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Ventilation Surveys and Modelling - Execution and Suggested Outputs

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VENTILATION SURVEYS AND MODELLING - EXECUTION AND SUGGESTED OUTPUTS

J A Rowland

ABSTRACT: The need for a pressure quantity survey is usually brought about by a lack of knowledge of the actual value of various roadway, branch and infrastructure resistances around the mine. If resistances are not known or are suspected to be erroneous then it is difficult or impossible to accurately replicate the circuit performance, on a ventilation modelling software program.

The challenge for mine operators is to carefully decide what level of survey detail is required so that the appropriate adjustments can be made to an existing model or the appropriate data collected so a model can be built in the first instance.

The level of survey detail required is totally dependent on the end use of the data and the criticality of the accuracy of the dataset, to the safety and viability of the business. Mine technical personnel should think clearly about the report outputs required that will help them better understand their mines and better prepare them to manage their own ventilation circuits, on an ongoing basis.

Some methods of data collection and circuit analysis required for surveys up to a high order of accuracy are detailed.

Some of the issues which are important when formulating a strategy to carry out the appropriate ventilation survey for the required purpose are summarised.

Some details that should be furnished within any survey and some survey/report outputs and/or omissions, which are clearly not acceptable, are highlighted.

INTRODUCTION

Most mines in Australia, at least in the underground coal sector, maintain a validated model to assist with the process of minor to major ventilation circuit adjustments. They also routinely utilise validated ventilation models to track ventilation system performance and thus effectively plan and budget for major ventilation infrastructure, as the mine expands. The modelling program of choice in Australia is "Ventsim" software which is now available in a fully graphical 3D configuration as well as the widely utilised 2D version, the models of which are operable on the newer format. The wide availability of this software, coupled with changes to legislation in both NSW and Queensland in the last decade, has ensured that most site ventilation personnel are well equipped to utilise the technology.

Probably the most vexing issue for site personnel is just when the model actually needs a professional "tune up" and to what use will the rebuilt model be put. There is arguably little or no value in carrying out a detailed mine pressure/quantity survey if the results are not going to be transposed onto a model interface and, more importantly, the model must be religiously and periodically updated, pursuant to such works.

Considerable thought should be put into the survey scope to obtain the desired result dependent on site needs. As such the scope of the work is an extremely important component.

There is a diverse range of survey possibilities that may be considered depending on the use to which the data will be put.

The overall challenge for management is to decide the appropriate level of survey detail that is required to satisfy current and future site needs. It is possible that a working model could be built remotely from the site using raw experience, site supplied survey data and empirical values to build a rudimentary model that actually works. At the other end of the spectrum is the "*full PQ survey*" which may mean determining

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the resistance of all open areas of the mine from the bathroom to the fan blades and closing survey loops "a la" survey level run fashion. Obviously the time and dollar cost of two such contrasting assessments could vary ten to twentyfold. Management really need to consider the work that the ventilation model needs to be put to before asking the consultant to supply a quote for a "*full PQ survey*".

The challenge for mine operators and ventilation personnel is to decide when such a high level of detail is required and what options are available if a less accurate dataset will suffice, for the job at hand. All survey and model outputs should be carefully scoped according to the particular requirements of the mine at that time.

SURVEY SCOPE

It is routinely the case that the client is not familiar enough with the model assembly process to specify, or scope, what is exactly required from the ventilation survey process. Whilst they may be familiar with what the final outcome will be, they are sometimes unclear on the actual steps required to reach that objective.

It is prudent for the client to discuss with the ventilation surveyor: 1) what they hope to get out of the final assembled model; and 2) how and for what they plan to use it. The survey process may be dependent on the layout, age and gassiness of the mine along with numerous interrelated factors. Considerable thought and discussion should surround the intended purpose for which the model will be used. An appropriate survey strategy can then be devised accordingly. Often clients will request a full closed Pressure/Quantity survey when considerably less may be required. The concept of a fully closed survey loop of all mine roadways for all jobs is a simple way to oversupply a service that is often not needed. Ironically many fully closed loop surveys result in the provision of a basic stick figure schematic model. The value of such a model should be closely scrutinized by mine site staff.

Summarily the nature and complexity of the survey, and subsequent assembled model must reflect the needs of the client at all times but assisted by the experience of the ventilation surveyor to achieve a satisfactory outcome for all concerned.

SURVEY PLANNING

The initial survey preparation is of the utmost importance. Unless the surveyor intimately understands the circuit design, then the allocation of the appropriate station locations is virtually impossible. It is of prime importance to study the mine-plan sufficiently to understand all circuit flows, and considerable discussion and questioning of the client and/or his representatives is required unless the ventilation surveyor intimately knows the mine.

