PRACTICAL VENTILATION PLANNING FOR MINE MANAGEMENT USING A DIGITAL COMPUTER

By

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ABSTRACT

Mine management has a responsibility under the various acts of state parliaments for the adequate ventilation of existing workings. It also has a need to plan adequately for the ventilation of proposed workings. Future workings alternatives have become progressively more complex and ventilation planning of the various possibilities must be undertaken within an atmosphere of rapidly changing market circumstances, etc. Any non-optimal solution will prove more expensive than necessary on both capital and cost bases. Clearly these increasing and alternative ventilation demands of coal mines in Australia have multiplied the work load of ventilation engineers.

Management in general has for some time been aware of the advantages of using computers for commercial applications such as payroll and stores inventory. However, while the hand held calculator has replaced the traditional log tables and slide rules for smaller engineering calculations, the larger digital computer has not made the same progress into the larger and more complex technical applications such as mine ventilation problems.

Although a practical coal mine example is used to provide an insight into the ventilation possibilities, the ventilation principles and computer programs for ventilation network analyses apply to all underground mining. Similar computer programs are used by many universities and technical colleges in mining courses and as with commercial programs, ventilation programs are now available from bureaus for those smaller companies which do not have their own computers.

INTRODUCTION

As long ago as 1839 the South Shields Society produced what Turton (1981) described as a creditable report. It recommended mechanically assisted ventilation and that each mine should have at least two separate shafts. The disaster at the single entry Hartley Colliery in 1860 resulted in the death by suffocation of 204 men and boys trapped underground. It brought about a supplementary act of parliament requiring all mines to have at least two shafts and added further to public opinion calling for improved ventilation standards.

The United Kingdom's (UK) 1911 Coal Mines Act consolidated earlier legislation

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d defined, among other things, adequate ntilation. Similar requirements were efined in New South Wales (NSW) by the Coal Mines Regulations Act of 1912 as amended (CMRA). Amendments to this Act have continued to account for increasing ventilation requirements such as the introduction of booster fans and the wide acceptance of auxiliary fans. These technological changes are occurring as the seemingly insatiable demands for minerals of all types are forcing mines into less favourable deposits at greater depths.

The increasing depths at which mining is occurring today is increasing the capital cost of establishing new ventilation shafts, and fan installations. Ventilation operating costs are rising continually because shafts are getting deeper and larger installations are being required both on the surface and underground.

VENTILATION TODAY

Magnusson (1979) documented the cost of ventilation compared to other costs, and typically in NSW a coal mine will produce for approximately 225 days per annum while surface ventilation fans continue to run 365 days per annum. The ever rising costs cannot be passed on to the coal consumer where prices are subject to intense market competition.

In the past, mine ventilation engineers have applied known scientific principles, the traditional log tables and slide rules, combined with knowledge and judgement gained through trial and error experience, to ventilation problems. In some cases, air flow within these complex networks has not always flowed in the direction nor to the location expected.

As reported by Hempenstall et al. (1981) the digital computer is a tool by which a great deal of subjective design criteria can be removed, but it has not made progress similar to that made by the hand held calculator in replacing log tables. The advantage of the digital computer lies in its ability to perform enormous volumes of calculations in a very short period of time, and at unit costs far below those achieved by any other method.

Computer programs can thus automate many of the tedious manual calculations involved in ventilation planning. This allows the ventilation engineer to evaluate many different strategies in the time previously taken to evaluate one. Consequently more alternatives can be tested and the "best" one chosen with greater confidence.

There are many ventilation problems which lend themselves to analysis through computer programs, including the design of a ventilation system for a completely new mine, the design of individual elements of such a system and analysis of existing ventilation systems. This is particularly true in determining the best sites for facilities such as main fans, intakes, overcasts and certain types of airways. Additional information can be obtained to help in the determination of the number of openings required, the dimensions of air shafts, the size of fans, the number of overcasts and the regulation necessary in each split of air.

Computer programs for the analysis of ventilation networks have been developed and used extensively in Australia, the United States of America (US), the UK and South Africa. As reported by Brown et al. (1979), for example, their application is not restricted to coal mines.

