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Darren Brady

Mine Safety Institute of Australia Pty Ltd

David Cliff

University of Queensland

Geoffrey Nugent

BHP Billiton Mitsubishi Alliance

Seamus Devlin

NSW Mines Rescue Service

Steve Tonegato

NSW Mines Rescue Service

See next page for additional authors

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Authors

Darren Brady, David Cliff, Geoffrey Nugent, Seamus Devlin, Steve Tonegato, and Peter Mason

ENSURING THE SURVIVAL OF CRITICAL INFORMATION SOURCES AFTER AN UNDERGROUND INCIDENT - CAN IT BE ACHIEVED?

Darren Brady¹, David Cliff², Geoffrey Nugent³, Seamus Devlin⁴, Steve Tonegato⁴ and Peter Mason⁵

ABSTRACT: Through a risk management process ACARP Project C19010 (Emergency Response: Mine Entry Data Management) identified critical information decision makers required to make informed, risk based decisions on whether mines rescue teams could enter or remain in a mine in response to an incident. The project also developed a proof of concept software tool to assist making informed and considered, risk based decisions founded on predetermined relevant and reliable information. One of the questions that presented most commonly throughout this project was how can operations effectively sustain the systems which could provide this required information once an incident occurs. This leads to other questions such as; what level and type of incident could render our existing systems obsolete in an emergency? And what contingencies do operations have in place or available to them to counter this risk? To assist address these issues an extension to ACARP Project C19010 was sought and successful, allowing a scoping study to research and identify existing and future strategies, systems and hardware which have the potential to support and provide the information requirements of decision makers during or after an incident at an underground coal mine. This paper outlines findings to date, of the ACARP Project C19010 extension.

INTRODUCTION

In an effort to ensure that *emergency* mine re-entry processes were developed using risk management methodologies, Queensland Mines Rescue Service (QMRS) facilitated a comprehensive risk assessment involving all key stake holders including New South Wales Mines Rescue (NSWMR). The risk assessment took four days to complete and resulted in identifying what information was required to make a risk based decision on the deployment of rescue teams underground. A task group was formed that converted the risk assessment into mine re-entry guidelines from which the Australian Coal Association Research Program (ACARP) funded project C19010 "Emergency Response: Mine Entry Data Management" developed a decision support system. The system known as Mine Re-entry Assessment System (MRAS) incorporates check lists of the information determined to be required as well as the capability of accessing information known prior to the event. Making use of the this tool with underpinning risk management logic, assists decision makers to make informed, quality decisions in a timely manner (Brady, *et al.*, 2012).

Workshops in Queensland, New South Wales and New Zealand were held as part of the information dissemination process of the project as well as presentations at local and international conferences. A common question and one that was raised many times by the project team themselves was "will the systems providing the information identified as being critical survive the event?" This question led to others such as; what can mines do to protect these systems? What type and magnitude of event will compromise systems? What contingencies are in place or available to cover such events?

One of the main findings of this project was that mining operations give little consideration to the locality and survivability of information and communication systems critical to obtaining the required information after an incident of any type or size. The recommendations made in the project report (Nugent, *et al.*, 2011) included the following;

¹ Mine Safety Institute of Australia Pty Ltd

² Minerals Industry Safety and Health Centre, Sustainable Minerals Institute, University of Queensland, d.cliff@mishc.uq.edu.au, 07 3346 4086

³ BHP Billiton Mitsubishi Alliance, Broadmeadow Mine

⁴ NSW Mines Rescue Service

⁵ Coal Mine Technical Services

There is an urgent need to assess and determine the general capability and capacity of existing critical mine monitoring and communication systems to provide reliable and relevant information during emergencies of varied types and size. The research should include:

- The general status of Australian underground coal mines environmental monitoring and communications systems capabilities and capacities to provide adequate information after an incident.
- What structural design specifications and strategic positioning considerations (including contingences) for environmental monitoring and communications systems would be considered best practice for emergency response?
- The current status of existing systems available and suitable for Australian underground coal mines relevant to the scope.
- The current status of any research and development being carried out or pending applicable to the scope.
- What further specific research is needed to assist industry in implementing the functional specification developed in the original C19010 project and recommendations of how such research could best be achieved?

This is by no means the first time that recommendations of this type have been made. The report on the Warden's Inquiry into the Moura No.2 Mine disaster (Windridge, 1995) stated "The loss of telephone communication with the five South crew at the time of the first explosion left no means of ascertaining the status of those persons without some form of entry to the mine. There appears a need to examine explosion resistant means of communication".

The task group that was formed following the Warden's inquiry to look at Mines Rescue Strategy Development (Task Group No. 4, 1996) determined that with regards to existing practice, knowledge of conditions underground after an incident would be insufficient for accurate assessment of the mine environment. The task group identified "The highest priority need is for a communications system which would survive an incident and provide ongoing two way communications between escaping or trapped miners and rescue personnel on the surface".

