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A protocol and standard for mine ventilation studies

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ABSTRACT: Flawed mining studies have been major contributors to poor investment decisions in mining for many years, contributing to the long period of poor industry profitability. Most of the major mining houses have now adopted quite formal processes and quality standards for mining studies to reduce the potential for poor investment decisions in the future. Other organisations such as the World Bank also have specific requirements for particular types of studies, such as bankable studies. This increasing requirement for rigour and discipline means a highly structured and phased sequence of studies is now required along with the development and adoption of industry-wide standards in mine ventilation studies. New terms in the study process such as 'independent peer review' and 'hold and review' are assisting in this process. More traditional terms such as 'feasibility study' and 'pre-feasibility study' now have much more precise technical definitions. Specific standards for the ventilation components of the various phases of a mining study are proposed in this paper.

1 Introduction

The mining industry has returned to profitability in the past few years. Prior to this, there was a long period of poor returns on investment. This led to considerable reflection on why investment returns were so inadequate. The obvious answer revolved around too many flawed investment decisions (Noort and Adams, 2006); however in practice, the reason behind these faulty investment decisions was often the poor quality of the original study process. Major mining houses have now adopted quite rigorous standards for studies to reduce the potential for false positives (investing in a project that should not have gone ahead) and false negatives (failing to invest in a project that should have gone ahead). This is despite the additional cost, time and complexity that the phased approach imposes on the study process.

Similarly, international organisations such as the World Bank have now set out defined minimum standards that must be met before finance will be approved, irrespective of local national requirements.

The legal implications of the Duty of Care have also been growing and now extend well beyond the mine boundary or the mine owner to any person or organisation that provides services to the mine, including consultants (Anon, 1999; Galvin, 2005). Equipment manufacturers often have industry codes that provide some protection in terms of meeting their duty of care as they clearly identify what is an acceptable standard. Building codes and National (or International) Standards provide guidance and therefore protection for both end-users and designers. At this point, no such code has been developed for mine ventilation designs. To enforce Duty of Care, legislators in Australia now have clearly enunciated compliance policies that set out those factors that are considered in the event of a safety incident before launching a prosecution (Anon, 2001).

A corollary to the current situation can be found in the mineral economics field. In the past, the term "ore reserve" could have a wide and conflicting variety of meanings to different parties, and this resulted in damage to the industry and its various stakeholders. Terms such as "proved reserve" now have a precise and legally enforceable, technical definition in Australia (Anon, 2005) and there is a growing realisation around the world that some harmonisation and consistency in how these ore reserve terms are used is of benefit, particularly to the large mining houses that have to report on multiple stock exchanges and within multiple national legislative jurisdictions. In the same way, there is a growing trend to have more precise technical definitions for terms such as "feasibility study" or "concept study" or "scoping study".

Furthermore, some of the principles that apply in the quality assurance (QA) field are being adopted for mining studies and mine consulting generally. Peer review, which is a QA process that has stood the test of time with regard to the publication of technical papers in learned journals, is now becoming an accepted standard within the Australian mine consulting industry.

The requirement for an improved standard and categorisation of mining study requires a more formalised and precise definition for each type or phase of study. This increasing formalisation (codification) should, over time, allow a generally accepted industry best practice to develop with regard to what should be covered in a mine ventilation study and the quality of that study. This paper seeks to set out both a protocol and a standard for mine ventilation studies.

2 Peer Review Process: Key Elements

Peer review has no single definition, but could be defined as "an assessment of an opinion or study conducted by a person or persons of similar expertise to the author".

A ventilation study is often part of a much larger mining study. Due to its specialized nature, the ventilation component may often be completed by only one author. What happens if this author makes a mistake, perhaps by failing to understand part of the brief, incorrectly completing a calculation, or adopting an incorrect key assumption of some sort? In the past, mistakes such as these may not be detected until the mine became operational, which could be detrimental to the operation. But who is in a position to be able to identify these potential errors? It clearly needs to be someone who is comparable in technical skills and experience to the original author, and who can ask the probing questions that ensure the design is valid. This second person is a 'peer' to the author. Peer review is different to the type of review that a supervisor performs on a subordinate. It is a review of one equal to another equal, i.e. between peers.

