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The Nexsys Real-time Risk Management and Decision Support System: Redefining the Future of Mine Safety

Kerstin Haustein
CSIRO Earth Science and Resource Engineering

Eleonora Widzyk-Capehart
CSIRO Earth Science and Resource Engineering

Peter Wang
CSIRO ICT Centre

Dean Kirkwood
Mining Logic Solutions

Ricky Prout
Mining Logic Solutions

THE NEXSYS™ REAL-TIME RISK MANAGEMENT AND DECISION SUPPORT SYSTEM: REDEFINING THE FUTURE OF MINE SAFETY

Kerstin Haustein[1], Eleonora Widzyk-Capehart[1], Peter Wang[2], Dean Kirkwood[3] and Ricky Prout[3]

ABSTRACT: Underground coal mine control rooms are inundated with data but there remains a lack of information enabling timely decision making. Control room operators' cognitive abilities are stretched beyond their limits; processing of the vast array of data sourced from multiple, non-compatible proprietary systems coupled with old communications systems makes the job of a control room operator extremely challenging, if not impossible, particularly in emergency situations when speed and accuracy are of great importance.

The CSIRO has developed a real-time risk management software called Nexsys™. Nexsys™ is a decision-support system designed for the collection and integration of disparate mine data, real-time analysis of safety critical data and real-time risk profiling using rules-based trigger action response plans. The system allows access to a wide range of risk management data in an easily interpretable format and in real-time, such as, availability of messaging and tracking data to precisely determine the location of all personnel, vehicles and equipment at all times. Through compatibility with an optical fibre underground communication network, which uses intrinsically-safe equipment and keeps the data network alive during power shutdown, an access to sensor data during emergency conditions (power shutdown) is available. The software system has a risk preventive and predictive capability, ability to track people and equipment underground, and the provision of 2-way communication via the operator's interface. The system is designed to make risk management-related data immediately available to the operator and to reduce the amount of irrelevant and unnecessary data, such as false alarms.

Nexsys™ has the potential to radically reshape safety in the underground coal mining industry and has the future potential to be adapted to surface coal mining, metalliferous mining and non-mining applications, where safety and decision support are critical operational characteristics.

INTRODUCTION

The dangers associated with underground mining operations raise a compelling need for risk management and accident prevention. It is certainly true that the coal mine control room of 2010 is infinitely more sophisticated than its predecessors; however, during each shift, millions of bits of data can be transmitted into a control room from all areas of mine operation and covering everything from gas levels to temperature, movements of mining equipment, and personnel location. While significant advances in solving problems associated with transmitting data within mines has been made over the last several years, the challenge remains in the ability to analyse these massive amounts of data and convert it into useful information for both production and safety management. In particular, emergency situations place extreme demands on effective information management, both in the response to the development of a potentially safety-critical situation and, if unavoidable, during an incident itself.

Many incident and accident evaluations have shown that although predictive data was available, it was often too ambiguous, incomplete or scattered across a number of disparate proprietary systems to effectively deliver vital information to mine site personnel in a form that would allow appropriate pre-emptive responses (Einicke and Rowan, 2005). If this data had been properly managed and interpreted, it is likely that many of the incidents or accidents could have been prevented or their consequences reduced. Cliff and Grieves (2010) stated that "the control room in particular is a key area where accurate information is required during an incident especially in the early stages until a senior mine official can take charge. The control room remains the first point of contact during an incident for most personnel. Speedy evacuation and in-seam response is predicated upon knowing what is happening and

[1] *CSIRO Earth Science and Resource Engineering, Brisbane QLD 4069, kerstin.haustein@csiro.au*
[2] *CSIRO ICT Centre, Sydney NWS 2122*
[3] *Mining Logic Solutions, Mackay QLD 4740*

where everyone is located". They went on to say that currently it was often "impossible for him (the Control Room Operator) to carry out all his designated tasks in a timely and effective manner." This is especially true during emergency situations.