One such program was developed as a result of a research project sponsored by the National Coal Board (NCB) in the UK and it is commonly referred to as GENESYS. It is an example of the type of digital computer programs readily available today, and while GENESYS is not available commercially through the University of Wollongong, it is one of the airflow analysis techniques used there for research and as a students' teaching aid.

AIRFLOW ANALYSIS

PROBLEMS TO BE SOLVED

The solution of problems in ventilation networks is important in forecasting the effect on the airflow of any changes in the ventilation system of a mine. Such changes may include the driving of new roads or the introduction of a new ventilation shaft and fan.

Methods developed include analytical solutions involving the solving of one or more equations in high · degree, and the simulation of airflow using both analogue and digital computers.

HISTORICAL DEVELOPMENT

The foundations of ventilation network theory may be said to have been laid by Atkinson (1854) in his classic paper. He realised the importance of the subject, and the vital need for accurate pressure surveys. Atkinson brought forward evidence to show that the air in mine roadways flows to the square law and he advanced the law of the form, Pressure = Constant x $(\text{Quantity})^2$, and derivations have been formulated in various units.

However, while Upfold (1981) discussed Atkinson's equation in various units only the SI system will be discussed. The equation is then defined in terms of pressure, measured in pascals and quantity passing, measured in cubic metres per second. The resistance unit is defined as that resistance which absorbs a pressure of one pascal, passing a quantity of one cubic metre per second. Regardless of the units, variations of Atkinson's original equation have essentially formed the basis of all techniques of ventilation network analysis.

These techniques can be grouped into two types. The first technique is by analytical calculation of airflow. The second technique is based on successive approximations for solution of Kirchhoff's law.

ANALYTICAL METHODS

Analytical solutions to problems involving airflow in ventilation networks can be solved by reducing a ventilation circuit into a network of parallel and series resistances.

For roadways in series, equivalent resistance can be determined from the equation

$$R_{eq} = R_1 + R_2 + \dots + R_n$$

and for roadways in parallel

$$\frac{1}{R_{eq}^{1/2}} = \frac{1}{R_1^{1/2}} + \frac{1}{R_2^{1/2}} + \dots + \frac{1}{R_n^{1/2}}$$

where R_1, R_2 ... R_n are the resistances of the individual roadways.

By substituting these equivalent resistances successively into Atkinson's equation, for the various roadways in the mine, an equation is developed. Solving this equation will allow the determination of the various airflows in the mine.

However, the resultant equation becomes

more complex as the number of airway loops within the network increases. A network with "m" airway loops gives rise to an equation of 2^mth degree.

Typical mine ventilation circuits are quite complex. Mathematical treatment of such a network is possible but the nature of most problems would require an extremely tedious series of computations. Assistance was sought from electrical or electronic "calculators."

ANALOGUE COMPUTERS

Techniques

Two techniques have been used to solve ventilation problems, the non linear analyser and the linear analyser.

US Bureau of Mines Analyser

The US Bureau of Mines network analyser was developed for analysing gas, water, steam and electric distribution systems. McElroy (1954) reported its use on mine ventilation distribution problems. It is a typical non-linear analogue using low voltage tungsten filament lamps as the non-linear resistor elements. These lamps approximate the square law resistance characteristics of mine air flow over a certain voltage range.

The bulk of the time in analysing any network is taken in setting up and selecting and testing the resistor lamps to accurately represent the roadway resistances, in order that pressure drops and quantities may be read directly.

NCB Calculator

The development of the NCB ventilation network calculator at the University of Nottingham was reported by Scott et al. (1952).

Each roadway is specified by a separate potentiometer and the unit being of the linear type relies on a series of iterations until a balanced circuit is obtained. The potentiometers are given initial values and simple mean error corrections are applied to the potentiometers each iteration until the following is satisfied:-

$P = S Q$ and $S = R Q$

For the values of P applied, R given in the data and Q measured on analogue.

where P is the pressure
Q is the air flow
R is the airway resistance
S is the potentiometer setting, i.e. electrical resistance.

The instruments are calibrated to give values directly in practical ventilation units.