With regard to gas monitoring, Task Group four recommended that fixed tube bundles and gas chromatographs should be made available at all mines as the primary method of measuring post incident mine atmospheric conditions, something that many Australian mines have achieved. The recommendation went further stating that tube bundle systems should include:

- protection of tubes from damage,
- locations of sampling points designed for both normal and post incident atmospheric conditions,
- modularisation using boreholes to minimise delay in transmission and analysis as well as to make the system as robust as possible,
- techniques for verifying tube integrity which could be routinely applied post incident.

For real time systems the Task Group 4 recommended "*Research into the development of robust telemetric sensors for gas analysis and other environmental parameters, over ranges existing after incidents, should be prioritised.*" (Task Group No. 4, 1996)

Task Group 4 also highlighted that both pre-installed and post-incident boreholes should be considered when developing Aided Rescue Management Plans.

The New South Wales Department of Primary Industries Mine Design Guidelines MDG 1003 (Windblast Guideline), (Mine Safety Operations Division, 2007) states "The mine must establish and maintain a robust system of gas monitoring capable of providing real time gas analysis of explosive gases in the Hazardous zone - Windblast before, during and after a windblast."

The New South Wales Department of Primary Industries Mine Design Guidelines MDG1020 Guidelines for underground emergency escape systems and the provision of self rescuers (Mines Rescue Working

Group and Mine Safety Operations Division, 2010) identifies that a main risk in a mine's emergency escape system is that the monitoring system does not survive the event. The guideline indicates that integrity and protection of the system during an event, and contingencies in the event of a failure need to be considered. Also the design, construction and installation of hardware associated with the emergency communication apparatus, need to assure the integrity of the system during any event that causes an emergency, and that the risk assessment and risk management systems must aim to preserve the functionality of the system through a catastrophic event.

Even with all of these recommendations and requirements, the underground coal mining industry is not in the position it should be to ensure ongoing reliable information/data during and post incident. With this knowledge and knowing that the information identified in ACARP project C19010 as critical for decision makers was possibly not going to be available during an incident, the project team made a successful application to ACARP for an extension to the project to address the research recommended. The aim of the extension being to research and identify existing and future strategies, systems and hardware which have the potential to support and provide the information requirements of decision makers during or after an incident at an underground coal mine.

C19010 PROJECT EXTENSION

Industry risk assessment

One of the initial tasks the project team completed was an industry risk assessment to assess and analyse the potential incidents that could impact effective communications and mine monitoring systems supplying data and information. This risk assessment defined critical data/information sources (Figure 1), the types of sensors/hardware collecting data (Figure 2) and the transmission medium of that data/information (Figure 3). A detailed hazard analysis was then conducted to identify the incidents that could compromise the capture, supply and transmission of the critical data/information to the post-incident management team (Figure 4). These threats were analysed for their consequences and potential magnitude. The current preventative and mitigation controls employed to maintain access to this data and information were also identified. It became very apparent during this process that most of the systems set up to collect and transmit critical data/information were done so in a manner that addressed the day to day requirements for this information with little consideration given to expected measurements or increasing the chance of survivability during or following an event. Despite this it appears systems are scoped, designed and installed for "peace time mining". Where possible the industry risk assessment team identified areas requiring improvement.

An issue that was identified as requiring urgent investigation was the need for independent intrinsically safe power supplies for systems providing critical data, such as gas monitoring and communications, when underground power is lost. The use of battery backup to address this problem although useful to overcome short duration power supply issues, is not adequate for an ongoing response that may last more than several days. Recent events in Australia and at Pike River in New Zealand have involved responses and withdrawal to the surface best measured in weeks rather than days, and would far exceed battery backup capacity to keep systems operational. The project team have organised for manufacturers, certification experts and electrical inspectors to meet to try and come up with a solution to provide power for ongoing provision of critical data from such systems during extended periods of underground power loss.

Another area that became obvious during the risk assessment was the need for "hardening" of sensors and other hardware, including transmission media to protect against both over pressure and flying debris. It is recognised that hardening of the sensors by the manufacturers although important is not going to be achieved in the short term. For this reason the project team has recommended further investigation into designing retro fitted physical protection to critical hardware. There is also a need to investigate the most appropriate means of installation of hardware and transmission media (including tube bundle sample tubes). The positioning of the hardware also needs to be considered as part of the installation. Communication hardware such as telephones may be better placed in cut throughs rather than main headings to provide protection.

It is normal practice following an incident such as an explosion underground to ring all underground phones and regularly communicate over the intercom systems (DAC) to try and get a response from workers underground. One of the problems frequently faced at these times is knowing whether the communications are still operational. There is a need for a means of testing to be built into hardware. A

desirable feature on intercom type systems is an override button, allowing the surface operator to activate the talk function at the unit underground allowing them to hear what was happening in that area.