Decision on method

After a thorough knowledge of the ventilation circuit is gleaned, a decision is made on the intended survey method. Hopefully this should be known before the reconnaissance survey is carried out but often the findings during the reconnaissance survey alter the planned survey method. Direct survey methods rather than indirect are generally favoured as the chance of unacceptable errors using the indirect method is higher for whole mine surveys and results are often more difficult to reconcile. Having said that it is prudent to utilise barometers for specific or pointed resistance back calculations especially in areas of limited access and they are ideal for lengthy splits with very low pressure drops per unit length which may make the hose drag method unsuitable. Summarily though, a combination of direct and indirect pressure determinations may be recorded depending on the particular situation, to achieve an acceptable result.

On occasions, the lack of appreciable roadway pressure drops may mean that the model is assembled using only empirical methods. That is to say the model roadways are assigned measured parameters of dimension, and k factors can be allocated based on experience. This can result in models of adequate accuracy and overall flows and pressure drops can be refined using differential pressures only. Whilst this is acceptable, there is no real way to guarantee the actual pressure drops in either the intakes or returns, only in the combined sets of intakes and returns. In such cases circuit and roadway knowledge is of paramount importance if individual branch model resistances are to replicate real underground values. As such, considerable exploratory work and discussion with experienced mine site operational staff is required, and any shortcomings of the development of an empirical model should be properly explained.

Having due regard to the above comments, the final survey method may be ultimately determined by a number of factors including the ultimate planned use of the model in conjunction with client preferences, the speed of assembly, the final accuracy required, available equipment, and budgetary constraints.

Many circuits can be delineated with measured flows and a combination of frictional and differential pressures and the number of determinations required will depend on pressure drops per unit length, roadway conditions, access issues and intake and return conditions.

Preparing underground plans

Up to date underground plans are critical to a ventilation survey. They need to include details of existing driveages and those intended to be driven along with cross-cut numbers, panel names, air flow direction, location and description of various appliances along with all natural and artificial resistances or regulation. Obviously the plans need to be printed and prepared for use during the underground survey and should be both regularly updated and closely guarded throughout the project.

Identifying falls and other obstructions

Considerable discussion will be required with the appropriate staff to assess the impact or level of underground obstructions such as falls, water lodgements, stowage emplacements and the like. This information is pivotal in the selection of the process used to delineate roadway resistances.

Identification of probable station locations

Once the circuit is appropriately understood and a generic survey plan has been devised, the surveyor needs to plan where quantity survey stations and pressure station locations should be established. Whilst there is some flexibility in the establishment of these, they are primarily dictated by the circuit design and contribution of flows from and into adjacent air splits.

The overarching requirement of the number of stations required and their locations is that all circuit flows, whether intentional flows or uncontrolled leakage, can be identified and delineated.

Underground reconnaissance survey

A reconnaissance survey is of the utmost primary importance after the surveyor has chosen the selected survey method. The survey enables the following functions to be completed:

- Stations must be clearly and legibly marked up at the appropriate locations giving due regard to roadway velocity profiles, roadway uniformity, proximity to obstructions and the like.
- Quantity station areas must be accurately measured. This is a very time consuming process and should not normally be done during the survey. The survey should be carried out in the shortest and most efficient way possible and to measure and mark up stations during the survey is not normally a viable option. Bridge access across conveyors and door access into returns must also be identified which may impact on station locations.
- During reconnaissance attention must be paid to the collection of pressures as tubes may need to be run across regulators and other obstructions to collect differential and/or frictional pressure data. The reconnaissance survey is often the hardest work involving the longest days but is arguably the most valuable part of the process, without which, satisfactory results are highly unlikely.

CIRCUIT LAYOUT/PECULIARITIES ON DAY OF SURVEY

It is critical to know the exact circuit layout at the time of the actual pressure/quantity survey and face area peculiarities, are of paramount importance in this regard. For example, if an auxiliary fan is tightly bratticed up as in a weekend ventilation arrangement to push air through the exhaust ducting, then it is very important to be aware of such a scenario. This would then be resolved by measuring the pressure and flow and the resultant back calculated resistance could then be inserted into the model as a fixed resistance. Circuit knowledge is always a prime consideration.

It is obviously critical to ensure that the mine site does not alter circuit parameters or design during the survey. They must appreciate the need to ensure it is left in a stable state throughout the survey duration.

Survey execution

The following actions should be taken to ensure a successful survey.

