Underground Mining

The Difference between Optimal and Real

⟹ español disponible português disponível

Paul T Whillans
Whillans Mine Studies Ltd. Vancouver Canada
paul@whillansminestudies.com

CIM Management and Economics Society 2017-01-25 Toronto

WHILLANS
MINE STUDIES LTD.

Overly Optimistic Underground Mining Studies:
Agenda

1. Introduction (3 slides)
2. Factors which contribute. (15 slides).
3. Impact on operating mines and industry. (1 slide)
4. Recognition of milestones achieved. (1 slide)
5. Challenges ahead (2 slides)
6. Recommendations for improvements. (2 slides)

WHILLANS MINE STUDIES LTD.

The Composite Effect of Optimism

- Capital Costs [1] 
- Time to production 
- Tonnage output [2] 
- Dilution 
- Mining losses 
- Contingencies 

Average 40% over budget increasing since 2009

Credibility Issue with Full Feasibility Studies

1. T.Lwin & J.Lazo 2016-05

2. K.Long 2009

WHILLANS MINE STUDIES LTD.

Industry Best Practise

"Keep in line with what others are doing ?"

WHILLANS
MINE STUDIES LTD.

Agenda

1. Introduction
2. Factors which contribute (15 slides).
3. Impact on operating mines and on our industry. (1 slide)
4. Recognition of milestones achieved. (1 slide)
5. Challenges ahead (2 slides)
6. Recommendations for improvements. (2 slides)

WHILLANS MINE STUDIES LTD.

Factors Which Contribute to Over-Optimism

- Representation of Technical Issues.
- Disconnect studies vs. operations.
- Culture of promotion
- Dynamic of consultant - client.

Consultant Dynamics and Relationship with Client

Move the project ahead ⟸ Direct Honesty

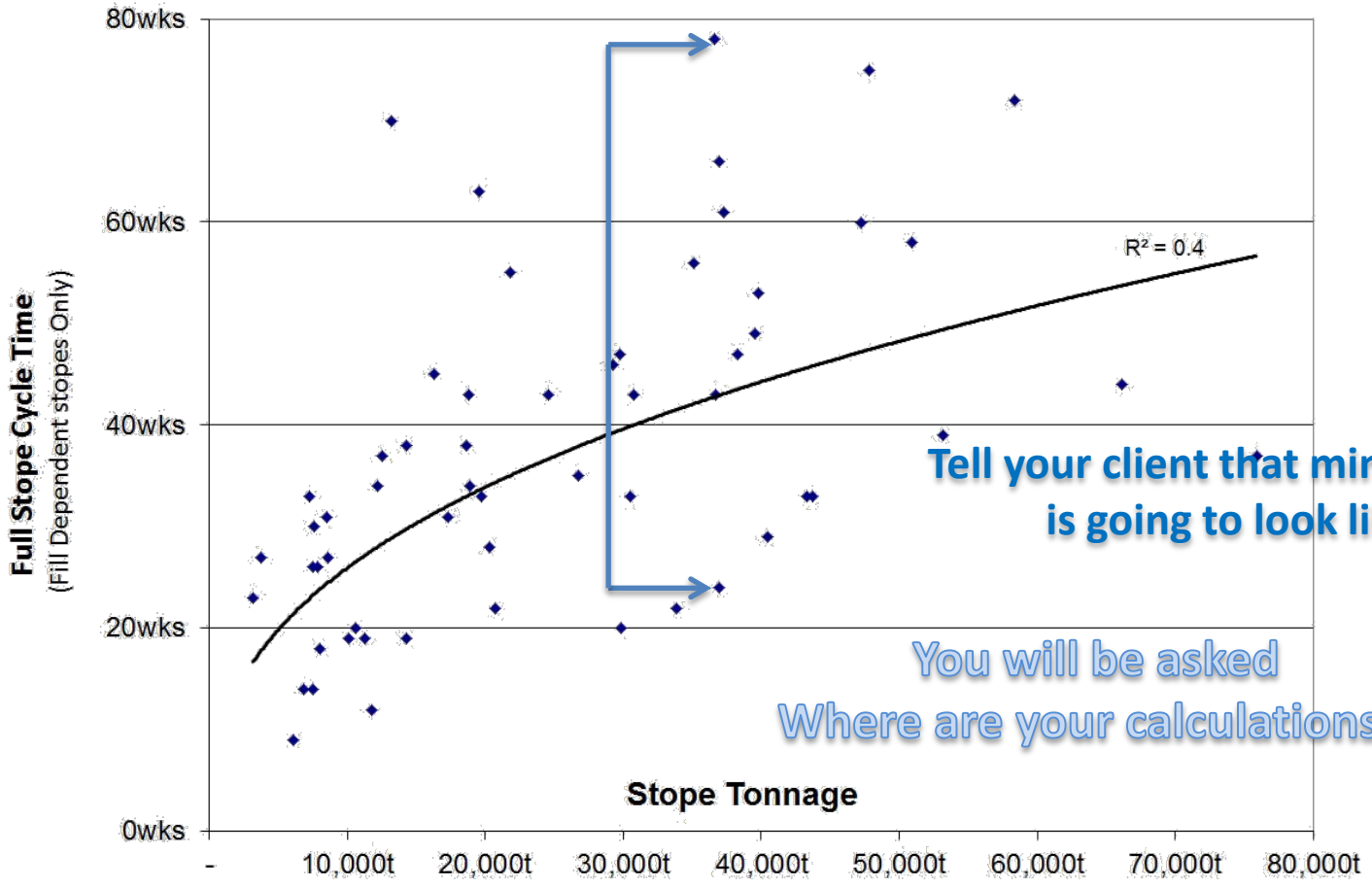
Intention
Industry Standards
Culture of promotion
Cooperate and get paid
Overconfidence in our own work*
Pressure to move the project forward
Ethics
Knowledge
Overly detailed work
Appropriate Experience
Information from Suppliers
Focus on specialized tasks in isolation
Time in the office versus time underground
If the numbers come out too low, shop for another consultant

*D. Kahneman

WHILLANS MINE STUDIES LTD.

