
THE BIG PICTURE: A SAFER FUTURE USING LERCHS-GROSSMANN PIT OPTIMIZATION LINKED TO CASH FLOW ANALYSIS

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ABSTRACT

This paper covers some aspects of project development that are frequently buried in the technical detail of a large feasibility study but need to be brought into focus early. Like a masterwork of art, the canvas you choose needs to be the right size and quality to preserve your big picture. Even more important is the desire that your project stays around to become a masterpiece.

Preliminary pit optimization studies can yield a wealth of useful information on a range of important issues. We begin with how to save money on development/resource definition drilling. Early analysis will help in scoping the right size of mill and mining operations. The merits of making early expenditure or deferring capital costs can be assessed. Finally the information obtained from a set of Four-D analyses is perfect for answering such fundamental "what if" questions as: "Should we select the maximum profit, most robust project or best resource utilization?" and "What are the risks, and what could they cost?"

INTRODUCTION - CREATING A MASTERPIECE

When dealing with the hyper-complex task of evaluating and developing a new resource project, it is hard to see the big picture, yet this is precisely the most important aspect in reducing risk. Before you can paint a masterpiece, there are certain fundamentals of the medium you must prepare, such as sizing the canvas and selecting the pigments. Pit optimization, linked with rigorous cash flow schedules that comprehensively look at a range of sensitivities, should be carried out as early as possible in the project development to provide a similar lasting foundation.

This paper covers some aspects of the project development that are frequently buried in the technical detail but need to be brought into focus early, thus ensuring that the canvas you choose will be the right size and quality to preserve your big picture and, more importantly, that your project stays around to become a masterpiece.

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SOME TERMS DEFINED

We will need to review a few general terms often used to describe some of the big picture concepts. They are quite common terms but may have a range of meanings when used in different contexts.

• RISK

Most of us understand risk as a chance of disaster or loss. A risky project is one where taking the chance is seen as dangerous in terms of losing your investment. However, few of us will agree on what the level of risk is. The professional gambler may prefer to evaluate risk in terms of the appropriate odds returned on a win. Long odds make a risk easier to take. Those accountants amongst us know that risk is claiming a travelling expense without a receipt.

Let us use a simple rule of thumb to detect when a change in parameter could be a significant risk to the project.

Significant risk $\pm 10\%$ *Change in Parameter* $\Rightarrow \pm 25\%$ *Variation in NPV*

We will consider a parameter to be a significant risk if a 10% change from expectation produces 25% or more variation in the project's net present value.

• ROBUST

This is a general term to describe something strong and sturdy, able to resist powerful forces.

In the context of a large project it can be used to describe that set of strategies for exploiting the resource so that risk is limited.

• ORE RESERVE

In this paper the term "ore reserve" is limited to the strict definition given in the JORC code.

- ◆ Measured Resources equate to **Proved Ore** within a feasible pit
- ◆ Indicated Resources equate to **Probable Ore** within a feasible pit
- ◆ Inferred Resources and Pre-Resource Mineralization within a feasible pit are not considered reliable enough estimates to be equated to any form of Ore Reserve.

Getting the assumptions in a project exploitation strategy clearly focused has more importance during the feasibility study than at any other point down the sequence to becoming a viable mining operation.

PREPARING THE MODEL

Early in a project's discovery period, you will probably reach a point where about 30-50 holes have intersected the mineralized body over its known strike length. This is the ideal time to prepare a simple model of the mineralization and start to select targets for infill holes, as well as to estimate the potential geological resource. Because of the drill spacing and doubts about the geological

interpretation, you will probably only be able to classify this as an Inferred Resource at best or, more likely, a Pre Resource Mineralization category. The model you produce will be ideal to get an overview of the larger scale economic assumptions and relationships. You can then use the Four-D software to carry out Lerchs-Grossmann pit optimizations and cash flow analyses, similar to the detailed stages of a feasibility study.

Many people may worry about the sense in building detailed work on a very preliminary geological interpretation. However, we are not trying to compute ore reserves. The objective here is not to produce the definitive resource extraction and exploitation strategy. It is to get the fundamentals right. The cash flows and mining sequences presented here are not expected to be accurate in a "bankable" way, but they will show you the robust path to follow in the resource definition and mine design stages to follow.

Ken Lane describes this well when he states 'It is better to be roughly right than to be precisely wrong.'

The first step is trying to interpret the shape of the possible mineral zone. The more elongated and discontinuous it is, the more difficult this will become. Yet the basics are much the same for any style of mineralization.

- I. Assess continuity and grade distribution
- II. Project the grade of the mineralization into a shape following the geological fabric
 - A. Using Cross Sectional Method
 - B. Inverse Distance Interpolation
 - C. Geostatistics/Kriging
 - D. Wireframing & block modelling (this is a combination of the above)

If you are using wireframing, or any other form of constraining shapes to restrict the block generation to the tightly interpreted shape, remember you will need to dilute your resource. You can use the ore loss and dilution factors in Four-D to do this.

At this early stage it is exceedingly unlikely that you will have sufficient geotechnical data to estimate the final pit slopes. However, it is generally quite a valid assumption to use 45° slopes. This is the average slope angle including haul roads. Unless the pit goes very deep or ground conditions are very bad, this is close to a large number of mining operations. Starting with 45° slopes means we can use a small structural arc file and optimizations will be very fast. Sensitivity to pit slope is something that can be evaluated in general sensitivity studies later if desired.