- Team discussion should focus on the planned method and goals to achieve during the shift and the intended work schedule adjusted according to the groups input. Ideally the route of travel should gather the intended data in the shortest possible time frame.
- Assemble the appropriate tools/survey aids including two way radios, anemometers, manometer, barometers, hose, watch, tape, sling psychrometers, paint, chalk, pro-formas and plans.
- Remember key items such as ample water and food because days often end up much longer than expected.
- Any new stations must be clearly and legibly marked up at the appropriate locations giving due regard to roadway velocity profiles, roadway uniformity, proximity to obstructions and the like. They should also be added to the mine plans.
- When frictional resistances need to be determined it should be done sequentially by measuring the branch pressure drops and determining the average branch flow at that time for resistance back-calculation. Obviously appropriate strategies for the determination of densities and the elimination of differential velocity pressures at each survey station must be exercised during this process. The author believes that many specific branch resistances may be determined in isolation to the survey as long as they are static splits and not likely to change. Examples of such branches would include airflows across overcasts with indeterminable shock losses, longwall faces, heavily timbered roadways and areas of fallen roof or stowage. The resistance of these can then be deduced at any suitable time.
- When the required frictional branch resistances are determined along with the corresponding differential pressures into adjacent splits such information should allow the skeletal framework of the ventilation model to be later assembled, ensuring roadway resistances in the model closely replicate those determined during the survey.
- Pursuant to the frictional pressure/quantity survey it is wise to carry out a full mine wide quantity/ differential pressure survey in the shortest possible time measuring data at all selected flow and differential pressure stations. This data gathered then reflects a concise and precise "point in time" data set that can be used to tune the model after the aforementioned specific attributes and predetermined resistance sets are included in the initial model assembly process. Speed is of the essence when gathering this "point in time" data and the observations must be sufficient to delineate all circuit flows and leakage paths.
- Any ancillary data that can be gathered during the survey is also collected. If the mine is gassy, it is a simple process to collect gas concentrations at every station and a complete mine gas balance can be determined. Such information can then be included in say a bar chart format in the final report.

ONGOING STATION USE

The pressure and quantity stations used during the survey should then be utilised by mine site staff to allow them to update the model on a regular and ideally monthly basis. Most model assemblies should result in a pro-forma of sorts for ongoing routine site validation. The biggest mistake most consultants make is data overload. Let Kirchhoff's laws work for you and use the laws to establish the minimum number of stations to supply the maximum data output for both the pressure/quantity survey and ongoing site staff validation.

FAN PERFORMANCE

Fan performance during the survey must be measured and the results compared against expected operating points according to available supplied curves. If no curves are available, it is prudent to identify at least a couple of measured operating points on the curve. This can be done pre or post survey by loading up the mine resistance or by reducing the mine resistance by opening pit bottom doors and determining corresponding PQ operating points.

It is important not to be overly concerned about the expected operating point at the fan itself. Some adjustment of shaft bend resistance may need to be factored in to get pit bottom pressures the same on the model as they are in the mine. More often than not, the supplied manufacturers curve as stated will just not be suitable.

Often, for a myriad or reasons, the measured operating points of fan pressure and total fan flow lie well off the manufacturer's curve. The most important thing however is to get the pit bottom ventilation pressures the same in the model as those measured in the pit. The balance of pressure losses in the shaft and shaft top appurtenances is of little consequence unless discrete changes or improvements are planned to them, which is unlikely.

Consider a situation where there is 2000 Pa available across intake to return at the bottom of the shaft and there is 250 m^3/s of available airflow. If the model can be tweaked to emulate this, both at that point, and all pressure and quantity stations inbye, then it can be reliably utilised. The fan curve issue can be sorted out at the first available opportunity.

RESULTS TABULATION

After all readings are taken, the data then needs to be reconciled. The process may highlight errors or omissions of data that need to be further explored before winding up the survey. To achieve this all data should be reviewed on each day of survey. If data is found to be questionable, it should be checked as soon as possible, preferably the next day. It is a little late to go and collect data a week later if there were important omissions and the circuit has since changed markedly.

Results are best tabulated on a spreadsheet and a complete analysis of the circuit can then be carried out and discrete leakage magnitudes assessed. Figure 1 shows the raw results data and Figures 2 and 3 shows the distribution of intentional and unintentional flow respectively.

Southfork Colliery Ventilation Survey Raw Data

STN	DATE	LOCATION	AV VEL m/s	AREA m2	QUANT m3/s	CH4 %	CO2 %	COMMENT
		MAIN INTAKES						
1	1/06/2015	NO1 INTAKE SHAFT EAST ROAD	6.46	10.40	67.18	0.00	0.00	
2	1/06/2015	NO1 INTAKE SHAFT WEST ROAD	6.23	11.50	71.65	0.00	0.00	
3	1/06/2015	NO1 INTAKE SHAFT NORTH ROAD	7.02	11.10	77.92	0.00	0.00	
				S/TOTAL	217			
4	1/06/2015	DRIFT INTAKE	6.98	13.17	92	0.00	0.00	Remeasureed arched stn Pit/b
				TOTAL	309			Southfork intakes
		MAIN RETURNS						
5	1/06/2015	NO 2 UPCAST SHAFT EAST ROAD	9.70	14.58	141.43	0.50	0.25	
6	1/06/2015	NO 2 UPCAST SHAFT SOUTH ROAD	6.98	12.42	86.69	0.50	0.12	New Stn est 15m O/B corner
7	1/06/2015	NO 2 UPCAST SHAFT NORTH ROAD	10.50	8.46	88.83	0.35	0.11	
8	1/06/2015	NO 2 UPCAST SHAFT DRIFT	0.60	8.74	5.24	0.10	0.00	
				TOTAL	322			Southfork returns