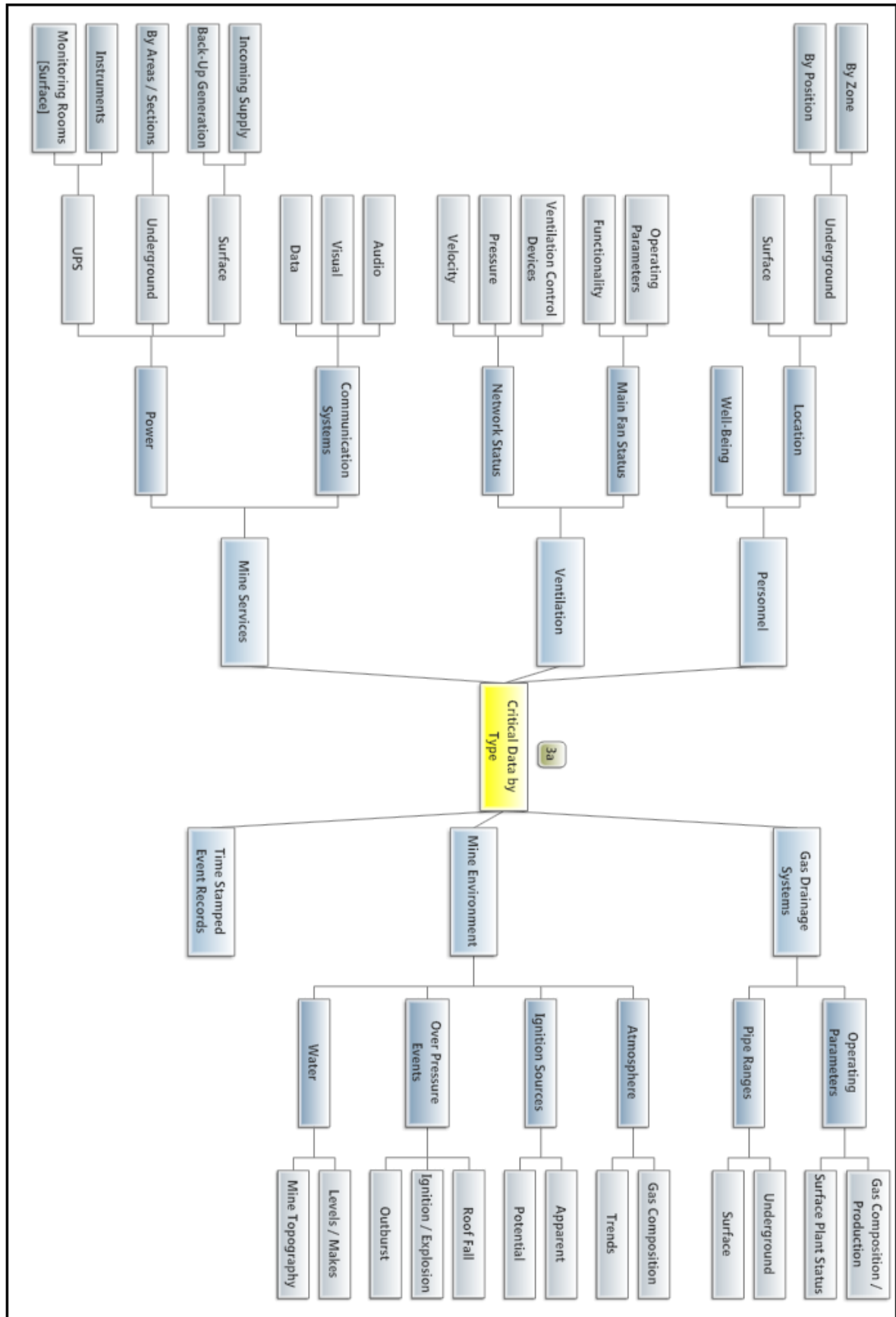


Figure 1 - Critical data by type

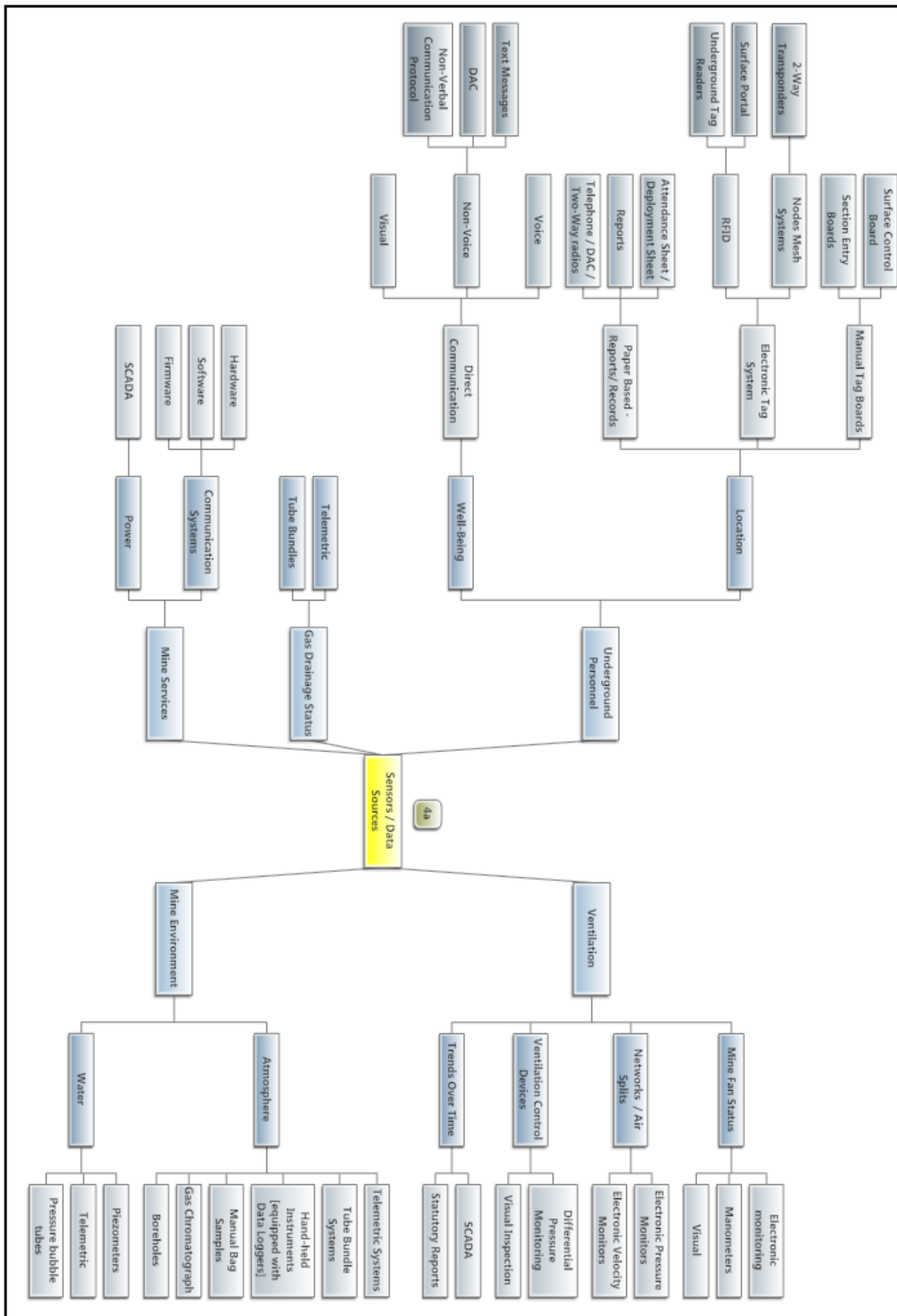


Figure 2 - Critical sensors/data sources

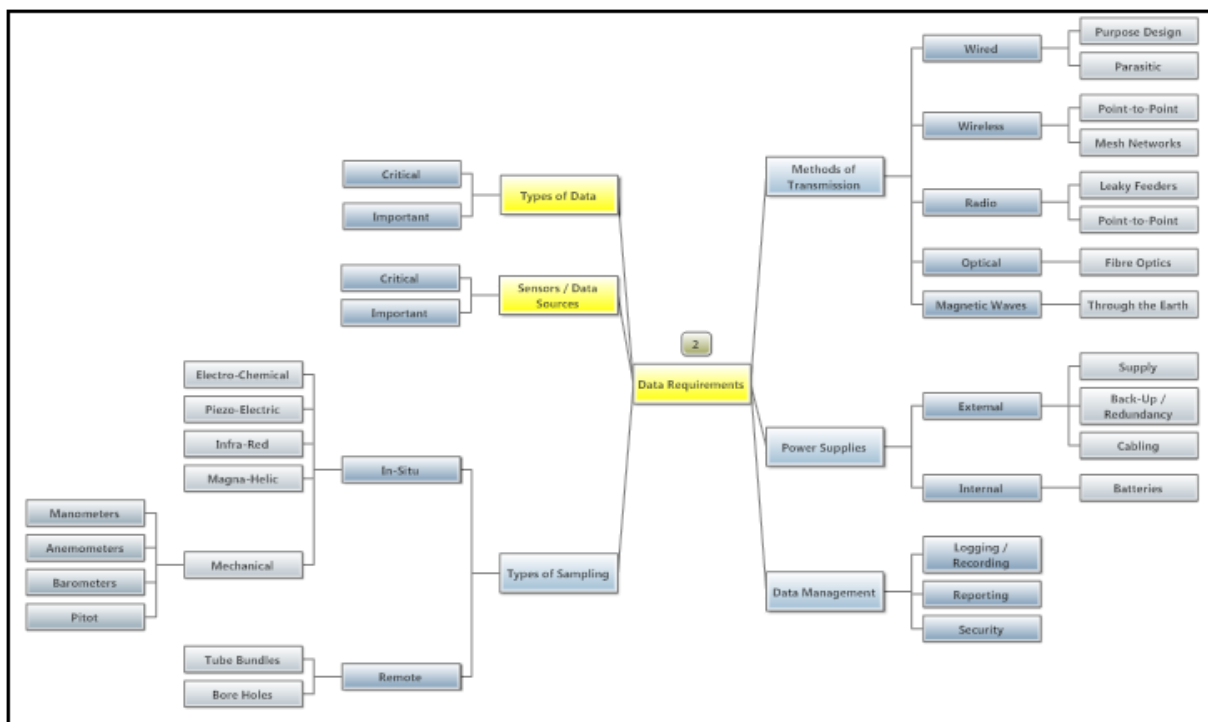


Figure 3 - Data requirements