Bray' and Plummer (1964) compared the application of a linear and non-linear analyser. They used a NCB calculator to obtain a solution to a fairly simple mine ventilation problem previously solved by a US Bureau of Mines analogue. Similarly, digital computer programs use a method of successive approximations to solve ventilation network problems even more quickly.

DIGITAL COMPUTERS

With the growing use of digital computers in most fields of engineering and commerce, programs were written for the simulation of airflow in mines. Most of these ventilation programs were developed to accept resistance values calculated from pressure and volume surveys, or to calculate resistance values from friction factors and airway size parameters.

The method of analysis of ventilation networks was discussed by Upfold and Adam (1983). It assumes that air is incompressible and applies Kirchoff's law, namely that the algebraic sum of air quantities at every junction of roadways must be zero ($\Sigma Q=0$) and that the algebraic sum of pressure drops around a closed circuit of roadways, termed a mesh, must be zero ($\Sigma P=0$).

Since $P = RQ^2$, $\Sigma RQ^2 = 0$

These equations are solved using the Hardy Cross method of successive approximations. In the successive calculations quantity corrections are applied around the meshes within the network.

Because of the approximations made in the derivation of the Hardy Cross correction formula, the correction factors do not immediately result in a balanced network. As with the NCB calculator it is necessary to reiterate the calculations until all the mesh correction factors become so small (less than $0.01m^3s^{-1}$) as to be negligible. Iterations then cease and the network is said to be balanced.

The following research project serves to illustrate a typical ventilation problem which may be solved easily using a digital computer. It should be noted that while the values are of the correct order of magnitude they are only indicative.

GENESYS, FOR EXAMPLE

Clarence Colliery, situated in the Western Coalfield of N.S.W. is currently ventilated via two intake drifts and an upcast shaft. A second downcast shaft has been sunk approximately 3km to the north of the existing entries. The new shaft is at seam level, but the workings are still approximately 450 m away from the inset. There has been some concern that when the shaft is holed that there will be some reversal of air direction in the intake roadways, and the reduction of volume flowing may cause dust and diesel exhaust pollution problems along the existing transport and conveyor roadways.

A standard ventilating pressure and volume survey between the stations in Fig. 1 was conducted throughout the mine. The results are presented, Table 1. These were then used for computer input data to the GENESYS program in the Univac computer at the University of Wollongong. The first model contained data which related only to the existing workings.

This model called the "Order of Magnitude" model was used to check the reliability of the data against known pressure and volume relationships for the mine. Table 2 presents the results as graphically illustrated in Fig. 2. From this accurate model including leakage, a second model was then developed to include the extension of the workings to the new shaft, and also the shaft itself.

This extended data was then run through the computer using the GENESYS program and the output examined. A comparison of Figs. 2 and 3 quickly identifies those roadways where the airflows will reverse and precautions will now be undertaken with confidence.

The presentation of a solution to this ventilation problem was completed without re-course to computing "jargon". The same is not true of this paper's use of mining

