UNDERGROUND MINING

THE DIFFERENCE BETWEEN OPTIMAL AND REAL

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ABSTRACT

An underground mining study that is done in accordance with NI43-101, JORC or similar reporting code is generally assumed by the public to be representative, independent and impartial. However, it has been well documented by academics and professionals in our industry that there is a sharp difference between the forecasts presented in these underground studies and the actual costs when a mine is put into production.[i ii iii iv v vi vii viii ix]

For underground mines, the risks associated with obtaining representative information are much greater than for surface mining and the cost of accessing underground ore is also proportionally much greater. There is a pressing need to align expectations, by improving the accuracy of projections. This will result in reduced risk to mining companies and investors and provide more reliable information to government agencies, the public, and more importantly, the communities in which the proposed mine will operate.

The objective of this article and an article currently being written titled "Mining Dilution and Mineral Losses" is to:

- Discuss the dynamics of intention that lead to over-optimism;1
- Provide simple tools to identify which studies are likely to be more closely aligned with reality;
- Identify some specific points where underground mining studies are generally weak;
- Discuss practices currently in use in our industry that lead to a composite or aggregate effect of over optimism;
- Describe the effects of overly optimistic studies;
- Outline specific changes that are necessary to overcome these challenges; and
- Stimulate discussion and awareness that will lead to better standards.

KEYWORDS

Mine Economics, Mining Risks, Mining Risk Assessment, Mining Studies, Feasibility Studies, NI43-101, Underground Mine Planning, Underground Mining Studies, Mine Economic Assessment

INTRODUCTION

Mineral project reporting guidelines such as NI 43-101 were created to prevent or help reduce the potential of fraud and standardize reporting for mineral projects. The guidelines for sampling and geological reporting are well defined, but the quality of reports is highly variable with regard to mine economics. T.Lwin and J.Lazo of Export and Development Canada have indicated that capital expenses average 40% over budget for underground projects and that since 2009 this trend has been increasing. It became clear in the course of writing this article that there are other components to underground studies some of which are identified here that also trend toward optimism and lead to a composite effect larger than that which is apparent by reviewing simply capital costs. Some key indicators that the author has found easy to identify are:

- Capital Cost Estimation;
- Time and resources to reach full production;
- Mill throughput;
- Dilution and Mining losses;
- Mine unit costs (if they are provided); and
- Contingencies

ELEMENTS THAT CONTRIBUTE TO OVERLY OPTIMISTIC MINING STUDIES

Intention

An important challenge to achieving an impartial mining study that represents true project economics is the perception of those working within the mining business of what these studies are meant to achieve. We are people of action and the natural collaboration in moving the project to the next phase dominates our industry. Endemic among the published studies are overly optimistic estimates of costs, mining rates and the grade of mineral delivered to the processing plant. Negative studies don´t get published. Less care is taken with Preliminary Economic Assessments (PEAs) which are often seen as a “way to move the project forward”. These should be based on properly benchmarked data and increasingly they are not. The assumptions made in the PEA often influence the expectation of subsequent feasibility studies.

Client Consultant Relationship

Here are some notes on the client / consultant relationship which affect reliability in reporting and costs to the investor:

- There is a requirement to use what are called “industry best practices”, but this is too often interpreted as a need to stay in line with what others are doing.
- There is a lack of appropriate training, appropriate in-depth or relevant experience and/or knowledge among some of those performing mining studies;
- There are budget constraints, lack of time and sometimes a lack of interest in getting to more representative results;
- There is the role of overconfidence in our own work as demonstrated by Daniel Kahneman [1] [x] and in some cases, ethics in producing overly optimistic studies;
- Draft cost models may be delayed many months which sometimes delays bad news; and finally
- If a client doesn´t like the numbers presented by the consultant they may shop for another consultant who will give them more favourable numbers;

Difficulty with Benchmarking

In operations where historical information is lacking, there are two approaches to scheduling and cost estimation; benchmarking and base (or first) principles calculations. A combination of both is always required.