The block size you use for your study is important in that it must reflect both the shapes and distribution of grade. Yet for this big-picture style overview there is also a desire to use the largest blocks possible to keep the optimization time as low as practical. The FDRB reblocking program is a great tool to find the best compromise block size.

• **"REGULARIZING" YOUR BLOCK MODEL**

Although regularizing is a term usually associated with Datamine's REGMOD procedure, I am using it here to describe the process of getting a more equi-dimensional block size. If you cannot get the person preparing your model to do this for you at modelling time, you can use the Four-D program FDRB. In our example we have a very irregular block size: 5 by 25 by 10m. At first

impression there is not a nice common multiple of these block dimensions (below 50 by 50 by 50m, which even I consider a big block).

If you read the new Four-D Manual, you will see that FDRB can be used to split blocks. You can even split and combine blocks in the same run. However this may not produce what you have in mind.

```

Do you wish to combine and/or split the blocks      (Y/N) [N] ? y
X direction combining/splitting factor [1/1] ? 2
Y direction combining/splitting factor [1/1] ? 4/5

Y direction framework extended by 3 blocks
Z direction combining/splitting factor [1/1] ? 2

```

The reblock program will interpret the 4/5 by first reblocking 4 times in the Y direction then splitting these into 5 smaller blocks (each with equal parcels). These can lead to a very "blocky" smoothing of the model. What is required in our example is to do the splitting first and then combine the blocks. This time we limit the number of parcels in the output model to "recombine" the equal splits of sub-parcels.

Firstly split the blocks into 5 sub-blocks

```

Y direction combining/splitting factor [1/1] ? 1/5

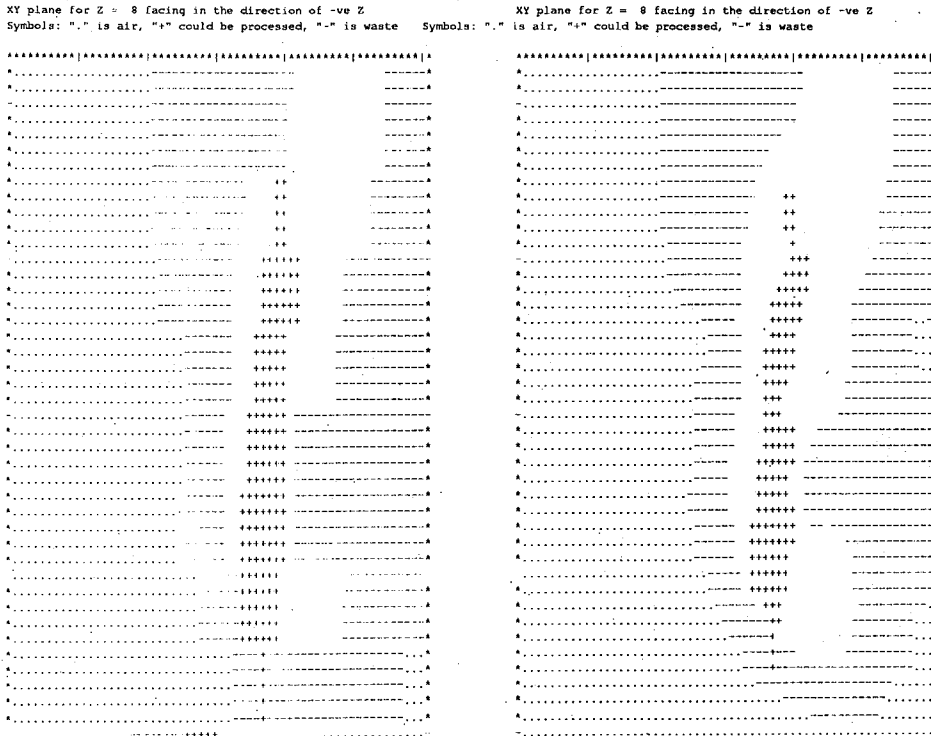
```

Next reblock again. This time combine all the smaller blocks

```

Y direction combining/splitting factor [1/1] ? 4

```



You can now get together a few assumptions about the project's economics and run an optimization.

SAVE MONEY IN THE RESOURCE DEFINITION STAGE

The Resource Definition Phase of a project is normally conducted prior to the detailed feasibility study and involves a considerable amount of drilling. The purpose of this drilling is to define as clearly as possible the mineralization that is being evaluated. At this stage, it is common to pattern drill to the optimal drill spacing (usually "guesstimated") that attempts to define as much mineralization as possible to either the Measured or Indicated resource categories.

To find the range of likely pit limits, we can run a pessimistic analysis using say \$8 per gram as the gold price (roughly US\$250/oz). We can also perform an optimistic analysis at \$16 per gram (roughly US\$500/oz).

Example of Pessimistic Analysis

Cost of mining a TONNE of undefined waste at the reference block
[0.0] : 1

Price to be obtained for the metal
[0.0] : 8

The nearest pit is pit 25, which is optimal, if the mine life is short, for an MCOSTM of 0.130, and for a price of 7.69.

