Secondary Ventilation as a Value Proposition – A Case Study

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ABSTRACT

Both primary and secondary ventilation is important in underground mining. Secondary ventilation refers to the provision of ventilation to development ends, stopes and services facilities, which constitute secondary circuits tapped off the primary circuit or main through flow of air.

An unbalanced primary and secondary combination can cause re-circulation, which is inefficient and potentially hazardous. These inefficiencies extend into operational and other considerations, such as power.

Most cost justification analysis covers capital and physical consumables. These analyses are often not comprehensive or holistic. This case study is an example of 'how to holistically justify' a secondary ventilation circuit and optimise it to meet all stakeholder needs.

This paper particularly addresses the following:

- how to account for all stakeholders in a secondary ventilation cost justification
- the secondary ventilation components
- the cost justification outcomes and how to measure them
- some of the sensitivities
- the stakeholders
- how to present the justification to meet the stakeholder needs
- secondary ventilation cost justification.

INTRODUCTION

Ventilation is a complex engineering exercise, with many papers written around set-up and ventilation planning. Most of the planning tools and cost justifications have focused on primary ventilation needs. Most ventilation engineers refine and cost justify the whole of mine ventilation with greater resolution around the primary ventilation circuits. This paper captures some of the secondary ventilation costs and how to justify them, based on equipment selection, ventilation and mining equipment matching and equipment types and characteristics.

Many inputs need to be considered in ventilation engineering and cost justification analysis. All of these components are important for both primary and secondary ventilation analysis. Some of them are listed here:

- gas contents of orebody/coal seam and adjacent strata; issues of gas drainage
- spontaneous combustion potential
- outburst potential
- water inundation (flooding) potential
- dust audits and silica (or other contaminant) contents of strata
- production, development, diamond drilling, raise boring (or other vertical development) and production drilling schedules
- other important schedules or deadlines (eg construction schedules)
- staffing schedule, by job type and location – for both production and construction phases
- diesel fuel usage, average and maximum per shift
- fixed electrical plant and efficiencies
- any special areas requiring filtered air or special ventilation
- coal, ore, mullock/waste or other materials handling flow charts
- backfill system and operation, type of fill, method of placement
- locations of fuel and oil storage, refuelling, etc
- parking arrangements
- special firefighting standards
- emergency standards
- any maintenance arrangements impacting on egress (outages, inspections, etc)
- minimum medical/physical requirements for continuing employment or for visitors
- blasting arrangements
- ANFO and other explosives consumption rates: development and production
- cement usages and consumption rates
- oxidation rates (to SO_2 and/or CO_2)
- other special ventilation-related hazard protocols

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- internal corporate ventilation/workplace environment standards for each job type (ie typical ventilation arrangements)
- statutory (legislative) requirements
- internal (company or mine) generic standards, hazard management plans, etc
- any noise criteria (impacting on noise insulation or siting of fans, etc)
- dust controls (eg sprays) at drawpoints, tipples, conveyors and roads
- surface climate (wet bulb – WB, dry bulb – DB, barometric pressure – BP) by hour for minimum of six years
- surface elevation above sea level
- depth of mining operations
- near-surface virgin rock temperature and geothermal gradient
- rock thermal conductivity, thermal capacity, diffusivity and density
- method of auxiliary ventilation, type and size of ducts and leakage factors
- any existing ventilation circuits, fans (including fan curves), controls, etc
- any existing cooling devices
- usage and policy on air-conditioned cabins in mobile equipment and fixed plant
- mining (especially horizontal and vertical development) and ventilation (fan, controls, ducting) costs
- friction ('K') factors and shock losses used or measured in the operation
- any surface considerations (dust from quarrying, etc, prevailing winds, grass/bush fires, nearby plant)
- surface environmental limits on fans and shafts: noise, dust, water, smell and visual amenity
- shaft, raise and other major airway resistances and last time measured
- standards in regard to allowable pressures on ventilation control devices
- ventilation or isolation of caved regions or goafs; leakage and pressure balancing
- network analysis and validation (comparing to measured data)
- multilevel tipping controls or protocols
- ground/fissure water in mine (amount, location and temperature)
- location of shafts, fresh and return air raises, distances apart (determines typical auxiliary ventilation line configurations and lengths)
- wetness of shafts: if wet, potential for water corrosion or erosion on fans; potential for the shaft to be subject to erosion or sloughing or water plugging
- natural ventilation pressures; seasonal changes; impacts of refrigeration on natural ventilation pressures
- network simulation program used
- other computer programs in use or required to be used
- data on ventilation monitoring (eg strata gases, diesel exhausts, airflows, online monitoring)
- recent or relevant ventilation or feasibility studies
- any other safety aspects that need to be considered
- any recent ventilation audits completed
- any concerns from the operators or planners about current or future ventilation
- any monitoring or remote operation/control requirements
- fan size and cost
- speed of mine method, development and extraction
- leakage as tested
- K factor as tested
- cost of components
- resistance as tested
- mine maintenance practices
- electrical costs
- mine planning parameters
- humidity/temperature/dust/gas/contaminants
- air available to mine and fans
- equipment type
- commodity being mined
- what are the operational constraints
- mine ventilation pressures (Gallagher, 2005).

