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Block cave optimisation — a value driven approach

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Abstract

Optimising the footprint, production rate and block height of a block caving operation is a trade-off between technical and value parameters. After the technical constraints have been quantified (e.g. fragmentation, drawbell spacing, minimum hydraulic radius and footprint span for cave initiation) the key parameters to be assessed are:

- *extraction level elevation (and ultimately, block height)*
- *cutoff and shut-off (footprint size and draw limits)*
- *cave initiation location*
- *production rate (and ultimately draw rate).*

Because the extraction level position, drawbell layout and cave footprint are set early in the planning process with little or no chance for subsequent change based on mining outcomes, hill-of-value (HOV) techniques provide a powerful tool for optimisation. Value, defined by the corporate goals, may be assessed against any combination of design options. Techniques to rapidly generate reserves for the different cutoff and extraction level combinations are employed. A range of production rates and cave initiation locations with appropriate capital and operating costs applied can be modelled.

An example of this technique is presented. An additional advantage of the technique is the ability to analyse and quantify the risks associated with the optimal cave chosen on a value basis. The method can also be modified to analyse panel caving or front caving. Sensitivity to external factors, such as metal prices and discount rates, can easily be quantified. A value driven approach allows revenue, costs and productivity to be assessed to produce optimised design criteria. This approach should be undertaken early in a project's life both to optimise the value of the resource and to highlight any bottlenecks or constraints to achieving the optimal result.

1 Introduction

The optimal position of the footprint of a block or panel cave is governed by many competing and conflicting parameters. This paper focuses on the strategic imperatives, recognising there are many tactical initiatives that can be undertaken during the life of the mine.

The opportunity to influence the project value commences at the initial scoping study stage and progressively reduces to zero when the mine gate is closed at the end of the mine life (Figure 1).

Previous mining studies on non-caving mines (Hall, 2003; Hall and Stewart, 2005) have identified production rate and cutoff as major drivers of the value decision.

As discussed by Ward (1981), the production rate should consider economics. Production rate decisions are usually based on overcoming the initial hurdle of payback of project funding and then a suitable return. Rules of thumb (e.g. Tatum, 2001; Taylor, 1986) developed for production rate are not applicable to the massive orebodies typically exploited by caving mines. As pointed out by McCarthy (2002), the empirical approach may not be optimal. McCarthy (2002) proposes a methodology which can be used to establish the economic optimum, based on the relationship between mining rate and head grade. This approach is also not applicable to caving mines, as the method assumes continual vertical and lateral advance rates.

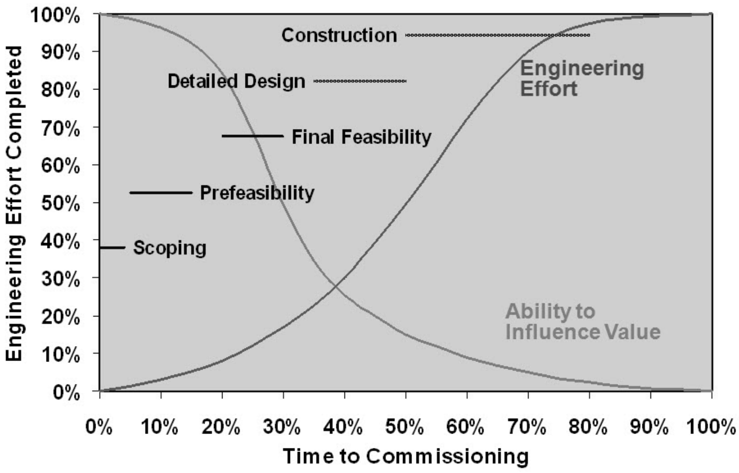

Figure 1 Ability to influence project value

As noted by Lane (1988) in determining optimum cutoff grades, *"... it is the economics of the mining process which determine the economic definition of ore"*. Cutoff can be a grade, an equivalent grade, cost or value. In this study, the Net profit per drawbell is used to define the cutoff. In block and panel cave mines, the cutoff decision defines the limit of the drawbell and drawpoint positions. Once selected, the footprint cutoff remains unchanged for that portion of the orebody. The selection of the shut-off, where draw from the drawpoint ceases, adds another dimension to the cutoff decision. In this study, cutoff equates to shut-off. Further analysis optimising the shut-off is beyond the scope of this paper.

In caving mines, where there is generally one extraction horizon, the selection of the elevation of this extraction horizon is also a major value driver.

2 Methodology

The proposed methodology outlined in this paper is a quantitative approach, incorporating the mining constraints typically found in caving mines. The process involves selecting the following:

- cutoffs (net profit per drawbell)
- production rates (likely sustainable rates versus capital trade-off)
- degree of mixing (geotechnically driven)
- extraction levels (geologically driven)
- extraction level layout parameters (geotechnically driven).

A set of nominal 'mining inventory' for each level/cutoff grade combination is then produced.

The value descriptor in this study is net profit value (NPV); however, other measures such as internal rate of return (IRR) or cash return on net assets (CRONA) can also be used, depending on corporate goals.