Select a pit number (1 to 38)
[25] : 25

Example of Optimistic Analysis

Cost of mining a TONNE of undefined waste at the reference block
[1] : 1

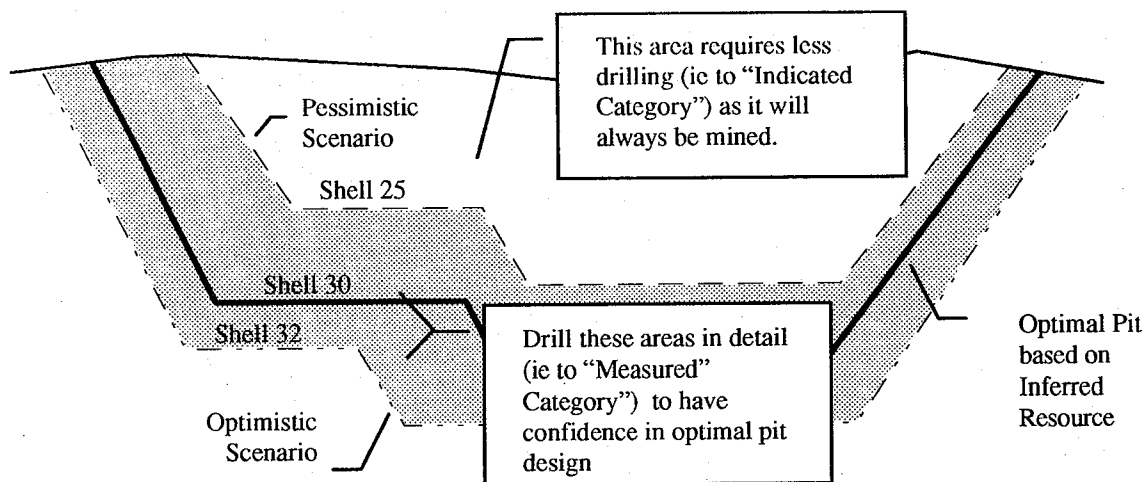
Price to be obtained for the metal
[8] : 12

The nearest pit is pit 30, which is optimal, if the mine life is short, for an MCOSTM of 0.080, and for a price of 12.50.

Select a pit number (1 to 38)
[30] : 30

SUMMARY OF PIT DESIGNS

Price per gm	Price per oz	Optimum Pit Shell	Rock tonnes	Mill tonnes	Mill Grade	Recovered Ounces	Strip Ratio
8	~250	25	33,777,615	4,192,124	3.89	471,529	7.06
12	~375	30	44,855,522	6,301,265	3.17	578,257	6.12
16	~500	32	48,368,749	7,581,186	2.81	616,009	5.38



• SELECT THE MOST IMPORTANT AREAS FOR DEVELOPMENT DRILLING

The shaded area between the most conservative outline is actually the zone that requires the most detailed drill definition. Inside the pessimistic scenario design it will always be economic to mine, so it may not be necessary to fully define the mineralization in this area. (Definition of the true ore outlines can probably wait to be defined in normal grade control). The area outside the pit defined for the most Optimistic Scenario is never likely to be mined and therefore does not need to be drilled with a detailed pattern. However the areas of potential mineralization between these two limits need to be drilled in detail as it is mineral resources within this zone that will determine the ultimate pit depth.

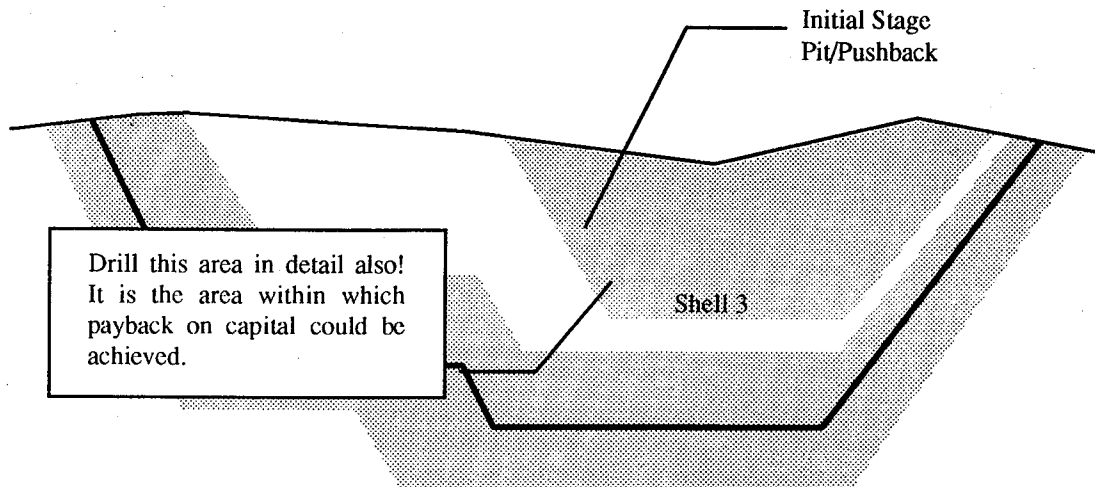
In the special case where the optimistic design also reaches the bottom of any good grade zones, then it is possible that additional extension of the high grade mineralization could take the pit deeper. So some consideration must be given to extending the drill pattern down plunge.