It is one thing to do the analysis and work through technical solutions; it is another to justify the solutions to the decision makers, to see which fits the stakeholder needs best. The holistic solution would cover all of these needs in the language of the stakeholder. If as an engineer, you can meet the stakeholder needs, then you are more likely to have your engineering strategy adopted. The adoption of a strategy is usually based on the value add to the business in safety, production, regulatory and financial spaces.

The savings from reduced power costs, bag replacement and downtime for bag replacement, far outweighs any perceived short-term costs benefits in using a lower airflow performance secondary duct system at a lowers $/m cost. A detailed analysis will highlight these differences and how best to optimise ventilation in each situation.

HOW TO ACCOUNT FOR ALL STAKEHOLDERS IN A SECONDARY VENTILATION COST JUSTIFICATION

Secondary ventilation directs the primary ventilation to exact locations and to specific requirements. Secondary ventilation is an important engineering control, both for ventilation of development headings and mine working areas, and also for the control of harmful contaminants such as dust, gas, mist, fumes, temperature, dust and diesel particulate matter (DPM).

Stakeholders include:

- technical services team
- occupational hygienists
- electrical and mechanical managers
- operational teams
- mine managers
- investors
- community
- environmental team
- customers
- mine accountants
- mining company directors
- mining company lawyers
- regulator
- the installers
- statutory officials (such as ventilation officers, check inspectors and union representatives)
- insurance providers
- mine safety advisors.

Consultation is integral in the cost justification process. By recording all the stakeholders and matching their needs with your solutions, the better solution can be selected from the series of technically suitable solutions developed. There are often benefits in your solutions that can be included that you were not aware of initially.

Justification on a secondary ventilation system needs to be presented with all aspects of the 'total cost' of ventilation being considered, in which with the costs of power being so significant, the focus should be to use the most energy efficient duct possible. The two key performance specs are the leakage coefficient, and resistance factor, which determine the ability of a given system to hold and deliver the air, as the case study in this paper shows. Comparison of two different bag construction methods are shown in Figure 1, affecting the K factor, leakage, roughness and thus the energy to drive the system. Figure 2 shows the differences calculated based on the fabric and construction of the ducting pictured in Figure 1.

WHAT THE COST JUSTIFICATION OUTCOMES ARE AND HOW TO MEASURE THEM

Power is likely to be the largest operational cost in ventilation – the secondary system should be designed to deliver maximum air, with maximum efficiencies in power consumption being of primary concern. Having only one primary ventilation system and multiple secondary ventilation systems changes the magnitude of justification outcomes.

There have been an increase in the use of seam sealed, low loss, energy efficient duct systems in Australia. These systems are already standard practice in Europe, the Americas and many mining regions globally.