Challenges with Benchmarking

Stope Cycle Times

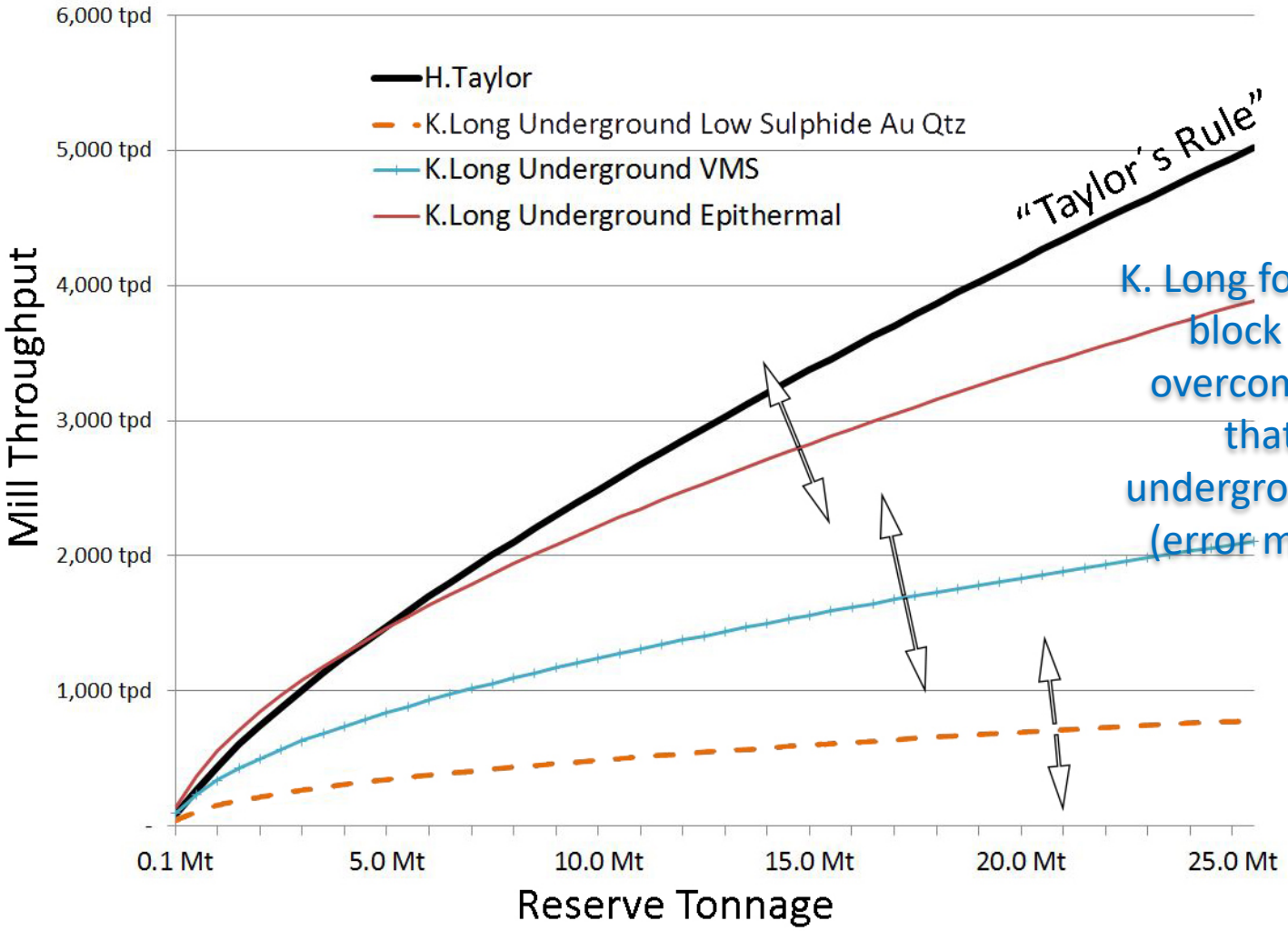


Tell your client that mine production is going to look like this !

You will be asked
Where are your calculations ?

WHILLANS
MINE STUDIES LTD.

Challenges with Benchmarking:
Taylor´s Rule (and subsequent revisions)



K. Long found that surface and block caving mines can overcome Taylor´s Rule but that other types of underground mining fall short (error margin is fairly large)

WHILLANS MINE STUDIES LTD.