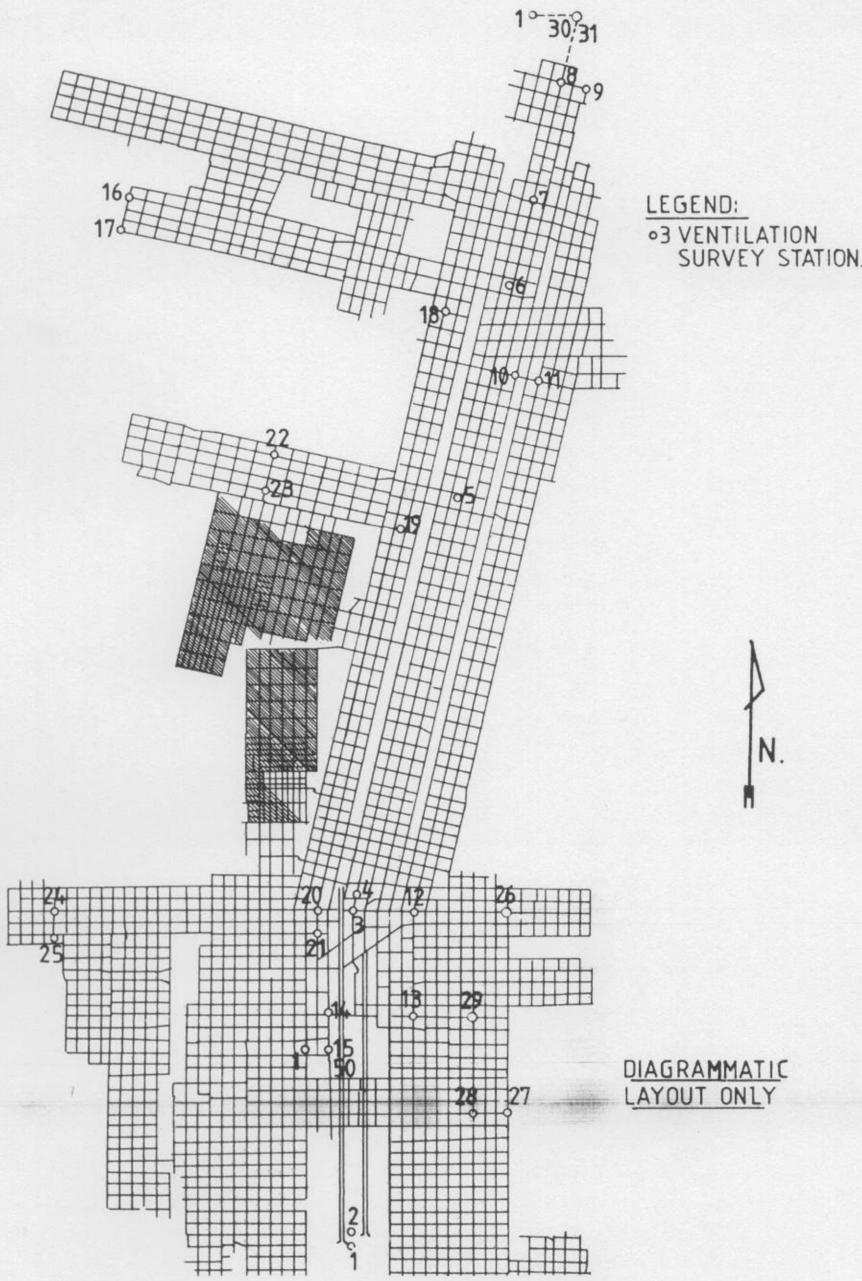

Fig. 1 - Mine layout schematic.

Table 1

Ventilation survey results

CLARENCE COLLIERY AUSIMM

'SURVEY'

R	F	T	T	P	R	Q	X	Y
1	1	2	0	0	0.0001	250.0	106	1
2	2	3	0	405	0.0	210.0	106	98
3	3	4	0	2	0.0	210.0	106	103
4	4	5	0	16	0.0	89.4	137	228
5	5	6	0	6	0.0	59.4	154	301
6	6	7	0	5	0.0	29.4	172	370
7	7	8	0	1	0.0	26.0	179	404
8	8	9	2	1	0.0	25.0	188	402
9	9	10	0	1	0.0	26.0	159	270
10	10	11	0	1	0.0	29.0	165	268
11	11	12	0	50	0.0	29.0	124	96
12	12	13	0	40	0.0	29.0	124	65
13	13	14	0	8	0.0	64.0	95	65
14	14	15	0	10	0.0	159.0	95	50
15	15	50	0	200	0.0	160.0	95	50
16	50	1	3	0	0.0	150.0	100	50
17	6	16	0	5	0.0	26.0	40	327

Table 2

GENESYS output

CLARENCE COLLIERY AUSIMM

'ORDER OF MAGNITUDE MODEL'

