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2005

## Real-Time Risk Analysis and Hazard Management

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### Recommended Citation

G. Einicke and G. Rowan, Real-Time Risk Analysis and Hazard Management, in Naj Aziz and Bob Kininmonth (eds.), Proceedings of the 2005 Coal Operators' Conference, Mining Engineering, University of Wollongong, 18-20 February 2019  
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# Real-Time Risk Analysis and Hazard Management

G Einicke<sup>1</sup> and G Rowan<sup>2</sup>

## ABSTRACT

Safety remains a critical priority for the Australian mineral resource industry and will receive increased focus in the future. This is particularly evident in underground coal mines where reserves are becoming deeper and more hazardous to extract. The CSIRO, through its Exploration and Mining Division, have recently delivered on two projects aimed at providing step-change capabilities in real-time risk management and hazard control. This paper describes the key outcomes of these projects.

## INTRODUCTION

The Australian Coal Association Research Program (ACARP) funded Location And Monitoring for Personnel Safety (LAMPS) Further Development project has completed the development of a system for the real-time location of personnel throughout the workings of a mine. The system includes:

1. an IEC EX ia (intrinsically safe) transmit-only tag that possesses an internal battery; and
2. an IEC Ex ia (intrinsically safe) tag reader for installation in explosive risk zones (ERZO or ERZ1).

The internationally funded Enhanced Mine Communication and Information Systems for Real-time Risk Analysis project offers unique capabilities for the real-time monitoring and management of hazards in our mines. The project, funded by the Japan Coal Energy Center (JCoal), ACARP and the CSIRO has been installed at Anglo Coal's Grasree mine and is currently undergoing extensive field-trials.

The system, known as Nexsys™ consists of both software applications and IEC Ex ia (intrinsically safe) hardware that provides for:

1. the real-time sourcing and integration of critical data sets from the range of propriety systems already in place at a mine, including the location of personnel and equipment, gas monitoring, strata, ventilation and SCADA systems;
2. analysis through a rules-based inference engine, development of 3D trigger action response plans, historical analysis and action logs; and
3. state-of-the-art 3D graphic interfaces and autonomous call-up the latest mine plans and current workings.

The system utilises fully managed, ethernet based communication protocols over multi- or single-mode fibre optic cables allowing for the future integration of the ever increasing array of ethernet enabled device (eg PDAs, VoIP phones, web-cameras, wireless ethernet sensors, virtual environments and base stations, training and emergency response technologies).

## RECENT DEVELOPMENTS IN LOCATION MONITORING

### Overview of LAMPS developments

The LAMPS system was developed by CSIRO and supported by two rounds of ACARP funding (see <http://www.acarp.com.au/>).

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The project commercial partner, MineCom Australia Pty Ltd, guided the developments.

The project outcomes include the development of the intrinsically safe LAMPS type II tag and the intrinsically safe LAMPS type I reader. LAMPS is the first system in which both tags and readers have been certified to the current international IEC standards for use in hazardous regions within underground coal mines.

Patenting action was carried out in the USA, Canada and Australia to protect the LAMPS innovations. The USA patent, No 6 339 709 (formerly Application No 09/448,898), in the name of CSIRO, was granted 15 January 2002, and its potential expiry date is 9 April 2018. The Australian patent, No 753 168 (formerly Application No 6 814 898), in the name of CSIRO, was granted 9 April 1998 and has a potential term of 20 years. The Canadian Patent, No 2 289 752 (formerly Application No 2 289 752), in the name of CSIRO, was granted 3 August 2004 and its potential expiry date is 9 April 2018.

### The intrinsically safe LAMPS type II tag

ACARP, mine personnel and MineCom have independently suggested the development of standalone (or self-powered) active tags. A transmit-only expendable tag, known as the LAMPS type II tag, has been developed. It is powered by an internal lithium battery and the entire tag is completely encapsulated in potting compound. The tag has been designed to meet the international intrinsic safety standards, namely AS/NZS/IEC 60079 Part 0 and Part 11 for Gas Group I.

The LAMPS tag II transmits a packet approximately every three seconds and has a lifetime of at least two years. A packet re-transmit time of three seconds was selected to permit detection of underground mine personnel travelling in vehicles at (say) 10 km/h  $\approx$  2.8 m/s. Suppose that readers can intercept tag packets at a minimum range of  $\pm 5$  m, then the minimum packet capture envelope for a vehicle travelling at 10 km/h will be 10 m/2.8 m/s = 3.6 seconds: thus a retransmit time of three seconds should be adequate. If the reader is mounted on the roof along the centre of the drive then underground mine reader ranges of at least  $\pm 50$  m can be expected. This provides a design safety factor of ten, in order to accommodate faster vehicle speeds, packet collisions, radio propagation anomalies and noise. A photo showing the potted LAMPS tag II is shown in Figure 1. The LAMPS type II tag for example can be easily attached to any cap-lamp battery cables as is shown in Figure 2.