Peer review is critical to the quality assurance process in mining studies. It typically involves an additional cost of 2 to 5% of the study cost (Anon, undated), but most of the larger mining houses now consider that peer review is an essential element in ensuring the study is as error-free and bias-free as possible, and are therefore willing to factor this additional expense into their own budgeting processes.

In Australia, at least two types of peer review are now being used for technical mining studies:

The first is internal peer review within a consulting firm. Where the consulting firm has more than one available comparable specialist in the required area, the peer review can be done by another employee in the firm; however, if the firm is too small to have a competent peer reviewer in that technical field, then this review needs to be undertaken by someone outside the consulting firm. This is creating an interesting conundrum for smaller (typically one-person) consultancies, as they may not be able to offer a peer reviewed design process unless they engage a potential competitor to review their designs.

The second is independent peer review arranged by the study client. A number of larger mining houses now have their own formal peer review process. One such mining house has its own team of experienced specialists that is dedicated solely to peer review of all major studies around the world for that company. Their purpose is to ensure the study project team delivers a quality product that is aligned to the company study standard. This requires each and every section of the study, technical and non-technical, to be peer reviewed. The peer reviewers are kept informed about developments during the study process and formal meetings between the review team and the project study team are held at key milestones. When the study is finished, it is the peer review team that prepares the formal close-out report for the project before it is presented to the Board of the company.

For peer review to be most effective, it is desirable that the reviewers are not only technically competent peers to the author(s), but also have no stake in the outcome of the review, i.e. are unbiased. This is not always practical, and to the extent that peer reviewers are also stakeholders in the outcome, the peer review process is potentially less effective.

Peer review requires careful documentation and should therefore ensure a clear paper trail exists to original source documents. In this sense, a quality peer review should ensure that the study is auditable and is in fact, an auditing process.

3 Hold and Review

The concept behind a hold and review milestone is simple. It is often the case that the client's study manager is responsible for a number of technical specialists or teams of specialists, perhaps encompassing rock mechanics, hydrology, mine design, ventilation, materials handling and others. Each consulting team is given its own brief with its own battery limits, deliverables and design parameters. However, it is very possible that the rock mechanics specialists may make some subtle change to the constraints in which their design should operate. Unaware of the domino effects of this subtle change, the expensive study process continues with each group doing its work in parallel with the other groups. If the client's study manager fails to detect that the various technical teams are now operating under incompatible assumptions or criteria, the final reports come in and a serious clash is detected between two different groups. For example, perhaps the rock mechanics specialists state that the maximum unlined shaft size can be 4 m diameter, but the ventilation specialists have developed a design that requires a 5.5 m diameter shaft. The implication may be that the mine design needs to be re-worked at considerable cost and delay.

To avoid these sorts of problems occurring, many mining houses, especially on their more complex studies, are conducting 'hold and review' meetings. These are formal meetings at which key representatives of all the consultants are present and each listens to the others' presentations. It might appear to be unproductive for ventilation personnel to be required to sit through a presentation by the geotechnical specialists or vice-versa; however, it is surprising just how often some point of incompatibility is detected when this occurs. Alternately, an opportunity may be seen that wasn't apparent before (constraints that can be relaxed), with potential cost or time savings to the project.

4 E-rooms

In the past, a major study would be producing dozens or hundreds of interim file notes and reports from a large variety of disparate teams. It was very difficult to ensure all those who needed to read these reports in the different teams actually did so and that their feedback and comments were properly communicated back to the original authors. Paper reports would often pass from one person to another, with the potential for these being lost, misfiled or simply delayed to the point where the project was adversely affected. With the almost universal adoption of computers for mine design (providing electronic documents), the ease of scanning paper documents, and broadband internet access (providing instantaneous transfer of electronic information), sharing documents is now much faster and easier to control. E-rooms are designed to facilitate a more collaborative approach to project execution, especially within multi-disciplinary teams perhaps involving multiple consulting firms. E-rooms allow documents to be posted by the client's study team or consultants and reviewed by anyone who has access to the e-room. Digital certificates prevent unauthorized access. E-rooms allow much faster review by a wide range of interested parties, and for much larger documents to be posted than can normally be shared via email. They also allow for much easier commenting on documents and provide much tighter control on documents by the project's Document Controller.