Figure 1 - Raw survey data

GRAPHICAL DATA REPRESENTATION

The final results are best transposed onto a plan type schematic of the circuit. This is paramount to the model update process. The schematic allows an iterative update of the model to be done by cross-referencing measured results against the changing model values during tuning and validation.
The use of a schematic also allows site personnel to better understand their own circuit peculiarities. Further to this it can be used as an ongoing statutory report inclusion and serves as an ideal circuit training tool for mine officials and the workforce in general. Microsoft Excel is perfect for this task.

Figure 4 shows an example of a circuit schematic generated in Excel which ideally should be fabricated during the survey and report process

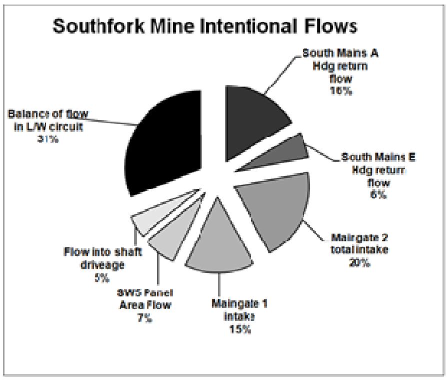

Figure 2 - Intentional flow distribution

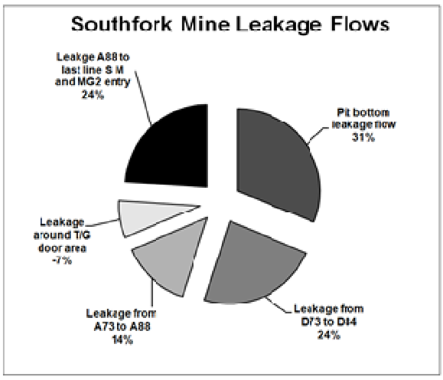

Figure 3 - Unintentional flow distribution

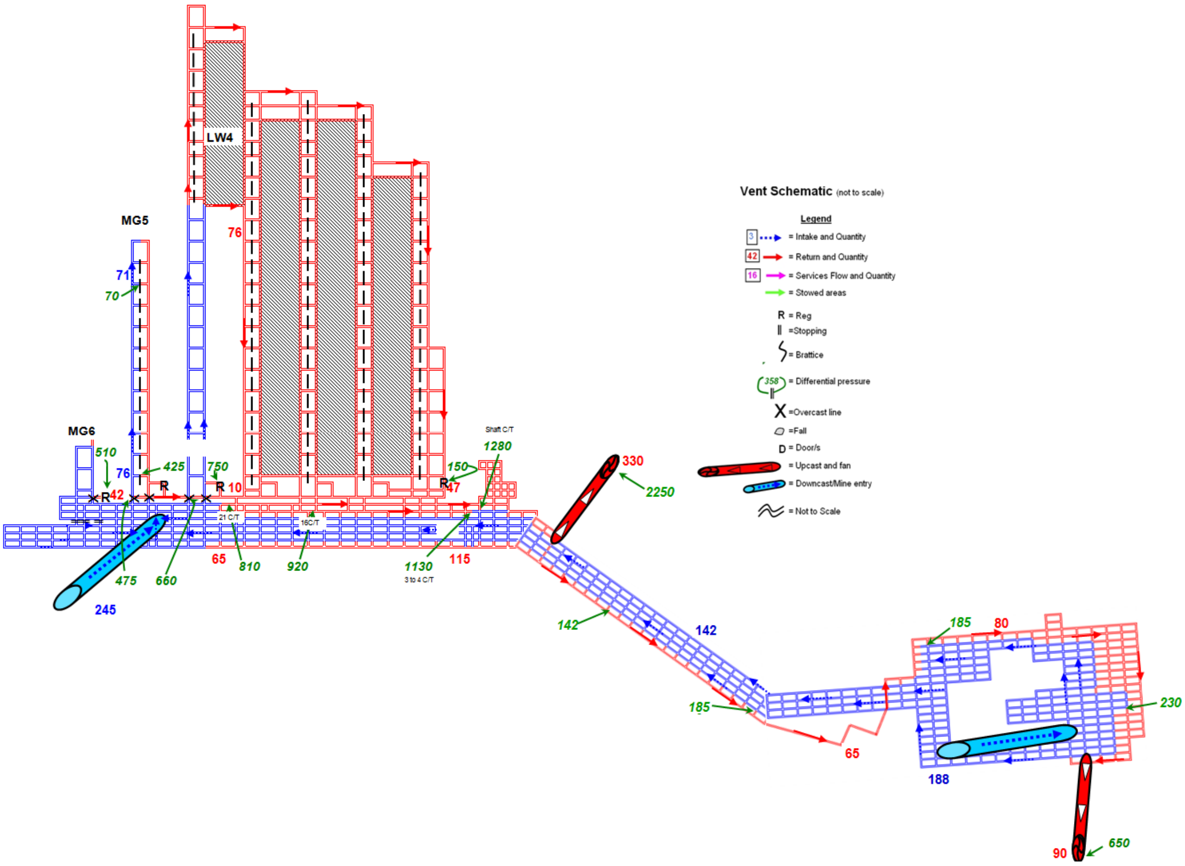

Figure 4 - Vent circuit schematic

MODEL ASSEMBLY AND TUNING

Assessment of generic roadway attributes

There is nothing more ridiculous than assembling a ventilation model that has grossly erroneous roadway attributes and for no logical reason. Models have been previously sighted with roadways with designated cross-sectional areas 10 times that of actually measured underground only to have unrealistically resistive k factors assigned to the branches to achieve the appropriate pressure drops. Whilst such a strategy does nothing in relation to confidence of the finished product the biggest risk with such a plan is ongoing validity when others attempt to update the model. If the true roadway area is used and realistic k factors and shock losses are designated the longevity of the model will be maximized. Considerable effort should be put into determining the approximate cross sectional areas of various roadways or branches of roadways and this is of far greater