The intrinsic safety assessment of the LAMPS type II tag has been completed by the Safety in Mines Testing and Research Station (SIMTARS) (see <http://www.nrm.qld.gov.au/simtars/>). The certificate of conformity is available for inspection at <http://www.mining-automation.com> and following the link to the LAMPS project. In 2004, the LAMPS type II tags are priced by MineCom at less than \$100 each. Since the tags are predicted to last for over two years, the annual cost of increased personnel safety is less than \$50 per person.

The primary application of LAMPS is to assist with personnel safety management. The system can provide last time and identified location of personnel. This information can be used to ensure that there is adequate provisioning of safety equipment underground. Some mines have up to 30 km of underground roadways. Consequently, considerable time is often spent searching for underground equipment. Since the LAMPS type II tags are standalone, they can be used to track any mobile assets such as vehicles, which is expected to have a productivity benefit.



FIG 1 - Potted LAMPS type II tags.



FIG 3 - External view of the LAMPS type 1 reader.



FIG 2 - LAMPS type II tags mounted on GT2 battery cord (left) and GT5 battery cord (right).

**Tag-reader performance**

Aboveground trials of the LAMPS type II tags were conducted between 25 and 27 October 2004, along a meandering section of roadway shown in Figure 5. A LAMPS reader was mounted on the bottom side of a metal boom at a height of 2 m above the roadway. A utility vehicle, with various numbers of tags located on the floor of the passenger side, was repeatedly driven underneath the reader at approximately fixed speeds.

The reader was oriented with the antenna side pointing downwards. The tags were oriented upright so that the antenna side is pointing upwards. The vehicle was driven under the reader, four times, for each combination of four, eight, 12, 16 and 20 tags, and ten, 20, 30, 40, 50 and 60 km/h vehicle speeds. The observed tag detection statistics are provided in Table 1.

**The intrinsically safe LAMPS type I reader**

An external view of the LAMPS type 1 reader is shown in Figure 3. The readers have three pairs of optical fibre HFBR 1414 transmitters and HFBR 2416 receivers for interconnection with other readers or computers. A media converter has been developed for RS232 and RS485 connectivity. The output of the HFBR 1414 optical fibre transmitters is around - 12 dB, whereas the sensitivity of the HFBR 2416 optical fibre receivers is at least - 30 dB, which provides a dynamic range of at least 18 dB. Allowing about 2 dB for connector losses, the length of fibre optic cable between readers can be at least 16 dB/4 dB per km = 4 km, which is consistent with the gate roads of longwall mines.

An intrinsic safety assessment and certification of the LAMPS type I reader has been completed by SIMTARS. It is recommended that readers are installed in pairs, which enables the direction of personnel travel to be inferred. Walls, pipes, conveyors and other obstructions in close proximity to readers can reduce the available tag detection range. Therefore readers should be installed over the centre of the roadway to maximise the tag range. It is desirable that multiple cables are installed from the readers to the surface in order to reduce the impact of underground failures. For example, installing two cables to the surface as shown in Figure 4b, is preferable to installing a single cable to the surface as shown in Figure 4a.

**TABLE 1**

*Observed aboveground LAMPS type II tag detection statistics.*

	10 km/h	20 km/h	30 km/h	40 km/h	50 km/h	60 km/h
20 tags	100%	100%	100%	100%	91%	90%
16 tags	100%	100%	100%	100%	92%	92%
12 tags	100%	100%	100%	100%	100%	88%
8 tags	100%	100%	100%	100%	100%	94%
4 tags	100%	100%	100%	100%	100%	100%

The tag detection rate decreases for increasing vehicle speeds and increasing numbers of tags in the vehicle. In the case of the above-ground trials, where there are no intervening obstructions between the overhead reader and the vehicle, it was observed that up to 20 LAMPS type II tags can be reliably detected when the vehicle speed is not greater than 40 km/h. There are two factors that contribute to decreased detection rates with increasing numbers of tags and vehicle speeds. First, since the detection range is fixed, the detection time window decreases with increasing vehicle speeds. Second, the tags transmit asynchronously, resulting in more packet collisions (ie packet errors) within increasing numbers of tags.