To help control room operators and other mine officials provide accurate, timely information and deliver a Decision Support System for the mining industry, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in collaboration with Japan Coal Energy Centre (JCOAL) and with sponsorship from Australian Coal Association Research Program (ACARP) has developed the Nexsys™ Real-Time Risk Management and Decision Support System. Nexsys™, within its risk management analysis system, is capable of integrating and interpreting data from various proprietary systems to provide safety-critical hazard analysis in real-time, with reference to relevant industry standards.

Prototypes of the Nexsys™ software developed by CSIRO were demonstrated at three mines: the Xstrata Beltana mine, the Anglo Coal Grasstree mine and the JCOAL Kushiro mine, with a commercial version of the software planned for release in 2010 through CSIRO partner, Mining Logic Solutions.

The main characteristics of the Nexsys™ system are described and the outcomes of the system deployment at an underground coal mine in the Bowen Basin, Queensland through the partnership between CSIRO and Mining Logic Solutions are presented.

NEXSYS™ SYSTEM

In September-October 2002, Rowan *et al.*, (2002) undertook a series of discussions with the representatives of the mining industry at Kestrel, Crinum, Oaky No. 1, Oaky North, Moranbah, Grasstree, Central Colliery, North Goonyella and Newlands mines, which focused on the current status of the control room monitoring systems. Subsequently, a number of recommendations towards new developments were compiled addressing the following issues:

- Interface to CITECT, SafeGas and RSVIEW monitoring systems;
- Interface to real-time gas monitoring equipment such as Trolex;
- Reduction in the number of nuisance or false alarms;
- Improvements to the reconciliation/interpretation of underground data;
- Provision of information about the possible courses of actions in the event of critical alarms;
- Provision of appropriate Trigger Action Response Plans (TARPs), in the event of critical safety alarms, and
- Automatic generation of reports to alleviate the workload of control room operators, where possible.

This study formed the basis for the CSIRO-led Nexsys™ Project. Nexsys™ is a mine-wide hazard reporting system that monitors real-time critical data to detect potentially hazardous mine conditions. It integrates data from a range of proprietary systems and independent sensors within a single concise system, providing real-time safety-critical hazard analysis and enabling operators to make informed decisions in safety-related areas. Whereas other mine monitoring systems typically focus on specific aspects of a mine's health and provide relatively simple data analysis and low-level decision support through alarms, Nexsys™ can draw information on the condition of the entire mine and provide a fully interpretative and preventive analysis. Through its data analysis capability over a multitude of domains, Nexsys™ is designed to reduce the uncertainty and variability in the interpretation of this data. It provides continuous monitoring, evaluation and reporting of mining conditions, supports operators in the decision-making process by providing information relevant to activities being undertaken, and allows rapid communication between mine site personnel.

Nexsys™ characteristics

There are several key features of the Nexsys™ system including risk profiling and rule engine, anomaly detection, data analysis for decision support, and mine wide communication and reporting. The Nexsys™ system has been developed using modern C#.NET programming methods. In general, the system consists of a Server, a Client and a Database Management System, each of which can reside on

separate machines located at various sites around the world. In mining applications, the system is usually located in a mine control room. The Client, however, can effectively be located anywhere on the Internet. A typical Nexsys™ installation at an underground coal mine might include a Nexsys™ server in the mine control room connected to and importing data from various proprietary mine computer systems and sensors. Nexsys™ Clients might be located in the mine control room, in offices, or on the laptops of various personnel on and off site. Nexsys™ could also be connected to a personnel and equipment locating system, which would transmit location information back to the Nexsys™ Server and hence the Nexsys™ Clients.

Risk profiling - rule engine

A key feature of the Nexsys™ system is its unique risk profiling matrix, dynamically populated by automated rules based on the mine's TARPs, with each rule having a condition (potentially a rule or hierarchy of rules) that must be met to trigger a particular response. The Nexsys™ Risk Profile matrix (Figure 1), which is based on a standard mine risk profile template, is displayed in real-time on the likelihood-consequence diagram with a user-enabled view of the change in risk over a specified time period. A multitude of rules can be used to generate the overall risk profile.