Drilling the area where you expect to start mining can have a significant impact on reducing risk on investment. Finding this can be a little bit of a chicken and egg problem (to estimate capital outlay will need a few assumptions about project size and other “scoping” decisions which may not yet have been made). This is covered later in the paper. Once you have made a few assumptions on likely capital, finding the payback is easily achieved by looking at the NPVs produced by the Four-D analysis program FDAN. We must look through the inner pit shells seeking a quick cash flow. In this analysis we can estimate an initial capital cost of twenty five million.

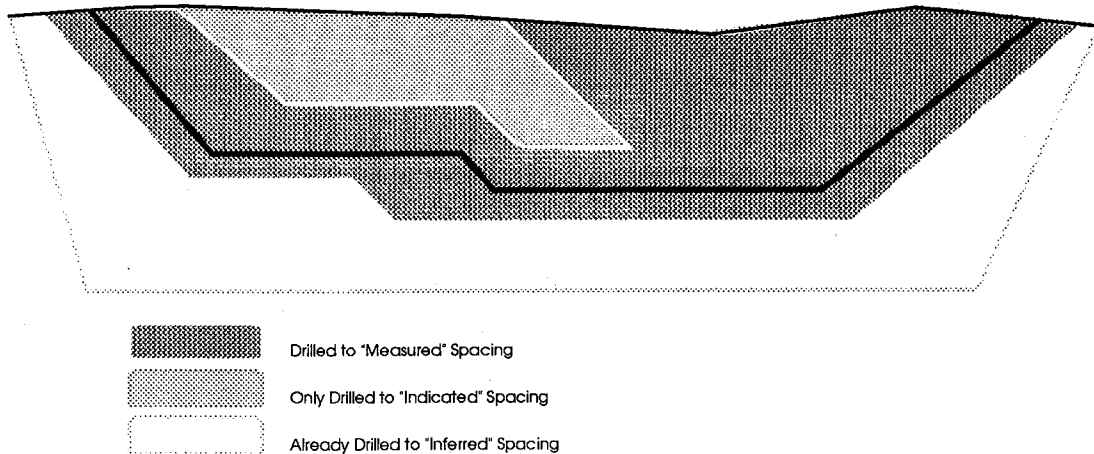
SUMMARY OF ANALYSIS OF INNER SHELLS

Pit Shell	Rock Tonnes	Mill Tonnes	Mill Grade	Actual Cash flow	NPV	Life
1	1,635,338	744,521	4.85	5,878,311	4,441,464	0.31
2	1,820,926	793,795	4.85	7,771,560	6,145,691	0.33
3	1,846,288	815,620	4.77	8,078,046	6,391,852	0.34
4	1,875,370	822,943	4.77	8,342,217	6,627,295	0.34
5	1,985,513	857,870	4.76	9,574,435	7,720,661	0.36

If we want to find a shape that could give us payback on this investment (ie capital plus 25% for fees and interest) we will have to look for an NPV of approximately six and a quarter million. If we mine out to shell three as a stage 1 pushback, we could achieve this in four months (one third of a year)!



The overall drilling strategy can now be sketched out. The drill spacing can be confidently reduced in the cross-hatched areas. In this example, as the area outside the pit for the "Optimistic Scenario" has already been adequately defined as the Inferred resource level, no additional drilling is required.



In this example we could save approximately 30 diamond drill holes and around 2,500 meters of drilling, which at \$40 per meter would save \$100,000 in drilling costs alone.

Even on a modest 100,000 tonne ore body close to the surface you can easily save drilling around 10 holes with an approximate total length of 750 meters. If it cost \$40 per meter to have these diamond drilled, we would have saved \$30,000 (twice the cost of the full Four-D package) on drilling alone before even considering staff, samples assaying etc.

WHAT IS THE BEST PROJECT SIZE?

This question can be asked in a series of more specific questions such as -

- ◆ How big should the mill be?
- ◆ What is the best size for the mining fleet?
- ◆ What is the best strategy mining sequence?

These are fairly fundamental questions that have a major impact on the final outcome of pit design. Unfortunately they can be tightly interrelated and have a complex interaction. Furthermore there is usually a wide range of possible options and the relative merits of each option may not be clear. In the past, project sizing has normally been an area of considered expert opinion (“gut feel”) rather than comparative analysis. Four-D now allows this to be completed in a very short time frame.

Generally the size of the operation will be restrained by one part of the process. In CIP or flotation plant, it may be the crusher and grinding circuit which forms the limit. In a Heap Leach operation, it may be the mining fleet which will determine how much material can be hauled out of the pit. In the first case, increasing the crusher capacity could have a significant effect on improving a project’s NPV. In the second case’, buying extra trucks could be the right choice.

Let us consider a simple example. We may have three logical sizes of the mill for a new project upon which we are about to embark with a feasibility study. The size of the mining fleet has also been “guesstimated” to match mill throughput.

Mine Capacity	Mill Capacity	Capital Cost	Mining Cost per Tonne of Rock	Process Cost per Tonne of Ore
5mil t/a	1.2mil t/a	\$ 17mil.	1.20	11.50
7.5mil t/a	2.4mil t/a	\$ 25mil.	1.00	10.50
10mil t/a	5mil t/a	\$ 37.5mil.	0.90	10.20

Superficially the last option looks the best because the processing costs are the lowest.