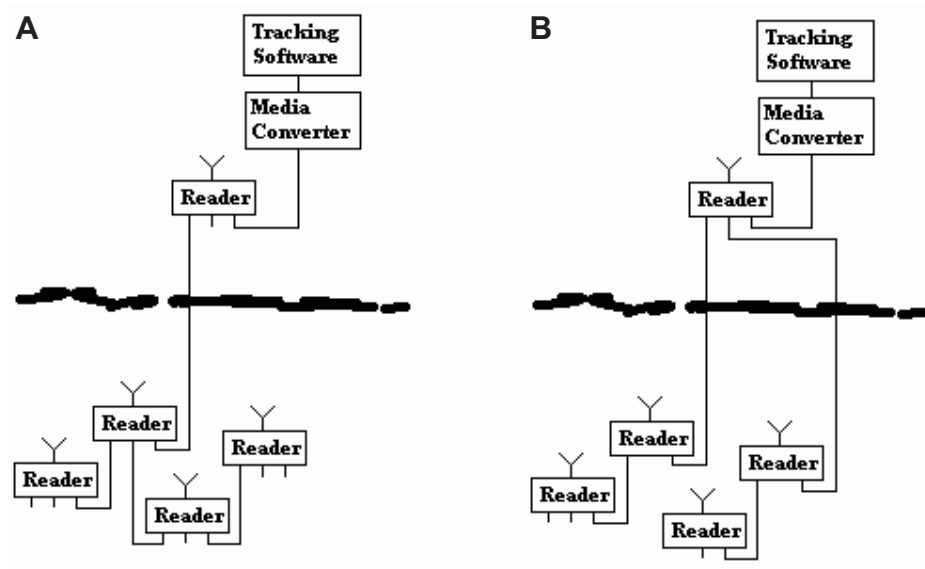


FIG 4 - Underground to surface reader cable connections. (A) A single cable connection to the surface is vulnerable to underground failures. (B) A two cable connection to the surface is more robust to underground failures.

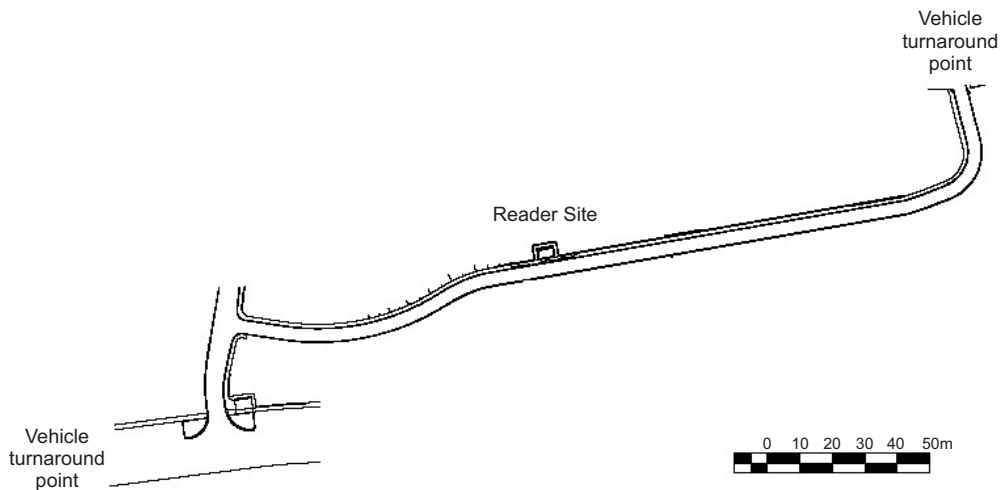


FIG 5 - LAMPS surface trial site map.

It was observed that the aboveground detection range was around 100 m from the reader. In some underground mine trials at the Enterprise Mine in Mt Isa, detection ranges of around 50 m were observed. Therefore, it is expected that up to 20 LAMPS type tags could probably be detected at 20 km/h underground, provided that similar reader/tag orientations and geometries prevail.

**REAL-TIME RISK MANAGEMENT**

**Drivers**

Over the past 20 years, there have been an array of catastrophic incidents resulting in tragic losses of life and millions of dollars lost in capital items and sunken costs.

Spontaneous combustion events have resulted in:

- open fire leading to the closure of the Leichhardt colliery in 1982;
- CO levels in Aberdare North’s goaf rising from 100 - 3000 ppm in 12 hours – the mine was sealed at the surface; and

- CO levels at the fan in Ulan in 1991 jumped from 0 to 3000 ppm in 60 minutes with the mine remaining off-line till March 1992.

Fires at Appin 1976, West Wallsend in 1970, Liddell State in 1971 and Avon Colliery in 1976 all had significant financial and social impacts. Gas and coal dust explosions have also left their legacies on the Australian mining psyche – Appin 1979 (14 lives), Box Flat 1972 (17 lives), Kianga 1975 (11 lives), Moura No 4 1986 (12 lives), Moura No 2 1994 (11 lives) are disasters which still serve as a constant reminder of the vigilance required in underground coal mines.