5 Implications of Duty of Care Legislation

There is a general trend, at least in Australia, towards mining legislation that is based on the Duty of Care. This reduces (but does not eliminate) the prescriptive nature of the regulations. The perceived benefits are that legislation is not holding back innovation in operating practices or the adoption of non-complying but equally safe solutions. Duty of Care also aims to prevent mine owners arguing that meeting the prescriptive regulations has, ipso facto, provided a safe workplace. Duty of Care is often linked with the "as low as reasonably achievable" (ALARA) legal concept which puts a strong liability on mine owners to go well beyond minimum legal requirements.

However, Duty of Care raises several interesting questions regarding how Duty of Care is established and then regulated.

5.1 For the Client

How can a mine owner ensure that a mine design will meet the Duty of Care? The response is to examine good practice (sometimes best practice) within the industry in that area. This means good practice needs to be reviewed regularly and especially when a new design is commenced. In some cases, the client develops their own internal standards but this approach may suffer from the same problem as prescriptive regulations, i.e. restricts innovation. The trend with most global mining companies is to adopt consistent "good practice" standards that span all their operations, irrespective of local requirements except where local requirements may be more onerous.

5.2 For the Consultant

How can a consultant meet the Duty of Care? In part, the answer is similar to that for the client. However, some small clients may not be willing to meet "good practice" standards. In this case, the consulting firm needs its own internal standards or its own internal review of good practice to fall back on, and to insist these standards are met unless a formal risk assessment demonstrates that the client's alternative provides a similar level of ALARA risk.

5.3 For the Regulators

How can regulators check that operators (including mine designers) are complying with their Duty of Care when the regulations are not prescriptive? The response to this has been the development and publication of compliance policies. The Queensland mining regulations for both coal and metalliferous mines fall into this Duty of Care category (Anon, 2001). Typically, regulators supervising Duty of Care legislation take into account the following factors before determining if a party should be prosecuted or not:

- The sufficiency of safety management plans at the operation
- Implementation of safety management plans at the operation
- Training of personnel in terms of:
    - Content of the plans
    - Accreditation to be competent in the plans
    - Understanding of the implications of the content of the plans
- Communications in the organisation in terms of:
    - Internal communication within and between departments and individuals
    - External communication between the company and other organisations
    - Retention of the knowledge base (corporate memory)
- Previous incidents of this type
- The risk assessment process, especially controls in place
- Good practice across the industry
- What other options were considered, if any
- Audit systems in place

The various levels of mining studies (including ventilation) must now take into account this duty of care, the ALARA principles, and the regulator's compliance policies. Ventilation studies must therefore include examination of good practice across the industry, and demonstrate that various alternative solutions were examined within the study process, as well as providing documented formal risk assessments in key risk areas.

It is important to note that a good ventilation study now provides not only a traditional description of the design, but also provides the underlying risk assessments, an examination of good practice at similar operations (benchmarking), and often the development of the associated ventilation management plan that will support the design and is compatible with the risk controls.

6 Management of a Technical Study

There are analogies between a mine design study and a linear programming problem. A major mining study has multiple objectives with multiple constraints. The nature of any multi-disciplinary study process is therefore that some degree of iteration will always be necessary. Iteration is in effect another word for re-work; the concept that a study can be completed without any re-work is naive. It assumes that an arrow can be fired in a dark room and hit the target first time.

Continuing with the linear programming analogy, a key issue is whether the objective of the study is to find a "reasonable" (merely feasible) solution or an "optimal" solution. For phases of study up to and including the pre-feasibility study (PFS), the objective is to conduct only such work as is required to justify the next level of study (or to abandon any further studies) and also to short-list the options so that an increasingly small list of options is taken to the next level of study (Table 2). This might be called finding a "reasonable" solution. However, at a feasibility study (FS) level, the study should produce an optimized solution.

Any iterative process must be brought to an end at some point. Often, this will mean leaving some inconsistencies between different sections of the study. These are usually due to timing issues in the information flows and the fact that the iteration process is called to an end by the study manager when the study itself is "fit for purpose" rather than when every inconsistency has been eliminated. For example, the ventilation study will have examined certain options and produced certain ventilation models as a result. Subsequently, the mine design for some of these options may be changed (due to advice from the ventilation study or geotechnical review, etc) but the changes are not assessed as being material to the fitness for purpose of the ventilation study and therefore the ventilation models are not re-worked to reflect the new changes. This may lead to internal inconsistencies within the ventilation report or between the ventilation report and the mine design report or fixed plant engineering reports. Such inconsistencies should not be an issue and do not indicate a flawed study, providing each report notes that these inconsistencies exist and provides the reasons for same.