Yet is it really worth spending an extra \$12.5m on the mill and mining fleet to reduce the process cost by 30 cents and mining cost by 20 cents?

Perhaps, given the reserve figures, you could do a quick calculation on the back of an envelope. But wait, changing the process cost will reduce the cut-off and give you a better reserve. A few more iterative computations will be necessary on the back of your envelope, but these can only be estimates. The Four-D programs do give you the ability to carry out such “scoping” tasks in full and prepare easy-to-follow graphs to show the impact of economies of scale that may be achievable.

The first step is to design a spreadsheet output table that contains the parameters we are interested in, plus the actual cash flows, worst and best case NPVs.

Example SIZE.SSD file

```

Gra Pit/FI Rock/TG OPValue/CW
Gra Mill/TI Mill/GI Metal/UO Strip
Gra OPValue/DB Internal/B Life/B
Gra OPValue/DW Internal/W Life/w
Gra CapExIni Rock/L Mill/L
Gra Price Mill.Ore/PC CostM
    
```

Next we must run analyses for the range of scenarios we require through the FDAN program. It is convenient to run the three scenarios in the same run, only changing the capital cost and new processing costs.

Example FDAN log file to assess project size options

```

PrintFile #Leg2.pra
ParametersFile Leg2.par
ResultsFile Leg2.res
Output_spreadsheet_data? Y
SS_Definition_File Size
SS_Output_File #Size.csv
Run_Descn LEGEND PROJECT - Sizing Analysis
Timecost_Ovr? N
Initial_capital 17m
COSTM 1.2
PRICE 12
PIT 2-2-38
DISCOUNT 15
ROCK/L 5m
MILL/L 1.2m
METAL/L 0
Modify_params? Y
Your_Choice 7
MILL.ORE/P 11.50
MILL.OX/P 11.50
Your_Choice 99
Specified_schedule? N
Worst_case? Y
Best_case? Y
OK? Y
Another_request? Y
Initial_capital 25m
COSTM 1.0
PRICE 12
PIT 2-2-38
DISCOUNT 15
ROCK/L 7.5m
MILL/L 2.4m
METAL/L 0
Modify_params? Y
Clear_modifications? Y
Your_Choice 7
MILL.ORE/P 10.50
MILL.OX/P 10.50
Your_Choice 99
Specified_schedule? N
Worst_case? Y
Best_Case? Y
OK? Y
Another_request? Y
Initial_capital 37.5m
COSTM 0.9
PRICE 12
PIT 2-2-38
DISCOUNT 15
ROCK/L 10m
MILL/L 5m
METAL/L 0
Modify_params? Y
Clear_modifications? Y
Your_Choice 7
MILL.ORE/P 10.20

```

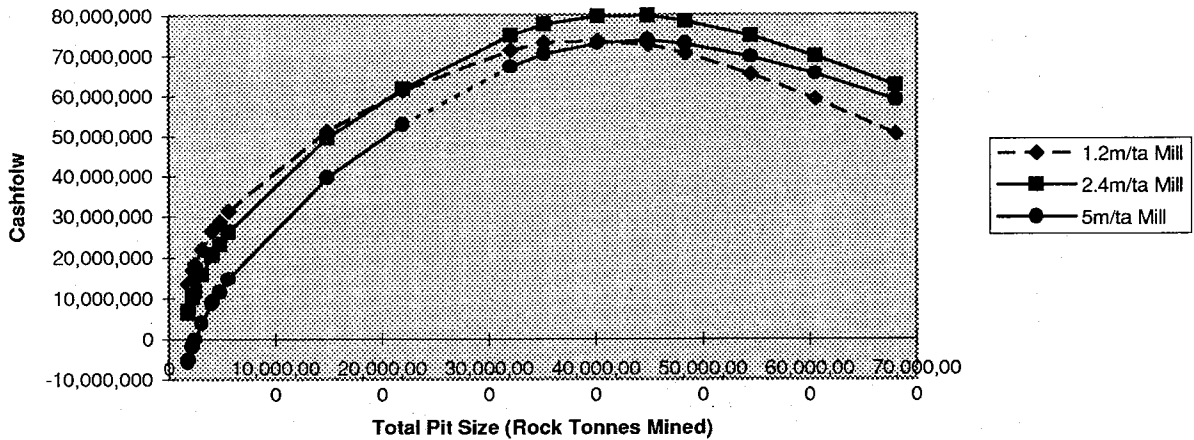
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MILL.OX/P           10.20
Your_Choice         99
Specified_schedule? N
Worst_case?         Y
Best_case?          Y
OK?                 Y
Another_request?    N
Full_print?         Y
    