2.1 Reserves generation

Techniques to rapidly generate the mining inventory for the different cutoff and extraction level combinations are employed. AMC Consultants have developed the 'cave footprint finder' (CFF) to rapidly evaluate the deposit at different cutoff grades or values.

2.2 Cave footprint finder

CFF is a series of Datamine macros and Microsoft Excel™ spreadsheets which have the advantage of being transparent and easily auditable. The CFF takes into account rock mixing and can be used for block caves, front caves or panel caves. AMC applies a different process for sublevel caving.

Numerous parameters can be flexed to determine sensitivity. The important parameters include:

- the dilution entry point (range 0–100%), with the lower number generating more mixing, typically applied in the range 40–60%
- operating costs, linked to cutoff and shut-off values used
- establishment costs, covering the undercut and drawbell activities required to establish individual drawbells or drawpoint (Figure 2)
- height of interaction zone (HIZ), representing the shape of individual draw zones. The ellipsoid is used to represent the ore recovery within each 20 m vertical increment (Figure 3). The draw dimension can be varied to represent no interaction and possible piping or ore loss
- profit footprint, used to flag high grade zones (onion rings).

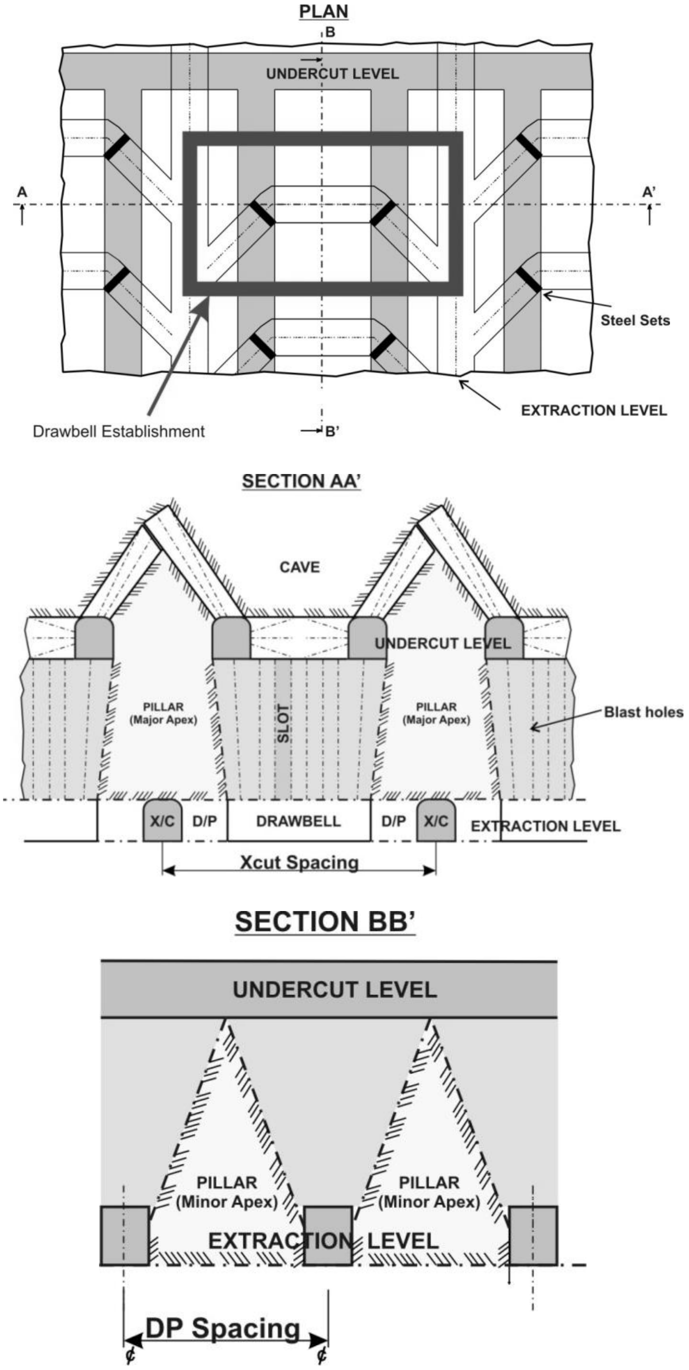

Figure 2 Drawbell establishment

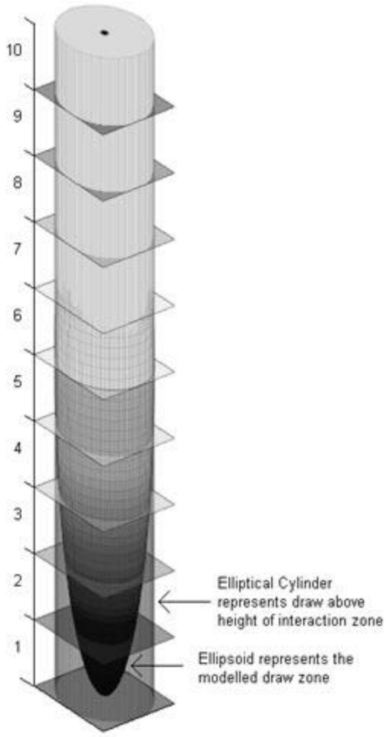

Figure 3 Example of cave draw ellipsoid

Initially, the resource block model is regularised to represent drawbell (DB) or drawpoint (DP) dimensions and equidimensional vertical slices. The rock mixing algorithm is then applied to the regularised block model. Data is then exported to an Excel spreadsheet where costs and draw zone factors are applied. Through careful selection of cutoffs, practical footprints are created with varying value (Figure 4).

