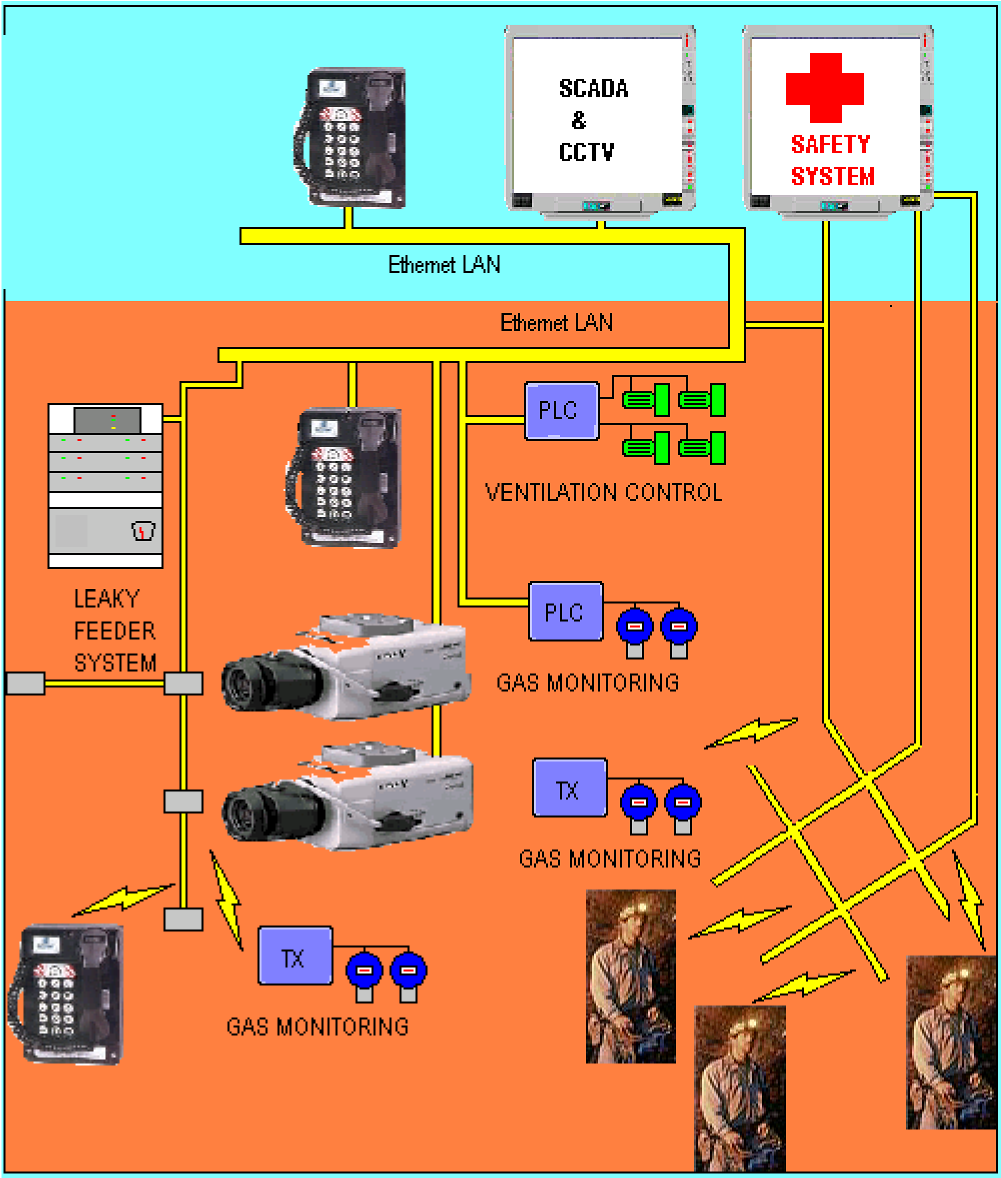

Figure 3: Proposed Communications System

This is a vision for the future in which the benefits of high bandwidth, standardisation and interoperability of emerging technologies enjoyed in urban environments, are available in underground coal mines. What needs to be done to deliver this capability to mines? The key activities in network technologies are migration, integration and quality improvement. These are discussed below.

2.1.4 A total mine communication system

A total mine communications system has both an integrated communications systems for operational functions of the mine, and an emergency mode of operating which allows for basic communications between the surface and underground even after an incident has damaged the main communications carrier.

The main communication system has a high bandwidth, and a common interface such as ethernet for all devices.