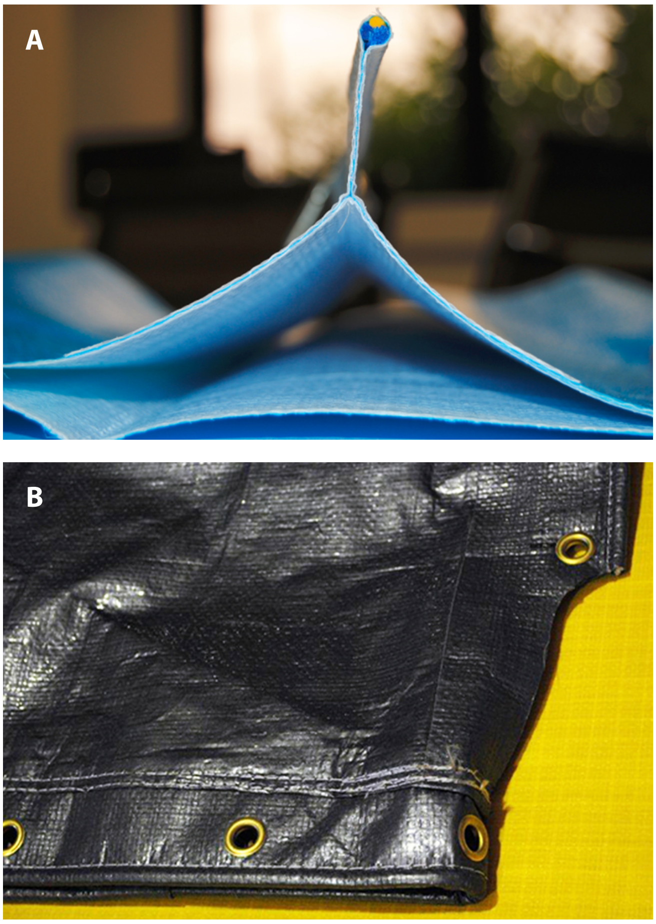
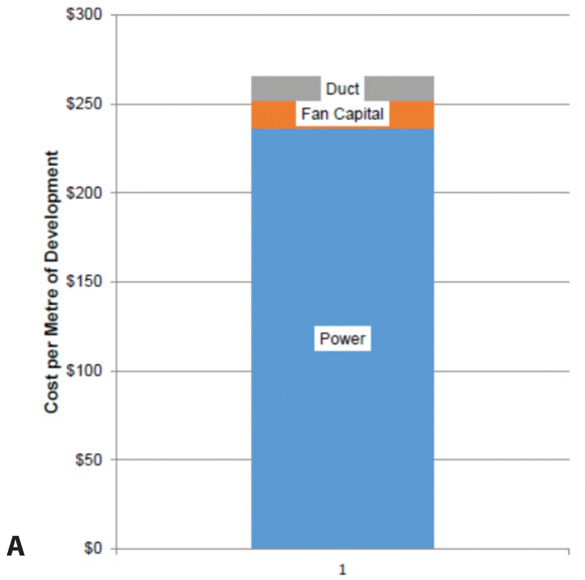


FIG 1 – (A) Mega Dukt seam (photo courtesy of T Wigg, 2015); (B) sewn ventilation bag (Wells Ventilation Australia, 2011).

The case study included in this paper calculates the cost of ventilation per development metre per month. Using a cost per metre per month is a frequently used cost matrix for

Heading advance per month (priority 1 heading)	100	m/month
Fan motor electrical power	180	kW
Power cost	18	¢/kWh
Fan power cost per month	$23,652	/month
Fan power cost per metre of development	**$237**	**/m**
Fan purchase price (inc starter)	$75,000	
Assumed fan life before repair/ rebuild/ replacement	4	Years
Fan capital cost per month (assumes straight line depreciation to zero)	$1,563	
Fan capital cost per metre of development	**$15.63**	**/m**
Duct cost/m (with allowance for some replacement)	**$13**	**/m**



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Assumed fan life before repair/ rebuild/ replacement	4	Years
Fan capital cost per month (assumes straight line depreciation to zero)	$1,563	
Fan capital cost per metre of development	**$15.63**	**/m**
Duct cost/m (with allowance for some replacement)	**$15**	**/m**

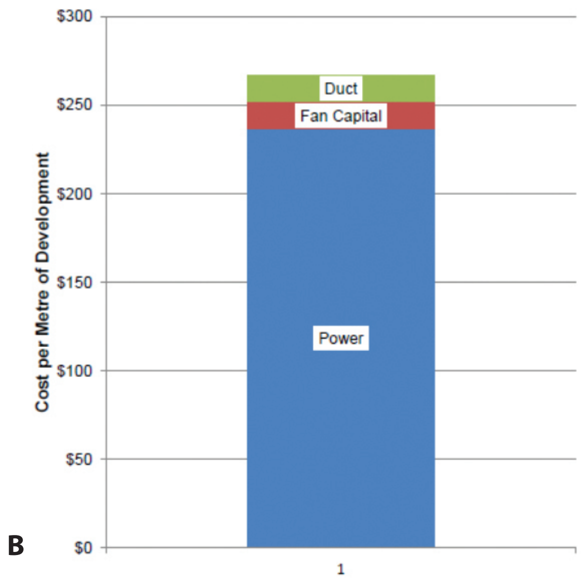

FIG 2 – Calculation comparisons on the (A) Mega Dukt seam (Wigg, 2015) compared to a (B) sewn ventilation bag.

operational teams on a mine site and is easily understood by the decision makers, noting the power cost per metre advance.

WHAT ARE SOME OF THE SENSITIVITIES?

Duct and fan purchase costs are usually less than the electrical power costs needed to run these systems over the life of the secondary ventilation system. However, some stakeholders look only at duct and fan costs. Perhaps the reason for this paradox is on what is tangible is focused on – and a large power bill paid each month by the mine accountant is fairly intangible to most of us.

Power costs vary widely across Australia, while using a conservative cost of 0.18 c kWh (some of Western Australian remote sites are paying double this with diesel generators) and a good priority heading advance rate of 100 m/mth – it can be seen how the cost of secondary ventilation duct and fan capital is eclipsed by the cost of power. With lower advance rates, the cost of power also increases as a proportion of the total costs, as shown in Figure 3.