Irrespective of the level of study, the solution presented should be tangible i.e. indicate the design can be implemented within existing knowledge, technology and experience. However, it is likely that any study will, at its end point, have identified opportunities to improve on the solution presented. Where these opportunities will require significant re-work of the study (increasing its cost and delaying its completion), and not improve its overall "fitness for purpose", then these opportunities are usually just captured and listed for examination at the next phase of study. This is quite possibly true even at FS stage, where minor tactical issues may need to be resolved or optimized in further separate studies.

To ensure the outcomes are tangible and the quality is satisfactory, larger mining houses usually require a formal risk assessment before ending each phase of study. This ensures residual risks meet the required corporate level for that phase of study. A project is not allowed to proceed to any subsequent phase of study until the identified risks are acceptable for that class of study. The exception to this would be projects that require new technology to be viable in the first place. These types of projects obviously have greater risk therefore require more reward.

In aggregate terms, the overall objectives for any study are to deliver the study on time, to the required confidence level, meeting the required objectives, and within acceptable cost. However, it is often difficult or impossible to meet all these simultaneously. The nature of an investigative study is that there are too many unknowns to be certain of the study time and cost, in particular, before the study starts. Study duration and cost will always only be reasonable estimates. By contrast, the consequences of the study not being completed to the required confidence level or not meeting its key objectives (i.e. not being fit for purpose) could be very damaging: a project is committed to when it should not have been, a project incurs substantial cost overruns on construction or time delays, or a project is sold that subsequently becomes very profitable to someone else. Therefore it is very important that the study manager and his superiors have a clear understanding that, whilst it is desirable to meet cost, time and quality objectives, the aspects of a study that cannot be compromised are its confidence level and its objectives. If the costs have to increase, or the time to complete the study has to increase, then this must be allowed to happen. The larger mining companies now recognizes that the subtle message in the past that the study must be finished on time and within budget has contributed to some very expensive flawed investment decisions due to studies being cut short or short-cuts taken to bring the study in on budget.

The key issues for a multi-discipline team therefore include the following:

- The purpose/objective, deliverables and level of confidence of the study must be clearly identified. Key business objectives and constraints must be well understood. In some cases, determining the business constraints is one of the objectives of the study.
- The study must have an experienced study manager who has a clear grasp of the overall picture and sufficient grasp of the key drivers to be able to deliver the study on time, on cost and with the appropriate level of confidence.
- The battery limits for the various sub-teams/disciplines must be clearly set out via consultation.
- The dependencies and deliverables between the various sub-teams must be established so that the logical flow and "interconnections" within the study are understood by each party
- Cost and time estimates for the study itself must be realistic and good cost and time controls must be put in place. At the very least, systems must be in place so that cost or time over-runs are identified at the earliest practicable time.
- There needs to be regular formal and informal communication directly between the sub-teams so that avoidable re-work or misunderstandings or miscommunication is minimised. Pre-start meetings involving the various teams help develop relationships that will facilitate this.
- There needs to be formal Hold and Review

meetings at key milestones that involve at least one representative from each sub-team. These are essential to clear up misunderstandings and resolve timing issues on deliverables, as well as for peer review of technical aspects of the proposals.

- A list of the key overall design specifications needs to be owned by the study manager and treated as a controlled document. This list contains the key technical drivers for the design (e.g. mining method, production rate, and sub-level interval). All sub-teams should jointly agree on what criteria will be in this controlled list. Having a list of controlled technical criteria means that if any group wants to change any of these, then the change must be notified to all stakeholders before any work is done using the new criteria. This way, all sub-groups are using the same key criteria at all times and, if a change is proposed, then the consequences of the proposed change are evaluated by each sub-team before being implemented, and if implemented, all teams change together.