Base Principles Calculations

Information from Suppliers, Contractors

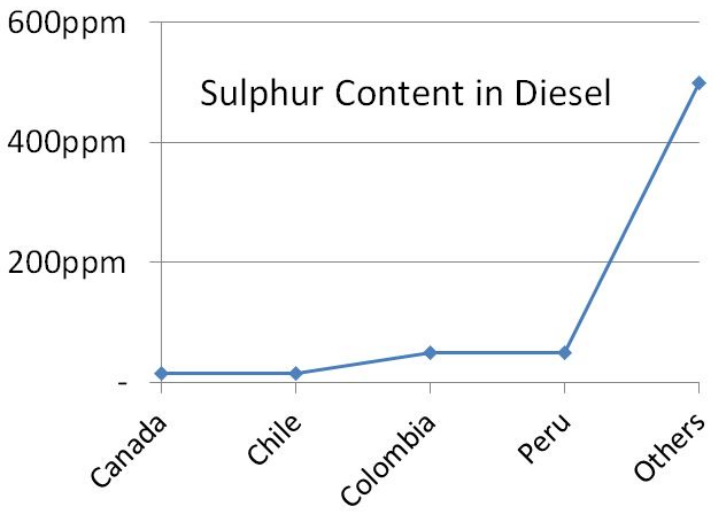
- To sell, must compare favourably to the competition.
- Product testing normally optimal conditions.
- Mine contracting, as much as 70% of overall costs may be hidden in the contract wording.

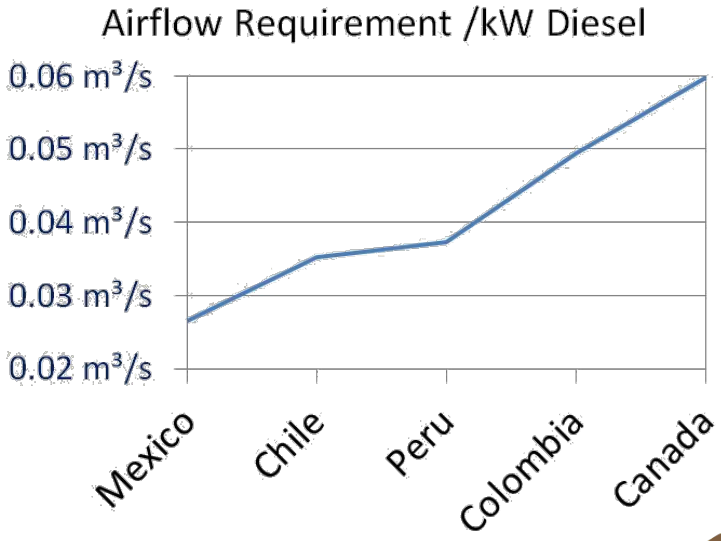
Benchmark
Fine print of contracts

WHILLANS
MINE STUDIES LTD.

Underestimation of Ventilation Requirements

Size of Mobile Fleet → Determines size of vent raises
capacity to produce & health of personnel





Health of the Worker

WHILLANS MINE STUDIES LTD.

Computer modelling

Precise

Representative

Dilution skins	.. amount of dilution more important
Geotechnical block model	.. smearing, overestimation
Detailed design in inferred resources	.. it´s inferred
Automated mine scheduling	.. step by step strategic approach still faster
Block models	.. tiny blocks don´t make it better
Variography	.. at times to make the deposit look better?

Optimized = Optimistic?

WHILLANS MINE STUDIES LTD.

Underestimation of Dilution

- Decisions made during geological modelling and design
- Decisions made during execution;
- Variability of the contact;
- Over-break;
- Variability of grade;
- Mine by lithology or grade;
- Visibility of the contact;
- Minimum mining width;
- 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;
- Rock quality and stress;
- Presence of water;
- Stand-up time;
- Alternating use of raises as orepass and wastepass; and
- Continued extraction of material (waste) after stope has been exhausted

Article in Progress

Here is a list items that need to be considered.

There are more to add

For most studies dilution is greatly underestimated

WHILLANS MINE STUDIES LTD.

Underestimation of Mining Losses

- **Efforts to reduce dilution;**
- Cut of grade of the reserve is not representative of what might be mined;
- Technical services decisions made during modelling, design and work quality;
- Mine supervision and miners decisions and work quality;
- Changes in the cut-off grade;
- Loss of tonnage through upgrading of resource;
- Support pillars in mineral;
- Pillars to prevent dilution from backfill;
- Sill pillars and crown pillars in mineral;
- Pillars to protect infrastructure;
- Areas where a cost benefit analysis indicates economic loss;
- Mineral that is left in the corners while mucking a stope;
- Mineral buried under waste oversize when a stope fails;
- Mineral that is not mined due to variation in metal prices;
- Mineral that is lost in the mucking floor;
- Over-mucking of primary stopes; and
- **Mine call factor; Mineral that is not delivered to the mill and we don´t know why**

Here is a list of 17.
Are there more to add?

For most studies, mining losses are greatly underestimated

Article in Progress

WHILLANS MINE STUDIES LTD.