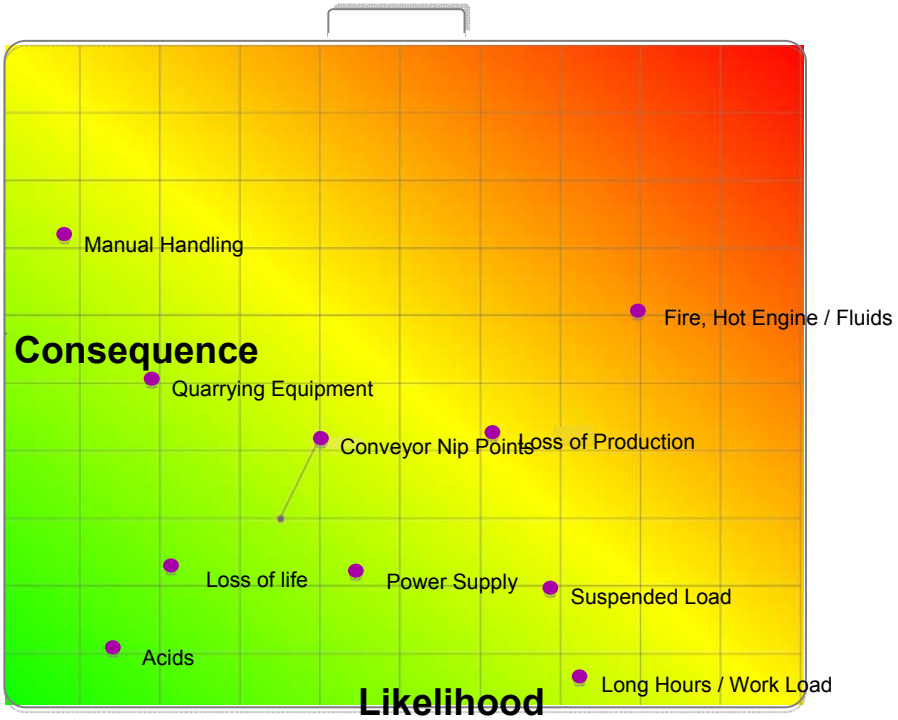


Figure 1 - Nexsys™ risk profile view for underground coal mining applications

The Rules Engine determines a set of actions to be taken based on the state of the data in the Nexsys™ database and a particular sequence of events. This engine can interrogate any data in the system using Boolean logic comparisons. Rules can be defined for each installation of the system at different mines and may be grouped to enable testing of a particular rule in relation to the outcome of another rule. The grouping feature is particularly important when an event, such as equipment stoppage, triggers another event, such as stoppages of equipment down the line.

Nexsys™ provides various alarms triggered by the Rules Engine or the system. When an alarm is raised, a diagnostic analysis is performed, which generates appropriate response plans. This information can be forwarded to the appropriate personnel by way of email/SMS, messaging personnel using a mine messaging system or by updating the Nexsys™ Risk Profile, which compels the personnel to undertake defined actions. For example, if gas sensors readings are above a specified level triggering an evacuation action, an alarm is raised and an evacuation message (as per the appropriate TARP) is sent to miners carrying paging devices in a designated area.
The alarms are divided into three categories:

- New Alarms, which have not been acknowledged by the operator,

- Action Alarms, which have been acknowledged and also require a response from the operator, and
- No Action Alarms, which have been acknowledged but are only alerts requiring no response from the operator.

Each Alarm is categorised as high or low, gas or equipment-related, and, if applicable, its TARP-level is listed. The control room operator can initiate automated responses from the Action Alarms, such as notifying appropriate personnel of their required actions. All triggered alarms are displayed on the operators Alarms View (Figure 2).