For benchmarking to be representative, comparisons must be made to operations with similar characteristics, including comparable orebody dip, width and continuity, similar ground conditions, similar mining methods, preferably in the same country. Benchmarking requires an in-depth knowledge of conditions at the operations being investigated and there is a lack of professionals with appropriate experience or time to perform these comparisons. Operating mines are disinclined to share detailed cost and productivity information because it may ultimately have an effect on share prices. It goes without saying that in spite of its reliability, benchmarking is not being used as frequently as it should.

Extensive work on benchmarking reserve tonnage vs. production rate has been done by K.R. Long, [xi] W.D. Menzie, D.A. Singer, C.R. Tatman [xii] and H.K. Taylor, (Taylor´s Rule and subsequent revisions) on numerous mining operations. A recent revision is shown in Figure 1 below. This benchmarking work is increasingly being ignored because it indicates lower production rates than are often considered desirable.

Benchmarked numbers already include availability, utilization and all possible contingencies compared to calculated values, an important reason why they may appear too conservative or pessimistic to a client. This forces the consultant to resort to base principles calculations, ***a method which by its nature will yield overly optimistic results if not tempered with experience and understanding, the calculations are done properly and the appropriate allowances included to reflect realistic operating scenarios***.

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[1] "Overconfident professionals sincerely believe they have expertise, act as experts and look like experts. You will have to struggle to remind yourself that they may be in the grip of an illusion." Daniel Kahneman; nytimes.com 2011-10-23

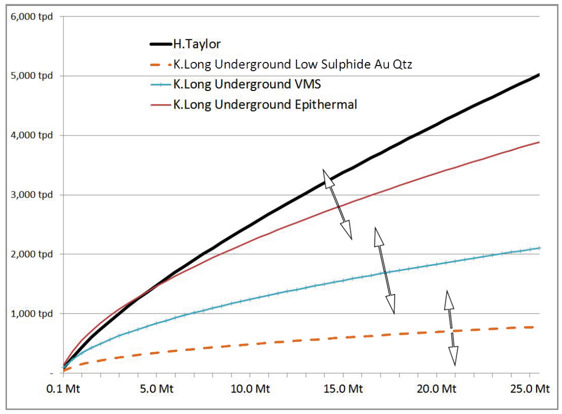

Figure 1: Taylor´s Rule compared with Findings by Keith Long for Underground Mines

Information from Suppliers

The mining industry tends to give weight to information from suppliers which is normally backed up by field tests. Suppliers are mindful that for products to sell themselves they must be shown in the best light, so test conditions tend to be optimal. Here are just a few examples of information from suppliers that deserve consideration:

Diesel machine suppliers may not be transparent about the need to de-rate for altitude because there is a loss of machine power associated with derating and if a client doesn´t understand the need to de-rate, providing undesirable information could result in the loss of a sale. Ventilation is affected when machines are not appropriately de-rated, but operating mines may not make the connection between de-rating and poor ventilation. This is part of the reason some mines require workers to wear filtered breathing masks (which incidentally can be uncomfortable to wear all the time and lead to questionable compliance.)

Ventilation fan suppliers may offer fan calculations based on 90% efficiency, but in reality, it is very hard to optimize fan efficiency to that level as actual underground conditions tend to be highly variable.

Suppliers of ventilation ducting will often focus on operational improvements rather than the parameters they have provided for calculating ducting performance. Rips in vent tubing, installation challenges and human error in installation of ducting are part of the reality of operations and are exacerbated by the pressing economies of reducing the dimensions of mine accesses. It takes the experience of someone who has measured actual pressure drops in operating mines, is aware of the frequency and size of the inevitable rips in the ventilation tubing, of how tubing is normally hung and based on this experience, can make calculations to determine the size and type of the required fan, ducting and the resulting airflow at the face.

Mine cost databases are available that will provide estimates for fuel consumption, parts and maintenance. The source of this information comes from suppliers. The suppliers need to show their machinery costs when things work as they should. (i.e.: No operator abuse, good roadways, appropriately sized muck, no oversize, well-maintained machines, LHDs not used as taxis.)

