Monitoring and control of underground ventilation systems using VUMA-network®

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ABSTRACT: Ventilation conditions in mines must be monitored to ensure safe and healthy conditions. However, the multiplicity of ventilation branches and equipment make it impractical to automate measurement of parameters all over a mine. It is more practical to monitor a few critical measurements that are fully reliable and extrapolate to 'predict' remaining conditions using ventilation network software. In the past, predictions made by VUMA-network have been verified against manual measurements and these have given confidence in predicted conditions in the remainder of the circuit. The paper describes work being undertaken to link the simulator with monitoring systems to enable accurate predictions of conditions in areas not covered by instrumentation. Information from a monitoring system will be linked to an existing network file. The measured and predicted data will be compared with predictions and verified predictions will be used to examine conditions in areas without instrumentation. Potentially unsafe situations will be highlighted and operators alerted to rectify the situation.

1 INTRODUCTION

In any underground mining operation, ventilation conditions must be monitored to ensure that safe and healthy conditions prevail and that effective operation and management is maintained. Mine-wide monitoring systems are used to a greater or lesser extent for this purpose on many mines. However, the multiplicity of ventilation branches and equipment, as well as the numerous ventilation parameters of interest, make it impractical to locate measurement transducers all over a mine. Those systems that attempt to do so, generally become too large and complex and are often unreliable, lack credibility and are ultimately ineffective. Furthermore, the actual transducers for ventilation parameters are notoriously difficult to maintain [e.g. air flow and wet-bulb temperature sensors]. The installation of many of these transducers all over a mine network is very expensive in first cost and can only be effective with high maintenance efforts. Older mines with a limited life expectancy would not be able to justify the expense of an extensive communication and environmental monitoring system. In most mines these systems are generally doomed to unreliability. Even with a large budget, there will inevitably be areas in a mine that lack instrumentation.

It is more practical to have a few critical measurement sites that are fully reliable and, from these critical measurements, extrapolate to 'predict' conditions all over a mine network using ventilation network software. Thus in both the design phase and the operation of a mine, underground ventilation systems can be accurately simulated to ensure that they are efficient, safe and cost-effective. VUMA-network® simulation software has been and is extensively used to satisfy this role. In the past, predictions made by VUMA-network have been verified against manual measurements and these have given confidence in the predicted conditions in the remainder of the circuit. Work is now being undertaken to link the simulator with mine monitoring systems to enable accurate predictions of conditions in areas not covered by instrumentation. As part of the South African FutureMine collaborative research programme, work has commenced to integrate VUMA-network with automated monitoring systems. Information received from a mine monitoring system will be passed through trending/filtering routines to remove noise and the data will then be linked to an existing VUMA-network file, which accurately represents the current mine ventilation circuit. The measured data will be compared with predictions made by VUMA-network and any differences at measurement locations will be reported. The verified predictions will be used to examine conditions in areas of the mine which have no instrumentation. Potentially unsafe situations will be highlighted and operators can be alerted to carry out pre-determined tasks to rectify the situation. This system diagnostic tool will be tested towards the end of 2003 in conjunction with a deep hot gold mine monitoring system. Obviously, there is future potential for control functions to be automatically carried out. Future work will also examine the possibility of identifying locations/sources of differences and extracting reasons for the differences from a knowledge base.

2 VUMA-NETWORK

Increasingly stringent standards are being set with regard to occupational health and safety. In the mining industry, maximum allowable pollutant levels are being reduced, medical compensation levels have been increased, medical surveillance requirements are increasing, and standards regarding escape and rescue equipment are more stringent. Furthermore, production rates have increased, mining depths are greater, mines are more mechanised and the network of excavations more extensive. On the other hand, the majority of commodity prices are low and the mining of coal, gold, platinum, gemstones and base metals has become an extremely competitive business world-wide. One of the disciplines that affects the well-being and profitability of the modern mining industry is that of mine underground ventilation control. It has become essential for ventilation practitioners to plan and design ventilation and cooling systems to a high degree of accuracy. These systems need to take modern mining methods into account as well as the costly infrastructures needed for future ventilation and cooling requirements. To enable the practical and economical design of mine ventilation and cooling systems, ventilation practitioners need effective and modern tools.

Given that the planning and design of underground ventilation control systems for future mines will require extensive optimisation, it will be necessary to evaluate a number of scenarios, not only for the ventilation systems, but also for the overall design of mines. Due to the integrated and extended nature of high production mines, seemingly small changes in design could have significant global effects on the underground ventilation control system.