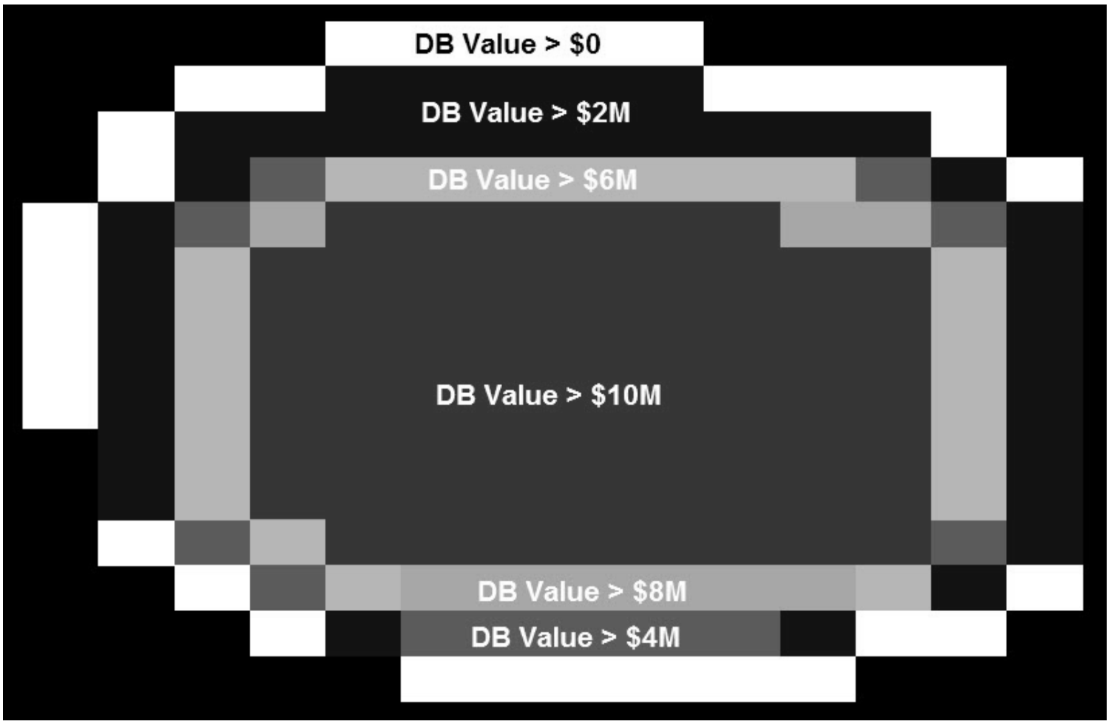

Figure 4 Example of cave footprint (in plan view) at different cutoff values

The capital and operating physicals for each footprint are determined and schedules created for each footprint at varying production rates. Finally, the results are exported ready to be used in the HOV modelling.

2.2.1 Hill of value

The evaluation model incorporates the following cost inputs:

- mining
- processing
- general and administration (G&A)
- project capital
- sustaining capital.

Realisation costs are considered in the calculation of net smelter return (NSR) which is the value to project calculated at the mine gate.

Capital and operating physicals for each footprint are then determined and schedules created for each footprint at varying production rates. The results are exported to the financial model to create HOV.

2.3 Strategy optimisation — HOV techniques

HOV strategy optimisation modelling makes use of an Excel model which has been constructed in such a way as to be capable of handling all the combinations of various ‘strategic decision’ variables that can be independently specified (Hall and Stewart, 2005). The HOV technique provides a clear picture of how a mine might change its strategy to optimise a particular goal parameter or the trade-offs between various goals.

3 Data

In the author’s experience, deposits with more complex geometries are not evaluated in a rigorous fashion, selected options are valued without recourse to a full suite of potential options. The data set for this study has been selected with this premise in mind.

A ‘porphyry copper/gold deposit’ resource block model was generated with the following properties (Figure 5):

- high grade core/low grade halo
- inverted teardrop geometry vertically – i.e. constricting with depth
- ratio of ~3:2 strike to width in plan with some additional asymmetry.