importance if a full mine wide pressure/quantity survey is not envisaged, as empirical resistances of various branches need to be determined. The colliery mine surveyor is usually a key resource in this case and can also assist with accurate values of shaft depths and diameters which are obviously required for the model assembly process.

Physical model assembly tasks

Centerlines from a dxf drawing file need to be imported into the modeling software assuming that all or most roadways intend to be utilised in the finished model.

There is no reason why virtually all open mine roadways cannot be included in the model. Having said that it may be a benefit to make irrelevant roadways schematic by design if they have no real bearing on the model. (Examples of this may be an open inaccessible goaf area that is flowing air but cannot be accessed to assess the roadway status or flow distribution. A further example may include multiple flood intake or flood return roadway sets that may be simplified in discrete locations).

It is important however to at least make the model circuit look like the mine circuit.

There is arguably little value in turning a 2000 branch mine circuit into a 50 branch ventilation model. The main reason for not utilising all or most circuit branches in bygone days was the inability to be able to properly view the network model. This was particularly relevant in metal mines where plan and elevation views were almost always confusing. Thankfully modern software such as the "Ventsim Visual" 3D screenshot shown in Figure 5 makes such viewing simple and practical from any conceivable angle. If the consultant has the ability to fabricate the model the technology is now available to easily view and understand the circuit.

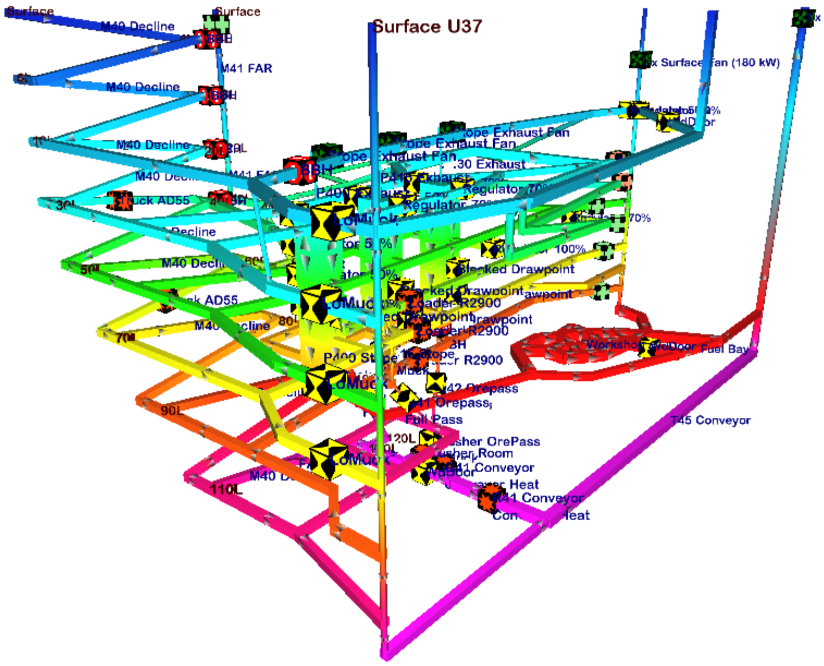

Figure 5 - 3D view in "Ventsim Visual"

What really is the point of turning the mineplan shown in Figure 6 below into a stick figure style ventilation model such as that depicted in Figure 7?