Such a process would require numerous predictions for network conditions, system design and performance. It would be virtually impossible to make such predictions without simulation tools that are accurate and flexible enough to evaluate rapidly all possible options and scenarios.

The VUMA-network simulation program is specifically designed to assist underground ventilation engineers to plan, design and operate mine ventilation systems. VUMA-network is an interactive 'MS-Windows' program that allows for the simultaneous steady-state simulation of air flow, air thermodynamics and gas and dust emissions in an underground mine. The program caters for a wide variety of mining methods. A fundamental feature of VUMA-network is user-friendly interfaces that allow simulation networks to be constructed and viewed graphically and what-if studies to be rapidly performed to determine optimal designs and system requirements.

Some other aspects of VUMA-network are:

- Network consists of branches, starting and ending with nodes, and depicting network components such as shafts, tunnels, etc.
- Input data for branches is used to calculate the air pressure drop and air thermodynamic and contaminant level changes in a specific component of a network.
- Input data for nodes consists of the X, Y and Z co-ordinates, Barometric pressure [BP], Virgin Rock Temperature [VRT], and air temperatures. The BP, VRT and wet-bulb and dry-bulb temperatures only need to be set for the start-node as these parameters are calculated for other nodes throughout the network.
- Simulation networks are constructed in a two-dimensional [2-D] graphical editor on a level-by-level basis. Different levels are then interconnected, typically by shafts, declines or production zones.
- Network is viewed in 2-D format in either geometric, strike, or section view.
- Input data for each branch is entered in a specific input screen for that branch-type before a solution is obtained for air flow, contaminants and air thermodynamic properties.
- If only an air flow solution is required, only information relating to the geometry and air resistance characteristics of the branches needs to be entered.
- Iterative network solution algorithms are used to solve for air flow, and updated heat flow models are used to calculate the thermodynamic changes in each branch.
- VUMA-network contains an extensive help function to assist with the development of a simulation model.
- Three-dimensional [3-D] graphical viewer is used to view the network and colour coded results.
- In addition to the 2-D and 3-D graphics output display, results may be viewed in a tabular format.

The solver within VUMA-network is the result of theoretical and empirical models that have been developed and verified by engineers and scientists at both BBE and CSIR Miningtek over a number of years. Further details on the program are given by Marx *et al*, 2000.

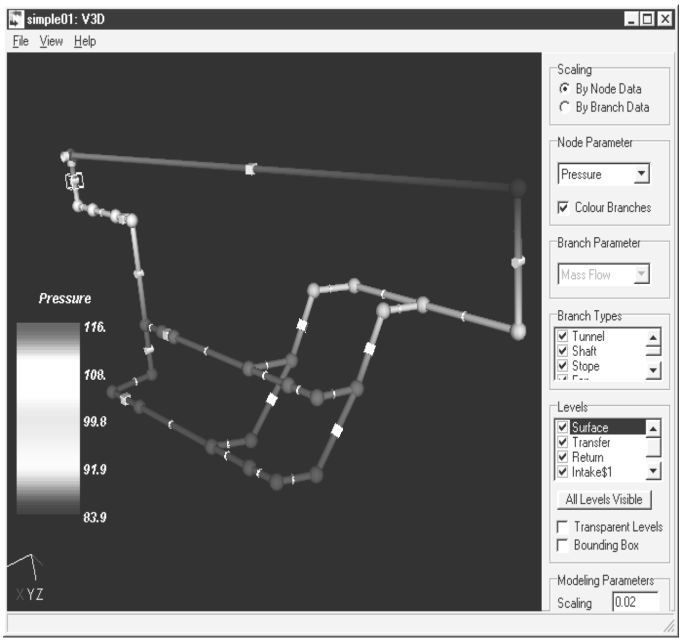

Figure 1: Network in 3-D viewer

3 LINK TO MINE MEASUREMENT SYSTEM

A project to examine the possibility of monitoring parameters at only a few key locations and then predicting conditions in the rest of the mine was undertaken as part of the FutureMine collaborative research programme. A survey of mine monitoring systems and the relevant ventilation instrumentation included in these systems was carried out on sponsoring mines. Of the 14 mines surveyed, all had systems in place that included automatic fire detection instruments and most of the mines monitored underground water flow, water temperature and dam levels. Six mines continuously monitored air flows and temperatures at key locations, while four mines were in the process of implementing such systems. Two mines monitored the status of ventilation doors, while five mines were in the process of installing such systems. Where large refrigeration plants were installed, remote access to the plant PLC systems is possible via the mine-wide monitoring / communication system.