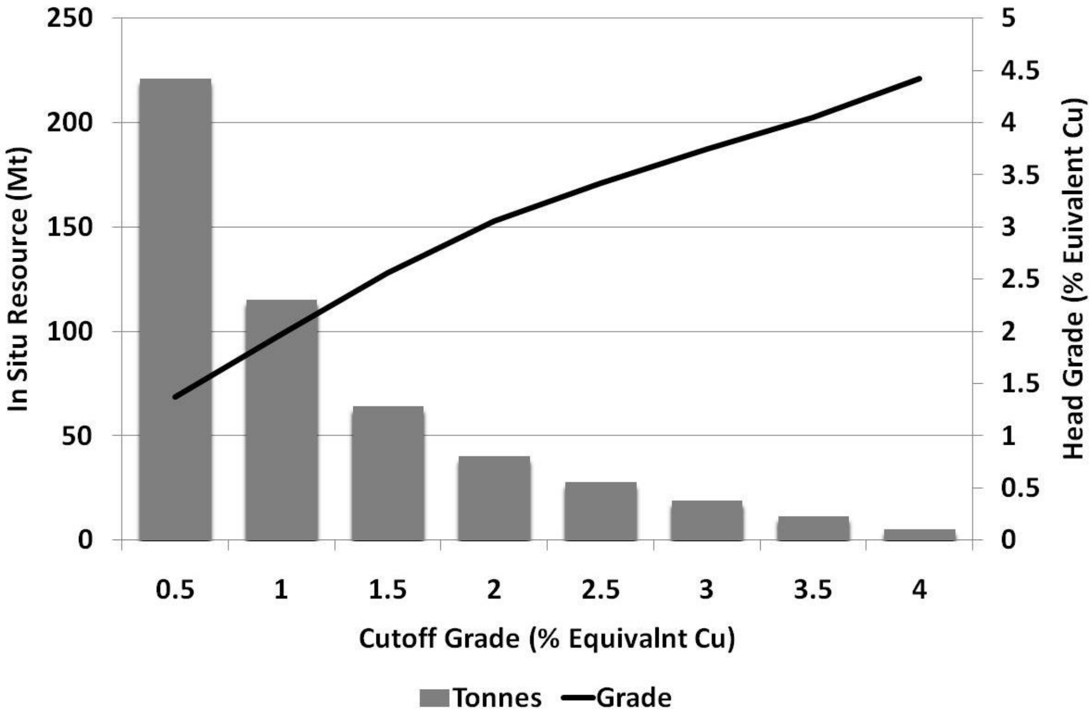

Figure 5 Grade tonnage curve of 'resource'

The granularity chosen was deliberately quite coarse, with elevations (RL) being evaluated at 40 m intervals, based on a cell spacing in the block model of 20 × 20 × 20 m. A plan, long-section and cross-section of the 'deposit' are presented in Figures 6–8. Cell colours are equivalent copper (ECU) grade where: ECU = Cu% + 0.8 x Au g/t. The example has a nominal 'resource' of 290 Mt at 0.74%Cu and 0.47 g/t Au (> 0.3%ECU).

Typical values include: Cu:Au ratio 1.7:1 (%:g/t), with maximum scheduled grades in the order of 0.8–1.4%Cu and 0.4–0.66 g/t Au, depending on the cutoff value chosen.