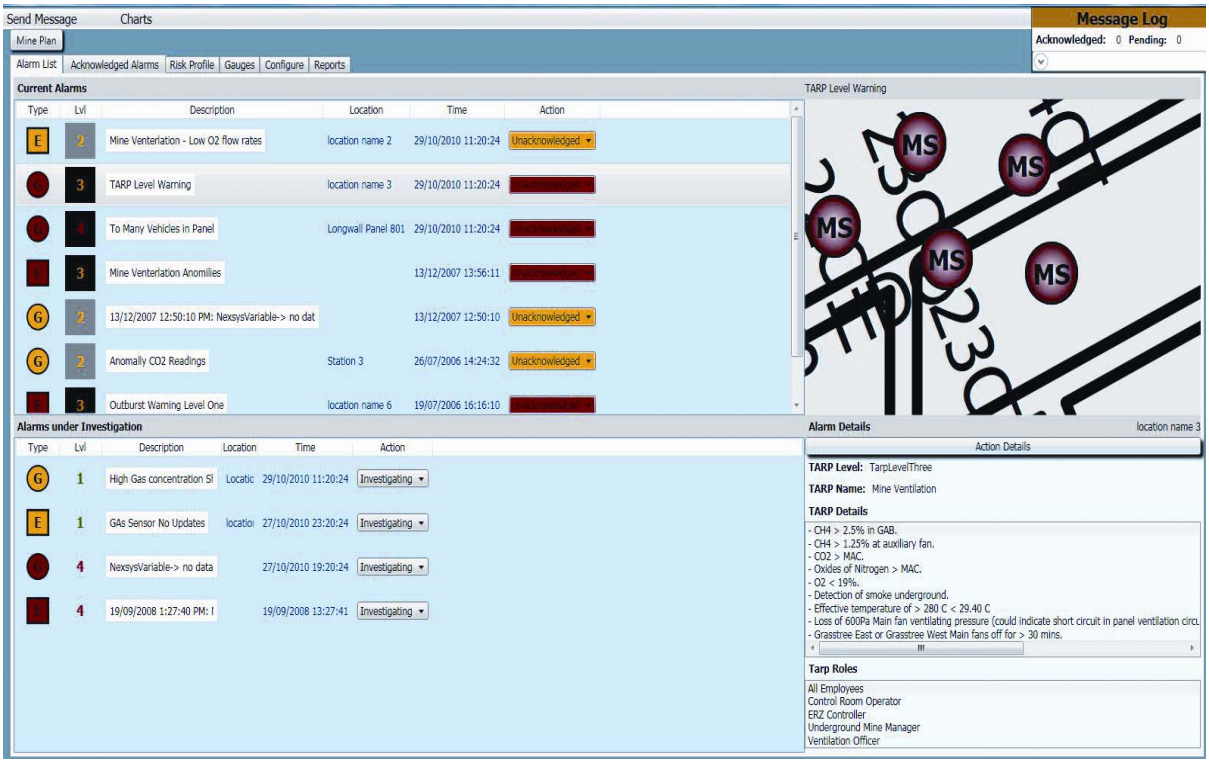


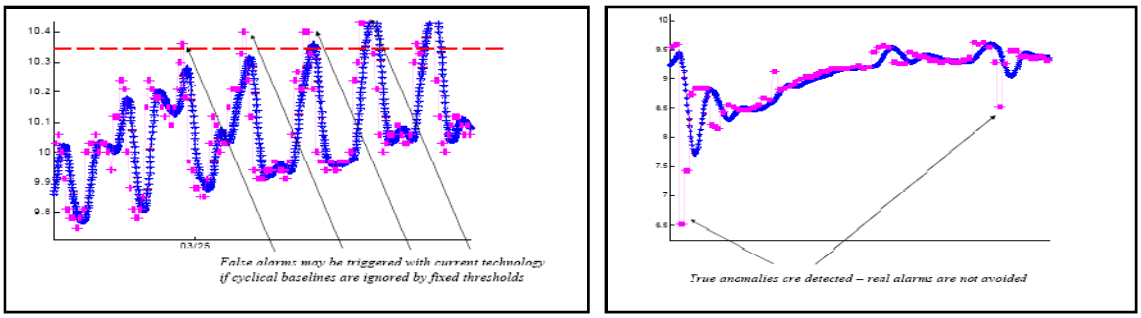
Figure 2 - Nexsys™ alarms view

Anomaly detection

Another unique attribute of the Nexsys™ system is its predictive and anomaly detection functionality, which uses historical mine data to predict future hazards, evaluate associated risks, and eliminate false alarms. This feature enables pre-emptive and preventive actions to be initiated before an event reaches a critical state or, in case of false alarms, it can indicate whether a certain state of events is, in reality, a non-dangerous event despite above-threshold sensor readings (Figure 3). The results of the predictive analysis and anomaly detection are used to trigger alarms and update the Nexsys™ Risk Profile. The Anomaly Detection module is integrated with the Rules Engine enabling prediction of sensor values and anomaly detection in the available data.

User interface and decision support

The user interface (UI) development for the Nexsys™ Real-Time Risk Management System focused on the design that would allow the system operator to monitor human and machine activities throughout the mine, display sensor information, and provide the operator with information to allow rapid assessment of emergency situations and guidance for corrective actions. The design of the user interface took into account human capabilities and limitations to ensure ease of use and improve operational performance as well as to enhance safety and user satisfaction while reducing operation errors, operator stress, and user fatigue.



(a) **(b)**

Figure 3 - Nexsys™ predictive analysis and anomaly detection: (a) cyclical baseline, (b) true anomalies

The Nexsys™ UI design process followed typical steps of iterative design (Carrol, 1997) based on the concept of iteration within the usability engineering lifecycle design (Porter, 1964), that is:

- An initial interface design was completed based on the designers' knowledge of Nexsys™ system requirements and capabilities (both Human Factors and mining experts were involved)
- The design was presented to several test (end) users, a process during which various mine site personnel were interviewed. These interviews were conducted at the mine site to enable assessment of the current end-users working environment in terms of their cognitive abilities. Initial interviews of mine personnel were conducted to: (1) obtain information on the use of the existing user interface, (2) determine deficiencies in the current system, and (3) learn of desired features for the future interface. Control room operators, engineers, and supervisors were interviewed to determine the specific needs of personnel for the delivery of information