The outcome of this project has been a number of software modules that are capable of:

- Communicating between the mine monitoring system and VUMA-network
- Real-time solving and calibration of mine models
- Anticipating potential problems by displaying warnings when changes in measured parameters exceed specified limits.

By linking the modules to VUMA-network, users can use existing network information and there is no need to switch between operation of two different programs. It is obviously important that the VUMA-network file accurately represents the current mine layout and that the user has verified the accuracy of input parameters such as airway friction factors, and linear heat loads. The system increases the coverage provided by existing instruments through extrapolation of measured values in VUMA-network to provide an expanded real-time view of the mine.

The modules include: Linker to a mine control and data acquisition [SCADA] system, Diagnostic faulty-instrument checker, Comparison-solver [which include calls to VUMA solver] and Reporter.

The Linker interacts with the mine SCADA system through a common open interface [OPC]. The Linker matches measurement locations with nodes within a VUMA-network data file and passes measured information to the Comparison solver.

The Linker screens the input data for ‘noise’ and also carries out some basic smoothing of data to minimise false alarms as a result of sudden but short-lived extreme changes in measured conditions.

The Diagnostic faulty-instrument checker scans the measured data for validity and consistency. If the measured reading is not valid or consistent with previous readings or with neighbouring measurements, a report is produced and the program is returned to the control of the Linker. The user will be requested to check the relevant instrument[s]. Checks carried out include whether the instrument is displaying a fault code, whether the measured data are within the range of the instrument and whether the measured value is within acceptable range for current conditions.

The Comparison solver calls the VUMA-solver to establish a reference prediction based on user input. The predicted values at the first measurement node are compared with the actual measurements and the difference displayed. For subsequent steps the parameters for that node are defined to be the same as the measured parameters so that downstream branches in the computer network will have the same starting point for calculation as the actual ventilation system. The VUMA solver is repeatedly called until the parameters at each measured node have been compared with the predicted values.

When the final measurement point has been compared or calibrated, all predicted values at measurement nodes will correspond exactly with measurements – any differences in intervening nodes/branches will be due to input parameters not corresponding with actual values or due to changes in the actual ventilation system which have not been taken into account.

Control is then handed back to the Linker to await the next series of measurements.

Figure 2 shows typical program logic.

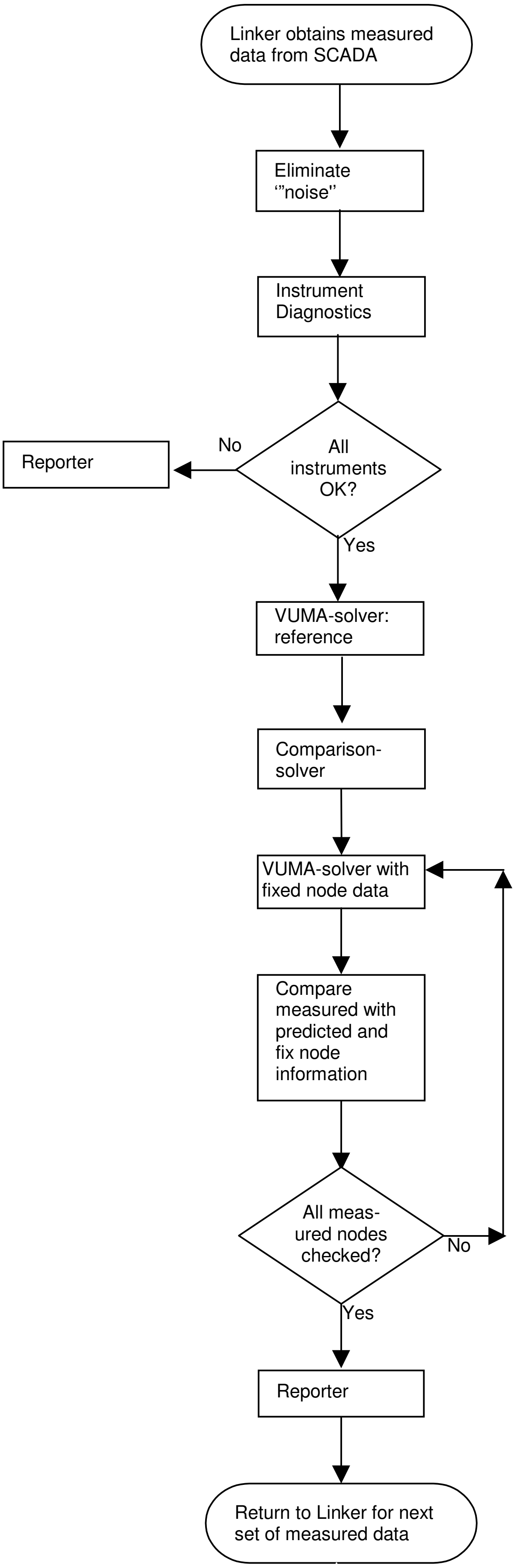

Figure 2: Program logic.