Yet, close scrutiny of the various inquiries, inquests and reports lead to the observation that in many cases, predictive data was available as precursors to these events (Figure 6). However, this data was often incomplete, only available from separate and proprietary monitoring systems, could be difficult to access, and was sometimes ambiguous and often contradictory.

Further analysis of the post-incident management of these catastrophic events indicate a number of inherent difficulties faced by those charged with ‘incident management’. Such issues include having to make decisions based on less than ideal data,



## Complex Communication Channels – Level 1 Exercise 2002

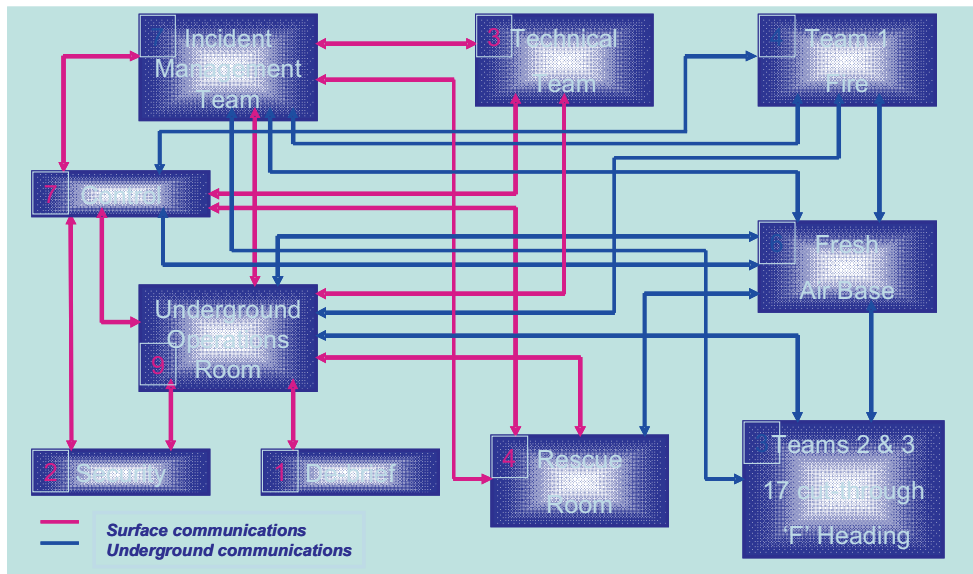


FIG 6 - Complex communication channels.

these decisions are often made without the knowledge of their ultimate consequences and sequences of events once initiated, are often irreversible.

Further, the control systems in place are often algorithmic in nature and follow a simple, straight-line logic with each action preceding another, viz:

1. at the first sign of smoke don your self rescuer,
2. gather at the crib room and wait for advice,
3. if instructed, evacuate via the primary escapeway, and
4. if unable to use the primary escapeway, evacuate via the second egress.

Such procedures, whilst elegant in their simplicity, do not however, allow for the inevitable complexities that encompass an underground mining disaster. They do not allow for experience or intuition (no-one will put on a self-rescuer at the first sign of diesel exhaust), they do not provide for people to consider options or develop 'what-if' scenarios before taking action (why wait, for how long, what if everyone doesn't arrive, what if someone's hurt, what if smoke is coming but not yet arrived) and they do not allow for the human decision-making process (will they evacuate as individuals or teams, will they risk lives to help others, will they or should they be told the 'best' way to go).

Today, mine monitoring and data communication systems are increasingly complex and diverse. Different proprietary systems monitor the mine atmospheres, the strata devices, machinery and equipment, conveyors, pumps, fans and other infrastructure as well as report on haulage systems and belt winders. In fact, today's modern computer networks and SCADA systems can pour over 20 000 separate data bits into our control rooms every few seconds – most of which is fastidiously collected and recorded, then studiously ignored.

People don't have the time or capacity to digest all the data. The Nexsys™ Real-time Risk Management System seeks to provide a solution to some of these issues.

### Nexsys™ Real-time Risk Analysis System

The Nexsys™ Real-time Risk Management System is a combination of IEC Ex ia (intrinsically safe) certified hardware devices and integrated software programs.

Funded by the Japan Coal Energy Center (JCoal), CSIRO Exploration and Mining and the Australia Coal Association Research Program (ACARP) the project is in its third year of development. Field trials and installation tests are being conducted with the invaluable support of Anglo Coal's Grasree mine with a recent installation being trialled at the Kushiro coal mine in Japan. Plans are underway for the installation of the system at a third (yet to be selected) operating longwall mine in Australia.