The minimalistic skeletal model depicted in Figure 7 would add very little value when trying to add on the five year mine plan as shown. Worse still, how would you then model what happens when discreet changes are made such as modelling the effect of segregating the total conveyor system, or trying to model emergency escape protocols according to contamination velocity?
To further this point and considering a more crucial scenario how could anyone go about sequentially recovering the mine in practice if it was sealed due to say a fire and then needed to be recovered?

There is no conceivable reason why the model supplied pursuant to the survey cannot contain most of the branches as detailed on the mine plan shown in Figure 6. An example of such a model which would prove far more useful to mine staff is shown in Figure 8.

It is also important to ensure both the model and the mine plan utilise the same alignment to North and the same coordinate origin. In this way future drivages can easily be imported as the mine expands.

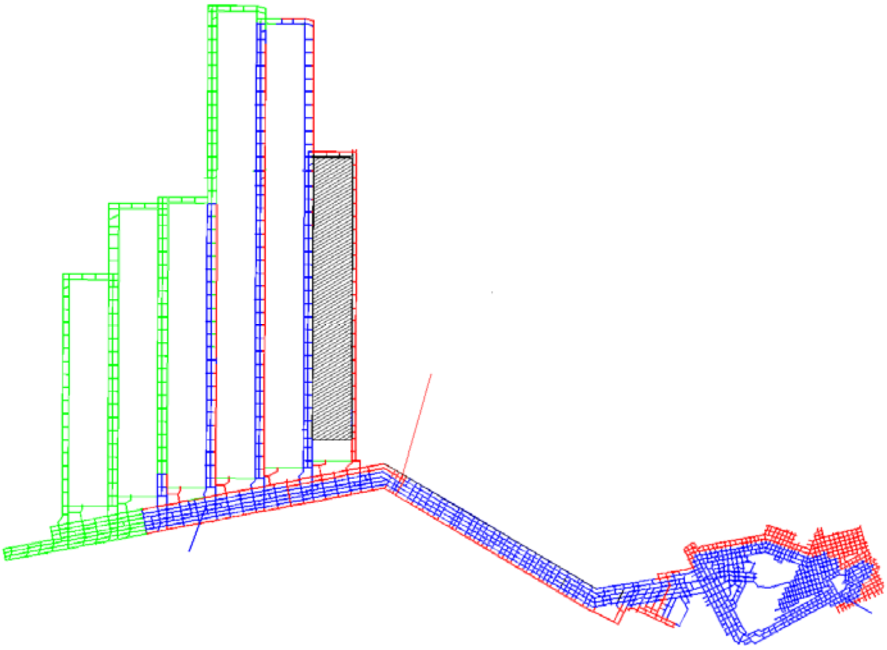

Figure 6 - AutoCAD mine plan of driven and future working

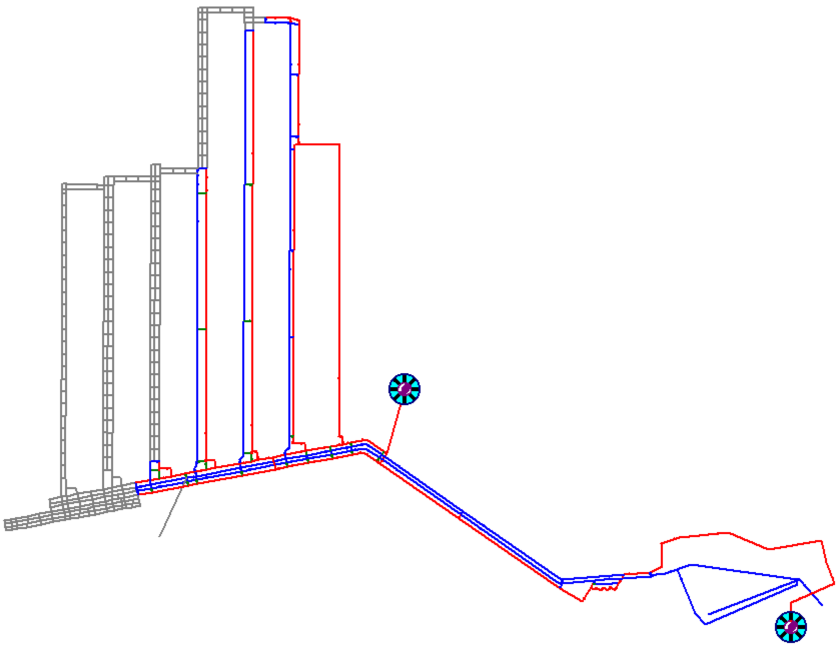

Figure 7 - Skeleton model of arguable value

Input of resistance determinations and final tuning

The results from the "hose drag data" or "barometric survey" are then interpolated to determine specific split resistances. The corresponding roadway sets in the model are assigned the appropriate k factors and/or cross-sectional areas to achieve the desired resistance whilst maintaining believable and substantiative roadway attributes.