```

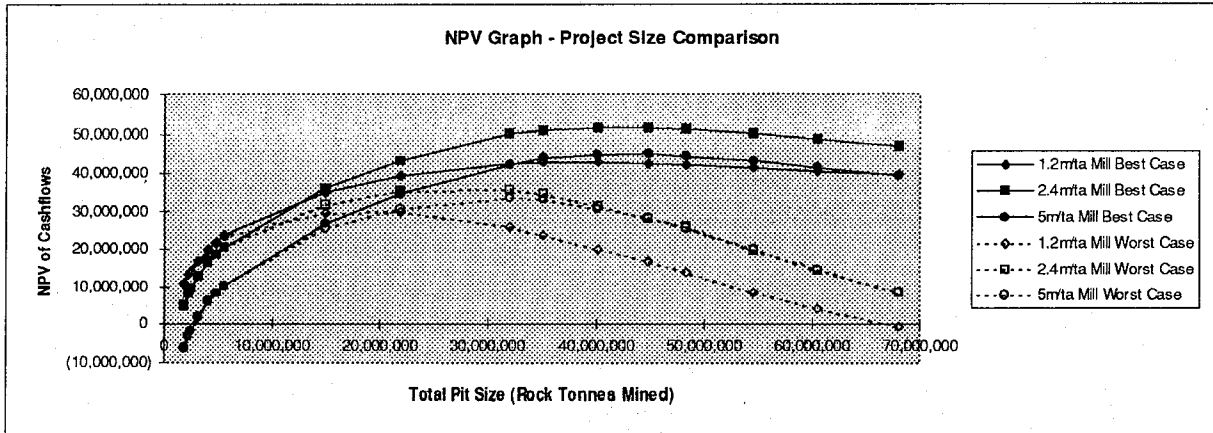
We can prepare a graph that shows the comparison of actual cash flows (plotted as the conventional Value/Size of Pit graph).

Example of NPV graphs

Cashflow Graph - Project Size Comparison



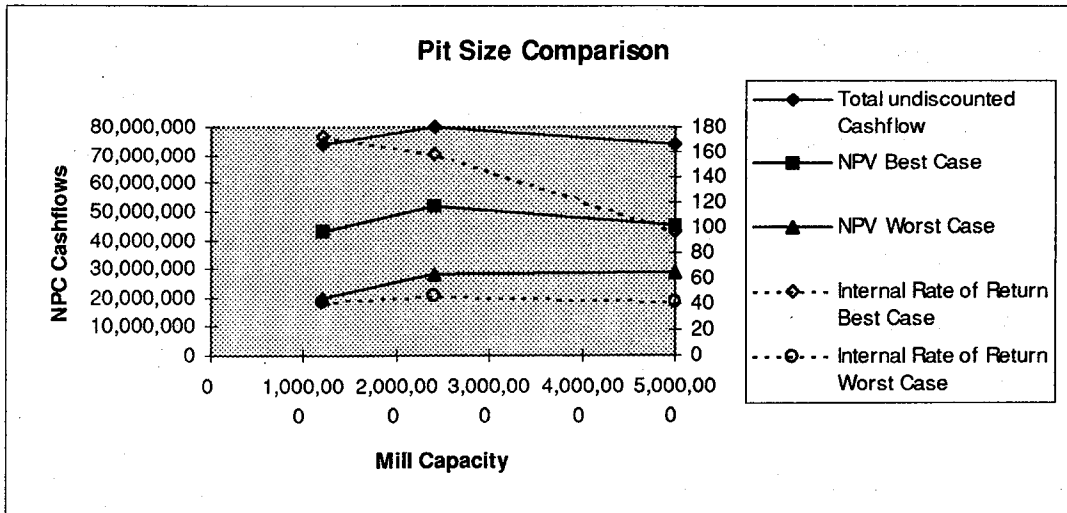
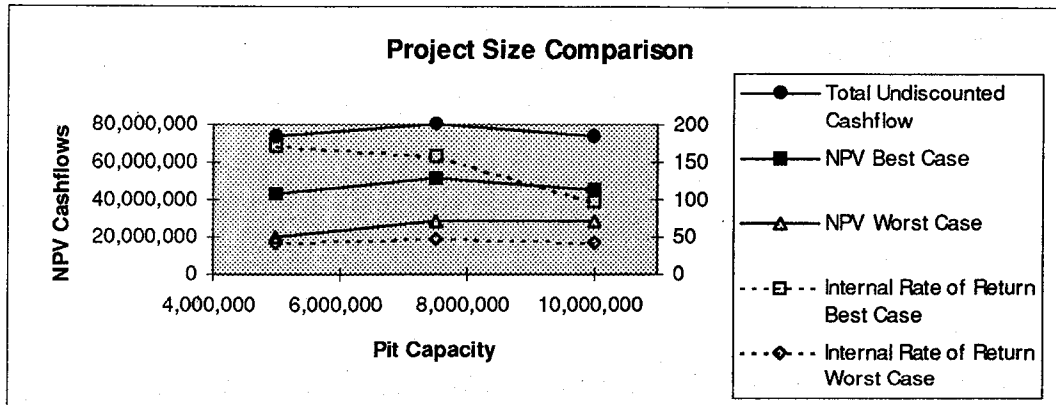
The 5 million tonne per annum option is clearly not as good as the 2.4 million tonne per annum mill. Its total cash flow (not discounted in this case) is approximately \$74 million whereas the smaller mill would have a generated \$80 million. However the two operations will have a different mine life, so how does this affect the cash flows in terms of net present value (NPV)? We can also plot a similar graph showing the effects of scheduling on Net Present Values.



We can see there is quite a large difference between the worst case schedules (top down mining) and the best case schedules (inner shell out sequence of mining, which may not be practical). In fact, the 2.4 million tonne mill capacity would yield only \$2 million more than the 5 million tonne per year mill

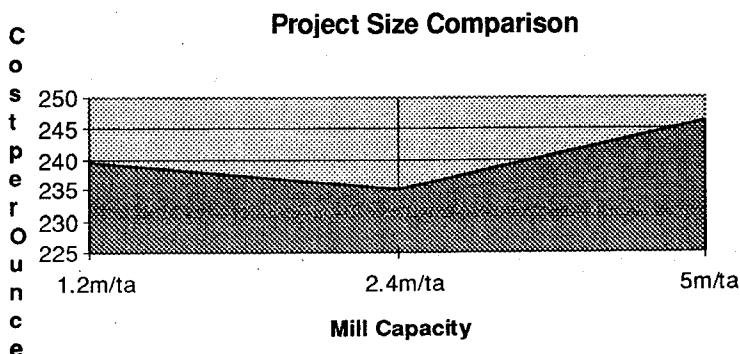
under worst case sequencing, but approximately \$10 million more under the best case scenario. This relates to the project shifting from being mining constrained during the early phases of a top down mining situation to a milling constrained situation under the best case schedule.

The graphs of mining and milling limits against NPV are very helpful and many suggest the best ranges for additional scoping analysis.



Perhaps milling capacity between 2.4 and 5 million tonnes per annum requires some further investigation.

Finally we should not forget to look at that magic number for a gold project's "cost per ounce recovered". This calculation takes only a little time to perform in our summary spreadsheet.



The best mill and mine capacities are now much clearer. The 2.4 million tonnes per annum operation has the lowest cost per ounce as well as the best NPV.

Mine Capacity	Mill Capacity	Total Rock Mined	Total Ore Milled	Grade Milled	Total Ounces Recovered	Cost Per Ounce
5,000,000	1,200,000	40,161,301	5,800,852	3.28	550,834	239.46
7,500,000	2,400,000	44,855,522	6,301,265	3.17	578,257	235.22
10,000,000	5,000,000	44,855,522	6,394,652	3.14	580,844	246.36

In this case we have been running analyses that “stray outside” the parameters used in the optimization (ie since the processing cost has varied, then the CRATIO has also varied). In this example we could finally run three or more separate optimizations using the different CRATIO to confirm the observation above.

THE LARGE RISKS OF A SHORT MINE LIFE

In the past, a large mine development had plenty of time to make and fix mistakes. This could include over- or under-estimating the ore reserves, poorer than expected metallurgical recovery or mining difficulties, such as slope failures. The typical sort of unexpected issues that often turn up to convince us all that Murphy was an optimist.