Ventilation Considerations

Exposure to diesel fumes has long been a source of study [xiii] because of its effect on worker health. The following factors impact worker health and are normally underestimated or ignored in mining studies:

- Underestimation of fleet size is the most important factor leading to poor mine ventilation.
- Sulphur content in diesel fuel is an important factor affecting health. Some countries have maximum permissible levels set as high as 500ppm compared to 15ppm in others.
- In many countries, it is common for mines to use equipment that has not been designed for underground use. Some of these machines will have much higher levels of emissions.
- At higher altitudes, de-rating of diesel machinery ceases to be effective as a means of reducing contaminants. [xiv] Mining Regulations for some countries do not require any adjustments or derating to diesel machinery for higher elevations or additional ventilation.

Precise vs. Representative

Underground rock has not been optimized, yet we spend an increasing amount of time trying to optimize our computer modelling of it. The modelling will give us astounding precision and frequently we are misled by believing it gives more reliable results. However, a step by step strategic approach involving others will usually lead to more representative results faster, as complemented by the power of computing.

Computer modelling of dilution skins has become more common, yet in almost every case, the *amount* of dilution towers in importance over the grade of the dilution. A small effort into determining the *amount* of dilution by doing some simple sketches can save a lot of time.

Geotechnical block modelling relies on composites which are weighted average values. If the rock has a high variability in geotechnical properties, compositing will result in a smearing that gives a false impression of homogenization and frequently an over estimation of rock stability.

Animations of the mining schedule are the wave of the future because everyone from the miner to the manager can immediately see and understand the sequence of work to be done. However, it is often difficult for the operators of this software to gain in-depth experience in operating mines and currently there is a *severe lack of knowledge of alternate processes and of how the process of design could be sequenced strategically involving others, to get to reliable answers faster*. For example in one recent case, an entire mine schedule was completed without first figuring out the sequence of steps and how long it takes to mine a typical stope.

If the resource is inferred, [2] it means that we´re not absolutely sure it´s there, it´s a well-informed guess, so why do a detailed design? Don´t forget to include a factor for upgrading the resource from inferred to indicated. [3]

Geological block models are usually based on diamond drilling and calibration of the model to underground mapping, underground sampling and production output to the mill is now uncommon.

For some, the purpose of variography is to make the deposit looks better.

If the distance between drill holes is 30m will the result will be any more representative if the size of the blocks in the block model is reduced from 5 x 5 x 5 metres to 1 x 1 x 1 metre?

Underestimation of Mining Dilution

Operations personnel will often refer to over-break, (the unintended waste rock that falls into an opening after a blast), when speaking about dilution, sometimes excluding all other factors because it is what the operations are struggling to control. In fact, dilution comes from at least 14 different sources all of which need to be checked for their influence on mill feed grade. There can be great pressure from mine operators and clients of mining studies to show lower numbers for dilution. It is after all a key performance indicator.

Here again, "best industry practice" does not mean what everyone else is doing. Nor should it mean a number that is defendable among peers. Best industry practice is experience, knowledge, clarity, transparency and above all in-depth understanding to serve the best interests of potential investors and raise the credibility of our industry.

If a mining study has been done well, all categories of dilution will have been considered. The following are listed briefly and will be explained in an article currently being written titled "Mining Dilution and Losses":

- Decisions made during modelling, design and execution;
- Variability of the contact;
- Over-break;
- Variability of grade;
- Mine by lithology or grade;
- Visibility of the contact;
- Minimum mining width;

[2] Infer = well informed guess, speculate, surmise, hint, imply, suggest

[3] 30% to 70% of inferred pass to indicated

- Islands of waste in the mineral;
- Notching above and below sublevels;
- Impact of flatly - dipping structures;
- The necessity of providing an arched stable back;
- Floor dilution;
- Backfill dilution; and
- Alternating use of raises as orepass and wastepass

Underestimation of Mineral Losses

Dilution has become such an important topic that mining losses are overlooked. Reducing dilution will usually result in increased mineral losses, a shortening of mine life, and increased proportional cost of accessing new areas. In the context of this document, Mineral Loss includes mineral that should be subtracted in the resource to reserve calculations to reflect mineral that for any reason is not mined. Many mining studies will simply peg the numbers at 10% to 15% for mineral losses which in most cases, is a serious underestimation. We have identified to date, 16 factors that contribute to mineral losses which are included in the PowerPoint Presentation accompanying this article and will be described in more detail in an upcoming article dealing with Mining Dilution and Mineral Losses.