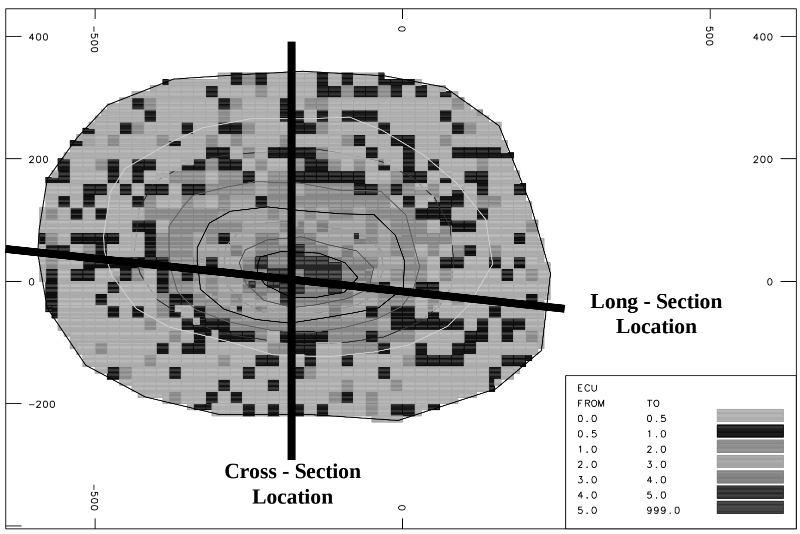

Figure 6 Plan view of deposit at 1,000 mRL

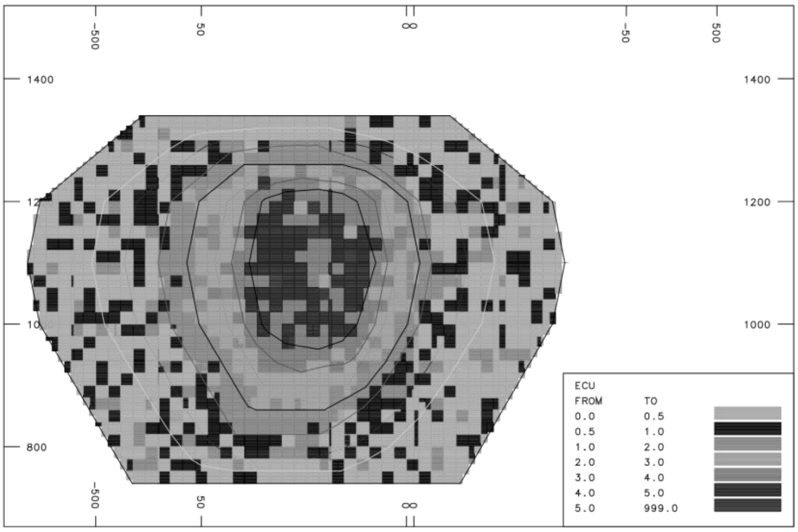

Figure 7 W-E long Section of deposit (refer to Figure 6 for location)

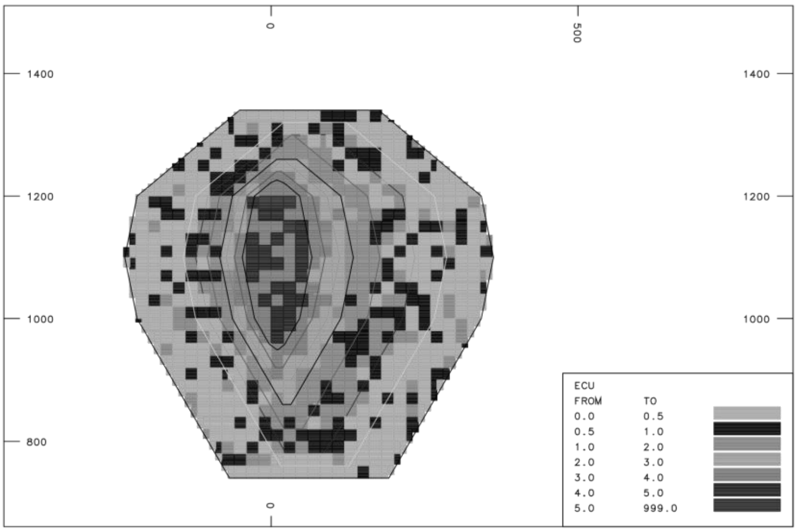

Figure 8 S-N cross-section of deposit (refer to Figure 6 for location)

In this study, six cutoffs were investigated based on net profit per DB (a breakeven \$0M and \$2–\$10M in \$2M intervals). Six production rates were investigated, 4–14 Mtpa in 2 Mtpa increments. The vertical position (extraction level) was evaluated over a 200 m vertical extent, with six levels at 40 m spacing investigated. Two hundred and sixteen options were investigated simultaneously (a total of 6 × 6 × 6 options).

The study mine has the following attributes:

- decline access from surface
- shaft haulage (and associated infrastructure, e.g. conveyors)
- primary ventilation shafts and fans
- pumping system
- crushing facility (one or two depending on target production)
- surface infrastructure
- general fixed plant.

Mobile equipment assumes load–haul–dump (LHD) extraction from DP, with secondary breaking rigs and integreated tool carriers (ITs) as support. Equipment numbers are derived from annual production quantities and assumed productivities. Timing assumes two years infrastructure development and three years cave ramp up to full production.

Lateral development incorporated into the analysis includes:

- undercut drives
- extraction level drives
- drawbells
- perimeter drives
- ventilation drives
- decline and stockpiles
- access drives
- miscellaneous.

Vertical development consists of a hoisting shaft and ventilation shaft/s, dependent on the target production rate.

A 30 × 18 m extraction layout has been selected for this study, with perimeter drives offset 40 m from the orebody.

3.1 Processing

Process recoveries can be generated for any metals under consideration, in this case, two metals (Cu, Au). This allows for varying recovery with changes in head grades as the cutoff varies. Capital and operating costs are then established for the target production rates. Fixed and variable operating costs are utilised, enabling flexibility where the target production is not met.

3.2 G&A

Operating costs have been established for the target production rates. Operating costs have been assumed to be 100% fixed for the purpose of this study.

All off-site costs associated with transport, handling and treatment and refining costs of the products are incorporated into the model with metal prices to provide the NSR.

3.3 Financial modelling

Financial calculations can be simply modelled (e.g. cash flow before tax), or can involve a full discounted cash flow (DCF) analysis leading to project net present value (NPV). In this study, consideration is given to royalties, inflation, depreciation and taxation.

4 Results

The mining inventory results for the six extraction levels and six cutoff values are tabulated in Table 1.

