The Effect of Cut-off Grade and Mine Value Optimization on Mining Projects in South African Mines: A Mini-review

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***Abstract*—-** Mineral reserve is an economically minable part of measured or indicated resources and all have varying distributions in terms of grade. The focus of this review is to briefly cover information related to the positively skewed ore reserves which have a portion considered negative in value in contrast to the holistic viewpoint of the ore reserve. Since the negative portion of the ore reserve is small and mining companies are not considering it, there could be a hidden loss that becomes significant once the market trend is unfavorable and increasing costs. The determination of an adaptive cut-off grade will expose sections in the ore body which are negative in value and provides opportunity for optimization.

There is extensive research conducted in the aspects of cut-off grade and mine value optimization with researchers discovering a variety of problems which my research wants to address and investigate as far as mine value is concerned.

***Keywords*—** Cut-off grade, block model, negative value, optimization, positively skewed ore reserve, net present value.

I. Introduction

The investment necessary to start or buy an existing mine is on the order of tens to hundreds of millions of rands. For the investment to be profitable, the potential mineral in the ground must present adequate quantity, quality and value to justify a decision to invest. Mining and processing systems used to extract the products must then operate so as to produce revenue to offset the planned investment and provide an acceptable profit. Clearly, all technologic and financial decisions regarding planned production are built on an understanding of the mineral assets which are available. A small difference between planned (estimated) and realized production grade or a small change in metal price can have a large impact on mine profitability. In achieving this goal research conducted throughout history in cut-off grade and mine value optimization dates back to the early years of 1964 and 1997 where Ken Lane developed a theory on how to optimize net present value (NPV) in relation to cut-off grades. It has been in use by mining industry for 50 years (Lane, 1964; Lane, 1997) in the mining industry which remains conservative in the use of break-even cut-off grades for stating ore reserves.

Ken Lanes theory was fundamental as it paved a way for advanced algorithms to determine mine value optimization and cut-off grade, they include the Lerchs-Grossman algorithm implemented as the nested Lerchs-Grossman algorithm (Lerchs and Grossman, 1965; Whittle, 1988 & 1997; Whittle and Rozman, 1991). While there may be geophysical and technical considerations as far as value is concerned this review focuses mainly on economic aspects of the mine related to positively skewed ore reserve through an adapted cut-off grade.

Lane (1964,1988) made the crucial discovery that the cut-off grade is constrained by the capacity of the different interdependent elements of the mining operation, not just by the grade distribution. Each mine component has its own set of costs and capacities, as well as its own ideal cut-off grade. The outstanding cut-off grade for a given operation is one that integrates the mine, mill, and refinery capacities. The grade that maximizes the NPV of future cash flows is Lane's optimum economic cut-off grade. Each of these three factors has its own capacity restriction for handling ore or product, as well as its own set of costs. Furthermore, the entire operation has a set of fixed expenses that are not tied to any particular stage or amount of production. Lane's optimum cut-off grade policy establishes the optimal cut-off grade among the inadequate economic and balanced cut-off grades for maximizing a mining operation's net present value (NPV).

The mining limiting cut-off grade, concentrator limiting cut-off grade, and refinery limiting cut-off grade are the three limiting economic cut-off grades. Changes in economic and technical elements affect these limiting cut-off grades. They are dependent on the separate mining stages' capacity and associated costs at each phase, as well as the commodity's price. The mine and concentrator balancing cut-off grade, refinery and concentrator balancing cut-off grade, and mining and refinery balancing cut-off grade are the other three balancing cut-off grades. The grade distribution of the mined material and

Manuscript received September 12, 2021.

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capacity at each stage of production are used to determine the balancing cut-off grades as a means to optimize mine value.

II. THE CUT-OFF GRADE

Cut-off grade plays a significant part in a mine because it enables a mine to forecast the quantities and qualities of the material, that is ore and waste to be mined for profit or loss purposes. In the series of understanding cut-off grade, Brian Buss (2018) stated that there is no centralized approach to establishing cut-off grade and it depends on the discretion of competent person conducting the assessment of the deposit or operation to take into account the various technical and economic drivers, and business objectives of the organization at any point in time. While the average grade of ore is estimated, it can be stated that the competent person needs to consider all the costs associated with extracting the material for cut-off grade to be accurate.