Overestimation of Availability

Availability is divided into three categories. Machine, Labour and Ambient.

Machine availability is not the same as mechanical availability. Mechanical availability is often considered as the percentage of time a machine machine can be operated. Machine availability includes instances when the operator had to be reassigned to another task if the machine was not available at the start of shift. Machine availability will therefore be a lower number than mechanical availability. Mining studies often set mechanical availability between 85 and 90% which in itself is high and does not consider the actual availability of the machine to the operation.

For labour availability, there is a tendency to look at holidays and shift schedules and a few other items. All reasons for not being at work, including training need to be included as well as worker substitution in case of absence. Effective work time also needs to be included and this is affected by travel time, shift fatigue and cultural factors. Work assignment needs to be considered, the frequency with which an operator is in fact assigned to their primary task, which of course varies according to the skill of the worker. The more highly skilled workers are more frequently reassigned because of their flexibility and therefore their labour availability will be lower.

For those of us who have worked underground we know there are shifts where nothing seems to work. Those shifts when a truck broke down in the ramp and people were reassigned to work in another area that didn´t have air or water and they found out the compressed air and water lines had rusted out. The frequency of these type of events and more minor ones is called Ambient Availability and it is often not even considered. If possible, measure it, our experience indicates these numbers may be significant.

Pushing the Limits of Design

Figure 2 below, shows a tool for calculating the size of mine openings for remote entry, The Mathews Stability Graph and compares typical design criteria to historical data from an operating mine. [xv] It can be seen that over 20% of the stopes that plot within the "stable zone" experienced caving. The method is not at fault, but it is based on ***probability of stability***, and therefore does not reflect the fact that a small portion of stopes that experience failure might have an enormous impact on the mine schedule and production. Indeed, there are many factors that affect stability that are difficult to consider in the planning stage. These include unexpected faulting or human error in the design and execution of drilling and blasting.

We have visited only one mine where the design was conservative enough that stope failures were extremely rare. As a consequence mine production was more predictable. Working against these prudent efforts at conservatism are:

- Overly optimistic predictions that make their way into the budget (that´s where the problems start);
- Operations personnel who see advantages to increasing stope size.

- Lack of appropriate knowledge or experience

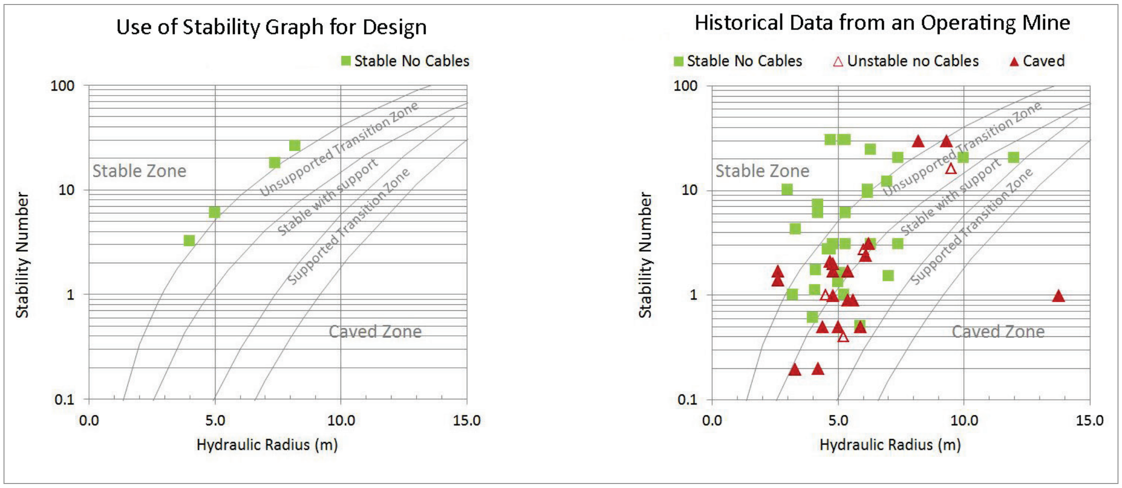

Figure 2: Use of Modified Mathews Stability Graph. Design vs. Historical Data

Interpretation of Project Sensitivities

Spider graphs (see below) may be used to represent the viability of a project showing different variables.