Operating Decisions

The Human Factor

- Operations is another reality
  - Different set of people with different priorities.
  - Safety and managing people vs. NPV

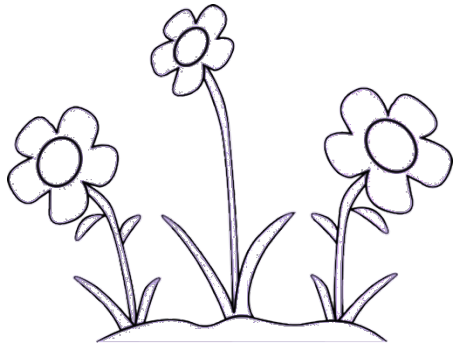
- How many of you have stories about how far a plan has differed from reality ?

- The human factor very important. Rarely properly considered in studies.

The Flower Planting Metaphor

The First pitfall of base principles calculations

"Extensive tests on our new flower-planting shovel show that the average time to plant a flower including tamping is 5 seconds based on 1,500 observations……"



Flowers planted per minute

60/5=12. Sounds good.

Flowers planted per hour.

Let´s use a 50 minute hour to be conservative. (Industry standard)

50x12= 600 flowers per hour.

That sounds like an awful lot.

Benchmarking would provide a more reliable estimate

Flowers planted per shift, let´s use a 6.5 hour shift to be conservative

3,900 per day. Wait! This number is getting out of hand!

WHILLANS MINE STUDIES LTD.

Overestimation of Availability

- **Machine** ≠ Mechanical Availability

- **Labour** Availability
  - Attendance
  - Substitution
  - Effective time at work
  - Assignment

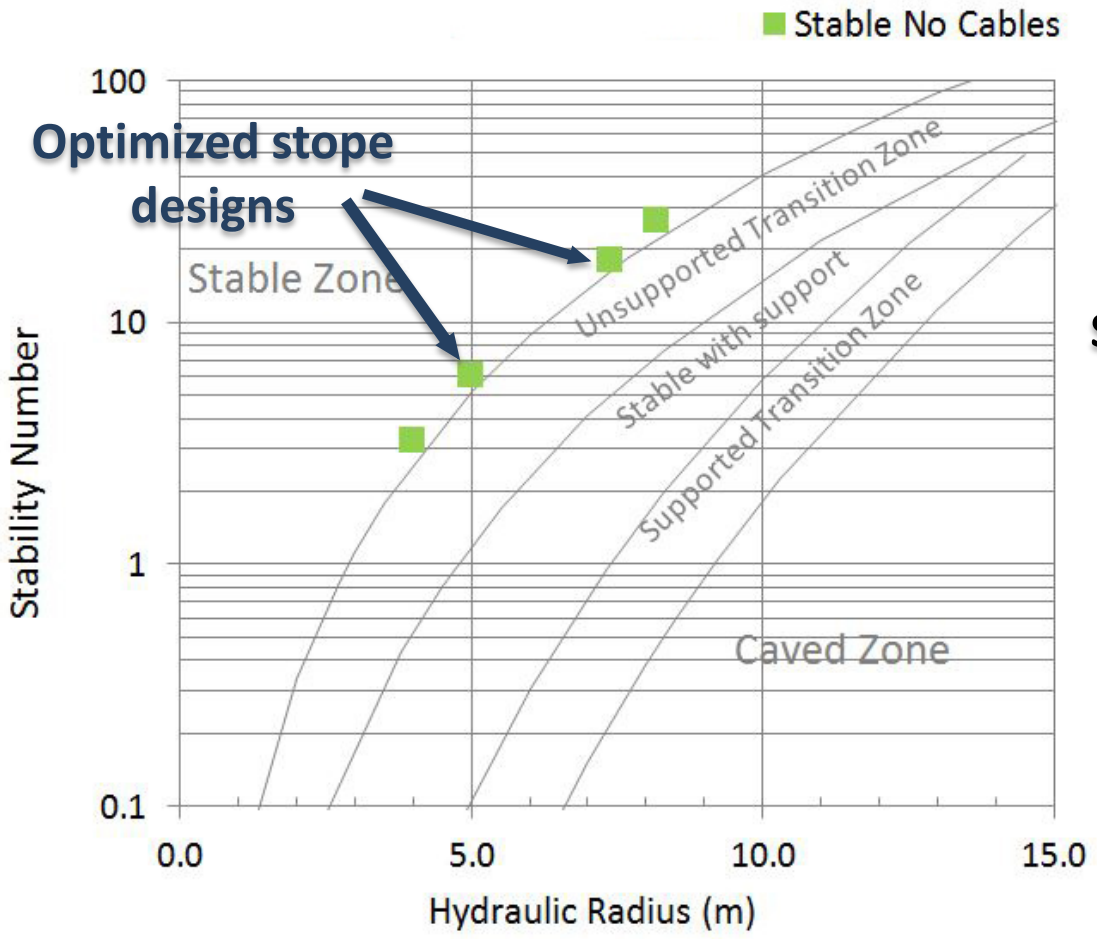
- **Ambient** (or system) Availability
  - Normally not even considered in studies.
  - Many factors
  - Measure if possible

For most studies Availability is greatly overestimated

In depth understanding of underground environment

WHILLANS MINE STUDIES LTD.