- Any problems identified by the end-users were used in the development of user interface requirements. This material was used to produce a set of drawings of the UI, which were subsequently presented to the relevant mine site personnel during follow-up interviews to solicit further feedback and refine the design (several iterations)
- During the final user interface-related site visit the acceptance of the design by site personnel was sought. Final minor refinements were then incorporated within the final UI design
- Assessment of user interface compatibility with Nexsys™ software was then undertaken by software engineers
- The final user interface design was completed and transferred for implementation within the site-deployed Nexsys™ software.

The resultant UI provides an integrated view of mine-wide data via Alarms, Risk Profile, Charts, Reports and Mine Plan views. The Mine Plan View (Figure 4) can display information, such as gas and equipment sensor readings and locations, personnel locations (including messaging), views from video cameras, mine ingresses and egresses and airways. This concise view allows the operator to make quick decisions in emergency situations. For example, they are able to locate personnel, exits, gas leaks and clean airways and then message these personnel to notify them of a safe exit in the case of evacuation. All the information the operator needs to make these decisions is spatially located in the same place so that the relationships between all the objects and features in and of the mine can be easily identified and correlated.

In addition, Nexsys™ can provide mine-wide reporting to all levels of personnel, offering many mediums of communications from messaging personnel via Northern Lights messaging to their cap lamps, SMS capability and email. This reporting occurs by way of Alarms, automated Trigger Action response Plans (TARPs) and standard Reports. The location function on the Northern Lights tracking and messaging system assists with this task, as the operator can select which staff member to contact based on their location within the mine.