7 Scope of a Mine Ventilation Study

In terms of mine ventilation, a study should provide at least the following deliverables or have the following scope:

- Review of the various airborne contaminants (dust, gases, radon, heat, etc) and how these will be managed. Included in this would be filtration, dilution, exhaust or other control strategies and any cooling or heating required, and the location, type and size of such devices.
- The primary ventilation network at all key milestones in the development, construction and production phases. This should include the system of airways and their sizes, friction factors and shock losses, and the location and specification of all fans and ventilation control devices. This is basically addressing the issue of the volume and distribution of air throughout the mine life.
- Secondary/auxiliary ventilation design.
- Review of egress and entrapment provisions in the mine over its life.
- A ventilation management plan which covers the day to day operation and management of the ventilation system and any trigger action response plans (TARPs), standard work or operating procedures (SWPs, SOPs) for ventilation-related tasks, etc.
- Formal risk assessments covering both the normal operations and day-to-day activities and all credible abnormal operations or events (power failures, fire, collapse of a major airway, etc)

During the study process, there is a tendency to focus almost exclusively on the production or final mine design. However, in some cases, the ventilation of the mine during the development, construction and pre-production phase will be far more difficult and involve more risks (especially to the project schedule and cost, or to safety) than the final design.

Compared to a “greenfields” site, a study involving a “brownfields” site has special issues including:

- The competition and inevitable conflict for the limited plant and equipment resources (airflows, intakes/returns, plant and equipment) between the existing mine (necessary for current production) and the new mine (necessary for future production).
- The inevitable human resource conflicts and personality issues between the management team of the existing mine and the project management team for the new mine development.
- The problems of adopting necessary new safety standards and/or changing the existing workplace culture or operating practices for the new operation whilst leaving the “old ways” intact in the existing operation.
- The overall higher complexity of a brownfields mine well into its production life compared to a greenfields operation yet to start

8 Required Inputs for a Ventilation Study

A list of factors or inputs that should be considered before commencing any ventilation design is given in Table 1. These are not shown in any particular order and not all inputs will be relevant to every ventilation study. However, it is important that all potential factors be identified early in the scope process and validated data be obtained, or assumptions tested. Where the client states that a factor can be ignored but there is no reasonable basis for this opinion, then the subsequent study report should not this.

Table 1 Key factors to be considered before commencing any ventilation design

- Dust, radon and/or methane or other airborne gaseous, fume or particulate contaminants or asphyxiants (e.g. nitrogen)
- Gas contents of orebody/coal seam and adjacent strata; issues of gas drainage
- Spontaneous combustion potential
- Outburst potential
- Water inundation (flooding) potential
- Dust audits, silica (or other contaminant) contents of strata
- Production, development, diamond drilling, raiseboring (or other vertical development) and production drilling schedules
- Other important schedules or deadlines (e.g. construction schedules)
- Mining methods, layouts, mine design, etc
- Manpower schedule, by job type and location – for both production and construction phases
- Major mobile equipment schedules, especially diesel equipment (maximum kW rating, dimensions, speed loaded and unloaded, up and down ramp, tonnes moved)

- Mode of operation of diesel equipment (where travel, when, truck/loader combinations)
- Diesel fuel usage, average and maximum per shift
- Fixed electrical plant and efficiencies
- Any special areas requiring filtered air or special ventilation (e.g. control rooms, crib rooms, offices, ventilation at crusher jaws, transfer points on belts, tipping points)
- Coal, ore, mullock/waste or other materials handling flowcharts
- Humidity limits for ore/waste including transfer points
- Humidity limits for ground control/rock strata
- Backfill system and operation, type of fill, method of placement
- Locations of fuel and oil storage, refueling, other major stores, combustible material, etc
- Parking arrangements
- Special fire fighting standards
- Special egress or entrapment standards
- Any maintenance arrangements impacting on egress (outages, inspections, etc)
- Minimum medical/physical requirements for continuing employment or for visitors
- Blasting arrangements: development and production, bins, chutes, etc, including frequency of blasting: development and production
- Re-entry times after blasting etc
- ANFO and other explosives consumption rates: development and production
- Cement usages and consumption rates
- Oxidation rates (to SO_2 and/or CO_2)
- Working in heat protocols
- Other special ventilation-related hazard protocols
- Internal corporate ventilation/workplace environment standards for each job type (i.e. 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)
- Any sources of dust, e.g. due to cutting, loading, etc
- Dust controls (e.g. sprays) at drawpoints, tipples, conveyors, roads
- Other sources of heat
- Surface climate (WB, DB, 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, density
- Maximum heading lengths for auxiliary development, development heights and widths
- Method of auxiliary ventilation, type and size of ducts, 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, visual amenity
- Shaft, raise and other major airway resistances and last time measured
- Standards in regard to allowable pressures on ventilation doors (airlocks) or other ventilation controls
- Ventilation or isolation of caved regions or goafs; leakage and pressure balancing
- Network analysis and validation (comparing to measured data)
- Multi-level tipping controls or protocols
- Ground/fissure water in mine (amount, location, temperature (if very hot))
- 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 (e.g. strata gases, diesel exhausts, airflows, on-line 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 problems
- Any telemeter, remote monitoring or remote operation/control requirements