Optimization of the Limits of Design

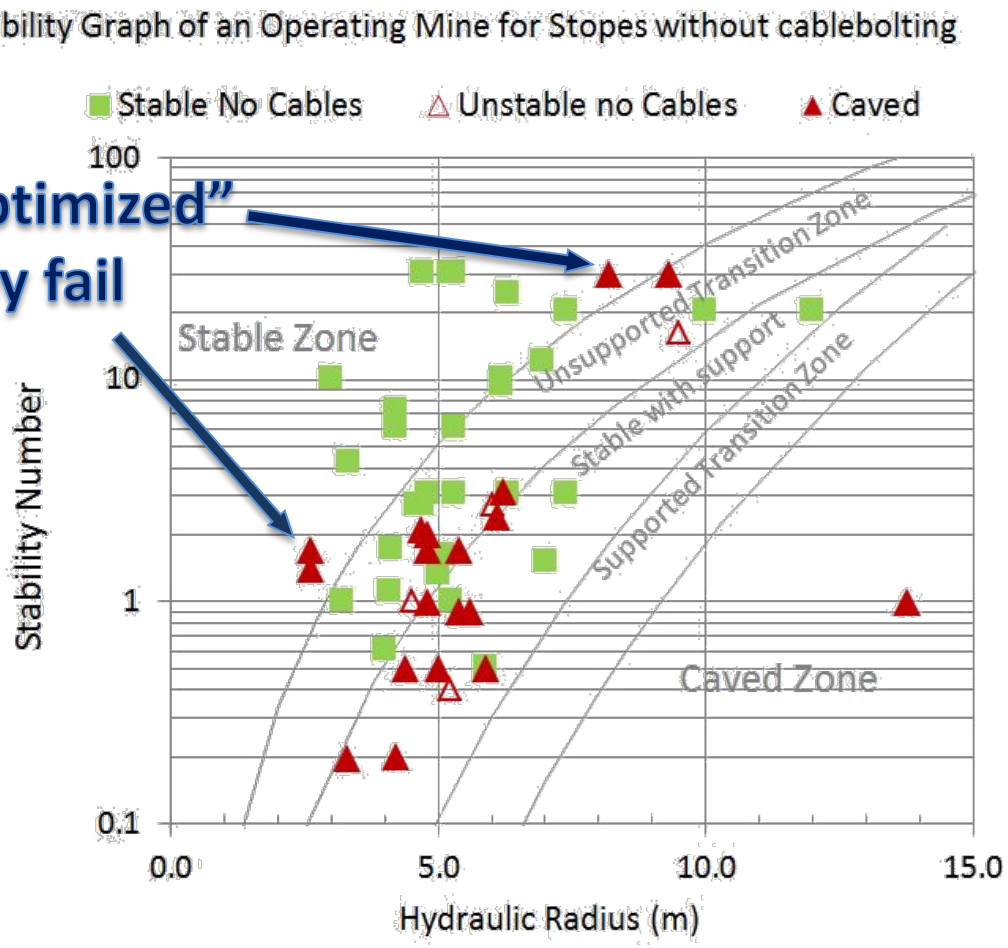


The Modified Mathews Stability Graph is used for determining stability of open stopes

WHILLANS MINE STUDIES LTD.

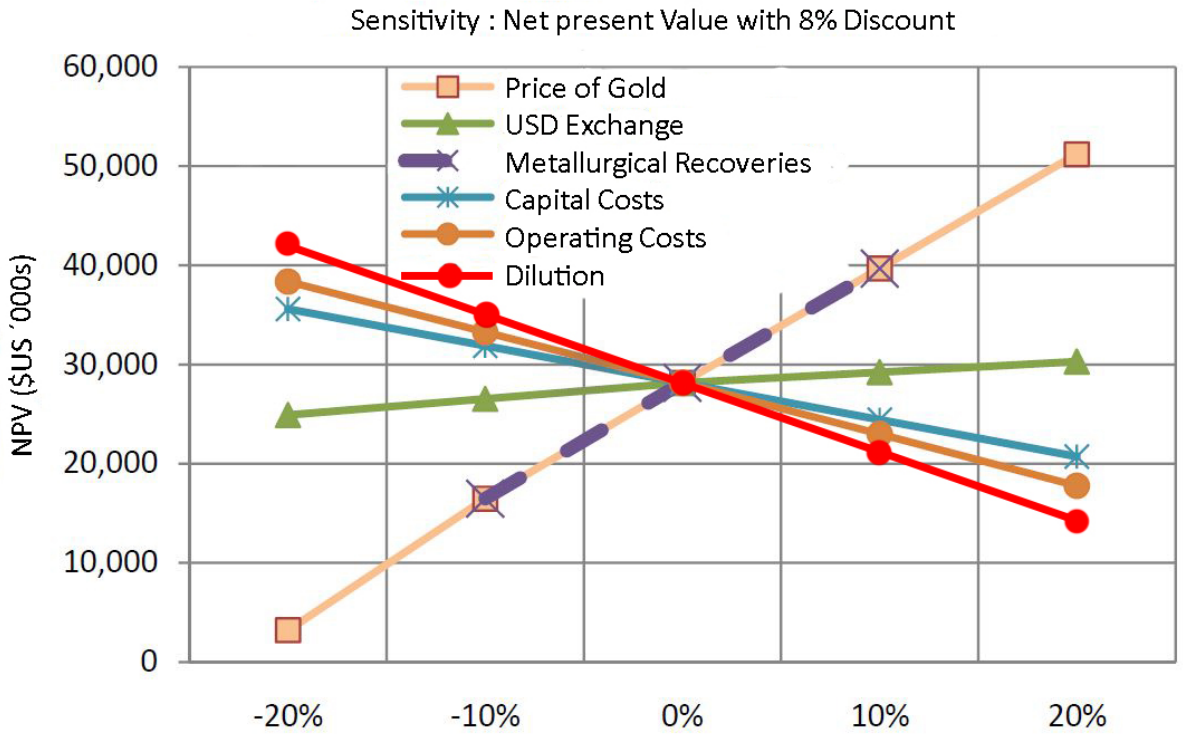
Actual Historical Data

20% of the "optimized" stopes may fail



WHILLANS MINE STUDIES LTD.