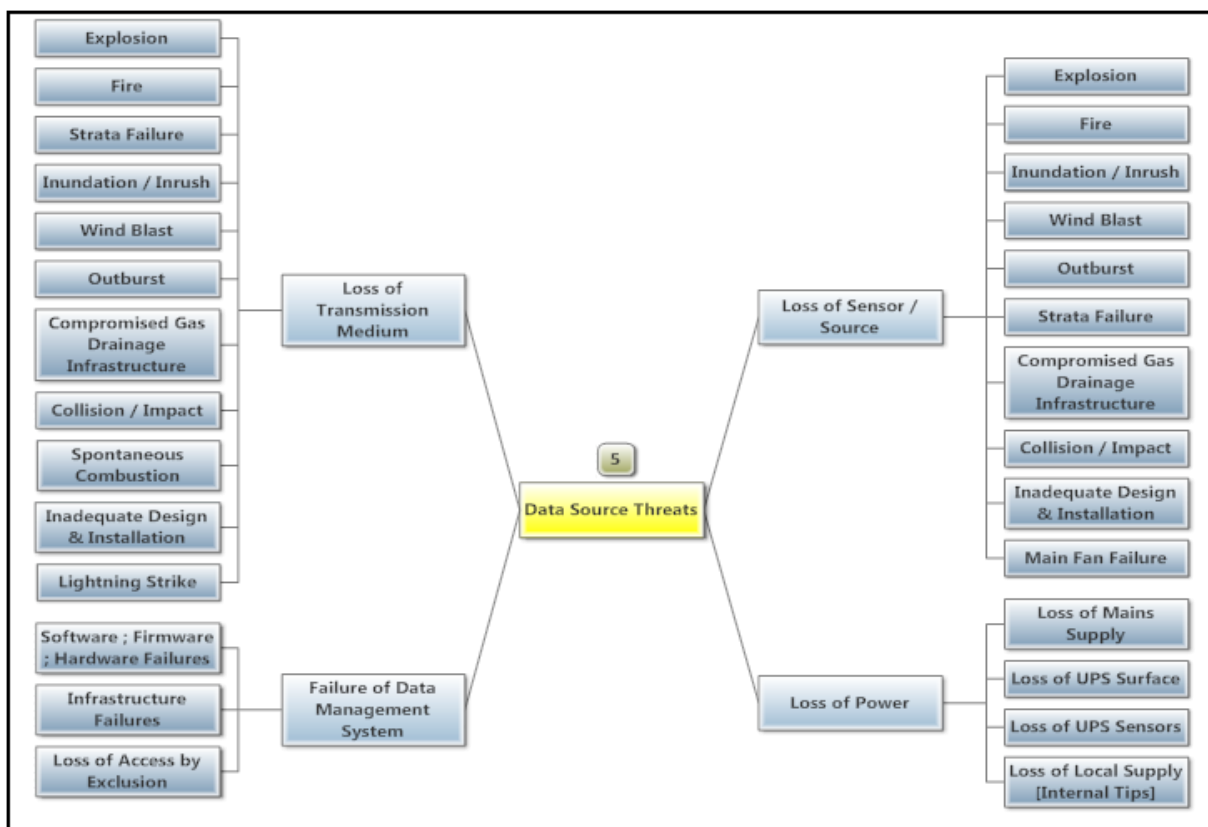


Figure 4- Data source threats

The need for systems with inbuilt component redundancy, to increase the probability that the system could survive an explosion, was also identified. It was determined probable that borehole based systems would be required and if information was to be available in a timely manner these bore holes would need to be pre drilled with a risk based approach utilised to determine required locations.