ROAD	FROM	TO	T	FAN-P	RESISTANCE	QUANTITY	PDROP	X	Y
1	1	2	0	0.0	0.0001	173.62	3.0	106	1.00
2	2	3	0	0.0	0.0092	173.62	276.8	106	98.0
3	3	4	0	0.0	0.0000	96.96	0.4	106	103
4	4	5	0	0.0	0.0020	96.96	18.8	137	228
5	5	6	0	0.0	0.0017	60.56	6.2	154	301
6	6	7	0	0.0	0.0058	25.00	3.6	172	370
7	7	8	0	0.0	0.0015	25.00	0.9	179	404
8	8	9	2	0.0	1.7220	25.00	1076.3	188	402
9	9	10	0	0.0	0.0015	25.00	0.9	159	270
10	10	11	0	0.0	0.0012	29.06	1.0	165	268
11	11	12	0	0.0	0.0595	29.06	50.2	124	96
12	12	13	0	0.0	0.0476	29.06	40.2	124	65
13	13	14	0	0.0	0.0020	79.86	12.5	95	65
14	14	15	0	0.0	0.0004	173.62	11.9	95	50
15	15	50	0	0.0	0.0078	173.62	235.5	95	50
16	50	1	3	1738.3	0.0000	173.62	0.0	100	50
17	6	16	0	0.0	0.0074	25.00	4.6	40	327

