Real-Time Airflow Monitoring and Control Within the Mine Production System

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ABSTRACT

Computer software has been developed to link real-time information generated by underground mine ventilation airflow monitoring sensors into a network simulation program to undertake network simulations and allow interpretation of key system data and operational changes. Results were used in the development of a computerised monitoring and simulation system to provide immediate or real-time data on air behaviour within each branch of an underground mine ventilation network through linking of sensors to the ventilation network simulation software. The outcome of the project is an online system that can report changes in the mine ventilation system, allow causes of changes to be isolated and rectified, improve balancing of available air throughout the mine, allow improved approaches to regulator setting and dispense with much of the labour used for underground ventilation measurement. The work activities in both coal and metalliferous Australian mines have involved examination and modelling of regulators, software modification and considerable mine site testing and optimising activities.

There is some discussion on approaches to control of flow through ventilation systems with increased information. New systems will be part of a total mine information management system. They will have to be cost effective and justified by gains in productivity. New systems will need to provide simulation of contaminant production such as diesels, vehicle heat, strata heat, radiation, blast fumes and other gases. More robust real-time ventilation simulation systems will be required. Personnel and vehicle identification and production tracking will be collected to provide integrated ventilation system monitoring and control.

This paper examines a study to gain greater understanding of computerised real-time airflow monitoring and control within the mine production system to provide immediate simulated information in each branch of an underground ventilation network and to allow interpretation of key system data and operational changes. A case study implementing a real-time airflow monitoring and control is discussed. Approaches to control of flow through ventilation systems with increased information are discussed. The concept of a system that can be linked to or be part of a total mine information management system is developed. Such a system can form the base for mine automation that allows mines to incrementally and cost effectively implement monitoring and control to further seek gains in productivity.

INTRODUCTION

The application of computer technology within the mining industry for design and system optimisation has developed significantly over recent decades. Solutions now exist for many of the problems associated with overall mine design and development and operational monitoring/control. The adoption of this technology has allowed an increased emphasis on the design, safety and economic conditions within which the overall mining system operates.

As an important consideration in underground coal mining operations, ventilation network design and remote monitoring has also been increasingly computerised. The fundamental requirement of ventilation is to provide controlled air distribution within the underground mining operations to satisfy statutory and safety requirements with respect to air quantity and quality. Ventilation design facilitates this distribution using modelling and predictive tools. The analysis of an operational ventilation network during both normal and abnormal conditions can be very complicated both on a theoretical and analytical level and in

practice requires computer based solutions. Remote monitoring systems provide the ability to observe many aspects of the underground environment. The application of monitoring to the ventilation network improves understanding of airflow, pressure, psychrometric and gas concentration observations.

The study examines the integration of real-time environmental monitoring and ventilation network analysis to develop systems that allow refinement of ventilation design and predictive modelling and provide an analysis of the operational ventilation network to identify abnormal conditions. The development of 'what if' scenarios can then be simulated using a refined and robust ventilation model with a high degree of confidence in the predicted behaviours.

Real-time control over a ventilation network can be achieved through the utilisation of modern monitoring systems and controllable ventilation components. Through integration with a calibrated model representative of the actual ventilation conditions and identified airflow requirements, control and optimisation of the ventilation network may then be achieved with significant safety and economic benefits.

One of the objectives of this study has been to develop a computerised monitoring and control system to provide immediate or real-time information on each branch within an underground ventilation network. The system measures airflow or air pressure changes in selected ventilation branches and simulates flows through all other branches. This approach to ventilation network understanding provides improved understanding of airflows through all mine sections and allows quantification of peak, instantaneous and average readings and possibly heat, gas or other contaminant levels for production purposes.

It allows mine airflow balancing through parallel splits to be undertaken. It serves as a useful aid to incident and emergency management. The popular Australian ventilation modelling program VENTSIM has been used as a simulation engine within the system. This software has been altered to accept real-time information generated by underground mine ventilation monitoring sensors, undertake network simulations and interpret key system data and operational changes.

The system can be operated as an independent entity, with no effect on the existing mine information and monitoring system or could be part of a total mine information management system. Once the simulation program has updated readings it can remodel the whole mine ventilation system, report the flows in all branches and compare individual branch readings with expected values. If flows vary significantly, an alert signal can be initiated to question why the change has occurred.

This paper examines a study to gain greater understanding of computerised real-time airflow monitoring and control within the mine production system to provide immediate simulated information in each branch of an underground ventilation network and to allow interpretation of key system data and operational changes. A case study is discussed. Results of a four mine comprehensive survey on attitudes to implementation of real-time airflow monitoring and control are given and analysed.