International mining industry

Communications with international research, statutory and mines rescue organisations revealed similar issues and concerns with the survivability of critical data and communication infrastructure during or following an event. There has been no evidence that any country has found a solution. The approach of most is to make use of bore holes for monitoring where possible. International attention seems to have focused more on communications rather than data with the United States leading the way.

Following the Sago, Aracoma, and Darby disasters in the United States in 2006 the Mine Improvement and New Emergency Response Act of 2006 (MINER Act) was introduced requiring mine operators to adopt underground communications and electronic tracking (CT) systems to meet specific performance goals (NIOSH, 2011). Two requirements were;

- Submission of an Emergency Response Plan (ERP) that provides for a means of communication with the surface for underground workers with inbuilt component redundancy such as a secondary telephone or equivalent two-way communication. The ERP also must provide for above-ground personnel to be able to determine the current, or immediately pre-accident, location of all underground personnel. Any system so utilised must be functional, reliable, and calculated to remain serviceable in a post-accident setting.
- Submission of plan for approval that provides for post-accident communication between underground and surface personnel via a wireless two-way medium, and an electronic tracking system that permits surface personnel to determine the location of any persons trapped underground or set forth within the plan the reasons such provisions cannot be adopted. Where such plan sets forth the reasons such provisions cannot be adopted, the plan must set forth the operator's alternative means of compliance. Such an alternative must approximate, as closely as possible, the degree of functional utility and safety protection provided by the wireless two-way medium and electronic tracking system.

These wireless systems often make use of nodes that if configured with redundancy and survivability in mind can continue to operate if a node is destroyed as they are able to "re-route" the communication via an alternative pathway not using that node. There are however still some uncertainties as to the survivability of these systems as they exist but work is continuing to improve them.

Other industries

The project team looked at other industries that also rely on data and information transmitted to a central point from which decisions are made. What was obvious was that underground coal mining was unique in the conditions under which these systems have to operate and what they would be exposed to by way of undesirable events. The petrochemical industry uses similar types of gas sensors but these are installed in open areas unlike those in the confinement of an underground coal mine. In general the installation standards are higher in the petrochemical industry with use made of cable trays and protective ducting for transmission cables. Because they are located on the surface, exclusion zones don't pose the same problems as they do for underground installations and provision of more than one power supply for gas monitoring systems as a contingency to power monitoring systems is much easier to accommodate.

CASE STUDIES

There are enough example cases of data and communications remaining operational after incidents to know that it is possible for systems to survive and worth the effort to protect them in case of such events. There are also cases where systems are destroyed so survivability will depend on amongst other things the nature, location and magnitude of the event. The following are a few examples that highlight where systems have continued to provide information.

Moura No 2 Qld Australia

Workers in the 1NW section at Moura No 2 reported ears popping and some were thrown at the time of the explosion. Contact with the surface was however possible via telephone (this was how the surface learnt of the event). The estimated over pressure at the site of the explosion (512 Panel) was 8psi (Stephan, *et al.*, 1994). A tube bundle system was installed at Moura No. 2 and although not all tubes were sampling from intended locations results from the system and subsequent gas chromatograph

analysis of samples collected via the tube bundle system provided valuable information on the status of the underground environment. These tubes were unprotected but installation was performed to a high standard with tubes attached to a catenary wire being tied off every 300 mm. Subsequent analyses of data coming from the tube bundle system (Golledge, *et al.*, 1995) determined the most likely sampling locations for tubes following the initial explosion to be as detailed in Table 1.

Table 1 - Likely sampling locations following initial explosion

Sampling Point	Original Location	Status
1	4 South	Relocated to same air split as Point 9 17 CIT Dips
3	Fan North Return	Unaffected
4	Fan South Return	Unaffected
5	512 Seals	Severed in 4 South Level
6	5 South Bottom Returns	Severed in 4 South Level and severely pinched
7	5 South Top Return	Severed in 4 South Level
8	1NW Return	Unaffected (integrity doubtful)
9	17 C/T Dips	Unaffected
16	512 Top Returns	Severed in 4 South Level
19	Dips North Return	Unaffected