III. BREAK-EVEN CUT-OFF GRADE

According to JM Rendu (2014) minimum or breakeven cut-off grades apply to situations in which only direct operating costs are considered. Capacity limits are not taken into account. There is no discounting of cash flows. Other financial and non-financial repercussions of changing the cut-off grade on mining and processing schedules and cash flows are not considered. Also, the model follows a stagnant process where it ignores the grade-tonnage distribution of the deposit. Bascetin & Nieto (2007) stated that the model assumes that every ton classified as ore pays for itself at the time it is treated, leaving it open to different interpretations as to what constitutes cost used in the calculation of the break-even cut-off grade. In this regard, the extraction according to this grade does not lead to value optimization of operation.

Minnitt (2004) also stated that when determining the optimum cut-off grade that maximizes the net present value, mining operations are affected by economic parameters such as metal prices, mining costs, processing, as well as mining operations, including mining capacity, the processing plant, as well as refining and distributing the ore deposit. The relationship between cut-off grade and NPV provides a means by which cut-off grades are optimized.

Given as:

$$x_c = \frac{(M_o + P_O + O_o) - (M_w + P_w + O_W)}{r * (V - R)} \quad (1)$$

Where:
X_c = Cut off grade

M_o = Mining cost per metric ton processed for ore

P_o = Processing cost per metric ton processed for ore

O_o = Overhead cost per metric ton processed for ore

M_w = Mining cost per metric ton processed for waste

P_w = Processing cost per metric ton processed for waste

O_w = Overhead cost per metric ton processed for waste

r = recovery of ore from mined tonnages

V = value of one unit of valuable product

R = transportation, refining, cost of sales and additional costs incurred per unit of valuable product.

Poniewierski (2016) discovered the problems connected with the adoption of break-even grades to state or reserves, which result in what the author refers to as "negatively geared ore reserves,". Negatively geared reserves can also be referred as positively skewed ore reserves represented by the relationship between net value per tonne and tonnage percentage.

Distribution of tonnage by value in an ore reserve for a real and typical

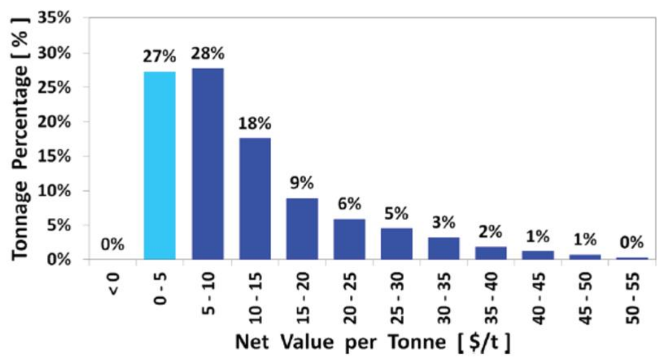

Fig 1. J Poniewierski (2016)

copper–gold open pit mine.

Errors associated with negatively geared ore reserves according to J Poniewierski (2016).

a) VALUE ERROR

The author determined that a 0.13 g/t miscalculation in cut-off grade computation will result in a $5/t variation in predicted revenue. Because of the costs incurred to achieve the estimated $5/t of revenue, the loss in profits associated with this loss in revenue will be more than $5/t. This indicates that errors can be made when the value of a mine is determined.

b) THE ERROR LEVERAGE EFFECT WITH A PRICE FALL

If the price of a commodity falls by $15/t, the value of the commodity drops by $15/t. It's worth noting that a starting value of $735 M on the negatively geared ore reserve can decline in value by $1500 M, which is 2.2 times the $674 M value drop of the +$5/t cut-off value ore reserve.