The emergency system LAMPS is unique, in that it becomes part of the everyday network of the mine. Under normal conditions it is connected via ethernet to the main communications carrier, and any data it provides can be accessed from any other ethernet connection in the system. In addition to this "operational" function, if the main communications are lost, it has an inherent capability to maintain a reduced level of functionality, connecting to the surface stations through radio links passed between the LAMPS modules. By making the LAMPS emergency part of the everyday mine communications, it will be regularly maintained, and much more likely to be available at times when its emergency capabilities are required. Its cost can also be justified as it contributes to normal production activities in the mine, whereas special emergency systems are not usually given a high priority by mine management

3 RISK ASSESSMENT

Risk assessment has been adopted as the basis of safety management for mines. It is a generic process that is applicable to any situation, and standard processes have been developed which can be applied in any industry.

Risk management systems all develop a risk level assessment by consideration of the likelihood of a situation developing and the impact of the event occurring. Common events with high impact represent the highest risk levels, and uncommon events with low impact have the lowest risk levels. By applying numerical values to likelihood and impact, quantitative assessment of risk can be determined.

This can be done on a one-off basis to determine where the risks are in an operation, which leads to safe operating procedures being developed to manage the risk. The level of risk will dictate the priority given to the safe operating procedures within the mine operations.

3.1 Technologies to Assist Risk Assessment in Mines

In mining, conditions underground change continuously, and hence risk profiles change as mining progresses. This dynamic process is accommodated in the safety management system, but requires:

- data on the changes to be measured and available
- analytical processes that determine the significance of the changes
- lines of communication which convey data and responses around the mine
- decisions for appropriate action
- a method to intervene to manage the risk

3.1.1 Communications

Earlier sections have discussed the status of mine communications and the potential for new systems. The need is for systems which

- Extend to all parts of the mine
- Interface in a standard way with all types of sensors and communication devices
- Supports real time response
- Implement instructions for action plans to functional areas in the mine

3.1.2 Decision Making Processes

Decisions are made at appropriate times in the safety management process. These can be made by the intervention of a nominated person who considers the evidence and reacts according to agreed guidelines. It is also possible to develop computer programs which take in data and automatically determine a response from a set of pre-programmed options. It is common for there to be some mix of these procedures, where a person is advised of a set of options with the implications of each action predicted. The choice remains with the responsible person.

For complex situations the implications of new data may only be able to be assessed by using specialist modelling programs. The output from these programs may still be ambiguous, and require considerable judgement on the part of mine staff.

3.1.3 Presentation using Visualisation

Virtual reality is a new technology which can be a powerful tool in conveying the significance of events, as part of safety management. Its use can be incorporated into procedures adopted by a mine. It is particularly powerful for real-time assessments. To achieve this, however, the visualisation programs need access to capable communications systems that can deliver data immediately, and modelling programs that determine the effects of the changes, which are then fed to the visualisation program for presentation to users.

3.2 Examples of Risk Situations in Mines

The following discussion explores some possibilities of typical hazards which could be addressed in a research and development program to improve mine safety management systems.

3.2.1 Mine atmospheres

The control of mine atmospheres is essential to

- Provide safe air/oxygen for miners underground by controlling the level of methane, other noxious gases, dust and particulates from sources such as diesel vehicles, and temperature in work places
- Remove seam gas emitted into the workings from exposed coal
- Control spontaneous combustion/heatings in the workings or goafs.

Ventilation fans

The main method of maintaining safe working atmospheres in the mine is by ventilation with fresh air. The fans in an average Australian underground coalmine (3 to 5 million tons of coal per annum) will move from 200 to 300 m^3/s of air and will run at constant speed, with monitoring of mechanical performance, power consumption, air moved and gas composition. It is necessary to balance air flows in different parts of the mine, and a mixture of flow controls (doors and brattice) and supplementary auxiliary fans are used.

Ventilation flow models are being used to analyse and design ventilation systems. There is usually not enough information gathered in the mine to measure ventilation performance in real time and to implement any necessary changes. If real time modelling of the ventilation is to be developed, there will need to be better sensing of gas concentrations, and air pressure and air velocity throughout the mine, and improved mine ventilation models capable of real time output.

Air Quality

Sampling of underground air is carried out routinely in Australian mines and tube bundles are used to collect samples continuously for analysis at a central laboratory located on the surface. Depending on the length of the sample tubes, there may be more than half an hour delay in getting an analysis. Instantaneous readings are sometimes collected from electronic gas sensors distributed through the mine. Most mines use tube bundles and analytical systems attached to a computer system which has set warning levels to alert the mine at the onset of high risk conditions.

Monitoring for heatings and fires

The first indications of heating or fires in mines are seen in gases measured in the ventilation air. Gaseous products of heatings and fires are related to the temperature of the coal and an initial heating will be indicated by an increase in carbon monoxide. At higher temperatures hydrogen and higher hydrocarbons are generated, and the percentages of different gases give a reliable indication of the temperature at the seat of a fire. It cannot be assumed that normal ventilation flow continues once a fire commences, as bouyancy effects can reverse flow directions. Better data collection, communications and analysis are required to determine what is happening in the mine.