The objectives of the project are to:

- deliver step-change capability in critical monitoring, data integration, decision support and personnel safety;
- development of an intrinsically safe communications backbone using broad-band, high speed ethernet protocols and fibre-optic data highways;
- provide real-time hazard analysis and risk profiling; and
- develop 'knowledge management' capability.
- *must be in use as part of normal day-to-day activity.*

### Developments to date – hardware

Key to the delivery of risk management critical data to the end-user, is a robust, high speed, intrinsically safe communication backbone. It was determined early in the project that the most suitable communication system would be the one that the world at large has embraced and which appears to have unlimited potential – the ethernet.

To this end, two devices have been developed. The first is a communication protocol converter (Figure 7) that can convert the serial communications protocols used by most current-loop sensors, into the language of the ethernet – TCP/IP and UDP. For those not so technically minded, it is in effect a language translator. This first such device developed was a Modbus Serial into Modbus Internet Protocol converter (akin to an Spanish-English translator) but recent developments have seen the device further developed with the capability of converting *any* serial protocol into internet protocols (a universal language – English translator).



FIG 7 - NEXSYS communication protocol converter.

The second device is a high-speed, fully managed ethernet switch. Using the latest in fibre-optic transceiver technology, the switch can be configured in any combination of 10 Mbps and 100 Mbps transfer speeds over either multi-mode or single-mode fibre. The switch has up to four ports and can be daisy-chained together and provide true V-LAN trucking capability.

Both powered by independent IEC Exia power supplies, these two IEC Exia designed devices will provide the capability to connect any serial output monitor and/or sensor with any other ethernet enabled device onto a single, high speed communication highway that is not limited by distance, will remain active during power loss, ventilation failure or the accumulation of explosion atmospheres and provide multiply redundant pathways and routing.

A further hardware device developed as part of this project is the e-Reporting System (Figure 8). This device is a stainless steel tablet that captures handwritten information, such as deputy reports, production reports, maintenance reports, etc that are typically written underground and transferring then instantaneously across the LAN. In this way, people can be made aware of the status of the section and/or schedule the next shifts maintenance and production based on the latest information. The time differences between the writing of a report and its posting on the surface, together with the time consuming tasks of contacting people underground so that the next shift plan can be drawn and the crews briefed represents a significant cost that the e-Reporting System could help alleviate.



FIG 8 - e-Reporting System.

## Developments to date – software

### Integration

One of the early challenges facing the project was establishing a means whereby the critical data from the different proprietary systems could be identified, sourced and integrated into a single set for further analysis and query.

The key deliverable from ACARP Project No 12011 Mine Integration of Robust Gas Monitoring and Communication was a generic group of software ‘connectors’ that can be installed at any mine and configured to connect a central data-base to the range of other data monitoring and collection systems (eg CITECT, Macro-view, Access, any OPC compliant systems and SQL database). This group of modules – referred to as the Integration Layer thereby provides for a single database to interrogate and read all of the safety critical data sets from these different source systems and separate them from the noise of 20 000 other data bits typically being monitored at today’s modern mines.

### Application

A software system known as the Nexsys™ Real-time Risk Management System is the cornerstone of the project.

### The role of the Nexsys™ Real-time Risk Analysis System

The Nexsys™ system is a risk and hazard management tool for underground coal mines. The tool monitors real-time critical data from a collection of sources and detects potentially hazardous combinations of mine conditions. Mines will be able to define their own critical sources of data from any monitoring system they have in use, such as ventilation, strata, and pre or post-gas drainage systems, etc. Users can define rules for combinations of data sources. A rule inference engine continuously checks whether the prevailing mine conditions satisfy the rules and if warnings or alarms are warranted. In the event that alarms are raised, appropriate diagnostic guidance and trigger action response plans are then communicated to the appropriate personnel.

The system resides in the control room but, through its client-server architecture, can be accessed by any personnel connected to the LAN either on-site or remotely. Site senior executives and mine managers are able to view and analyse hazard profile data in a way that provides a big picture overview of the current risk status of their operations, to analysis current circumstances and to act upon any risks via the integrated decision support capability.

Statutory inspections are a critical necessity to a mine’s operation. The system includes capabilities to record and report any current and/or potential hazards in real-time to a mine-wide reporting system. Coupled with multilevel mine plans showing (among other things) the location of safety equipment together with interfaces to personnel/vehicle location monitoring, the system should reduce the level of unknowns when emergency incidents occur.

### A quick tour of Nexsys™

Nexsys™ automatically uploads the latest mine workings plan. This feature is not currently available within any real-time SCADA system. This feature allows the user to: view and navigate through a three dimensional view of the mine plan; zoom in/out to/from particular locations; fly through the mine manually or via a sequence of waypoints; specify a district; turn on/off different layers of the mine plan, and manage the decision support capabilities.