REAL-TIME MINE VENTILATION MONITORING

The ventilation in a typical Australian mine serves a number of functions and most importantly provides fresh air and oxygen for miners underground by controlling the level of strata gases, other

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noxious gases, dust and particulates from sources such as diesel vehicles and temperature in work places. It may also assist in controlling the temperature of exposed broken coal or ore to manage heating from spontaneous combustion.

The quantity of air flowing through the mine is also related to atmospheric pressure, which affects the differential between the fan pressures and pressure at mine intakes. It is also necessary to balance airflows in different parts of the mine through use of a mixture of flow controls (doors and regulators) and supplementary auxiliary or booster fans.

Computer ventilation flow simulation models are used to analyse and design mine ventilation systems. These are static models that make use of the existing data and proposed layouts to predict, design and optimise the ventilation systems for underground mines. These ventilation models can also be used to select optimum fan combinations for underground mines. There is a need to develop dynamic and real-time ventilation models to deal with emergencies or unforeseen situations. Computational Fluid Dynamic (CFD) programs are available for airflow dynamics modelling, but they are computer intensive and restricted for use in analysis of flow in limited areas such as working face areas.

There is usually not enough information gathered in the mine to measure ventilation performance in real time and to implement any necessary changes. It has been appreciated for some time that if real-time modelling of ventilation is to be developed, better sensing of gas concentrations, air pressure and air velocity throughout the mine and improved mine ventilation models are needed.

The mine atmosphere must comply with Australian state statutory regulations. The required dilution rates with fresh air can be calculated in a relatively straightforward manner where there is a constant supply of pollutants. This is not always the case and it may be difficult to predict pollutant loads where their production is erratic, for example with diesel equipment which does not operate continuously.

Sampling of both the quantity and quality of the underground air is carried out routinely in Australian mines, for example tube bundles are used in coal (and have been used in some metalliferous mines) to collect samples continuously for analysis at a central analysis point located on the surface. Depending on the length of the sample tubes, there may be more than a half hour delay in receiving an analysis reading. Instantaneous readings can be obtained from electronic gas sensors distributed through the mine. Most coal mines use tube bundles and analytical systems attached to a computer system that has set warning levels to alert the mine at the onset of high risk conditions. These are usually stand alone systems connected to a mine-wide monitoring and database management system. Gas data analysis and interpretation software, such as developed by Simtars, have also been installed at a number of Australian coal mines to obtain online analysis of the gas distribution and trends in gas concentration changes at various places in the mines.

The first indications of heating or fires in mines are normally seen in gas concentration changes 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.

An analysis of the spatial distribution of gases within the mine assists in indicating where the heating and source of gases is in the mine. It cannot be assumed that normal ventilation flow continues once a heating or fire commences, as buoyancy effects can reverse flow directions. Modelling is required to supplement results from monitoring to determine what is happening in the mine. The Simtars SAFEGAS system includes interpretation of the significance of gas analyses and plots the standard ratios of gases that are used to determine temperature of fires and the potential for mine explosions related to the gases produced by coal oxidation and fires.

Within the underground mining environment fires represent a serious potential threat to both human life and the operation generally. The outbreak of a mine fire can be seen to cause disturbances to the normal operation of a ventilation network. This is due to the thermal and chemical products of a mine fire creating unsteady, transient states in the airflows and the close relationship between the ventilation process and mine fire can be observed through the use of mine fire simulation programs such as VENTGRAPH (Dziurzynski, Tracz and Trutwin, 1988). The interdependence between fire affecting mine airflow and the available mine airflow altering characteristics of a fire through availability or lack of oxygen has been illustrated by Gillies, Wala and Wu (2004).

Development of real-time airflow monitoring and control systems

Real-time ventilation monitoring and automated control is a relatively new and innovative method of depicting an underground mine environment from alternative locations on a continuous basis. The concept of computer application has been prevalent in the mining industry since the 1960s. However, advancements in the field of continuous monitoring and remote control have only surfaced in the last decade and application to larger, more complex underground networks is still forthcoming.

With the two primary functions of mine ventilation being the adherence to statutory health and safety requirements and the distribution of air to support life and control various environmental aspects, the provision of such a capability is becoming more complicated with the development of larger-scale mining operations. Maximising operational efficiency has led to the development of real-time ventilation monitoring and automated control systems to reduce ventilation downtime and hence production losses. Due to the unique nature of underground conditions, different capabilities are required for different operational sites. As such, it is envisaged that the application of continuous monitoring and control to a simulated ventilation network will account for the detection of environmental aspects such as gas concentrations, heat load and radiation, in addition to airflow quantity and differential pressure.

