WHITTLE AND THE MUPPETS

Martin Staples[1]

ABSTRACT

Many deposits can be described in terms of more than one commercially significant property, the commercial significance of these properties can be either positive or negative. In the case of a lead zinc deposit, or a porphyry copper deposit with associated gold and silver, the operation may produce multiple products each making a contribution to the project revenue. In other deposits there may be properties of the deposit that reduce the value, these could be elements attracting a penalty in a concentrate or consuming reagents in the treatment plant.

In order to evaluate these deposits it is necessary to generate an artificial grade that combines the values (positive or negative) of all the economically significant properties into one equivalent grade field reflecting the economic value of the material. This presentation will examine the development of these equivalent grades and the power this gives us to examine the project's sensitivity to many different factors as diverse as metal price and bond work index. That is we shall look at the uses of Whittle and the Multiple Property Pit Evaluation Techniques.

INTRODUCTION

The objective of any open pit optimization study is to examine the economics of the resource under varying cost, product price, product yield and slope configuration scenarios. The speed of modern computers and optimization software allows us to evaluate the economic impact of varying our initial optimization parameters, it may be that by steepening the wall slopes and allowing for the costs of wall reinforcing the pit economics and dimensions change dramatically. The effect of these changes are specific to each deposit and so it is important to determine the properties that control the economics of your deposit. Factors to consider include;

- Grades of any commercially significant components
- Penalty elements which may impact on concentrate values
- Mineralogical considerations which may impact on recovery
- Mineralogical considerations which may impact on treatment costs
- Rock hardness and its impact on crushing
- Slope design options
- Treatment options
- etc,etc

1. MARTIN STAPLES
Qualifications: BSc (Mining Engineering), University of Newcastle upon Tyne, UK.
Membership: AusIMM.
Experience: ZCCM, Zambia. Bougainville Copper Ltd, PNG. Canning Resources Pty Ltd, Australia.
Currently: Senior Mining Engineer, Australian Mining Consultants, Australia.

In this discussion consideration will be limited to the aspects of the project which impact on the value of block before the removal of waste mining costs.

The considerations that go into the determination of a blocks pre waste mining value for optimization are essentially the same as those used in the determination of a cut off grade. The main focus in considering the blocks value will be the determination of a single grade which encompasses all the properties impacting on a block's value. This **equivalent** grade can then be used for assigning values going into an optimization or for determining whether a block lies above or below a value determined cut off grade in a planning or operating context.

VALUE OF THE BLOCK

The pre waste mining value of the block going into the optimization is determined by the position of the block and the material which has been modelled into the block. The position of the block may influence it's differential ore mining costs, the properties of the material may influence it's mining cost, treatment costs and the revenue that it generates. It is important to remember that the estimation of value will be restricted by the detail that has been included at the resource modeling stage. If there is a possibility of a property being significant it should be considered until such time as the level of it's significance can be established.

The basic definition of the value of a block is;

$$\text{Value} = \text{Revenue} - \text{Costs}$$

in the simplest case the revenue can be defined as;

$$\text{Revenue} = \text{Grade} \times \text{Recovery} \times \text{Commodity Price}$$

There are however many deposits in which the revenue is generated from the sale of more than one product. In these cases it is useful for the purposes of setting values and cut off grades to reduce these grades to a single **equivalent grade.**

TWO PRODUCT CONCENTRATE

Consider the simple case of a two product deposit with a single process stream. This would be typically the case where a concentrate is being sold and credits given for the different components of that concentrate.

A fictious case where a copper cobalt concentrate is produced is considered below. Here in addition to different prices for the different metals there are different costs of marketing the metals and their metallurgical recoveries are different.