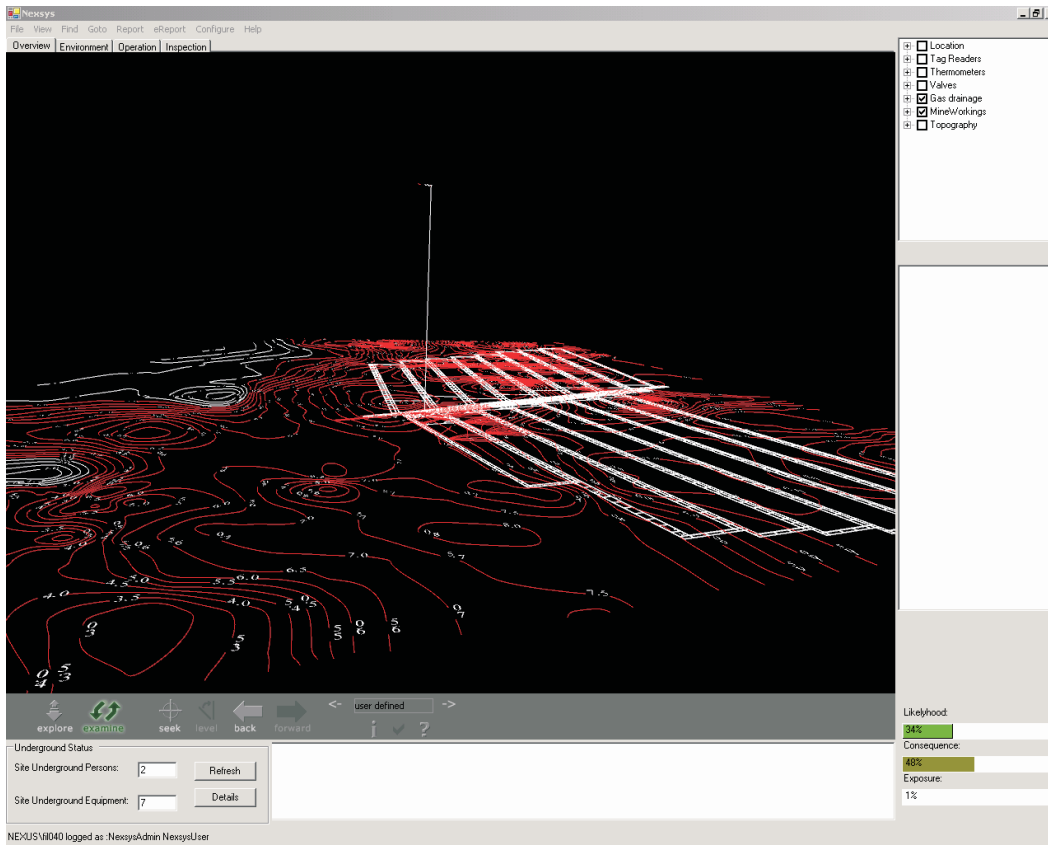


FIG 9 - Viewing mine plans.