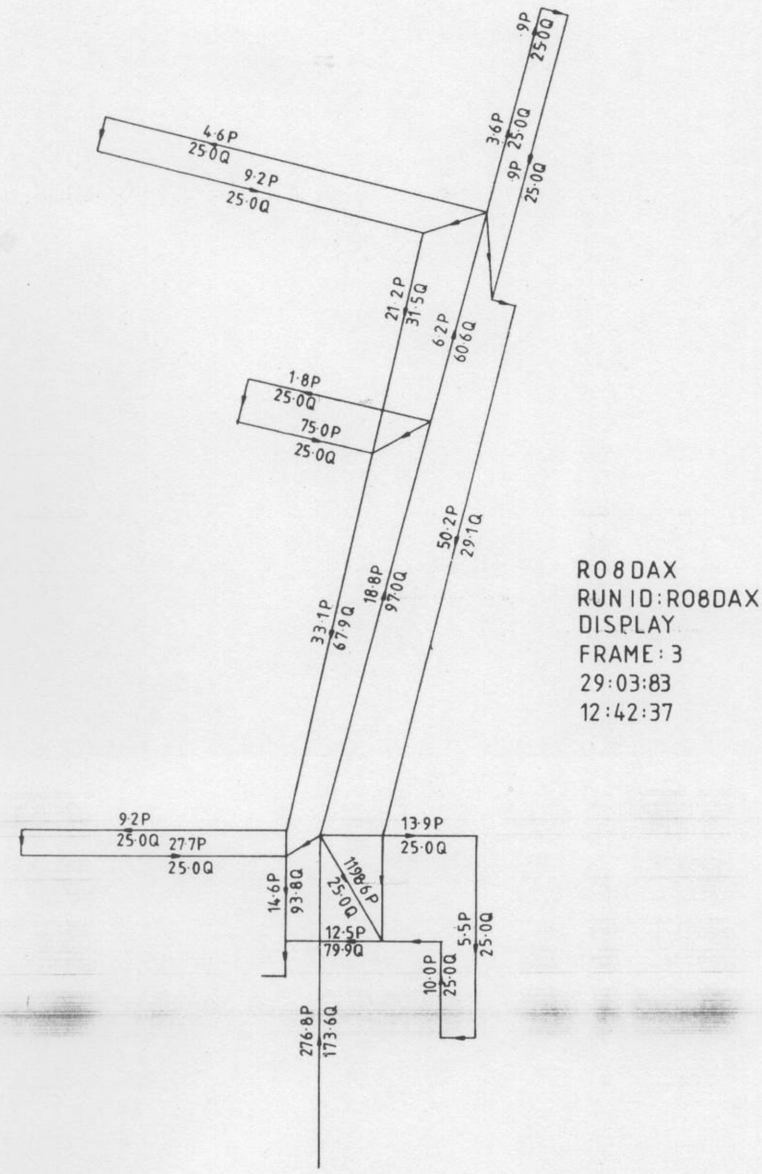

Fig. 2 - Current Ventilation

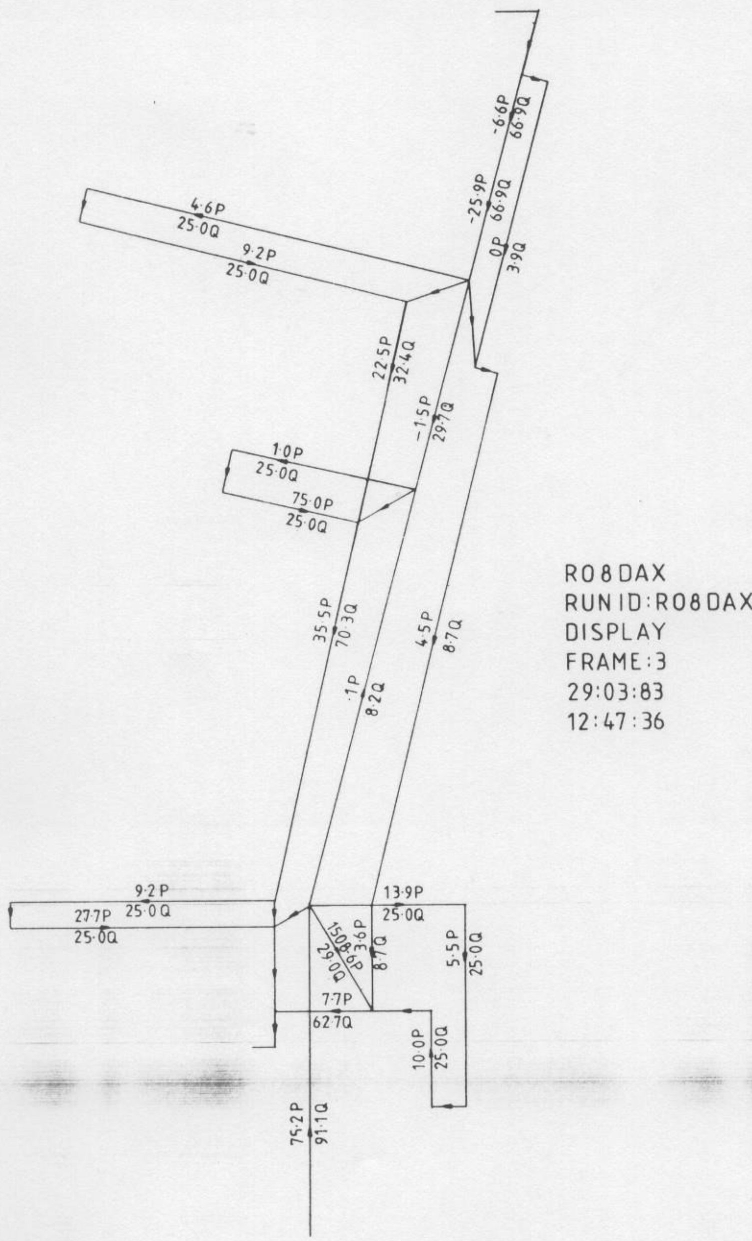

Fig. 3 - New Shaft Ventilation

"jargon".

COMPUTING AND MINING "JARGON"

PREREQUISITES

Ventilation engineers have required computer programers to learn, for example, that the metric mining industry measures pressure in KPa but talks of inches water gauge. Alternatively ventilation engineers had to gain some proficiency in writing computer programs.

To use commercially available packages, Genesys, for example, or to make a decision on the use of available alternatives some knowledge of elementary computer "jargon" such as hardware, software and data is necessary.

HARDWARE

The concept of hardware is, in fact, extremely easy to understand. Hardware are those items which can be physically touched. Terminals, plotters, etc., are pieces of hardware.

The parallel concept with analogue computers is the machine itself. The machine can be physically touched. Other concepts can similarily be simply explained.

SOFTWARE

Software are the set of instructions required to solve, for example, a ventilation problem. Software cannot be physically touched. A copy of the software can be read, understood and carried out by a digital computer or by the operator of an analogue computer reading an appropriate instructions manual.

But while parallels can be drawn between hardware and software for digital and analogue computers, neither can solve a ventilation problem without data.

DATA

The same data is required for the solution of a ventilation problem whether it be by analogue or digital computer. Results are presented in graphical and tabular form. This data is communicated through the operator to the analogue computer by the turning of dials.