Interpretation of Sensitivity and Risk



Composite effect often ignored

Not addressed By Monte Carlo Simulations unless aggregate effect can be identified. (Alternate simple solution proposed by Larry Smith)

If capital +40%

- operating costs also probably underestimated.
- Almost certain pre-production time estimates overly optimistic.

WHILLANS MINE STUDIES LTD.

Agenda

1. Introduction
2. Factors which contribute to overly optimistic studies.
3. ⟹ Impact on operating mines and on our industry. (1 slide)
4. Recognition of milestones achieved. (1 slide)
5. Challenges ahead (1 slide)
6. Recommendations for improvements. (1 slide)

Impact of Optimistic Studies on Operating Mines

Inadequate Infrastructure - have to meet targets.

↓

Shortcuts. Production crisis frequency. Compound errors.

↓

Manipulation of numbers

↓

Promises to investors not met

↓

Promises to communities not met

↓

Damaged credibility and reputation for the industry.

The PEA sets the bar

WHILLANS MINE STUDIES LTD.

1. Introduction
2. Factors which contribute to overly optimistic studies.
3. Impact on operating mines and on our industry.
4. Recognition of milestones achieved.
5. Challenges ahead
6. Recommendations for improvements

WHILLANS MINE STUDIES LTD.

Significant Improvements in Recent Years

- Safety and working conditions
- Diesel machinery
- Underground support and bolting practices
- Adoption of Equator Principles by 26 major banks.
- Better gender equality.

1. Introduction
2. Factors which contribute to overly optimistic studies.
3. Impact on operating mines and on our industry.
4. Recognition of milestones achieved.
5. Challenges ahead
6. Recommendations for improvements

WHILLANS
MINE STUDIES LTD.

Challenges Ahead 1

Crisis of Credibility - difficulties financing new projects.

Align mining studies with reality

- Gain trust, confidence with investors, governments, local communities.
- Should lead to more favourable financing agreements.

Requires

- Stepping away from the bar of current practises;
- Close links with and in depth understanding of the underground environment and its challenges.

Challenges Ahead 2

- Non-traditional models for mining.
- Ventilation and long term health.
- Mining regulations needed in many countries.

1. Introduction
2. Factors which contribute to overly optimistic studies.
3. Impact on operating mines and on our industry.
4. Recognition of milestones achieved.
5. Challenges ahead

⇒ 6. Recommendations for improvements

WHILLANS
MINE STUDIES LTD.

Clarify Intention of Mining Studies

Protect investors with representative economic picture,

Align expectations

Accountability

WHILLANS MINE STUDIES LTD.

Industry Best Practises: Technical Improvements

- Use of benchmarking, improvements to benchmarking (no terms of reference yet)
- Refer to Taylor´s Rule and subsequent modifications;
- Illustrations to show calculations for dilution and mining losses;
- Quantify all sub-items of :
  - Dilution,
  - Mining losses,
  - Machine Availability,
  - Labour Availability,
  - System Availability, and
  - Contingency (no terms of reference yet)

Industry Best Practices
Minor Improvements

Early delivery of a draft cost model by the consultant;

Consider recommendations from all previous consultants;

Mine planning or geotechnical QP must inspect drill core;

Thank you for Listening

Questions?

paul@whillansminestudies.com

 +1 (604) 250-1119

WHILLANS
MINE STUDIES LTD.

paul@whillansminestudies.com

+1 (604) 250-1119

WHILLANS
MINE STUDIES LTD.

Notes

Scheduling Parameters

A miner may provide assurances that he can advance his tunnel 3.5 metres every shift just as a driller will assure you he can drill 150 metres a shift, but the long term scheduler at the same mine may schedule only 40% of those rates.

The driller or miner will remember shifts when things worked out, whereas the long term scheduler simply benchmarks how much was done in previous months. The gap between what can be achieved in a good shift vs. what can be achieved in a normal shift is significant for underground mining.

So what is a reasonable expectation of reality and what do we have to do to improve the accuracy of our estimates? The following paragraphs outline some pitfalls in mine scheduling and common errors in base principles calculations and how these might be avoided.

The Flower Planting Metaphor

Data from suppliers can lead to erroneous results, because for products to sell themselves must be shown in the best light. Here is an example in this metaphor for planting flowers:

"Extensive tests on our new shovel show that the average time to plant a flower including tamping is 5 seconds based on 1,500 observations……"

How many flowers can be planted in a day using this new shovel?

Flowers planted per minute would be 60/5=12. That sounds good.

Flowers planted per hour. Let´s use a 50 minute hour to be conservative. That would work out to 600 flowers per hour. That sounds like an awful lot.

Flowers planted per shift, let´s use an 8:00am to 4:00pm shift with an hour for lunch and two 15 minute breaks = 3,900 flowers per day. Wait! This number is getting out of hand!