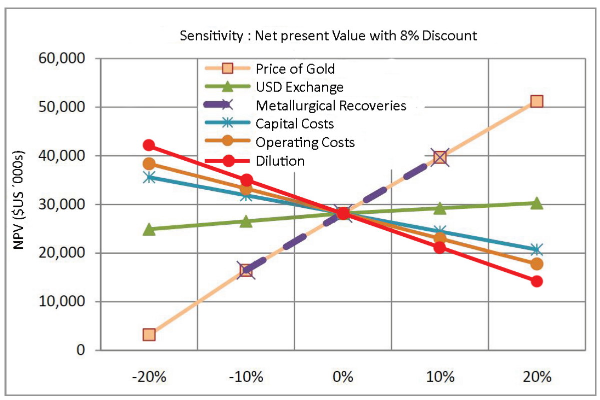

Figure 3: Project Sensitivity

There is an implied level of accuracy of +/- 20% for this graph done for a Pre-Feasibility Study based on an "optimal" mine plan. In a mining operation, there is more often than not a combination of factors that can combine to increase the impact on project viability and a discussion should be included on the effect and likelihood of *various factors working in combination*. A Simulation such as the Monte Carlo *will not pick up on the composite effect of variables working in combination* unless the probability of that occurrence is identified.

If in the example of Figure 3, the capital costs were underestimated by 40%, the chances are high that operating costs and sustaining capital are also underestimated. That being the case, almost for sure the production ramp up time has been underestimated. Therefore, if Figure 3 above meets current standards in our industry, there would be no project.

The Human Factor

Mine operations is a different reality from mining studies. The priorities are different. For the study it is important to reflect a positive return on the investment. For the mine operator, the safety of the people is paramount, as is managing them to be productive while at the same time producing the required tonnage.

Errors are made at every level of the operation and include head office decisions, site supervision, logistics, mine supervision, technical services as well as the miners. They may be caused by altruistic but ill-informed actions, by differences in perceived priorities and at times, apathy. Our industry is full of folkloric accounts of mistakes which compound when an operation is under great pressure to produce. The human factor is not normally considered in feasibility studies unless benchmarking is used as a way of allowing for these types of problems.

Contingencies

There is currently much confusion on the meaning of contingency and how it should be included. Studies should quantify each area where contingencies need to be applied and discuss the composite and cumulative effect of these contingencies and as mentioned above, on the effect and likelihood of various factors working in combination.

IMPACT OF OPTIMISTIC STUDIES ON MINE OPERATIONS

Mine Infrastructure

The problems faced by operating mines can be decreased by planning in advance for the appropriate size and amount of machinery, travel ways, ventilation raises as well as appropriate electrical, drainage, pumping and backfill networks combined with realistic scheduling and costing. So for a mine to operate properly and predictably, the plan must be achievable. Mistakes compound when the schedule is too optimistic.

Shortcuts and Production Crisis

An unrealistic mine plan with inappropriate infrastructure puts mine operators under tremendous pressure so when problems arise, reactions will be based on short term requirements. For example, if ore is buried under oversize when a stope fails, operators may pressure to fill the stope, leave the ore and start mining the next stope to ensure the flow of production. The same operators may also decide to blast a few extra rings in the next longhole stope to squeeze out more production which in turn might lead to further stope failures. These types of risks may appear reasonable in the short term but as an operating policy it is disastrous because just a few caved stopes can have an enormous impact on the schedule. Lower grade stopes may be abandoned after a cave and the stope backfilled, burying the ore in the hope for better results in the next stope in the sequence. Mucking may continue in higher grade stopes which may fill every nook and cranny with oversize but the resource allocation for handling the oversize is high and work in other areas of the mine will suffer. It takes a very senior person to step in and weigh the short term benefits with the long term losses.