Assigning all known attributes is then carried out. All known appliances should be inserted with approximate resistance values depending on condition of them noted underground.

Initial adjustment of appliance resistances is carried out according to leakage rates and magnitudes measured across the site during the survey.

Continued model refinement is then carried out to enable the assembled model to properly mimic the measured underground data.

REPORT ASSEMBLY AND STANDARD

The report should be assembled in an easy to read manner so that mine-site staff can easily understand it. There is really no value in overcomplicating the survey. Whilst a discussion on the limitations of the survey may be valid there is no value padding out the report with theoretical issues such as generic reasons for survey errors, advantages of indirect over direct methods, anemometer yaw and related sources of error. The client needs functional practical solutions to the physical problems found at the site.

The report should ideally contain:

- Introduction
- Agreed scope according to pre survey meeting.
- Executive summary listing key issues.
- Interim practical solutions to circuit problems/ restrictions identified.
- Raw data results of all measured or determined values.
- Schematic layout of the circuit detailing all flow and pressure results.
- Model displays of both flow and pressure to demonstrate validity against the assembled schematic.
- Graphical comparison of measured versus modelled values in the case of a new model. In the case of a rebuild a comparison of the both the client supplied model and the refurbished model should be made to the measured data. These would take the form of:
  - Flow validity of a model supplied by the site when compared to the underground data measured. (Similar to that shown if Figure 9).
  - A demonstration of improved model flow correlation after the survey and model tuning process is completed. (Similar to that shown if Figure 10).
  - A similar approach should be utilised to demonstrate pressure validation also.
- Sector chart of all intentional and mine leakage flows
- Gas make/temperature/dust or other contaminant contributions if applicable.
- Long term hit-list of improvement initiatives to improve circuit performance.

The last item (k) is probably the least done by ventilation consultants but is the sort of information the client needs and appreciates. A snapshot of the circuit in time without any immediate improvement suggestions is of little value to the client in practical terms, especially if the circuit is severely constrained at the time of survey.

FORWARD PLANNING

If centrelines of intended driveages have been made available then future capacity simulations can be run as and if required. It is fair to assume that the previous performance of the circuit and appliances as determined during the survey can be replicated in future. Having said that though, if appliances have been measured to perform poorly during the survey it is reasonable to elevate performance in line with industry standards as long as that point is made to the client. Any number of ventilation iterations can be modelled as required.