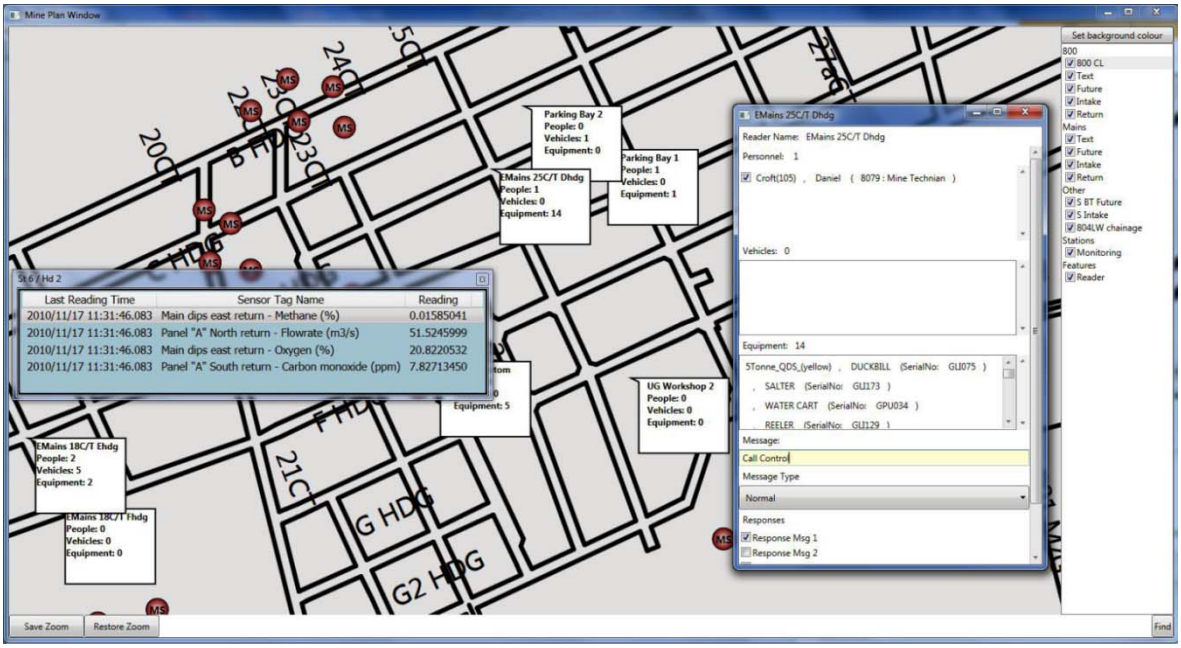


Figure 4 - Nexsys™ mine plan view - case study

NEXSYS™ SYSTEM – CASE STUDY

Nexsys™ prototype testing

The Nexsys™ system was originally developed for the purpose of increasing coal mine safety and, as such, a prototype system was successfully demonstrated in 2005/2006 at three mine sites: Beltana and Grasstree Longwall Coal Mines in Australia and the Kushiro Longwall Coal Mine on the northern Japanese island of Hokkaido. During the original Grasstree trials of the Nexsys™ prototype system, Nexsys™ was connected to Citect's Supervisory Control and Data Acquisition (SCADA) system and Location and Monitoring for Personal Safety (LAMPS), a CSIRO-developed system for personnel location and communications. During testing, Nexsys™ was able to send a signal to miners located underground through LAMPS, notifying them to contact the mine control room. Sensors detected gas levels (carbon monoxide, carbon dioxide, oxygen and methane) and ventilation status. Rules were created to trigger alarms and send emails to appropriate personnel if the risk produced by defined combinations of sensor readings exceeded safety thresholds. The research prototypes of the Nexsys™ system at all three mines continued to run for up to several months providing invaluable data for further development of the system.