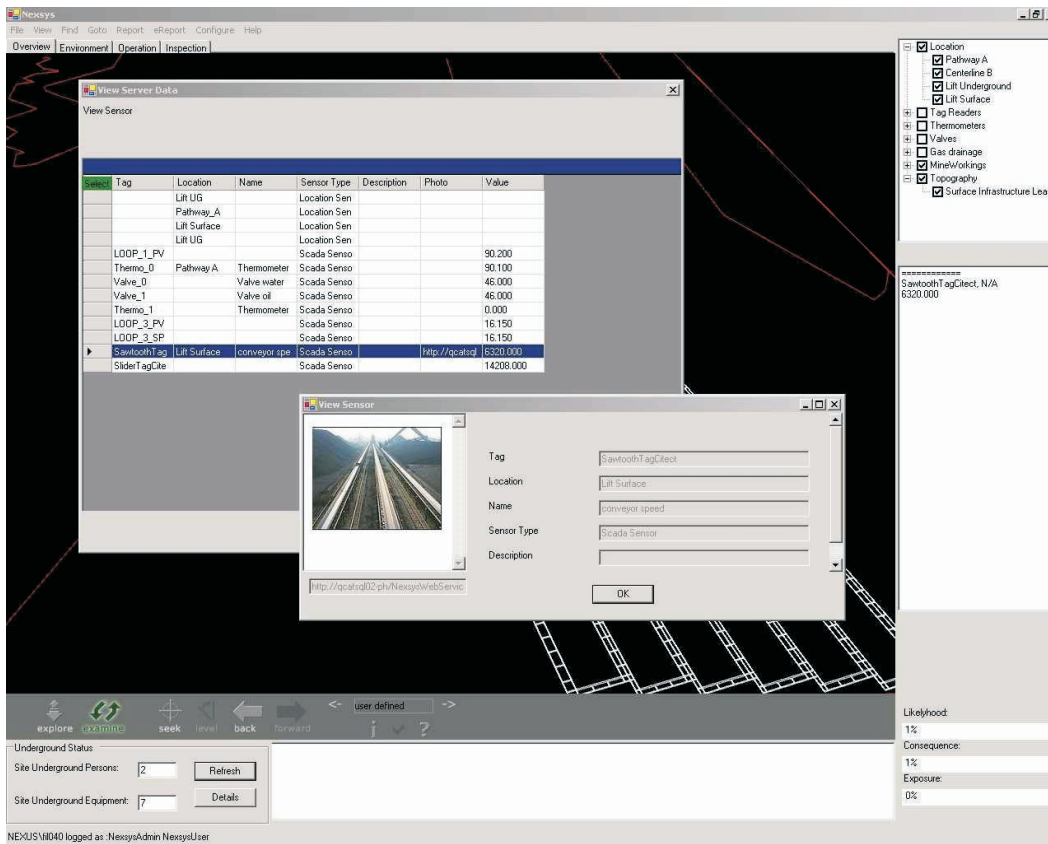


FIG 10 - Viewing sensor information.

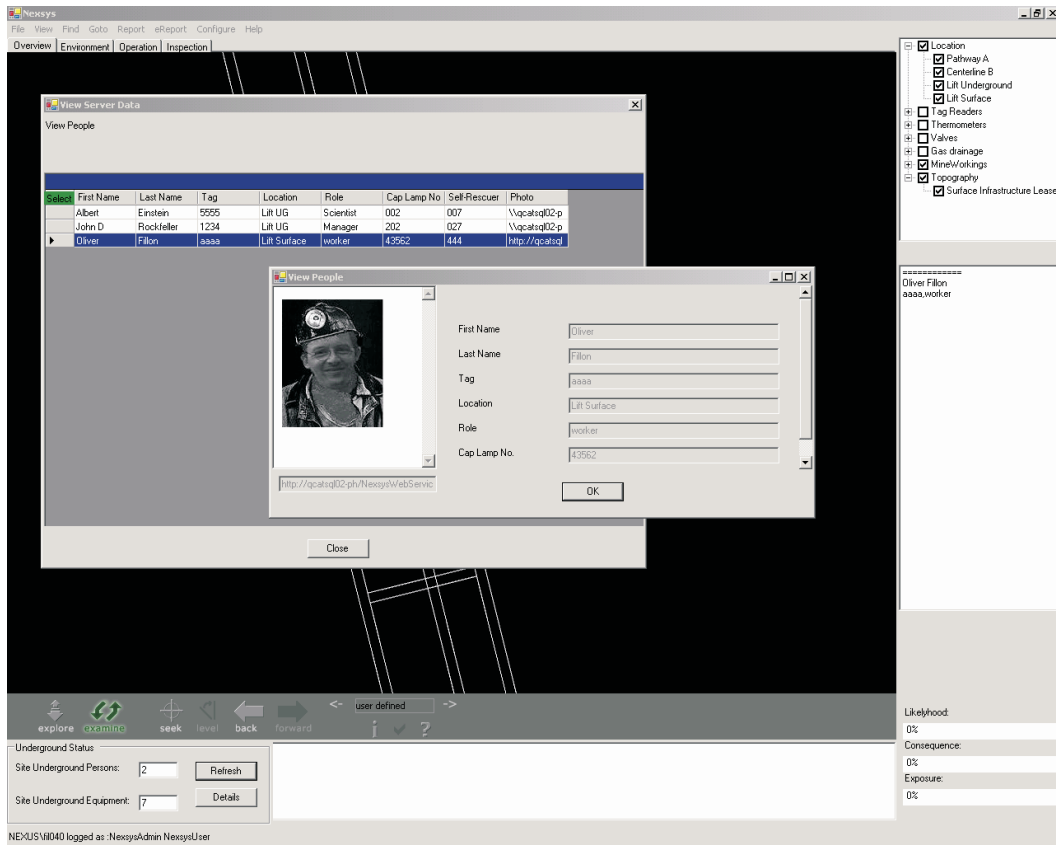


FIG 11 - Viewing personnel location.