Monitoring gas drainage

Drill holes are used within gassy underground mines to reduce the amount of gas flowing into mine workings. The effective performance of gas drainage systems is critical to maintaining a safe mine atmosphere, but there is very little monitoring of details of different parts of the system. Monitoring systems to determine gas pressure, composition and flow rates could be developed which could be used to control individual sections of the system remotely.

3.2.2 Strata control

Strata control remains one of the major areas for specialised safety activity in mines In contrast to normal industrial activity, mines expend most of their effort on maintenance of their working environment. Mining creates openings in the ground, and these must remain stable for the period that access is required to them. This might range from a few hours to access a specific ore resource, or decades in the case of access roads in long term mines. Inadequate rock support will lead to failures which interrupt the mining operation and generate risks to operators, and too much support is wasted effort. Rock deformation is a time dependent process, so mining engineering is a process of balancing the level of strata control engineering to just keep the mine functioning, and wasting money doing things which are not necessary.

In-situ ground conditions

A prerequisite for geotechnical assessments is the geology of a mine site. Information is compiled into geological models, and full 3D models are created with computer programs. These use data from boreholes, outcrop and geophysics to model the coal seams, and also the interseam rocks that affect the performance of the mine openings. Faults and fractures are a major control of strata behaviour, but are difficult to both measure and incorporate into models. New techniques are being developed to assist rapid collection of fracture data. Seismic and other geophysical methods can be used to build 3D images of the rock mass

All types of 3D information about the mine can be combined by virtual reality computer techniques. Data of different types can be displayed together in correct spatial relationship. In a predictive model information ahead of workings in a particular area of the mine could be combined to present an "X-ray view" of the ground about to be mined.

Monitoring mining effects

Monitoring changes in rock conditions during mining poses many challenges with respect to access to install instruments, the availability of intrinsically safe instruments, maintaining communication with instruments through the operation, the adequacy of models to interpret data being collected, and communication of integrated conclusions to operators.

Physical measurement of mining induced movements can be made with extensometers or lasers monitoring displacements on exposed rock faces. Deformations are associated with microseismic events, which can be monitored. Analysis of the small microseismic waves can indicate the location of the deformation and the type of rock fracture involved. By mapping these through time, any variation that might pose special risks can be identified by anomalous microseismic activity.

These data can be compared with computer modelling of anticipated strata performance. They can be used to update the model of site characteristics, and hence make adjustments to mine designs to make allowance for previously undetected hazards.

3.2.3 Mine Operations and Machine Monitoring

There are many areas of mine operations which might be selected as examples of activities for safety management. They might be related to a specific machine, or an area of works such as a longwall face. The data required from each of these situations would be integrated in an appropriate way with the communication system. New generation smart sensors will combine an analogue sensor with a microcontroller to give serial data output directly to the front-end computer.

3.2.4 Emergency Response capabilities

When a mine emergency occurs, each mine has a management plan which takes over the running of the mine, and organisation of escape and rescue operations. Traditional mines rescue brigades are becoming restricted in what they can do, as duty of care responsibilities prevent them being used in circumstances where it cannot be demonstrated that it is safe to work. A prime requirement is that adequate information is available on conditions in the mine following an incident.

LAMPS communications

The LAMPS communication system has been specifically designed for these conditions, and can provide:

- a robust communications system which will survive even if the main mine services are lost
- links to individual miners underground that can provide information from personal monitors indicating the person is alive and their location
- send simple instructions to trapped workers if a suitable unit for workers to carry is developed.

Emergency response decision support program

When data from a mine is integrated into a Virtual Mine system using the virtual reality techniques, all relevant information for analysing an emergency and planning escape and rescue operations could be immediately available.

The system can be customised to provide the data in a format which is most relevant to emergency management. These can be tested in training exercises. A typical scenario would be to present the whole layout of the mine and indicate where services relevant to emergency workers were, to help plan rescue activities. It could show the position of relevant equipment, location of people, or in the worst case, their location immediately prior to the incident. In the case of explosive gases being released the gas levels throughout the mine could be displayed, along with the output of analytical programs that tracked compositional variations through time and their significance. The source of fires could be identified and the state of the fire determined from gas analysis trends. The progress of any rescue efforts could be monitored.

4 DEVELOPMENT AND IMPLEMENTATION

CSIRO and JCOAL have developed a proposal for mine communications & information which would demonstrate real time risk analysis at a minesite. The objective is to improve mine safety by developing better mine communications and demonstrating its application to risk assessment and safety management

The safety management examples could address specific mine hazards. These can be based on real time risk management including monitoring a situation, communicating the data to the safety management system used at the trial mine and communicating response plans. They would illustrate the possibilities made available by the improved mine communications.

The program would be divided into two areas of work. The first is in development and demonstration of new and improved mine communication systems. The second is in the application of these improved mine communications to specific hazards which demonstrate the capabilities of the new communications. The work would be based at a trial mine, and research developments incorporated into the operations of the mine. The examples of risk assessment and management will be carried out within the framework of the mine's safety management arrangements.

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