The benefits that can arise from real-time ventilation monitoring and remote control capabilities may be observed from a technical, economic and safety perspective. By understanding the prevailing conditions of an underground network, personnel may plan ahead and optimise relevant development and production activities on the basis of long-, medium- and short-term planning principles. From an economic perspective, less downtime will be encountered, since controls may be adjusted immediately upon identification of a ventilation problem. Consequently, the capacity of the operation to undertake unobstructed production will be enhanced. Finally, adequate air will always be supplied to personnel and evacuation can be undertaken immediately upon earlier detection of the problem.

Although real-time ventilation monitoring and remote control capabilities have been developed for small- and medium-sized applications, such a system has yet to be proven in a large-scale operational environment. A number of factors weigh heavily against the successful installation of such a system, however, with the application of appropriate strategies and procedures, significant network improvements may be generated with minimal impact on the required infrastructure and services.

As preliminary work, two small initialisation projects were completed. These provided an opportunity to obtain a broad

understanding of ventilation monitoring systems that are currently utilised in underground operations and the range of modern technologies presently available through undertaking of an industry survey. As part of the work an industry survey gave strong evidence indicating growing interest in the utilisation of real-time ventilation and simulation systems.

To obtain practical experience successful trial exercises connecting mine airflow monitors to the Australian ventilation network program VENTSIM were undertaken using the University of Queensland Experimental Mine (Mayes, 1998) and an operating coal mine at Bowen Basin in Queensland (Gillies *et al*, 2000).

Under these projects additional executable programs and a macro were created performing as the interface data transformation and conversion intermediates to enable VENTSIM to gain access to the real-time ventilation information produced by the real-time ventilation monitoring system. The macro and executable programs were created solely for fulfilling the requirements of the VENTSIM data import specification. The project has substituted these systems with simpler, more efficient data transformation methodologies (Gillies *et al*, 2000).

These trial exercises were successful. It could be seen that ventilation changes in any selected airway with sensors caused the VENTSIM model to resimulate the whole mine network and output the changed flows in all airways Through utilisation of the system an economical, fast and effective way has been achieved to monitor and predict the ventilation environment in a selected area, or in the entire underground workings.

Subsequently, Queensland coal and base metal mines at three sites have been supporting research to allow the latest electronic instrumentation and simulation software to be used to improve mine ventilation. The aim of this funded foundation mine ventilation research was to develop a computerised monitoring and simulation system to provide immediate or real-time information on each branch within an underground ventilation network through linking of sensors in a small number of selected branches to the ventilation network simulation software. Software has been developed to link monitoring sensor real-time information generated by underground mine ventilation instruments into the simulation software to undertake network simulations and allow interpretation of key system data and operational changes.

The project commenced in late 2000. The first stages have involved selection and purchase of appropriate instruments and communication links, system calibration and design of software links. A major section has involved investigation and mathematical modelling of impedance characteristics of a number of types of underground regulators. In many cases sensors measuring differential pressure drop across regulators and accounting for leakage are used to give accurate airflow readings.

The ventilation simulation program used is VENTSIM, which has been modified as part of the project to allow input of real-time digital data. VENTSIM is now available with 'real-time' routines built in to allow reporting of airflow or gas readings and illustration of mine network schematics. These routines have been developed by the Australian VENTSIM author, Mr Craig Stewart in conjunction with this project. They are available in a new form of VENTSIM accessible to all VENTSIM owners.

The outcome of the project is an online system that can report changes in the mine ventilation system, allow causes of changes to be isolated and rectified, improve balancing of available air throughout the mine, dispense with much of the labour used for underground ventilation measurement and checking, improve power usage and assist emergency incident management. The main work activities involved software modification and considerable mine site installation, testing and optimising activities (Gillies *et al*, 2004).