A couple of examples of as tested K factor and leakage coefficients are shown below in Tables 1 and 2.

SECONDARY VENTILATION COST JUSTIFICATION – A CASE STUDY

Factors considered in the case study model include:

- fan size and cost
- bag length
- bag type

Heading advance per month (priority 1 heading)	120	m/month
Fan motor electrical power	180	kW
Power cost	24	c/kWh
Fan power cost per month	$31,536	/month
Fan power cost per metre of development	**$263**	**/m**
Fan purchase price (inc starter)	$75,000	
Assumed fan life before repair/ rebuild/ replacement	5	Years
Fan capital cost per month (assumes straight line depreciation to zero)	$1,250	
Fan capital cost per metre of development	**$10.42**	**/m**
Duct cost/m (with allowance for some replacement)	**$20**	**/m**

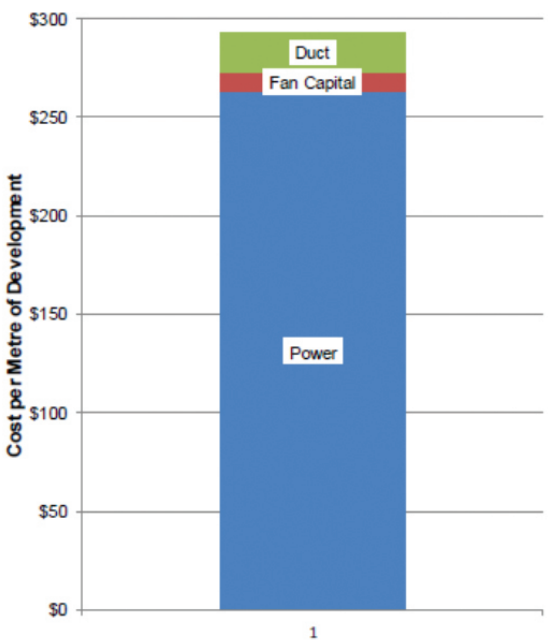

FIG 3 – Increased power cost per metre advance based on a slower development rate (Wigg, 2015).

TABLE 1

Friction factors of tested ducting (Wu and Gillies, 2014).

Ducting	Friction factor (Ns²/m⁴)
450 mm LH	0.0023
915 mm LH	0.0021
915 mm S	0.0041

TABLE 2

Quoted friction factors for non-ridged auxiliary ventilation ducting of varying construction (Gillies and Wu, 1999).

Reference	Friction factor (Ns²/m⁴)
Barret and Wallman (1983)	0.0051
Jones and Rodgers (1983)	0.0023
Vutukuri (1983)	0.0038
Hartman and Mutmanski (1982)	0.0037 to 0.0046
Le Roux (1979)	0.0030
Telyakovsky and Komarov (1969)	0.0054

- construction of the bag – seam welded, low leakage
- speed of development
- industry standard damage to bag
- leakage as tested
- K factor as tested
- size of bag – 1400 mm
- cost of bag
- installation and removal of bag
- ventilation constrained model
- no T/Y connections in model
- round bag, not twin bag in the model
- drive length
- fan maintenance
- electrical costs
- fan power
- calibrated to the AC ventilation product Mega Dukt.

Does not consider:

- drive K factor
- size of drive
- bends in drive
- humidity
- dust build-up
- air available to fan
- temperature of the air
- mine total resistance
- fan set location
- poor installation.

Table 3 shows using the same inputs except for the leakage coefficient and the K factor, the differences in power costs based on using different ventilation ducting.

CONCLUSIONS

The stakeholders in the decision-making process should focus on using the most energy efficient duct possible (as this meterage cost is relatively insignificant), and then optimise fan requirements on this. Instead of putting in a bigger fan because of not enough air at the face – which is often due to poor airflow performance of the duct system (eg using lower performance sewn type systems which leak excessively).

TABLE 3

Predicted annual power costs for Duct A and Duct C ventilation ducting systems (Wu and Gillies, 2014).

Duct type	Air Q inlet (m^3/s)	Fan pressure (Pa)	Power cost ($/kWh)	Power efficiency (%)	Annual power cost ($)
Duct A (Welded)	39.5	2417	0.1	70.0	119 230
Duct C (Sewn)	41.1	3731			191 504

The calculator takes into consideration the rate of advance, the fan motor size, power cost per kilowatt-hour, fan purchase price and service life, depreciation and the cost per metre of duct. These are all cost variables that are entered in and provide a graph snapshot of the breakup of ventilation cost per development metre per month.

The highest influencing inputs into the model were the K factor, the leakage coefficient, equipment matching and the most influential cost output was the power usage.

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