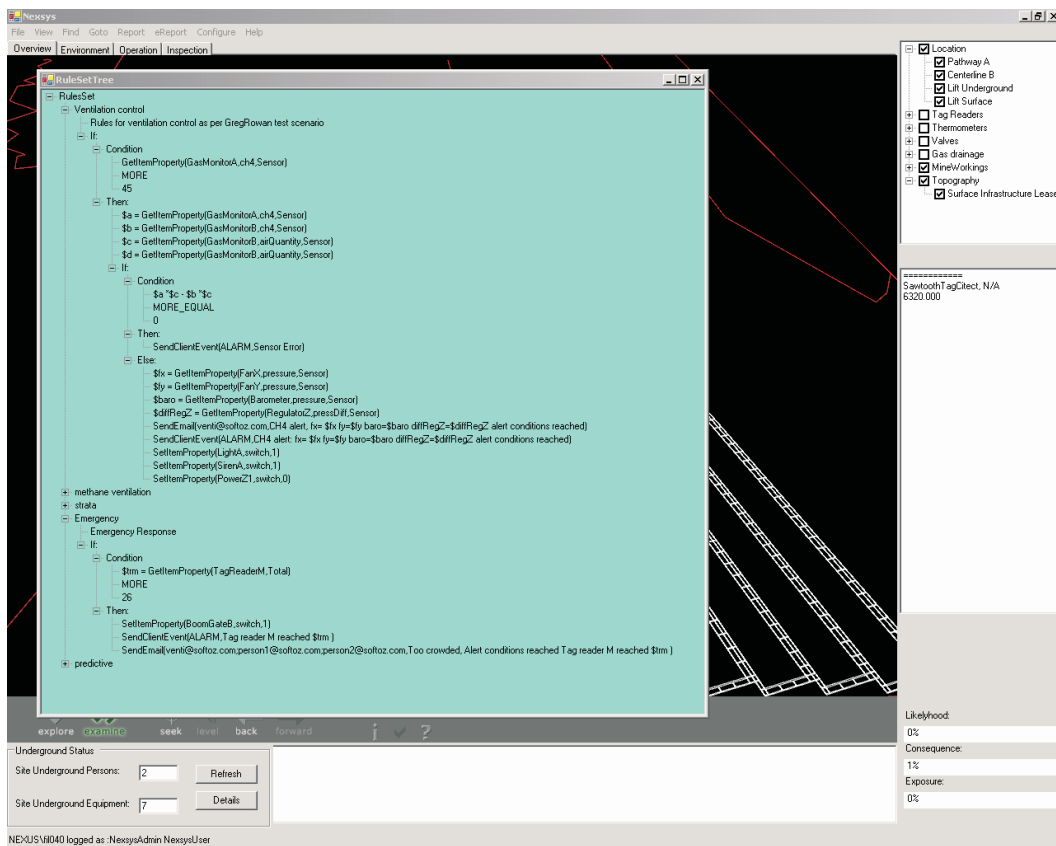


FIG 12 - Viewing decision support rules.



The main graphical user interface system is shown in Figure 9. The mine plan can be seen in the main window display. All mine plans are automatically updated from a surveyor drawing file (ie a dxf file). Users can select to view various levels of the mine plan via the use of the check boxes shown on the top right-hand-side of the figure. The navigation controls can be seen along the bottom left-hand-side of the figure.

Any number of SCADA systems can be connected to the Nexsys™ system and selected sensor information displayed in one composite view. An example screenshot of sensor information is shown in Figure 10.

Nexsys™ can connect to location monitoring systems and display the last known location of personnel, vehicles and equipment. The location information is displayed as icons on the 3D mine plan. As is the case with sensor icons, users can click on location icons to access corresponding textual and image information as shown in Figure 11.

The decision support capability provides users with current status information and notification when rule criteria have been met. A combination of equipment, gas, ventilation, geotechnical and location information can be used to within rule definitions. An example rule definition is shown in Figure 12.

## CONCLUSION

This paper has reported the key outcomes from two recently completed ACARP projects.

The LAMPS project has produced intrinsically safe tags and readers. This is the first location system that can be installed in hazardous regions of underground coal mines. The system reports the last known location of personnel. In 2004, tags are priced at less than \$100 each. Since the tags are predicted to last for over two years, the annual cost of increased personnel safety is less than \$50 per person.

Knowledge of the last known location of personnel and equipment is only a part solution to the problem of improving the management of safety. The Nexsys™ developments provide a step change in risk and hazard management. In particular, the system performs the functions as follows:

1. it integrates multiple disparate systems, including LAMPS and SCADA systems such as CITECT, within one common application;
2. the latest multi-layer mine plan information is automatically uploaded and accessible in the control room; and
3. provides a decision support capability in which a rule inference engine filters incoming mine data, checks whether hazardous conditions exist and optionally provides notification of warning advice including trigger action response plans.

However, irrespective of the introduction of new technologies, the responsibility for managing risks remains on the shoulders of our proactive and vigilant workforce.