4 TRANSIENT ISSUES

The objective of the Comparison-solver will be to ensure confidence in predicted conditions in the rest of the mine where measurements are not available. The predictions will be used as an ongoing management tool to monitor conditions throughout the mine. Predictions based on accurate upstream measurements will also allow abnormal and emergency situations to be highlighted. For example, if an air cooler is not operating and the conditions immediately downstream of the cooler location are known, it will be possible to identify downstream areas of the mine which could experience potentially dangerous conditions.

Work is currently underway to define what magnitude of temperature variation [from one measurement to the next or from an accepted mean value] should lead to an alarm situation. The alarm would request an operator to check/verify conditions at the measuring station. In addition the operator would check predicted downstream conditions to determine if alarms should be raised in other areas.

Although the thermal solution in VUMA-network is based on steady-state algorithms, minor temperature variations at a measurement location will not significantly affect the accuracy of predicted temperatures at a downstream location. In Figure 4, note how changes in inlet temperature conditions at '18 level mixing point' are not reflected in the conditions in the return airway. Smoothing/trending routines will be included in the Linker to remove minor variations and noise in the measured data.

Large variations in parameters at a measurement location will result in a variation downstream, but although the correct trend will be seen, the predicted value may differ from the actual value because of thermal inertia and other effects in the path from the upstream measuring station. Because of this effect an acceptance or uncertainty band around a predicted condition will have to be defined before an alarm situation is raised.

A companion program to VUMA-network, VUMA-transient® [Bluhm *et al*, 2002] has been developed to investigate the effect of dynamic temperature and flow variations in a network. This program will be used to examine the potential error that is obtained by using the steady state model of VUMA-network.

5 COMPARISON OF MEASURED AND PREDICTED PARAMETERS

As part of the FutureMine programme, management at Beatrix Gold Mine No. 4 Shaft agreed to provide data to allow the ventilation system to be set up in VUMA-network. The mine is ventilated using a downcast air flow rate of 600 kg/s which is cooled to a nominal mixed temperature of 7 °C on surface, [Rose & Burton, 1992]. The fresh air is sent underground in two downcast shafts. The fresh air is supplemented by 300 kg/s of reconditioned, recirculated air underground to give a total of 900 kg/s to the workings. The recirculated air is cooled to a temperature of 18 °C in three spray chambers on 17 Level [at a depth of 1855 m]. Inputs to the model were adjusted so that average predicted conditions corresponded with average conditions underground. Figure 3 shows part of the network.

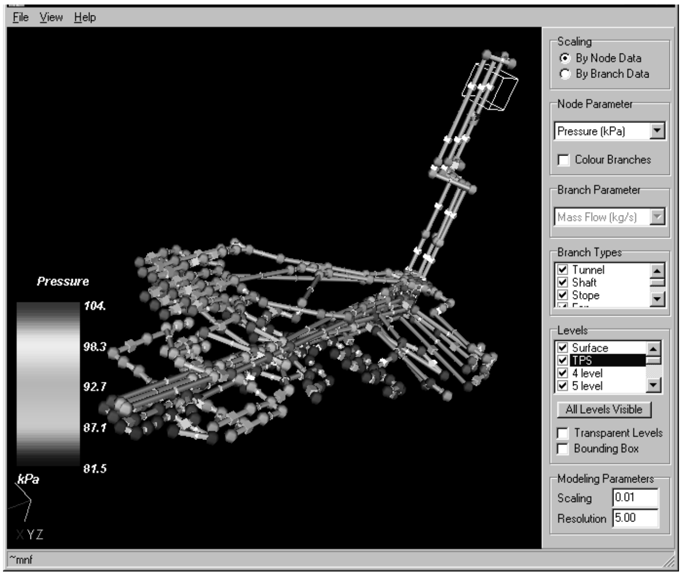

Figure 3: Network layout

A SCADA system is installed at the mine and temperature measurements were obtained at a number of strategic locations. For testing purposes the data were stored in data files in a format which can be read by the Linker and then passed on to the Comparison-solver, as if the data were being obtained 'live' via the OPC interface. Data for a typical day are shown in Figure 4.