Pike River New Zealand

It is rare that video evidence of an underground coal mine explosion exists, however the video camera at the portal at the Pike River Mine in New Zealand captured footage of all four explosions in November 2010. The images from the camera provided useful information during response to this disaster including the direction of ventilation flow. The camera was in a position that meant it survived all four explosions. The video along with observations and the condition of the two survivors allow an estimation of the forces and velocity of the initial explosion. The velocity of gas exiting the portal was calculated as being between 30 and 70 m/s (108-252 km/h). Almost 2000 m inbye the portal, was a telephone positioned only one metre from the corner of the main drift and the outbye rib of B1 cut through (Figure 5). In this position the phone would have been exposed to most of the force travelling up the drift. This phone was fixed to a rib bolt whereby the bracket of the phone slipped over the bolt and a nut used to hold the bracket in place. The cable was also firmly anchored so that it could not stress the connector, directly below the phone. The cable then ran up the main drift predominantly in the centre of the roadway clipped to a catenary wire. This phone withstood the velocity and over pressure of the explosion and was operational and used by one of the survivors to phone the surface. The standard of installation is the most likely reason the phone remained operational. Observations of installation standards of phones in Australian underground coal mines would suggest that many would not have withstood such an event. Although this phone remained operational after the initial explosion, it may have been better placed on the inbye rib of the cut through where it would have been less likely to be exposed to flying debris and the force of the explosion. The mine's Voicecom (intercom system) at the portal was also operational after the initial explosion but it is not known for certain whether this system or telephones inbye of the phone used at B1 were operational. The mine's real-time gas monitoring system was not operational following the initial explosion.

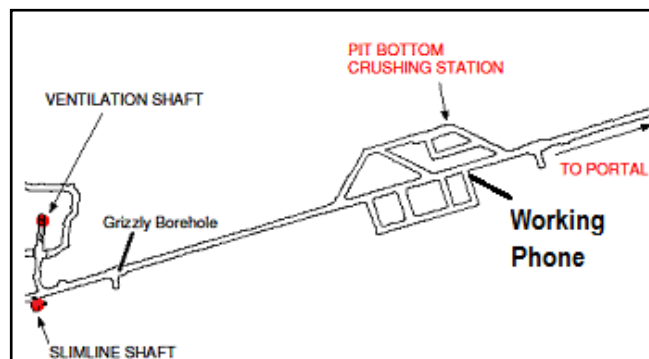


Figure 5 - Location of phone used after initial explosion

Roof fall in drift

A recent significant roof fall in a drift at a mine disrupted communications and power, however six of the eight tube bundle lines in service that were run in the drift survived. The tube bundle installed was in two bundles of five core tube. The five core tube has five tubes encapsulated in an outer protective sheath. Review of vacuum pressures (Figure 6) and sample flow rates (Figure 7) post incident shows that the tubes were not broken but instead squashed. The two tubes that were not operational after the event were squashed to the extent that sample could not be drawn through them, so no measurements were possible.