There were additional errors that were discovered by the author which he provided solutions except for the value leverage effect with price fall errors. This results in a problem where a conversion from ore resource into reserves may result in blocks that there are marginal in value which means there are blocks that are at the boundary of being moved from block containing valuable material to block that needs to be sent to the tailing dumps. These blocks values are marginal such that should there be a change in the market prices they will be classified as valueless blocks. In such a situation a mine is dealing with positively skewed reserves, which can render a project from valuable to valueless. In no time a project that is deemed feasible may find itself being put under care and maintenance or retrenchment options will be considered to reduce costs.

Birch (2016) conducted an investigation to determine what adjustment should be made to the cut-off grade to reduce the financial impact of dilution or lost ore in typical narrow, tabular Witwatersrand gold operations with the following three options:

- Raise the cut-off grade to reduce the dilution – ‘the old adage that a low-grade ton should never keep a high-grade ton out of the mill’ – (Minnitt, 2015)

- Keep cut-off grades the same considering that the type I and type II errors would balance each other if there is no bias. Birch (2016) (A type I error is where material is identified as ore and mined, but the actual value is below the cut-off grade and the material is therefore waste. Type II error is where material is estimated to be below the cut-off grade and is identified as waste, whereas the true grade is above the cut-off grade. This material is not mined, and the value is lost).

- Lower the cut-off grades to ensure all the value from the orebody is obtained (thus recovering a higher percentage of the lost ore).

According to (Tolmay, 2016; Minnitt, 2016; Ackerman, 2016) they viewed the options differently as they did not agree with each other. No clear indication of how much the cut-off grade should be adjusted to take into consideration the uncertainty of which the author tends to use to address the three options. The author discovered that there was no agreement and no clear indication as to how the cut-off grade should be adjusted considering this uncertainty. This proved the views of (Tolmay, 2016; Minnitt, 2016; Ackerman, 2016) to be correct. This problem must be further investigated by taking marginal blocks into consideration which in turn result in an accurate optimized value.

IV. VALUE OPTIMIZATION MODELS

Birch (2016) conducted a study in the same year to determine the effect of discount rates on cut-off grades for narrow tabular gold deposits like those found in the Witwatersrand Basin of South Africa. Simple break-even calculations to complex software packages that analyze a range of variables to maximize the cut-off grade are all accessible techniques for establishing the cut-off grade. A basic financial model that connects the ore flow, block registry, and cash flow was built in Microsoft Excel® for the study. It enabled the cut-off grade to be optimized considering the impact of the cost of capital and discount rate on cash flow.

The method that was used to optimize cut-off grade was to consider the cash flow, which includes the variable gold income tax, variable mineral resource royalty tax, as well as the discount rate. By comparing the resultant NPVs using discount rates of zero, 9%, and 12%, the effect of the discount rate on cut-off grades. The ore block listing, as well as the output for the grade-tonnage curve, should be the starting point of any cut-off grade determination as it determines the estimated tonnes to be extracted which contribute to mine value significantly.

The author’s result indicated that determining cut-off grades with a method that omits the cost of capital and discount rate into the calculation results in lower NPVs when a discount rate is later applied. Solely optimizing on NPV results in a restricted extraction of economic ore, consequently lowering mineral reserve value. This has a negative impact because investors are mostly interested in ore reserves for investment decisions and prospects.

TABLE I
IMPACT OF DISCOUNT RATES ON CUT-OFF GRADS FOR NARROW TABULAR GOLD DEPOSITS

Table III

Proven and Probable Reserves calculated using different methods

Description	Cut-off grade (g/t)	Tons milled (millions)	Life of reserve	AMG (g/t)	Rec. grade (g/t)	Rec. ounces (millions)	Profit 0% (millions)	NPV @ 9% (millions)	NPV @ 12% (millions)
Basic break-even	5.25	9.69	12	8.39	4.41	1.37	R2 034	R1 258	R1 098
Break-even, No royalty	6.17	7.26	9	9.26	4.80	1.12	R2 316	R1 564	R1 395
Break-even, 3% royalty	6.54	6.45	8	9.56	5.03	1.04	R2 386	R1 651	R1 482
Break-even, 5% royalty	6.63	6.45	8	9.63	4.94	1.03	R2 262	R1 598	R1 442
NPV-optimized, 0% discount	6.56	6.45	8	9.57	5.03	1.04	R2 394	R1 659	R1 489
NPV-optimized, 9% discount	7.04	5.50	7	9.95	5.37	0.95	-	R1 690	-
NPV optimized, 12% discount	7.57	4.84	6	10.38	5.45	0.85	-	-	R1 548
NPV -optimized, variable cut-off 9%	5.68-7.61	7.26	9	8.79-10.41	4.77	1.12	-	R1 557	-
NPV optimized, variable cut-off 12%	4.20-7.61	6.45	8	7.77- 10.41	4.58	0.95	-	-	R1 181