One of the Queensland operators has, in parallel with the project, developed an automated system for control of airflow. This involved the use of a robust 'roller-door' form of regulator that can be remotely operated from the surface (Figure 1). Differential pressure is measured across each regulator and through understanding of regulator impedance, a quantity flow's value is derived. Mine control operators are able to set regulators to deliver recommended Mine Level flows. Prior to blasting all regulators can be to be opened and then reset at the beginning of the subsequent shift. The system also reports gas concentration levels in mine air passing through each regulator. Gases sensed are carbon monoxide, nitrogen oxide, nitrogen dioxide and sulfur dioxide.
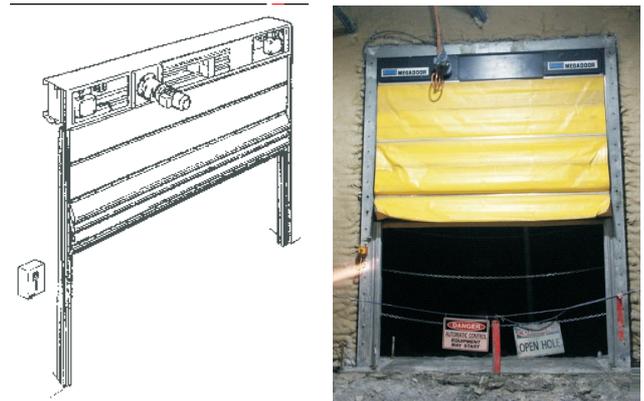
FIG 1 - Schematic and photographic views of a roller door regulator.

One major point of interest in such a system is the setting of the position of each remote controlled regulator at the beginning of each working shift. As the mine is not over-ventilated, it is important to maximise the availability of ventilation air to the active levels to effectively dilute the contaminants. The setting of remote regulator positions is an iterative process as once one regulator is positioned such that the required quantities of airflow are delivered to working areas on a particular level; the airflows on other levels are disturbed.

It is important that the process is efficient with respect to the time it takes (it should be quick enough to perform before the underground mining work is underway each shift) and the ease in which it can be done; that is it should be able to be learnt easily so that all personnel involved in the process can conduct it accurately from the early stages the process is put into place.

Ball (2003) suggested that procedures for the ventilation and shift engineers to follow on a shift-to-shift basis should include:

- periodic updating of the VENTSIM model;

- calculations of shift-to-shift airflow requirements;

- real-time linking to VENTSIM; and

- end of shift blast time remote regulator positioning to minimise re-entry times and risk of blast damage to the regulators.

To avoid regulators being damaged by air pressure resulting from nearby blasting, it is possible to incorporate a pressure venting rupturing device or arrangement using low rigidity or lightweight materials in the structure of the regulators as demonstrated in Figure 2. The construction is so designed that when a blasting pressure wave arrives at the regulator it will be released through the venting arrangement without causing physical damages to the regulator structure.
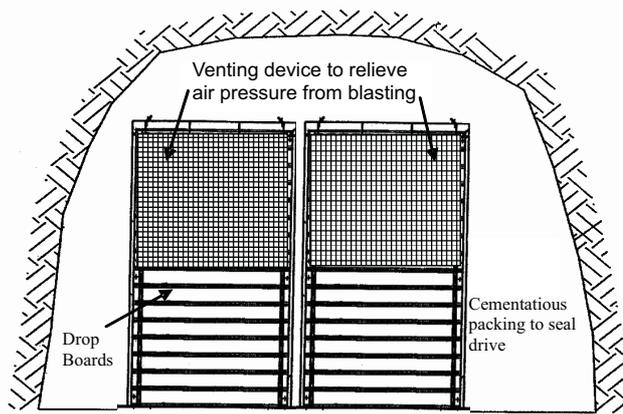
FIG 2 - Possible venting device or arrangement for regulators.

Many large Australian metalliferous mines have ten or more levels concurrently in use for stoping or development. The ventilation system is often at its limit, particularly under hot summer conditions, and so great care is needed in balancing air to ensure all areas scheduled for work on a daily basis receive adequate flow. There are options available in conjunction with remote regulators and a real-time ventilation monitoring system for ensuring adequate delivery of minimum airflow every day on each level or in each working section. Operationally requirements are for better control of air through improved supervision, the ensuring of minimum air wastage or leakage and the possible closure of work in some areas or on some levels. Change occurs on a daily basis and it is only too easy for short-circuiting and wastage to occur in some areas while there is a starving of air in other zones.

Normally, the mining system schedules filling of a stope after all ore has been removed. It is important to recognise that some time may elapse (days or weeks) between completion of stope ore removal and commencement of filling. Sealing of all stope openings at this time could save much air. In this case the parachute stopping, although originally developed for emergency ventilation response, presents a relatively inexpensive and effective temporary stopping that can be applied quickly when correctly sized and set as designed. There are other products such as tube or balloon stoppings that can be used as a temporary restriction to close vertical airways such as raises, open stopes or orepasses to avoid short-circuiting of ventilation air.

Maximising the benefit of remote regulators has the capacity to improve the mine ventilation system such that all working levels can have the best possible ventilation on demand. Consequently the risk of worker heat stress and fume inhalation will be minimised. Any improvement in ventilation in a mine has great potential to move in step with improvements in production.