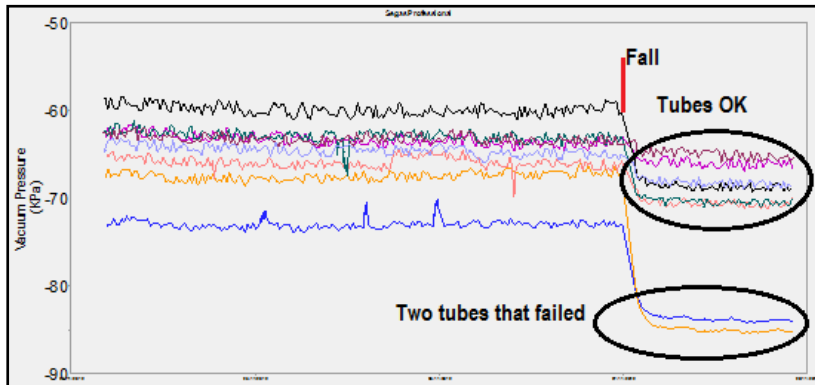


Figure 6 - Tube vacuum pressures

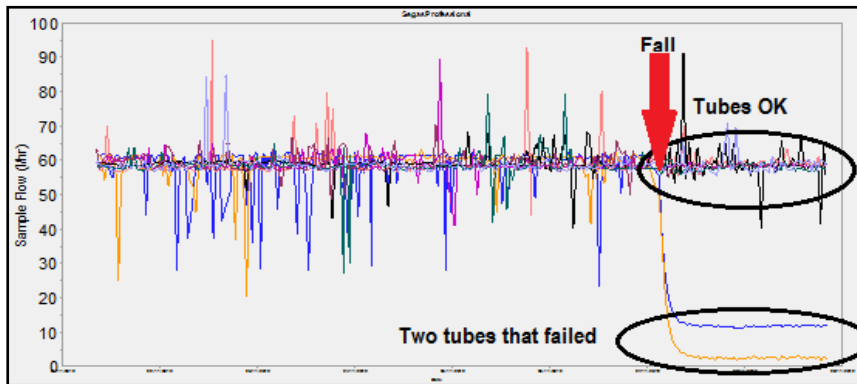


Figure 7 - Sample flows

When tubes are squashed it is important to remember that with the extra resistance leakage paths not previously favoured may eventuate. Any such leakage would influence the accuracy of the results. The onset of leakage in a sample line monitoring an area normally returning low oxygen concentrations (such as a sealed goaf) is easily picked up by an increase in oxygen. It is however more difficult to determine whether a general body type sample is still monitoring from the intended location as increases in oxygen when original samples contain those close to fresh air are difficult to detect. Figure 8 shows there was no change to the oxygen concentration for the location with approximately 10% oxygen and a slight increase in one of the tubes returning over 20% oxygen, indicating that at least some leakage was occurring in this tube. To be assured that general body type samples were still monitoring from the intended locations, review of other gas components would need to be undertaken in conjunction with changes to vacuum pressure.

This example highlights that additional protection of the tubing, in this case the outer sheathing of the five core bundle, can afford the protection required to allow ongoing tube bundle analysis even after a significant fall. Mine sites should evaluate areas of elevated risk for tubes where additional protection is required.

Willow Creek Utah USA

Four explosions occurred at the Willow Creek Mine over 31 min beginning 11:48pm 31st July 2000. A Personal Emergency Device (PED) system was in use at the mine, and was instrumental in alerting miners underground of the need to evacuate with miners working in active and remote areas of the mine

at the time of the explosion notified using the PED. These miners all safely exited the mine (Mckinney, *et al.*, 2001).

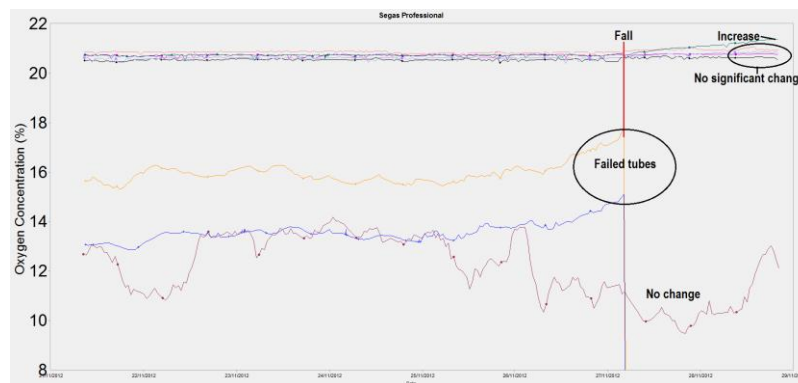


Figure 8 - Oxygen concentrations

Following the initial explosion on the headgate (maingate) side of the D-3 goaf elevated CO readings occurred in the bleeder entries and in the D-3 No. 1 headgate entry. The monitors near the headgate bleeder connector regulators experienced a communication failure. Data from the CO monitors near the tailgate regulators at the bleeder entries indicated concentrations in excess of 50 ppm (maximum sensor could measure) shortly after the explosion. Data from the CO monitor at MPL B2 showed that the concentrations began to increase approximately 21 min after the explosion and, within an additional two minutes, the readings were in excess of 50 ppm. Data from the CO monitors in the No. 1 headgate entry outbye the face revealed that elevated concentrations of CO occurred at the monitor locations near the longwall face. Data from each outbye sensor also showed elevated concentrations. This explosion occurred in the No. 1 headgate entry of the D-3 section near the longwall set-up rooms and is estimated to have generated pressures of approximately 5 psi near the origin. The force exiting the headgate into the bleeder entries was approximately three psi. The force reaching the tailgate bleeder regulators was probably two psi.

This example shows how monitoring sensors are not all necessarily destroyed. It also highlights the problem of measuring ranges for these types of sensors, often limited to 50 ppm, which is fine during normal operations but off scale during an event.

THE NEXT STAGE

Although the extension project is still not completed, the project team has collected enough evidence to show that the likelihood of survivability of data and information sources can be increased by fitting mechanical protection and improved installation standards including the siting of hardware. To assist mine sites improve the chance of ongoing data and information supply ACARP have approved further funding for the project team to conduct testing that will expose modified/protected hardware and transmission media to over pressure events and flame fronts to establish best practice based on scientific and engineering testing.

CONCLUSIONS

- General practice at most Australian underground coal mines is for mine communication and monitoring systems to be designed, located and installed to address the proactive risk management of principle and major hazards but give little consideration to a system's purpose, requirements or functionality post any incident - systems are currently designed and installed for "peace time mining".
- It is possible for monitoring systems and communications to remain operational after events, including explosions.
- Installation standards and siting of hardware can have a significant influence on the survivability of systems delivering critical information.

- Post incident use should be considered in specifications, installation standards and location of data and communication infrastructure.
- More can be done to ensure that data required and communications are available post incident.
- Unless improvements are introduced to increase survivability of critical sources of data and information, significant delays to aided rescue can be expected.

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