Table 1 Mining inventory at various extraction levels and cutoff values

Mining Inventory at Various Drawbell Cutoff Values													
		$0M		$2M		$4M		$6M		$8M		$10M	
Option	Extraction Level	Tonnes (Mt)	Grade (%Ecu)	Tonnes (Mt)	Grade (%Ecu)	Tonnes (Mt)	Grade (%Ecu)	Tonnes (Mt)	Grade (%Ecu)	Tonnes (Mt)	Grade (%Ecu)	Tonnes (Mt)	Grade (%Ecu)
1	800	119.9	0.81	102.2	0.87	84.0	0.94	75.1	0.98	63.8	1.03	57.6	1.06
2	840	109.9	0.86	96.2	0.92	78.9	0.99	69.8	1.04	58.5	1.10	52.3	1.13
3	880	102.5	0.89	87.5	0.97	71.7	1.05	63.0	1.10	54.5	1.15	46.2	1.21
4	920	91.0	0.94	78.3	1.01	63.1	1.10	56.4	1.15	47.5	1.21	39.1	1.27
5	960	84.2	0.96	71.7	1.04	57.2	1.14	50.3	1.19	41.9	1.26	32.0	1.34
6	1000	67.3	0.97	56.5	1.06	43.8	1.16	35.7	1.24	28.6	1.30	22.4	1.37

The mining inventory was scheduled at various production rates to feed into the financial model to further analysis. A typical schedule is shown in Table 2.

Table 2 Typical caving schedule

		tpa	10,000,000														
			500,000	2,500,000	5,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	3,936,741
		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
PROD_TONS																	
988,594				988,594													
2,680,306				1,177,875	1,502,431												
3,949,090					3,164,038	785,053											
4,794,946						4,794,946											
5,286,600						4,420,001	866,599										
5,286,600							5,286,600										
5,286,600							3,846,801	1,439,799									
5,286,600								5,286,600									
5,286,600								3,273,601	2,012,999								
5,286,600									5,286,600								
5,286,600									2,700,401	2,586,199							
5,286,600										5,286,600							
5,286,600										2,127,201	3,159,399						
5,286,600											5,286,600						
5,286,600											1,554,001	3,732,599					
5,286,600												5,286,600					
5,286,600												980,801	4,305,799				
5,286,600													5,286,600				
5,227,200													407,601	4,819,599			
5,138,100														5,138,100			
4,722,300														42,301	4,679,999		
4,336,200															4,336,200		
3,534,300															983,801	2,550,499	
3,059,100																3,059,100	
2,554,200																2,554,200	
1,930,500																1,836,201	94,299
1,425,600																	1,425,600
950,400																	950,400
504,900																	504,900
118,800																	118,800
875,853			291,951	291,951	291,951												
1,133,951		504,606	546,186	41,580	41,580												
121,936,741	Tonnes		**291,951**	**2,458,420**	**4,958,420**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**3,093,999**
	AU		0.40	0.11	0.12	0.17	0.24	0.31	0.36	0.41	0.42	0.41	0.36	0.30	0.25	0.20	0.16
	CU		0.80	0.16	0.20	0.29	0.43	0.59	0.71	0.80	0.84	0.81	0.69	0.57	0.46	0.38	0.30
	TOTAL	**504,606**	**838,137**	**2,500,000**	**5,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**10,000,000**	**3,093,999**
	INFRASTRUCTURE																
	LATERAL (m)	5,530	5,530														
	VERTICAL (m)	1,400	1,400														
	Infra (t)	504,606	504,606														
	WASTE DEV (m)		747	747	747												
	WASTE DEV (t)		41,580	41,580	41,580												
	ORE DEV (m)		5,243 m	5,243 m	5,243 m												
	ORE DEV (t)		291,951	291,951	291,951												
	DRILLING (m)		179,187	179,187	179,187												
	CHARGING (m)		148,927	148,927	148,927												
	DB SLOT (m)		831	831	831												
	STEEL SET		237	237	237												
	WEARMAT		119	119	119												
	drawrate (mm/day)			**22**	**48**	**104**	**104**	**104**	**104**	**104**	**104**	**104**	**104**	**104**	**104**	**104**	**31**

Results of the strategic optimisation are typically presented in three formats, HOV, contours-of-value (COV) and lines-of-value (LOV).

A HOV graph for the 960 mRL is presented in Figure 9. Targeted production rate and cutoff values are plotted on the x-y axes and NPV on the vertical z-axis. In this case, the peak of the hill coincides with an 8 Mtpa production rate and a cutoff value of between $4M and $6M.