9 Required Level of Confidence for a Ventilation Study

There was often a tendency in the past to proceed very quickly to a final feasibility study. Eliminating or compressing any earlier phases of study was seen as reducing the overall study cost and allowing an end-point to be reached much faster, improving the potential to start production much earlier. However, this approach often meant that alternate design options were not properly considered. At best, the mine often ended up with a sub-optimal design; at its worst, the mine ended up a failure. The benefits of systematically examining all possible options without spending excessive time or expenditure on options that can be easily eliminated is the basic reason for the phased approached to studies. Using a formalised phased approach to studies results in a much higher probability of arriving at the correct decision, with an optimal design, in the least study time and with the lowest study cost.

The most common phases of mining study are shown in Table 2 and are (in order): Scoping (or Magnitude) study, Conceptual study, Pre-feasibility study (PFS), Feasibility (or Definitive) study (FS) and Firm (or Final Engineering) study (McCarthy, undated). A Bankable feasibility study is a feasibility study that meets the quality standards of an external financing body, such as a bank. In many cases, the monies loaned to the project are limited recourse to the project itself so that the risk profile needs to be lower than for exactly the same project if it was being financed internally or if the assets of the entire company were used to secure the loan.

Of particular importance to ventilation professionals is the ventilation design deliverables in this table for each phase of study, shown in the last row of the table.

This phased approach of study and development of a new project is characterised by:

- An increase in knowledge and confidence
- A reduction in risk to acceptable limits (risk is never eliminated completely)
- Significant increases in expenditure on project evaluation (design, drilling, metallurgical testing, etc) for each stage
- An increase in allocation of resources and personnel to the project and study
- An increase in third party stakeholder involvement, and
- Escalating internal momentum and expectations making major changes in direction or cancellation of the project increasingly difficult

The basic objective of having a systematic and phased program is to maximise the value of the study process itself by:

- Screening projects so that excessive monies are not spent on projects that could have been rejected at a lower level of study. i.e. to avoid spending unnecessary money on projects that will not meet corporate objectives.
- Ensuring that at a more detailed study stage, it is not possible to come up with credible options that should have been considered at an earlier phase, and which may then require a substantial amount of additional work to either adopt or eliminate these options, i.e. to avoid unnecessary re-work on design concepts that should have been captured in earlier phases.

Contingency is used to cover (minor) changes in scope, escalation, foreign exchange fluctuations, industrial disturbances, estimating errors and omissions, abnormal weather or other conditions, scheduling problems etc.

The level of confidence intervals are two standard deviations either side of the average expected result. Hence for a project quoted as \$100 M $\pm$25% (2 standard deviations), there is a 95% probability (95% confidence interval) that the final project cost will be between \$75 M and \$125 M. Note that for an estimate with an overall accuracy $\pm$25%, the accuracy of individual components can be much larger than $\pm$25%. In many cases, corporate policy may be for the final project estimate to include sufficient contingency to cover this range in the level of confidence.

The level of confidence allowance is usually added on a line by line or individual item basis and is to cover growth in quantities and the risk associated with the level of detail or quality of the information relied on for the estimate. It is important for all in the design process (including consultants who may need to prepare cost estimates) to understand whether contingency is to be added in line by line, or as an aggregate value.