Selection of pressure sensors for real-time airflow monitoring

Air velocity measurement techniques suitable for mine ventilation monitoring and control systems can be accomplished with the following types of sensors:

- vane anemometers,
- thermal mass cooling,
- vortex shedding, and
- ultrasonic pulse technique based instruments.

Vane anemometers are simply rotating vanes with the number of revolutions as a function of time electronically converted to a velocity. The sensor itself is mechanical and intrinsically safe.

The thermal mass cooling principal is similar to that of a hot wire anemometer; that is the greater the air velocity, the greater the cooling of a heated element. The vortex shedding technique involves creating vortices, or eddies, in the airflow path with a rod and measuring the rate at which the vortices are shed from the rod. The vortices are detected with a transmitter/receiver for ultrasonic pulses beamed across the path. The ultrasonic pulse technique uses transmitter and receiver pairs mounted opposite and diagonally across a passageway. The timing of the pulse train is measured in both upstream and downstream directions. With knowledge of the geometry of the installation, precise timing, and the velocity of sound in air, the air velocity is easily calculated electronically (Casten, Mousset-Jones and Calizaya, 1995).

Practical usage in mines over time has identified problems with air velocity sensors using vane anemometers, thermal mass cooling and vortex shedding techniques. All these sensors measure spot air velocity instead of average air velocity as done using the ultrasonic pulse technique. They are found to be difficult to re-calibrate to variable airflow requirements in operating mines, atmospheric dust can affect accuracy of measurements and the output signal has a tendency to 'wander away' immediately following re-calibration (McDaniel, Duckworth and Prosser, 1999). The unreliability and lack of repeatability of these instruments hampers the continued development and use of these types of sensors in the mining industry. Anemometers using the ultrasonic pulse technique suffer interference from particulate matter in the air stream and vehicle and personnel movement can interrupt the signal. Also, currently this type of sensor is not designed as an intrinsically safe sensor to be used in the coal mine environment.

Measurement of differential pressure across an opening or regulator can be undertaken relatively easily and with repeatability. Mechanical pressure sensors commonly measure the mechanical movement of an elastic diaphragm's response to pressure. This response can be measured electrically through a variety of techniques such as strain gauges or variable resistance. A number of electronic pressure sensors based on piezo-quartz technology are now available and have replaced many forms of mechanical sensors. These have high accuracy, reliability and repeatability but some may be easily damaged. In mining, air pressure measurements are of two types: differential or gauge pressures and absolute or barometric pressures. Process control and feedback loops in the processing industries have caused a wide range of pressure sensors to be developed. They are available for wide pressure ranges, hostile environments and with varying degrees of accuracy.

Accurate absolute and differential pressure sensors are expensive. A small number of manufacturers make digital absolute pressure sensors with accuracy suitable to replace the mechanical altimeters commonly used in the past for absolute pressure measurements. These sensors employ proprietary capacitance based methods. Differential or gauge pressure sensors are easier to produce and there is a considerable field from which to choose. There are a few manufacturers who make Intrinsically Safe differential pressure sensors that are currently used in a number of Australian coal mines.

Real-time airflow monitoring trial

A trial on the use of a real-time airflow monitoring system was undertaken in an underground medium-size base metal mine in Australia. The mine is accessed via a 5.2 m-high by 5.5 m-wide decline. The main hanging wall orebodies of the deposit are mined by transverse, longhole open stoping. A vertical hoisting shaft with a finished internal diameter of 5.6 m was constructed for ore haulage and ventilation purposes.

The ventilation system is designed around two main exhaust shafts from surface to two main return air levels for the two

separate sections. Return air from lower operating levels is exhausted through various return air raises (RARs) or sometime orepasses connected to collection drives on the main return levels.

To maintain an efficient ventilation system, it was decided to have one unimpeded open split on a level towards the bottom of the mine and install a series of regulators in the levels above to control airflow in each level. Levels below the open split can have booster fans incorporated within bulkheads to the RARs to assist airflow and improve conditions during hot and humid summer months.

Following the initial trial of the real-time mine ventilation monitoring system in one section of the mine, a decision was made to install a series of regulators in the working levels to control airflow in each level in the newly developed section of the mine. Various sizes of a variation of the drop board regulator were installed in the cross-cuts connected to the RARs at each levels.

The regulator can be installed in either half or full sizes depending on the magnitude of the airflow regulation requirements and the locations. A half size ventilation regulator consists of a total of 12 vertically installed drop boards that are secured with two steel bars to the frame structure. A full size regulator consists of 32 horizontally installed drop boards. The frame structure is secured in place using the rock bolts. Various forms of cementatious material packing are used to seal the drive around the regulator frame structure.