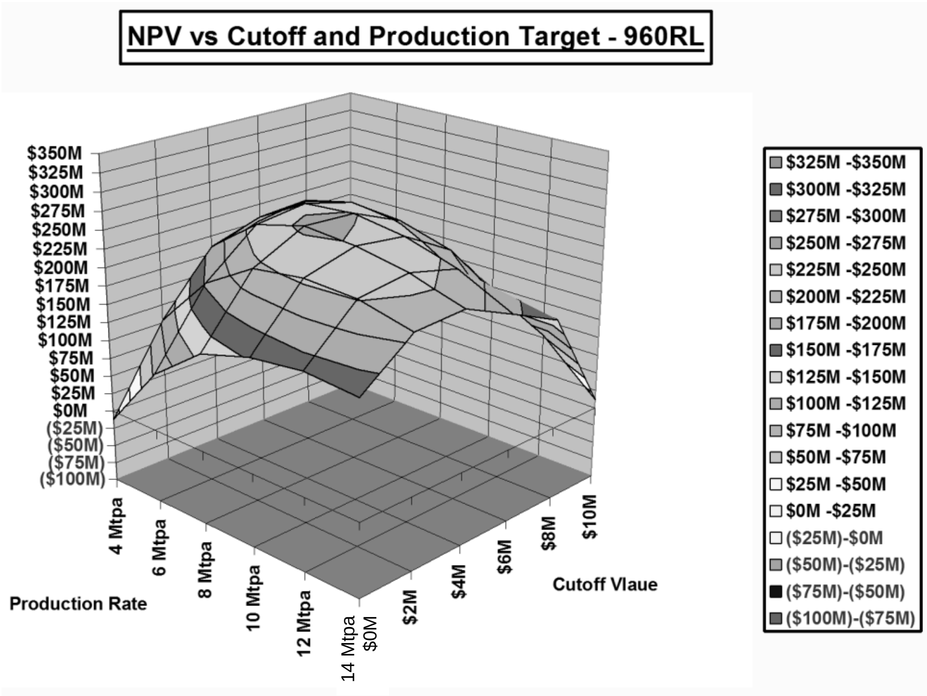

Figure 9 HOV – contours of NPV for the 960 mRL

A COV graph for the selected 8 Mtpa production rate is presented in Figure 10. Elevation is plotted on the y-axis and cutoff value plotted on the x-axis. The contours are NPV. The graph demonstrates a plateau between $4–$6M cutoff value and between 960 and 920 mRL.

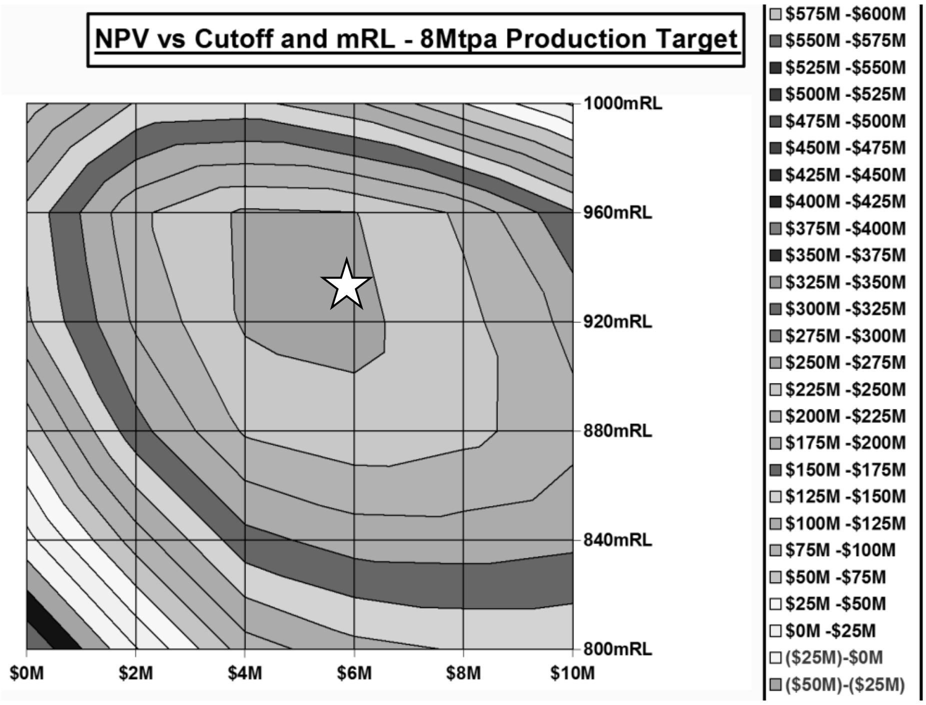

Figure 10 COV – NPV for 8 Mtpa

An LOV graph for the selected 8 Mtpa production rate is presented in Figure 11. Elevation is plotted on the x-axis, NPV on the y-axis and the lines represent cutoff value. This graph illustrates that there is effectively no value difference between $4 M and $6M cutoff, with the optimal elevation at 940 mRL, halfway between the two selected elevations.