Here is another actual case example of the type and flavour many of us have seen before:

- A bypass ramp was needed to connect two areas of the mine to ease haulage and ventilation. This required significant extra resources to keep up to the budget schedule for production preparations and meet the commitments to the lenders;
- The increase in expenditures from the ramp bypass required a *doubling* of the cut-off grade to pay for the extra capital development and the higher-than-predicted operating expenses. This sterilized parts of the orebody.
- Press release stated that the mine was achieving better grade than predicted. Confidence in the orebody had increased and as a result, a decision had been made to increase capital expenditure. All waste development was then capitalized so that operating costs could be brought down to what was considered reasonable. The increased mineral losses brought about by the increase in cut-off grade weren´t considered of prime importance because the geologists would find additional ore to compensate for the loss. Summary, the investor was misled on the true state of the mining operation.

Credibility and Reputation

Pressures to produce under unrealistic circumstances may lead to some form of manipulation or partial reporting of production statistics as indicated in the example above. It has happened the mines may no longer have budget to meet promises made to the community. We have also seen attempts to skimp on environmental practices. Both of the above severely damage our credibility and reputation.

IMPROVEMENTS TO BEST PRACTICES / REGULATORY FRAMEWORK

Regulations need to clearly state that mining studies should "present a representative economic assessment to diminish investment risk and align expectations of investors, local communities and governments" in addition to providing transparency on environmental impacts and labour relations.

Studies should include a list of all other consultants who have worked on the project and their recommendations, independent of whether those studies have been published or not.

An account of the attempts at benchmarking with similar operating mines should be encouraged but terms of reference for benchmarking need also to be developed;

State the need to include illustrations to show calculations for mining loss and dilution.

Quantify each item in the list of dilution, mining losses as well as machine, labour and ambient availability;

Studies should include a discussion on how proposed mill throughput compares to Taylor´s Rule and subsequent revisions;

Risk Analysis in summary and conclusions should include a discussion on the composite effect of combining project sensitivities.

The meaning and use of contingency needs to be defined and should include operational errors;

Each element contributing to dilution and mining losses needs to be quantified and sketches need to be included in reports.

Each aspect of Machine, Labour and Ambient availability should be quantified;

Qualified Persons (QPs) are not experts in everything and humility is necessary in seeking information from those who know more about areas where the QP´s knowledge may be weak. QPs should be encouraged to consult underground miners, supervision, electricians and technicians who know more about aspects of their work.

Consultants who have experience tracking their planning as a mine has moved into production are few and far between. If they have this experience it should be stated. We need to plan for a future melding of the worlds of consulting and mine operations.

Mining unit costs (such as cost per metre of development) should be stated and it should be stated what indirect costs these numbers include and what has been designated as indirect or fixed costs.

Encourage as a best practice, an early provision of a draft cost model by the consultant so the client can see up front how the project progresses and to prevent the delayed release of bad news.

Inferred Resources = inferred planning no more stope-by-stope detailed designs. Include the resource upgrade factor. (30% to 70% of inferred tonnes make it to indicated)

Encourage the use of max / min cost calculations as is done in the field of rock mechanics.

The Qualified Person for mining or geotechnical must look at the drill core.

CONCLUSIONS

The industry is facing a crisis of credibility which has resulted in difficulties obtaining financing for new projects. There is a pressing need to align mining studies with reality using the points listed in this document by improving reporting methodology and standards so as to gain trust and confidence with investors, governments and local communities.

Improvements in the reliability of underground mining studies would mean that companies can follow through more frequently on promises to shareholders and local communities. That would improve trust in our industry and should result in more favorable lending terms for mines moving into production. Trust has farther reaching implications in our relationships with governments, communities, suppliers and employees as it becomes easier for these groups to make their own plans and commit to mining projects.

We need to pay careful attention to ventilation and long term health issues, work with other countries to improve safety and environmental standards and ultimately consider non-traditional economic models for mining.

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