10 Summary and Conclusions

At present, there are no national or international standards or accepted “good practice” codes for a mine ventilation design or for a mine ventilation study process. It is unlikely that this will change in the foreseeable future. However, it is highly desirable from the viewpoint of both the end-users (such as study managers) and mine ventilation design specialists for a consensus to develop regarding what scope, deliverables and quality should apply for specific levels of mine ventilation studies. It is also likely that some of the benefits of the peer review process will become a requirement within mine ventilation studies, especially by the global mining houses, for whom codifying good practice across international boundaries reduces risk and improves corporate outcomes. Developing a formal or informal code is also important to both mine owners and technical specialists in terms of demonstrating that their Duty of Care has been met and that the risks from the design have been reduced to as low as reasonably achievable. This codification process is likely to impact on the nature of the mine ventilation profession over time; for example, smaller mine ventilation consultancies may struggle to provide an audited peer review process. This paper has proposed some guidelines covering both the issues that should be examined in a mine ventilation study, and the deliverables or quality standards that should be expected for the different phases of study. The purpose is to provide an initial platform for such a consensus to develop in the future, improving both the quality of mine ventilation studies and the standing of the mine ventilation profession within the global mining industry.

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Table 2 Key features of the different phases of mining study, and associated ventilation deliverables

Study Name	Scoping/Magnitude	Conceptual	Pre-feasibility/Preliminary	Feasibility/Definitive	Firm/Final
Order of study	**1 →**	**2 →**	**3 →**	**4 →**	**5**
Principal purpose	Identify issues esp key project drivers to be investigated in subsequent studies	Develop all credible concepts in project development, addressing key issues identified in scoping study	Reduce the list of credible concepts to single, preferred option	Examine the single preferred option to determine if the project should proceed	Detailed design, engineering, procurement, employee and contractor selection
Co-purpose		Screening of concepts not worth further studies	Commit to full feasibility study of single option	Commit to project development. Obtain project finance, esp if "bankable feasibility study" [BFS]	Provide all detailed design and drawings
Approximate time for study	2 weeks	2 to 6 months	3 to 18 months	6 to 24 months	1 to 2 years
Equipment/plant selection	None	Hypothetical	Preliminary	Optimised	Finalised
Study team	Small in-house team, with minimal input from consulting groups	Small in-house team, and one or two key specialist consultants in areas of particular technical concern	In-house personnel, a generalist mining consultancy and one or two key specialist consultants in areas of particular technical concern	In-house personnel leading a team of specialist consultants recognised by lending institutions (prospective funding bodies). For BFS, study must be subject to audit, with all key assumptions/facts traceable to competent source documents or independent third parties	Client project manager supervising EPCM contractor leading teams of external engineering designers, contract managers, etc.
Design basis	Suitable team brainstorming and risk assessment	Rough layouts and factoring	Layout take-offs, budget pricing and some factoring	Layout take-offs, vendor quotes, budget pricing with little to no factoring	GA and AFC drawings, tendered prices
Site visit	Unlikely	Possible	Recommended	Essential	Essential
Relative estimation effort	x	4x	10x	20x	50x
Capital & operating cost estimates	None	± 40 %	± 25 %	± 15 %	± 10 %
Ventilation design deliverables	• List of likely ventilation issues needing to be addressed in subsequent studies • List of critical information required for first-pass assessment • Scope and battery limits of study	• Conceptual ventilation plans incl egress • Estimate of overall mine airflow, cooling/heating and gas management requirements • Contaminant distribution and release or climate from available sources, e.g. AIRAH or ASHRAE • Key ventilation drivers • Ventilation impacts (pros and cons) of concept designs • Approximate capex and opex of concept designs	• Ventilation plan (circuits, flows, fans, egress) for each phase of devt/construction for each option • Ventilation model and contaminant concentration models (e.g. gas or temperature) of each option at full production only • Surface climate from local long-term records • Formal risk assessments • Preliminary review of construction and pre-production vent reqts • Approximate capex and opex of options	• Detailed ventilation plan (circuits, flows, fans, egress) for each phase of devt, construction, production. To show all activities in all workplaces on all levels & the intake and exhaust for each. • Ventilation models at all key vent milestones in project • Contaminant concentration models (gas, temperature, etc) at all key vent milestones in project • Surface climate from local long-term records • Detailed review of construction and pre-production requirements • Formal constructability and production assessments of risks, controls, contingencies • List of fans and duties and ventilation control devices and bulkheads at each key milestone • Performance specs and capex and opex of all ventilation equipment incl main fans, cooling/heating plants, other ventilation plant at each phase of operation	• Assistance with preparation of specs for fans, refrigeration, etc • Routine support for ventilation design and conflicts during project development, construction and pre-production phase • Involvement in formal risk processes, including HAZOP etc studies • Assistance with tender evaluation and award. • Client's representative for some contracts. • Performance and acceptance testing.