Dimensions of each drop board are 1.77 m wide and 0.2 m high. The maximum opening areas of a half size and a full size regulator are 4.25 m^2 and 11.33 m^2 respectively.

Based on regulators' relative positions to the airway carrying airflow into the RAR, the regulators installed were classified into two categories namely 'Tunnel' regulator or 'Flush' regulator as shown in Figure 3. A 'Flush' regulator is defined as a regulator installed on the sidewall of an airway carrying the airflow that is flowing into the regulator. Airflow in this case has to make an immediate 90 degrees turn before flowing into the regulator. On the other hand, a 'Tunnel' regulator is defined as a regulator installed at the end of an airway carrying airflow straight into the regulator.

Calibration of ventilation regulator

An attempt was made to calibrate all regulators but some were damaged and so not included in the exercise. Five regulators are classified as 'Flush' regulators and 12 are regarded as 'Tunnel' regulators of the 17 regulators installed in the two RAR systems.
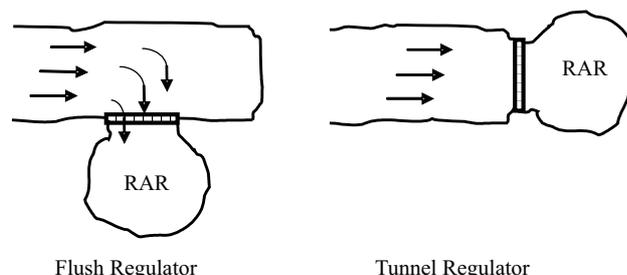

FIG 3 - Graphical examples of flush and tunnel regulator layouts.

In general, upper levels required more regulation and so half size regulators are installed. Full size regulators are installed in the lower levels.

A total of eight regulator calibration tests were undertaken to gain representative calibration relationships (characteristics curves or equations) between equivalent total regulator resistance, R_t in Ns^2/m^8 and regulator opening area, A_r in m^2 for both 'Flush' and 'Tunnel' regulators. The calibration test procedure applied has been well documented by Gillies et al (2002) and Wu, Gillies and Mayes (2003). A summary of the regulator calibration tests results is as shown in Table 1.

As expected, the average 'Tunnel' regulator equations compared well with the simplified or approximation equation suggested by Le Roux (1990). The small difference here between theoretical and measured relationships of R_t and A_r as described in the equations shown in Table 1 can be seen as contributed by (as suggested by Gillies et al, 2004) possible errors in measurement, the non-symmetrical condition and shape of regulator openings in practice and the extra leakage around the regulators. Equivalent total regulator resistance takes into account resistances of the leakage paths which parallel air paths through the regulator opening. The values of R_t would be expected to be lower than the regulator resistance in isolation.

'Flush' type of regulators exhibited different relationships between R_t and A_r due to the difficulties encountered in measuring airflow quantity and pressure drop across regulators with the extra shock losses induced by changing airflow direction before it enters through the regulator.

The 'Flush' and 'Tunnel' equations can be used to calculate the equivalent total regulator resistance by knowing the opening area of each regulator in the mine's ventilation system. By installing real-time differential pressure sensors to measure the pressure drop across the regulators and with calculated equivalent total regulator resistance for equations, it is possible to calculate the air quantity flow through the regulator using the square law of $P = R_tQ^2$.

TABLE 1
Summary of the regulator calibration tests results.

Type and location of regulator setup		$R_t = A*Ar^B$	Constant A	Constant B
Regulator at Level 2 RAR 1 (double width - 32 boards)	Flush	$R_t = 0.2027Ar^{-0.7937}$	0.2027	-0.7937
Regulator at Level 3 RAR 1 (single width - 12 boards)	Flush	$R_t = 1.0227Ar^{-1.6779}$	1.0227	-1.6779
Regulator at Level 3 RAR 1 (single width - 12 boards)	Flush	$R_t = 0.8050Ar^{-1.1372}$	0.8050	-1.1372
Regulator at Level 4 RAR 1 (single width - 12 boards)	Flush	$R_t = 0.7588Ar^{-1.4242}$	0.7588	-1.4242
Average flush regulator equation		$R_t = 0.7955Ar^{-1.278}$	**0.7955**	**-1.2780**
Regulator at Level 3 RAR 2 (single width - 12 boards)	Tunnel	$R_t = 1.069Ar^{-2.1103}$	1.0690	-2.1103
Regulator at Level 4 RAR 2 (single width - 12 boards)	Tunnel	$R_t = 0.9074Ar^{-1.9702}$	0.9074	-1.9702
Regulator at Level 7 RAR 2 (double width - 32 boards)	Tunnel	$R_t = 1.3004Ar^{-2.1058}$	1.3004	-2.1058
Regulator at Level 9 RAR 2 (double width - 32 boards)	Tunnel	$R_t = 1.6169Ar^{-2.0544}$	1.6169	-2.0544
Average tunnel regulator equation		$R_t = 1.2261Ar^{-2.065}$	**1.2261**	**-2.0648**
Simplified (approximation) equation by Le Roux		$R_t = 1.4153Ar^{-2.000}$	**1.4153**	**-2.0000**