C. Birch (2016)

Cut-off grade and mine value fall under major optimization problems found in mining operations which covers the scope of my research. The advancement of technology, computational power and processing has given rise to mining models which have been proven as the next frontier that needs critical attention. Most of the models are based on existing mathematical equations which were previously utilized manually to determine mining parameters, a procedure that was difficult to obtain results, as the parameters are complex. They are recently used as algorithms on software packages which include Datamine, Miningmath, excel solver and Mathlab which reduce the time to obtain results with improved accuracy.

Githiria (2020) highlighted the latest developments of mathematical models in the mining industry and their application. The author discussed ways in which the mining industry can increase the application of these models to improve the output generated from the mining projects. The mathematical models designed to undertake block economic evaluation, cut-off grade optimization, pit design and production scheduling should take into account the uncertainty of the mining parameters to improve the output (NPV).

Given as:

$$Maximise\ NPV = \sum_{i=1}^{N} \frac{P_{wi}}{(1+d)^{i}} \qquad (2)$$

P_{wi} = *Net value = total cash flow of a project*

d = *Discount factor*

i = *period*

The author discovered that uncertainty in mining is generated from quantitative factors such as price fluctuations grade-tonnage distribution and variations of operational costs. Also, it can be noticed that the NPV produced from most of the developed mathematical models has improved the NPV by 25% on average. However, the increased NPV results in the short life of mine which can negatively affect the long terms sustainability and growth of sounding communities on a mining project.

TABLE II
Comparison of the mine life, cash flow and NPV from the cut-off grade models

	Deterministic cut-off grade approaches			Stochastic cut-off grade approaches	
	Break-even cut-off grade model	Heuristic cut-off grade model	Cut-off grade optimiser	Maptek evolution®	NPVMining
Mine life (years)	35	18	10	10	9.12
Cashflow (US$ million)	863	885.60	825.44	760.10	887.09
NPV (US$ million)	163.42	347.08	435.52	413.84	467.17

Githiria, J (2020)

V. Conclusion

This paper has reviewed various researches in the aspects of cut-off grade and mine value optimization. Throughout the review, it can be stated there are problems that were encountered by researchers which include the usage of break-even cut-off grade to state reserves because it limits important parameters i.e uncertainty and opportunity costs which can add value to a mining project. The type I and II, value and leverage effect errors contribute significantly to an inaccurate representation of optimal mine value. Considering the marginal blocks in an ore block and economic parameters may add value in a mining project as it will identify blocks that negatively affect the whole value in terms of ore reserves. The utilization of mathematical models in software packages such as Data mine, Mathlab and mining math can be used to address the problem.

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Mr OC Ramphore is born in South Africa in 1994/10/07. I attended both my primary and secondary school in Mohlakeng a township located in Johannesburg. I furthered my studies where completed the national diploma and B Tech in mineral surveying at the University of Johannesburg South Africa. I acquired experience during exposure period and practical training in the years 2013 and 2016 at Anglo Platinum mines.

The completion of the Btech studies in the University occurred in 2019. Ofentse Ramphore joined the University of South Africa (UNISA) in 2020 as a junior lecturer and is currently registered for a master’s degree at University of Johannesburg. Conducting a research project is to investigate an adaptive cut-off grade for value optimization of positively skewed ore reserves. I am currently working at the university of South Africa Florida campus as A JUNIOR LECTURER with one year experience. My major field of study are mine economics and surveying.

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https://doi.org/10.17758/IICBE3.C0322209

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He is the inventor for several patents.
He has published more than 200 papers.

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