Note that two contingencies had already been included in the above calculation, 10 minutes off every hour and only 6.5 effective working hours per day, but the estimate is still overblown. It would be back-breaking for anyone to plant that many flowers in a day even if there were others who were occupied with the support tasks of supplying extra flowers.

This conundrum of the flower-planting rate is a metaphor for the first pitfall of using base principles for scheduling as well as cost estimating. Information from suppliers usually is backed up by actual field tests but those tests always simulate optimal conditions. The difference between optimal and real is significant.

De-Rating of Diesel Machines for altitude

We contacted a diesel machine supplier to ask how their diesel machines should be de-rated with respect to the altitude at an operation. The supplier replied that at the altitude in question it will not be an issue, don´t worry about it.

We challenged the supplier to contact their head office. A reply came back from head office that we were right only if we wanted to adhere to North American Standards and that yes, there would be a loss of effective diesel power in the order of 20% if the adjustments were made. In fact, although most countries in Latin America adhere to North American emission standards, the de-rating of diesel machines is not done frequently.

This type of information is considered somewhat sensitive because it can result in the loss of a sale. If the engines are not de-rated, emissions will be worse and the long term health of the workers will be affected. In reality, long term health issues are very hard to quantify and very difficult to differentiate from other environmental issues. Most countries in Latin America haven´t reached the point where attention is being given to long term health issues, but it will happen soon.

Not de-rating diesel machines where required damages the motors and results in reduced engine life and more frequent replacement of filters and such, thus favouring the supplier.

Ventilation technicians at operating mines rarely make the connection between faulty ventilation calculations caused by not derating machines for altitude. Many of the high altitude mines require workers to wear filtered breathing masks.

Use of Masks

Some mines require workers to wear filter masks. It´s uncomfortable for miners to wear a filter masks all day so do they wear them? Probably not. Professionals and technical staff, who spend less time underground, will wear masks as an example. It is very different to visit a location where the air is not optimal to actually being immersed in that environment all week.

There is an ethical issue here too, because the unspoken message to workers is that the visiting professional doesn´t like the air and see the need to protect their own health. Planning needs to incorporate proper ventilation infrastructure based on real operating conditions and monitor the air to sufficient ventilation so as to minimize the requirement to use masks.

Use of Inappropriate Diesel Equipment

Many mines outside of North America will introduce equipment that in North America would not be certified for use underground. An example is the use of surface dump trucks underground. Trucks have the largest impact on ventilation calculations but we know of no mine that calculates how to compensate for the increased emissions of these vehicles.

Moreover, it can be very difficult to obtain emission datasheets from suppliers of surface equipment.

Mine operators especially in Latin America, will often be strongly in favour of maintaining a fleet of surface equipment for use underground but there are at least four arguments that can be presented to operators to justify the purchase of the more expensive low profile underground trucks, the most important of which is the time it takes to drive a ramp and start production.

Geotechnical Block Modelling

To create a block model it is necessary to create composites. A composite is essentially a weighted average value over a certain distance. Let us say that we are interested in the geotechnical conditions in the 3 metres of waste rock next to the hangingwall contact. Let us say that Q´ readings indicate values over a wide spectrum, so to create the composite we have to weigh the values over the 3 metres and effectively smear the result. Geotechnical conditions will then appear more homogeneous than they really are.

Just as is the case for geological block modelling, a geotechnical block model will have to interpolate between data points. Often the proponents of this method say that it makes the design process easier. But it gives a false impression of homogenization. A stope may have excellent rock conditions in the hangingwall but one or two tabular faults with gouge material distant from the hangingwall can be devastating to ground stability.

This is an example where stepping back, discussing the issues making a few sketches and deciding a strategy is far more useful than going directly into detailed computer modelling.

Use of the Geological Block Model

A geological block model is an interpretation of the composites made from the raw data of diamond drill hole intercepts and hopefully takes into consideration geological underground mapping as well as chip samples. A good geological block modeller will attempt to calibrate their model to underground production results and will understand the discrepancies between the two. It is difficult to find people who will go beyond the call of duty to perform good reconciliations.

It is increasingly rare nowadays that an engineer will look at diamond drill holes in the field and or even in the computer, examine them and question the geologist on how the block model was interpreted. Most engineers consider this as unnecessary step, let the geologists do what they know how to do. I consider it as part of due diligence to compare the geological block model to the mine underground mapping to diamond drill intercepts and if available, to chip sampling. At a few mines and projects where we have worked, there has been only limited correlation between underground mapping and the block model. There is a tendency nowadays is to use only diamond drill holes. In a good working environment, questioning, debate and interaction between groups will stimulate discussion and discovery and will lead to better planning. Communication between geologist and engineer has been threatened for some time. We have become specialists and there is a dividing line between disciplines which is not crossed enough. How do you cross the boundaries of egos and execute a raid? Use humour .

.

Increasing Specialization Example 1

Mine engineering is traditionally a generalist field, with exposure to number of other disciplines to able to get the work done. Increasingly it is moving toward specialization which in turn needs increased coordination. The generalist skill set is lacking and this can lead to costly mistakes. Here are some examples:

Example 1

We were brought in to provide advice for advancing a mining study that had been in the works for many months but had been stalled. In one city, the mine planners were working on a high tonnage output scenario but the geotechnical information put together in a different city (that had been available for some time) indicated a much lower tonnage output. This is an example of a risk of working with multiple specialized departments and multiple projects on different timelines. It can happen that one area doesn´t know what the other area is doing. It also underlines the need for blurring the lines between disciplines. Mine planners should perform a quick due diligence on the work of others before proceeding.