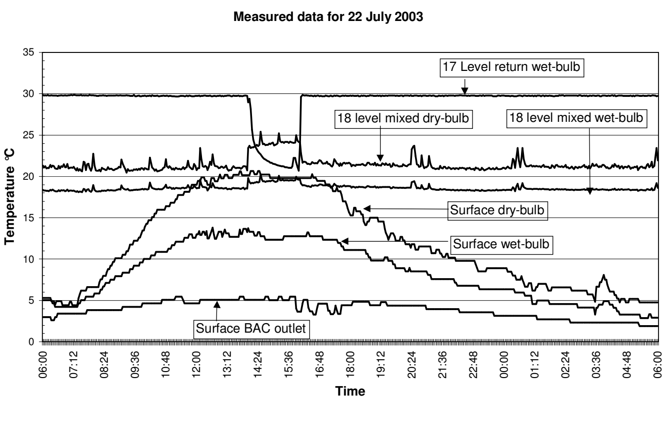

Figure 4: Typical measured data

Return air from the mine arrives on 17 Level, is cooled and reintroduced into the ventilation circuit and mixes with fresh air from surface on 18 Level. The blast occurs at about 14h00 each day and the recirculation system is automatically switched off for about 2 hours at this time. The drop in the measured 17 Level return air temperature in Figure 4 is due to the fact that the measurement location is downstream of the closed doors and the transducer does not experience any flow.

A comparison between measured and predicted temperatures at some measurement locations within the network is shown in the Table below.

Location	Time	Measured wet bulb °C	Predicted wet bulb °C	Measured dry bulb °C	Predicted dry bulb °C
18 Level mixing	06h00	18.38	18.70	21.33	21.58
17 Level return	06h00	29.98	30.57	32.86	32.68
18 Level mixing	13h00	18.56	18.72	21.14	21.57
17 Level return	13h00	29.93	30.56	32.75	32.69
18 Level mixing	17h00	18.92	18.73	21.58	21.61
17 Level return	17h00	29.95	30.42	32.78	32.68
18 Level mixing	20h29	19.46	18.71	23.70 [transient	22.09 effect]
17 Level return	20h29	29.76	30.57	32.77	32.68

Table 1. Comparison of typical measured and predicted values

The correspondence between the measured and predicted temperatures gives confidence in predicted values in the rest of the network. Further comparisons will be done at intermediate locations.

6 FUTURE WORK

Future work will try to identify the cause of any differences between measured and predicted parameters and will suggest ways of correcting the difference by altering network input data. For example, if the measured temperature downstream of a bulk air cooler is significantly higher than the predicted [or expected] value, the Comparison-solver would conclude that the air cooler is switched off and would display a message requesting the operator to check the status of the cooler. In the meantime, the program would switch off the cooler for subsequent iterations.

Other future work would be to identify 'events' that cause changes in the network. To implement this aspect of the program, a set of expert-system-type rules will have to be defined. The expert-system rules will be applied to each branch in an attempt to isolate and correct the cause of any difference. For example, if the predicted flow rate in a part of the network is too high, a regulator could be inserted to increase the overall network resistance. The operator would be requested to investigate a possible blockage or other restriction.

There is also future potential for control functions based on the analyses to be automatically carried out.

7 CONCLUSION

A set of software modules has been developed to manage measurement data obtained from a mine SCADA system via a Linker. The Linker passes the data to a Comparison-solver which assigns the measured values to nodes representing measurement locations and then calls VUMA-network to predict conditions throughout the rest of the network. Initial analysis has indicated that it is possible to confidently predict conditions in entire mine ventilation networks when parameters are measured at only a few key locations, thus minimising the costs of monitoring systems.

This system diagnostic tool will be tested in a real-time mode towards the end of 2003 in conjunction with a deep hot gold mine monitoring system.

8 ACKNOWLEDGEMENTS

The FutureMine Collaborative Research Programme was set up by South African gold-mining groups [Harmony/ARM, Anglogold, Gold Fields], CSIR-Miningtek and the National Research Foundation to ensure the long-term sustainability of gold mining in South Africa. The programme aims to improve safety and health in mines, increase the economic benefit, and minimise the environmental impact of gold mining. Permission from FutureMine to publish this paper is acknowledged.

The project team acknowledges the assistance of staff at Beatrix No. 4 Shaft [Oryx] in supplying measured data and setting up the trials of the software modules.

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