Calibration of real-time differential pressure sensors

A total of 17 real-time differential pressure sensors were installed in the trial. Initially, two different types of sensors were installed due to delay in delivery for the originally planned differential sensors. Site calibration tests of the two differential pressure sensors were conducted and the results showed some large discrepancies between readings of the sensors and the precise pressure transducers used for calibration.

Subsequently, all installed pressure sensors were replaced with the originally planned differential sensor type. Site calibration tests of the differential pressure sensors installed later were conducted and the results demonstrated better correlations between the readings of sensors and the calibrating pressure transducers. A summary of the calibration test results and correlation equations is as shown in Table 2.

TABLE 2

Summary of site calibration tests of differential pressure sensors.

Regulator information					DP sensor correlation
Level	RAR system	Type	Setting boards off	Equivalent resistance (Ns^2/m^8)	
1	I	Tunnel	6	0.30	y = 0.9846x - 32.5
2	II	Flush	4	0.60	y = 1.0006x - 48.0
3	I	Tunnel	4	0.51	y = 1.0004x - 30.4
3	II	Flush	5	0.38	y = 1.0001x - 33.0
4	I	Tunnel	4	0.51	y = 0.9954x - 76.3
4	II	Flush	4	0.60	y = 1.0007x -43.8
5	I	Tunnel	4	0.51	y = 1.0005x - 0.1
5	II	Flush	4	0.60	y = 1.0005x - 0.0
6	I	Tunnel	4	0.51	y = 1.0012x + 0.1
6	II	Flush	1	10.47	y = 0.9999x - 9.6
7	I	Tunnel	4	0.51	y = 0.9972x - 47.6
7	II	Tunnel	4	0.51	y = 0.999x - 40.5
8	I	Tunnel	7	0.25	y = 0.9999x - 9.7
9	I	Tunnel	3	0.74	y = 0.999x - 0.6
10	I	Tunnel	7	0.25	y = 1.0055x - 66.0

The outputs from the underground real-time airflow monitoring system are transferred to the mine control and monitoring system. There are 17 underground remote monitoring stations established; however, only 16 stations are used for real-time VENTSIM simulation purposes. These stations are located at various levels accessing both RARs in the new mine section.

A data file is created in the mine monitoring and control system and stored in the mine's intranet directory according to the specific format required by VENTSIM. Real-time underground monitoring data are displayed on the mine control and monitoring system. This information is displayed on a purpose made page for easy interrogation.

Due to some specific site operational constraints and blast damage, not all the regulators and sensors have been functioning properly. However, during the trial with all stations online, it was found that the real-time ventilation system had the ability to detect changes in the ventilation circuit and resimulate the network under the new conditions.

LARGE MINE REALTIME MONITORING AND SYSTEM CONTROL

A recent survey of four underground metalliferous mine sites across three Australian states was conducted in order to gain an understanding of how principal industry stakeholders perceive the concept of real-time mine ventilation monitoring and control system (McGrath, 2004). The survey was aimed at identifying and assessing current ventilation practices. Specific real-time mine ventilation perceptions of both individuals and site management were also sought. The future intentions of these sites were addressed and whether there was a scope for further investigation of real-time mine ventilation monitoring and control systems.

The survey revealed that apart from the monitoring and control of surface fans there is very limited underground ventilation monitoring and no remotely operated ventilation components on site at any of the surveyed mines.

However, one mine is planning to install fibre optic communications within the major accesses to the underground workings. This set up would involve copper wires running from the specific measurement areas to node points along the fibre optic backbone. This complex network could allow for the provision of equipment tracking, radio communications, remote control equipment and other services (McGrath, 2004). Possible ventilation monitoring through the use of real-time sensors may be incorporated into the network, however, the mine indicated that this alone will not be sufficient to justify the capital expenditure of installation and operation.