If you rely heavily on the financial analysis, particularly on discounted cash flow analysis, and are using discount rates of 10%-15%, you will surely have selected a relatively short 4 or 5 year mine life. While this gives you the best return, you now have to be absolutely correct in your predictions over the whole mine life. If you are not, you really risk disaster. You may not have time to determine and correct a problem or oversight before the ore runs out. For example, it may take a year or so to really detect and quantify an over-estimation of the reserves. In the meantime, trying to survive with lower head grades, the production will probably be lifted and the mine life thus reduced. Finally, because there is less ore than expected anyway, the mine can very quickly run out of ore. Trying to fix the problem will take more time and expense. If additional drill definition is required, it will take time. With luck this will be finished before the ore actually runs out.

This “double-whammy” scenario is becoming all too common. It can be assessed as a risk by performing what I call “sensitivity to resource estimation”. For this exercise I will choose to reduce the recovered ore by 10% and at the same time dilute what is actually mined by 15%. Again this can be achieved in an FDAN analysis run, changing the mining recovery and dilution parameters. You are in trouble if your projected NPV drops 50% or more with this change.

These figures are not in fact the worst case scenario. They are the normal cases for projects started in Australia over the past decade. A true worst case may be 20% ore loss and 30% dilution. Under such conditions, the high risk project will fail to make a profit. You must now look very carefully at extra drilling or a small capital start-up and/or trial pit to give you confidence in the reserve estimates before committing to the full sized project.

The under-estimation of a resource may seem a safer alternative (ie just put conservative assumptions in everywhere). It is actually just as disastrous to the profitability of the project. To see this effect, we can do some further FDAN analyses. Firstly we must find the expected profit. Next, run the better recovery case and these are the reference cash flows. Next, repeat the project sizing analyses with the better reserves. When we find that the project is now undersized, we can compute

the cost of conservatism as the difference between the best we can achieve with the current project versus the better large sized project results.

This cost of conservatism is seldom quantified but is a real problem in many modern mining operations. Spending a little extra on drilling to better define a mineralized resource is easily justified when the cost of conservatism is high.

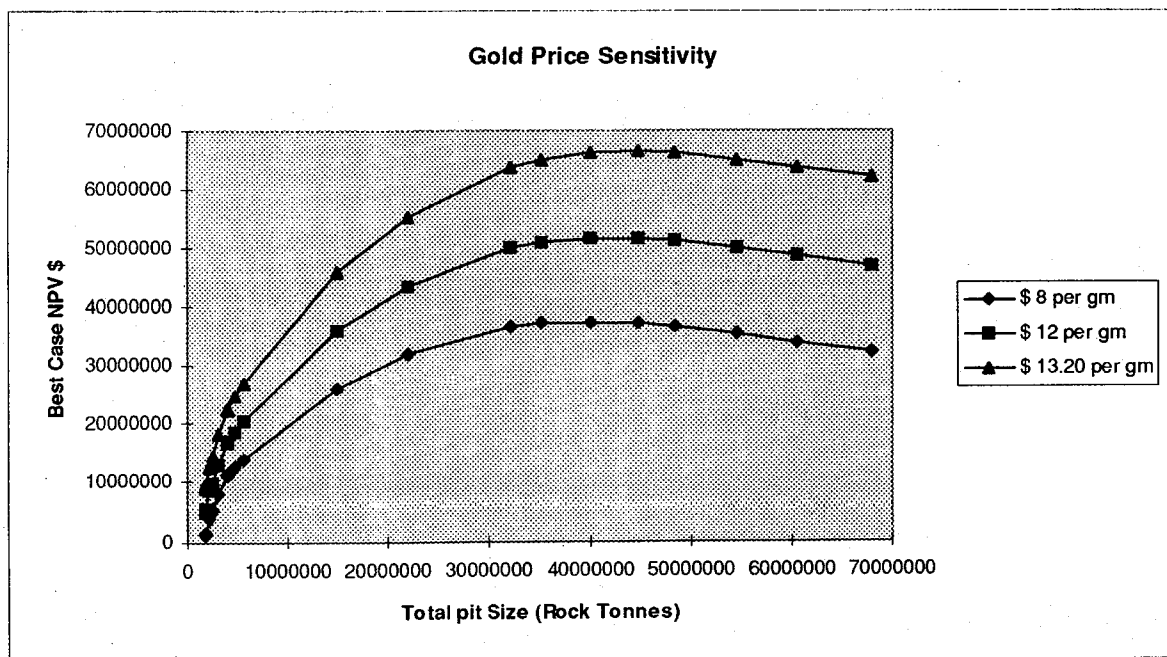
Many people assume that conservatism will be corrected by grade control and normal productions checks. What happens when everything turns out better than expected? Do people naturally expect a problem when things are going well? Are they likely to immediately tune up the project, increase production or are they more likely to rest on their laurels, knowing that the project is performing better than expected? Without wishing to sound too pessimistic, taking the conservative approach to stay safely under the best resource estimate and inflating costs just makes your project start too small and you are never likely to achieve full profit.