Nexsys™ deployment at Grasstree Mine

In September 2009, Mining Logic Solutions and CSIRO commenced a 12-month trial of the Nexsys™ pre-commercial system at Grasstree Mine. The overall aim of the trial was to confirm the Nexsys™ Real-Time Risk Management System as a state of the art safety software product feasible for commercial deployment within underground coal mining conditions. To determine the viability of the system, the trial had two distinct goals:

- to demonstrate that vital parts of the software operated correctly in a full operating environment, and
- to create and evaluate a specific user interface that contained all the required information for different levels of personnel employment status.

Nexsys™ trial - functionality

The functionality of the following components of the Nexsys™ system in full operating underground mining conditions was tested:

- connectors for man tracking and SCADA database;

- real time mine plan viewer;
- rules engine, and
- anomaly detection and predictive data analysis.

The Nexsys™ system received data from two proprietary monitoring systems used at the mine site: the Citect's Supervisory Control and Data Acquisition (SCADA) System and the Northern Lights Technologies (NLT) Man and Asset Tracking System

For the Citect Connector, the Nexsys™ Server collected data from over 40,000 sensors, distributed throughout the mine, in real time without error. In addition, service properties were successfully set to restart automatically on service failure. The criteria for successful implementation of the NLT Connector were to import and export location and message data to and from the NLT system as well as into and out of the Nexsys™ system. This was completed and verified by the mine site personnel. The connector service automatically reconnected to the NLT Connector and Nexsys™ Server after a server machine restart.

The successful implementation of the Real-Time Mine Plan Viewer was proven through mine plan updates when a new mine plan became available and/or changes to the mine plan were detected through the system. In addition, the location of most recent tag reader that personnel and equipment came into range were shown on the Mine Plan and the Mine Plan speed and accuracy were acceptable to the end users.

The development of the Rules Engine was undertaken during the second half of the trial and, by the end of the 12 months period, mine site personnel testing the system witnessed and confirmed effective functioning of the standard rules, the Anomaly Detection rules configuration as part of the standard rule set and execution of omission of the rules depending on the hierarchical set up of the rule set. Furthermore, the Anomaly Detection (AD) algorithms were successfully trained using historical data from methane, carbon monoxide, carbon dioxide and oxygen sensors and the anomaly detection rules were configured as part of the standard rule set. In addition, the AD module could process new sensor readings at run time from the methane, carbon monoxide, carbon dioxide and oxygen sensors based on knowledge obtained from previous training and graphical display of AD inference and likelihood results.

Nexsys™ trial - user interface

The second goal of the Nexsys™ trial was to create and evaluate a specific user interface that would contain all the required information for different levels of personnel employment status and thus addressing their needs and responsibilities. The user interfaces were designed for the Control Room Operator and the Maintenance Superintendent, however, during the 12-month trial; the interface design and implementation were primarily tailored towards the requirements of the Control Room Operator (CRO).

The user specific interface is intended to minimise the amount of effort the user must expend to interact with the system i.e. provide input for the system, quickly interpret the output from the system, and learn how to perform these functions. Accordingly, a successful interface implementation was linked to specific users' requirements determined through user interviews and agreed to with the mine management. The main criteria for the interface acceptance by the site personnel included:

- Gas Alarms sent to correct person via NLT system displaying;
- Description of alarm;
- Sensor that triggered alarm, including its location if available;
- Alarm acknowledgements sent to CRO via Nexsys™ UI and stored in alarm history;
- Non-acknowledged alarms could be acknowledged by CRO after verbal confirmation with appropriate personnel;
- Alarms acknowledged via NLT system and displayed on the CRO UI;
- Successful initiation, display, and acknowledgement of alarms using Nexsys™;
- Personnel and equipment tag reader location (NLT) displayed on mine plan;
- Ability to locate personnel and equipment using a search function;

- Gas sensor value displayed next to the gas sensor icon on the mine plan;
- Acknowledgement of TARPS messages by various personnel displayed on UI;
- TARPs available for display on the main screen when gas sensor trigger level bridged to alleviate need for manual searching of hard copies of TARPs (Figure 5).