Increasing Specialization Example 2

In another example, the geotechnical group based in one country provided recommendations for the sizes of underground openings (spans) indicating that in most cases a low tonnage, smaller span mining method would be the best option. However, by providing this information, the geotechnical group was being aggressive in two areas:

They didn´t know about the hydrological conditions which was being handled by another group, albeit of the same company, so they didn´t take into consideration the presence of water for an environment that would most certainly be wet. As the presence of water is a factor that affects rock stability, this was the first area where aggressive information was being supplied; then

A geotechnical block model was built which has its own inherent problem of smearing and overestimating rock quality.

The mine planning group then took the recommendations from the geotechnical group for the sizes of underground openings but disregarded the recommendation for smaller spans and chose a bulk tonnage mining method which is what the client wanted.

This example we refer to as compounded aggressiveness, factors that can very quickly blow the accuracy level of a study out the window. I leave it to the reader to decide what is at play here: appropriate training, appropriate in-depth or relevant experience, appropriate knowledge, organization, communication, ethics, carelessness, the desire to please the client, fear of not getting paid for work that the client doesn´t like or delaying the bad news so as to get paid for ongoing invoices. Budgetary constraints I do not consider as an excuse for not doing good work .

Ambient Availability: Some examples

Ambient Availability is sometimes referred to as System Availability. The miner is present, assigned to his or her primary task and ready to work. The machine is in operating condition but something is preventing productive work from being accomplished.

The list of factors that may affect ambient availability is extensive and may include:

- Travel ways blocked by loading of trucks, vehicle break-downs that block transit, or the work of electricians pipefitters, surveyors or technical staff impeding movement in the mine;
- Power outages that may result in downtime and flooding;
- Clogged pumps;
- Backfill spills;
- Problems with water or air supply;
- Ore and waste passes full (impacts mucking or haulage to transfer points);
- Issues with ventilation;
- Problems with oversize such that resources must be dedicated to address the problem;
- The need for unexpected movement of primary equipment such as to re-drill lost holes; and
- How priorities are perceived for different tasks in the mine

It is possible to measure ambient availability and we recommend it as a best practise. For example, we measured ambient availability for truck haulage for and came up with a surprising 60% ambient availability. We then redesigned the truck loading bays, made a provision for passing bays, and sought further enforcement of the right of way for trucking, among other changes.

Attitude, Humility and Getting to the Right Answers

Mining is a human endeavour. The work of underground mining is dark, dirty, noisy and can be also be lonely. It would be a very difficult environment to work in if it weren´t for the people. Strong-willed, capable, ingenious, usually intensely humorous and full of fascinating stories and useful information. We need to listen to those people who have had day in, day out experience to the right answers. We need to be humble, we need to:

- Create dialog.
- Listen attentively.
- Without agenda.
- Be curious.

Truths will surface that are unexpected.
Do it playfully, with humour, direction and intention

If we are slightly outside our area of expertise we will need to check our assumptions and search out those who know those who have a depth of experience in that area. University can train us to be selfish hoarders of information for mine plans to be representative we need to do what in school is called “cheating” ie asking others what they think to get to the right answers. Don´t be put off if the miners tell you you´re full of it. It´s part of life. Surf the wave, chill.

We underestimate the knowledge stored in the people around us who have done specific work in particular fields like blasting for example, mucking remote or what it feels like to work shifts like 12 hour 4 on 4 off or 12 hour shifts 3 weeks in 2 weeks out. This is where openness, transparency and involvement of others in the planning process are absolutely critical.

Attitude, Humility and Getting to the Right Answers

After reading the accompanying articles on Mine Dilution do you still feel confident that you can sign off on dilution with the same degree of accuracy as before?
Are you qualified to sign off on the best alternatives for cycling crews for ramp advance?
Are you qualified to sign off on a life of mine plan? By that I mean, have you repeatedly seen your mine plans go into action and charted the difference between your plan and reality? Have you been able to make accurate predictions? What is your track record and how far off have your predictions been?
We cannot be experts in everything. At the age of 17 I think I was at the apex of my knowledge about the world and everything in it. Youth, ego, hormones and fluff in the brain. Now I realize I know a little bit and I have to ask others.

What of the mining consultant with many years´ experiences who goes to the mining fact book and picks a dilution of 13% for cut and fill without investigating conditions peculiar to that mine or talking with someone who has actually measured dilution in cut and fill?

On ego “In 2010 I did a ramp …..” Wait a second. Ramps don´t get done by one person. Rounds don´t advance by the force of one person. It takes a whole team of people to do this work. Be careful with your wording and be humble of your place within the team.

Disagreement and Debate

Disagreeing with the boss is risky business, you can lose your job, so most people are very careful about expressing disagreement. Here are some factors that affect the willingness to disagree:

- Work cultures where respectful disagreement is not encouraged;
- Societies that are poor and where losing one´s job has the greatest consequences; and
- Employees whose family welfare is more closely tied to the company;

But how we need those who are prepared to disagree! They are the window to creative solutions.