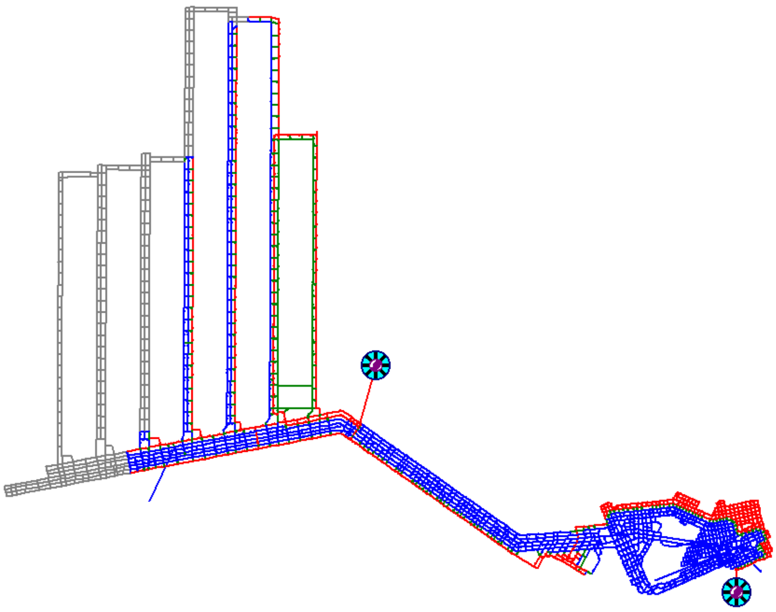

Figure 8 - All roadway ventilation model

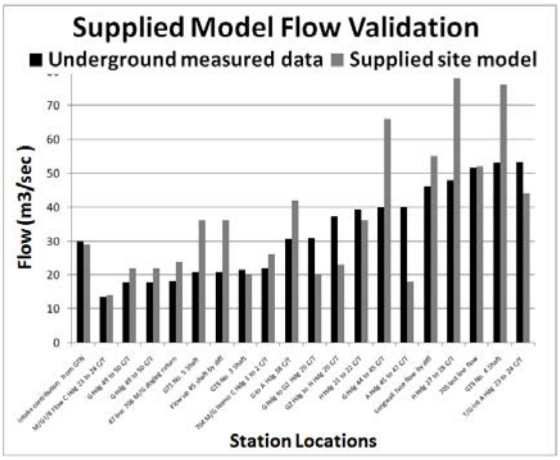

Figure 9 - Supplied model validation

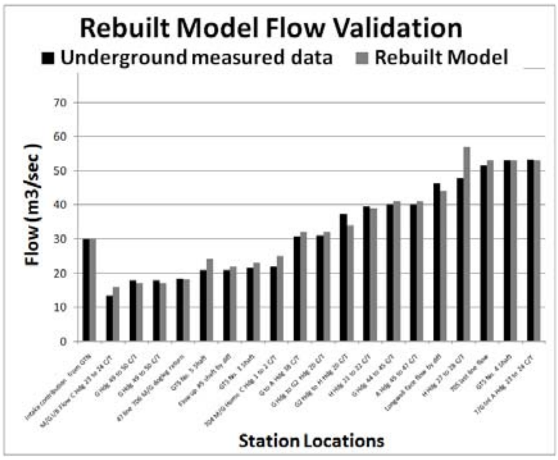

Figure 10 - Rebuilt model validation

ASSISTING MINE-SITE PERSONNEL TO OWN THE PROCESS

The mine should be encouraged to then take the "appropriate readings" on a regular (ideally monthly) basis to properly maintain the new tool whilst minimizing assistance from outside consultants.

The "appropriate readings" are those required to allow an accurate ongoing delineation of the circuit such that the consultant could remotely tune the model from offsite if required.

Obviously the mine should not have to rely on outsiders to maintain the model *ad infinitum* and thus management should strongly consider resourcing the ventilation department such that they can effectively tune and maintain their own model into the future. Whilst this may be somewhat problematic in the early stages, numerous mine site models have been adequately maintained by relative journeyman, as long as some personalized training is provided. Like any skill the more the site staff are exposed to the software the more capable they become at tuning the model. What is often a sketchy update in the early days quickly transforms into confident routine tuning of the ventilation model by site staff.

INAPPROPRIATE VENTILATION SURVEY/REPORTING PRACTICES

The following practices are simply not appropriate:

- Non disclosure of all measured survey data.
- Model validation of only one unknown. There is little evidence demonstrated of model validity if only the flows or pressures from the model are compared against the measured survey data. If there is insufficient validity in either the flows or the pressures then the model resistances are clearly incorrect. If both are not disclosed then this should prompt some questioning.
- An ad hoc approach to an over simplistic model which bears little resemblance to the mine layout.
- Not utilising mine site survey department dxf co-ordinates in the model assembly process. (This is important for future additions of longer term mine plans.)
- Apportioning inappropriate time and resources into measuring and detailing microscopic and thus irrelevant values of natural ventilation pressure. Such work should be only included according to the sensitivity of that phenomenon.
- Using unrealistic roadway k factors or dimensions to adjust branch resistances.
- Not getting sufficient data to properly assess all intentional and unintentional flow paths and magnitudes.
- Furnishing the client with a report filled with scholastic type issues such as generic instrument or method errors, advantages and disadvantages of chosen processes or research findings, and the like.
- Collecting insufficient data to allow the suggestion of simple common sense solutions to the ventilation problems that are immediately at hand.

CONCLUSIONS

The execution of a ventilation survey and the fabrication and/or maintenance of a properly tuned ventilation model are intricate components of modern underground safety management systems. Such systems in Australia revolve around the routine use of risk based logic. Obviously the assessment of risk with regard to ventilation changes and ventilation circuit designs utilise ventilation modelling software as a key tool to assist in this structured process.

As such the measurement of the underground circuit and its replication on a working model is extremely important work. To organise such important work without carefully scoping the job to suit the particular needs of the operation is less than adequate.

There is no set rule on either the level of detail or which survey method should be adopted. Such parameters need to be decided by management dependent totally on site needs at that time.

Considerable expense is involved in the execution of such work and it is vitally important that the final outputs complement the mine requirements and ultimately improve the safety of the operation for all persons employed therein. It really is a responsibility of management to ensure the scope of works complements the needs of the mine at any particular time and the ventilation survey is done to a level of detail that complements those needs. Considerable discussion and scoping is required before the call goes out for a "*full PQ survey*".

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