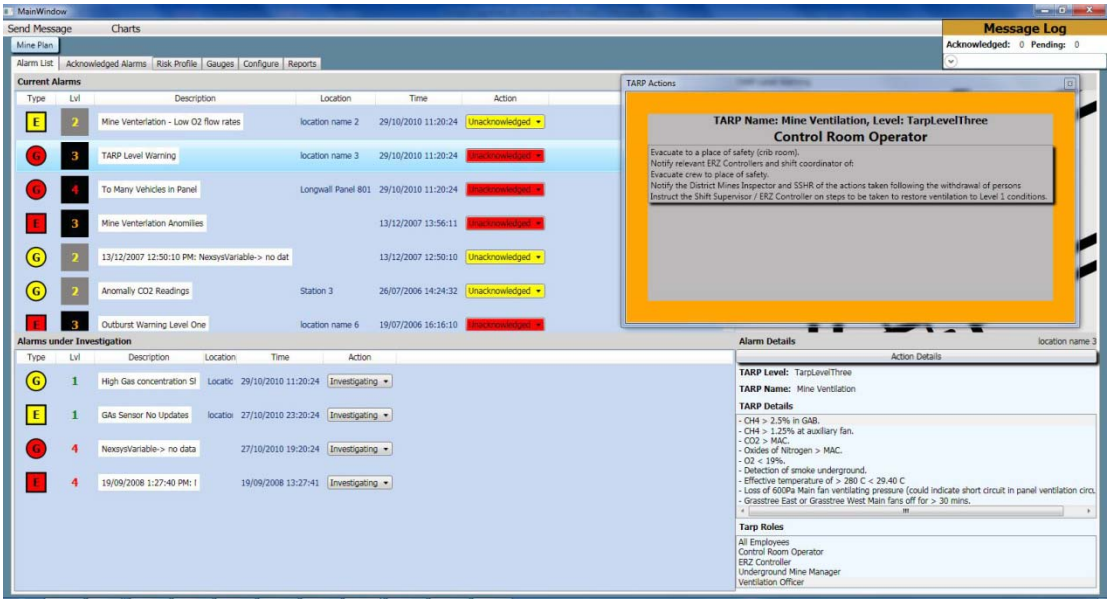


Figure 5 - Nexsys™ TARPs display: window becomes available to CRO for Level 3 Alarm

CONCLUSIONS

The Nexsys™ Real-Time Risk Management decision support system is able to improve mine safety through its continuous monitoring of the state of a mine, integrating critical mine data from various systems and sensors and notifying the appropriate personnel using a variety of decision support tools.

Through the system trial, Mining Logic Solutions (MLS) and CSIRO were able to demonstrate that the Nexsys™ Real Time Risk Management System could store data from multiple propriety databases and use that data to create four dimensional rules that took into account anomalies and false alarms. Information was shown on a specially designed user interface that enabled the user to locate all the information required to solve the alarm on one screen. The information provided to the operator included TARPs and the locations of the alarm, people and equipment within close range of the alarm. The successful completion of this trial has convinced both MLS and CSIRO that the product is now ready for commercial deployment. The Nexsys™ Real Time Risk Management System will be available to market from November 2010.

Due to the importance of effective risk management in mine safety and the lack of similar systems, Nexsys™ has a great potential to contribute to safety improvement in the international mining community. With its unique features, Nexsys™ is ideally suited for export to many other countries including India, China, the USA and Canada. In addition, the Nexsys™ application is not limited to the underground coal domain; future directions for Nexsys™ implementation include surface mines (coal and metalliferous), underground metalliferous mines, and non-mining domains wherever the assessment of risk and risk-based analysis is critical to the health and safety of the operations and personnel, such as emergency and rescue services

ACKNOWLEDGEMENTS

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ACARP is also acknowledged for recognising the importance of a real-time risk management system for underground coal mining in the early days of the project and providing CSIRO researchers with funding towards system development.

Special thank you is extended to the management and personnel at the Anglo Coal Grasstree Mine for their continuing support and faith in Nexsys™ capabilities.

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