The data is communicated to a digital computer program through a terminal and a program called an editor. These two transfer a written list of results to an electronic list within the digital computer.

EDITOR

As Genesys is a set of instructions for the solution of a ventilation problem, an editor is a set of instructions (program) for the solution of the communications problem between the hardware (terminal) and software (Genesys). Since it is program, the editor is also part of software.

A knowledge of the interaction of hardware, software and data provides the basis for an evaluation of the possible alternatives. But there is one piece of computer "jargon" that is applicable to any problem - Garbage In Garbage Out (GIGO).

ALTERNATIVES

The use of consultants separates mine management and the ventilation engineer from the need to learn the instructions of the editor and the ventilation program. However, this does not remove management from the GIGO problem.

It is mine management that is intimately familiar with the colliery and its particular anomolies. Any result produced by a consultant that does not "look right" deserves questioning. Clearly questioning is more easily and efficiently carried out if the work has been completed by the colliery's own ventilation engineer, but this does involve a "trade off".

While ventilation programs on digital computers are used by a number of universities as part of their degree courses and by technical colleges as part of their certificate courses, few undermanagers retain their familiarity with the programs. Other duties, including statutory ones, frequently do not allow sufficient times for the undermanager to maintain an interest in ventilation programs. If, however, a large number of ventilation options have to be evaluated and if colliery manpower is available then the time required to regain sufficient familiarity may be cheaper than the employment of a consultant.

As part of regaining familiarity with digital computer ventilation programs short courses are advertised in the AUSIMM Bulletin at universities including the University of Wollongong. Ventilation programs available through the Universities of Wollongong, NSW, Queensland and other establishments can then be used by appropriate colliery staff. Larger companies which have their own computers have a further option available to them.

Rather than having undermanagers and ventilation engineers learning computer "jargon", they can have their programers write question and answer style programs for the input of ventilation survey results and projections. This "trade off" however, is not cheap or easily accomplished as programmers must now gain an insight into ventilation problems. The programs typically must be written in such a way that typing errors can be easily corrected by the inexperienced, in computer terms, user.

Clearly, the selection of the appropriate alternative will vary from company to company. What is equally obvious is that digital ventilation programs are readily available to all prospective users by one way or another.

CONCLUSIONS

Everyday practical use of computers in the commercial world and heavy industry is quite common place. It is paradoxical that an industry older than most has been so slow in making use of such a device.

Regardless of the ventilation software or the implementation alternative chosen, digital computers are a practical replacement for analogues. Data files describing various alternatives are retained and can be readily modified to evaluate alternative ventilation proposals.

The print out and plotting of results avoid transciption errors. Suitable reports can be included directly into the presentation of results to mine management.

Turton (1981) concluded that the reliabilitiy of ventilation apparatus must be paramount to ensure stable conditions and continuity of operation. The digital computer is one piece of reliable ventilation apparatus which has not been fully utilized to date in ensuring the ventilation stability of proposed workings.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the permission of their respective employers to publish this paper.

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DISCUSSION

D.R. CHALMERS (Dept. Technical and Further Education): With the programme which has been running for Clarence Colliery, how long did it take from the time that the pressure-quantity survey was done to get the order of magnitude model up and running? Secondly how long would it take after the model is running to determine the feasibility of any proposed changes?

J. HEMPENSTALL (Australian Iron and Steel Pty. Ltd.): To get the hand-written pressure quantity survey results into the computer in a neat typed up form where all the dots lined up for the decimal places etc., and all the plots for this paper were produced, took four hours one Sunday morning. That included the proposed change of holing into the bottom of the shaft which took ten minutes and partly answers the second question.

Once the first order of magnitude model was up and running, the changes were very easy to do. One of the questions asked recently was - What would happen if, subsequently, the fan was moved from the top of No. 1 shaft over to what is to be a downcast shaft? This problem was solved on the computer in less than ten minutes.

The first model takes longest, particularly if both the Editor and the program have to be learned. Phil Mitchell from B.H.P. runs a question and answer type program. Any Ventilation Engineer could use that style of program to produce his results quickly without having to learn any Editor.