• PAY-BACK PERIOD

The pay back period, which is the time taken to get a full return on investment, is another sound way to assess the special risks in defining a project with a short mine life. Desirable mining investment should attempt to achieve payback within the first third of the project life. (This can be quantified as mine life divided by pay back period). If the payback period carries over to the last third of the mine life, after looking at the standard reserve sensitivity, then your project is in the high risk category. Specifically it now becomes essential that you have as much confidence as possible (ie all the drilling, trial mining and testing you can afford) in the material to be mined within the payback period.

• SENSITIVITY ANALYSIS

You may like to now look some sensitivity analysis. Firstly sensitivity to price, which can be shown nicely using the standard NPV/ Project Size style graph.



The profit is very sensitive to a $\pm 10\%$ change in gold price, but the pit size you choose is not! This makes choosing the ultimate pit a lot safer.

SENSITIVITY TO CHANGES IN PROCESSING COSTS

Pit Shell	Rock Tonnes	Mill Tonnes	Mill Grade	NPV Best Case	Milling Cost
30	44855522	6649146	3.05	56143607	\$9.45
30	44855522	5981192	3.29	47404834	\$11.55

SENSITIVITY TO CHANGES IN MINING COSTS

Pit Shell	Rock Tonnes	Mill Tonnes	Mill Grade	NPV Best Case	Mining Cost
31	46088428	6382865	3.16	54191877	\$0.90
29	41888712	6175604	3.17	49171221	\$1.10

SENSITIVITY TO CHANGES IN METAL RECOVERY

Pit Shell	Rock Tonnes	Mill Tonnes	Mill Grade	NPV Best Case	Metal Recovery
30	44855522	5928811	3.31	37108418	81%

The project is likely to be most sensitive to changes in recovery and this is just on the 25% change in NPV that identifies this as a risk. So it will be wise to spend a reasonable amount of time and money on metallurgical testing and analysis to ensure that the estimated recovery of metal is reliable during the feasibility study.

CONCLUSION

There is considerable merit in preparing a rough inferred resource block model and undertaking a series of Four-D Lerchs-Grossmann optimizations very early in a project's development. This can actually save money by improving the strategy for resource definition drilling and reduce the amount of drilling required. However, the greatest advantage comes from the rigorous overview it can give you of your project's economics and sensitivities. Specifically it can allow you to quantify the risk, in a way that unlocks the hyper-complex interaction of project valuables. "What if" questions can be fully evaluated in terms of cash flows in little longer time than it takes to do the traditional back-of-envelope numbers. Finally, bringing the big picture into focus early means that there is time to concentrate resources and expertise on those areas of high risk, and formulate strategies to keep away from potential problems. In other words, you will have time to polish those rough edges and make a project that succeeds elegantly and stays around to become a highly acclaimed masterpiece.

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