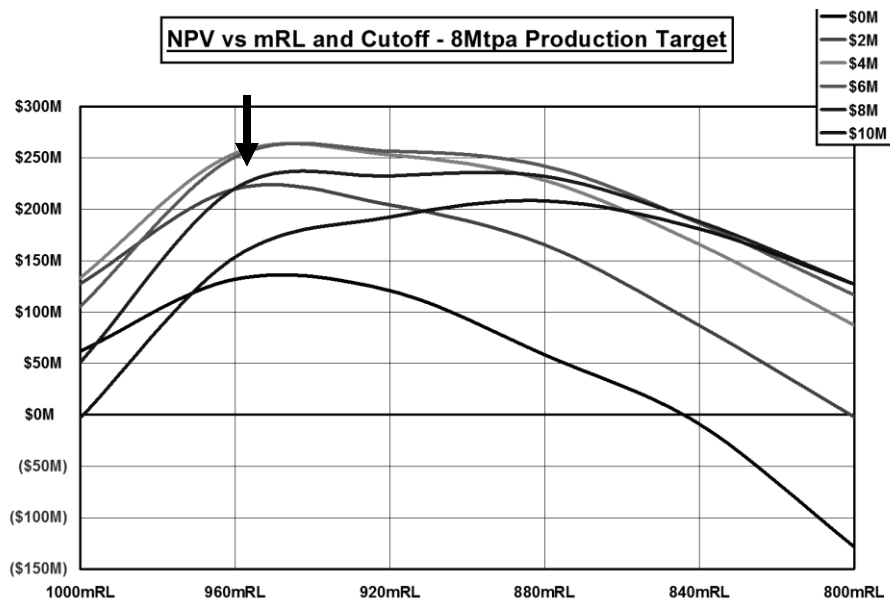

Figure 11 LOV – NPV for 8 Mtpa

Sensitivities to factors beyond the control of the project (e.g. metal prices, foreign exchange rate, realisation costs and discount rate) can be modelled. Figure 12 is an example whereby selecting the optimum result at the forecast metal and foreign exchange rates (i.e. $5M cutoff value, 940 mRL and 8 Mtpa); the sensitivity to copper price (+/-20%) and foreign exchange rate (+20%) reveals the robust nature of the selected parameters. Importantly, selection of lower than optimal cutoff values can lead to marginally profitable operations becoming unprofitable.

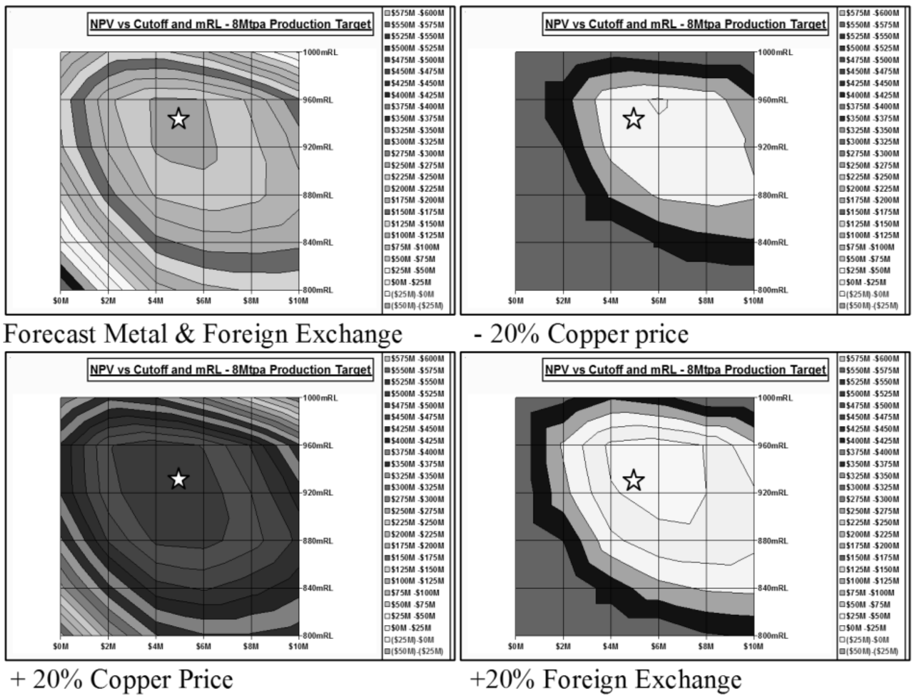

Figure 12 COV (NPV) versus cutoff (x-axis) and elevation (y-axis). The star represents the optimum case at forecast metal and foreign exchange rates

In this study, modelling of factors within the control of the project (e.g. costs – mining/milling/G&A – capital/operating) have also been undertaken, however, they do not exhibit the same degree of sensitivity as metal prices and foreign exchange rate factors mentioned above.

5 Conclusions

The processes outlined in this study provide a simple but powerful tool to quickly value the optimal block caving parameters:

- production rate
- cutoff
- extraction level position.

The optimised solution is typically the most robust based on the major inputs, demonstrated in other mining studies of this type (Hall and Stewart, 2005).

The results presented in this study simultaneously modify ('flex') three parameters only, however, many others could be flexed. Drawbell dimensions, price and cost projections allow evaluation of not only how strategies change as external parameters change, but also how far off optimum we would be if we set up for one scenario and another happens. The process allows investigation of the trade-off between upside reward and downside risk if forecasts are wrong, and allows selection of not just the strategy that maximises value for one set of circumstances, but also the range of strategies that minimise the downside if it is wrong.

An additional advantage of the technique is the ability to analyse and quantify the risks associated with the optimal cave chosen on a value basis. For example, the risk associated with a larger reserve and the attendant longer mine life.

A value driven approach allows revenue, costs and productivity to be assessed to produce optimised design criteria. This approach should be undertaken early in a project's life both to optimise the value of the resource and to highlight any bottlenecks or constraints to achieving the optimal result.

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