The survey also examined the status of equipment and personnel tracking in these mines. The ability to track equipment could lead to a mine's adoption of processes aimed at developing a real-time ventilation monitoring system with the ability to facilitate reporting of diesel emissions and heat loads in specific branches of a network. Three of the mines surveyed had some form of continuous equipment and/or personnel tracking system. In particular, one of the mines has installed tracker sensors and software packages of the form described by Kent and Kirkpatrick (2005). In this system all equipment and personnel are fitted with electronic beacons. The mine has strategically positioned station points located in designated 'hot' and 'cold' spots on four mine levels as well as at the portal entrance. Station point beacons are read on a continuous basis as personnel and equipment pass. The mine controller is able to analyse current locations and the time at which the last beacon was read.

As a result of the trials discussed and findings from the survey, further research is needed to evaluate the integrated mine real-time monitoring and system control that will extend the approaches already developed in the foundation research project into a robust system that can reliably handle the complexities of a large mine system for real-time mine ventilation monitoring as described by Gillies *et al* (2004).

The new research proposed is to develop a system that can be linked or be part of a total mine information management system to form the base for mine automation that allows mines to incrementally and cost-effectively implement monitoring and control to further seek gains in productivity. New steps to improve the process could include mobile vehicle production tracking, personnel identification, vehicle location and ventilation system monitoring and control with an integrated ventilation system simulation as already described.

Concepts already developed under the foundation ventilation project plus the new system information acquisition and control, approaches need to be implemented and tested in additional mines to ensure robust performance. Subsequent research stages are needed to take proven research concepts and develop use across the industry.

One of the key areas to be investigated is the data network communication platform that could provide reliable data communication in the underground environment. Kent and Kirkpatrick (2005) have described a Wireless Local Area Network (LAN) Technology system. The system is described as providing a mine robust communications infrastructure to support the deployment of mobile data applications such as:

- mobile vehicle data solutions, for example monitoring on production, ore flow, vehicle utilisation and optimisation, condition, tracking, equipment scheduling and traffic control;

- voice over internet protocol (VoIP);

- mobile data applications such as equipment operators' logs, shift log, surveying input, geology input and materials management;

- mobile and fixed video over internet protocol; and

- provide wired LAN connectivity in remote areas of the mine.

To complement one aspect of the development, in relation to individual miners underground, a new cap lamp battery module has also been developed by Mine Site Technologies that can be readily adapted to include items such as VoIP phones, UHF radios, as well as the more traditional Personal Emergency Devices (PED) receivers, VHF radios and Tags. These developments provide a form of support to the mine's infrastructure requirements for the next steps in mine automation remote control that allows mines to incrementally and cost-effectively apply monitoring and control to further improve productivity.

CONCLUSIONS

The aim of the study was to gain greater understanding of computerised real-time airflow monitoring and control within the mine production system to provide immediate simulated information in each branch of an underground ventilation network to allow interpretation of key system data and operational changes. The system measures airflow in selected ventilation branches and simulates flows through all other branches. Investigations were undertaken in Australian metalliferous mining environments as to whether a real-time airflow monitoring system can detect changes within the mine ventilation system, examine accuracy of the system and identify constraints that will limit performance of the system. As a result of trials, it was further demonstrated that the system was able to detect changes occurring within the mine ventilation system and was also able to predict the changes accurately.

Maximising the benefit of the remote regulators has the capacity to improve mine ventilation systems such that all working levels can have the best possible ventilation on demand. Consequently the risk of worker heat stress and fume inhalation will be minimised. Any improvement in ventilation in a mine has great potential to follow with improvements in production. Therefore the maximisation of the beneficial use of the remote regulators in operations is highly likely to follow with increases in the mine's profitability.

The changing nature of the mining industry has warranted the application of new and innovative techniques to ensure that desired production and safety targets are met. Real-time airflow monitoring and automated control concepts have benefited from recent trials and studies at the WIPP, UQEM and operational mine sites such as Cannington and Central Colliery (Gillies *et al*, 2000, Gillies *et al*, 2002). Furthermore, wide-ranging perceptions have been derived from some of Australia's premier metalliferous mining operations through an industry survey. These concepts have provided a substantial basis for practical application to problems that are currently being dealt with at various Australian mines.

As a result of the trials discussed and findings from the survey, further research is proposed to evaluate the integrated mine real-time monitoring and system control that will extend the approaches already developed in the foundation research project into real-time mine ventilation monitoring as described by Gillies *et al* (2004).

Approaches to control of flow through ventilation systems with increased information have been discussed. A system that can be linked to or be part of a total mine information management system has been developed. Such a system can form the base for mine automation that allows mines to incrementally and cost-effectively implement monitoring and control to further seek gains in productivity.

ACKNOWLEDGEMENT

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