Example

Co price per tonne	$59,600	Cu price per tonne	$3,000
Co marketing cost per tonne	$2,401	Cu marketing cost per tonne	$188
Co recovery	20%	Cu recovery	85%

$$\text{Factor to convert Co to Cu equivalent} = \frac{(\text{Co price} - \text{Co market}) \times \text{Co recovery}}{(\text{Cu price} - \text{Cu market}) \times \text{Cu recovery}} = \mathbf{4.79}$$

In this example 1% cobalt insitu is equivalent to 4.79% of copper insitu. This is despite the factor that the ratio of their metal prices is 20:1, the lower recovery and higher marketing costs for cobalt greatly reduce the value of the cobalt in the ground.

In this case the only properties being considered are the different metal grades, recoveries and post concentrator costs, we have developed a factor which reduces the properties down to the properties associated with just one grade which we can call a copper equivalent grade.

POLYMETALLIC DEPOSITS

A more complex case would be a polymetallic deposit where the different products were treated through different treatment streams before reaching the customer.

In the copper/cobalt case discussed above the commodity price was effectively reduced by the marketing costs in order to derive a product price for the calculation of the grade equivalence factor. In the case of multiple process streams the treatment cost can be considered to be the costs of crushing, grinding and flotation (the processes which are common to all product streams), any costs which are incurred after these initial processes should be reduced form the net product value. This necessitates denominating these costs in units of the product rather than in terms of feed tonnages. This does not generally present a major problem as the initial processes usually deliver a float or concentrate within reasonably tight grade boundaries.

In this example the equivalence factors are set to calculate the recovered copper equivalent.

The market price for each commodity is established in appropriate units and the reduced by the direct treatment costs expressed in the same units. This produces a net commodity value, this value is then reduced to reflect the anticipated metallurgical recovery and hence a net recovered commodity price is calculated. This a net recovered commodity price is then divided by the net copper price to get the equivalence factor to go from the insitu grade to the recovered copper equivalent grade. In the case of the recovered copper equivalence factors for gold and silver they are multiplied by 100, to convert the g/t grades to percentages in keeping with the copper grade units.

In this case the multiple properties involved in the grades, recoveries and direct treatment costs of four separate products are reduced down to a single recovered grade property.

Multiproduct Equivalence Grade Calculation

Commodity	Market Price	Direct treatment costs	Net commodity value	Recovery	Net recovered commodity value	Equivalence Factor
Copper	1800 $/t	461.61 $/t	1338.39 $/t	76.6%	1025.20674 $/t	0.766000
Gold	13.3 $/g	9.883 $/g	3.417 $/g	47.0%	1.60599 $/g	0.119994
Silver	0.202 $/g	0.147 $/g	0.055 $/g	48.0%	0.0264 $/g	0.001973
Sulphur	155.13 $/t	60.34 $/t	94.79 $/t	82.0%	77.7278 $/t	0.058076

Recovered Copper Equivant Grade = (0.766000 * Cu%)+ (0.119994 * Aug/t)+ (0.001973 * Ag g/t)+ (0.058076 * Su%)

PENALTY PROPERTIES

In the cobalt/copper and the polymetallic case above we considered deposits where all the properties had a positive contribution to make to the block's value. This is not always true, we can also model properties which have an adverse affect on the value of a block. In this gold deposit example these include cyanide consuming copper minerals and material with a high work index.

These adverse affects all increase the treatment cost either by raising the rate of cyanide addition required or by increasing the crushing and grinding costs. The calculation of cut off grade and value in an optimization is difficult with a variable treatment cost.

One option is to group material and set its 'ore type' according to its cyanide consumption and work index. However in doing this there is a degree of smoothing and the number of ore types is limited, in a deposit with multiple variables occurring independently of each other a practical limit on ore types is soon reached.

A second option for optimization purposes is to use the processing cost adjustment factors. This however presents difficulties if there are ores of different type with different treatment costs within the same parent cell. In this case the processing cost adjustment factors are averaged with unpredictable results.

One solution to this is to extend the logic of reducing the commodity price by some component of the treatment cost. In this case we would reduce the applied treatment cost to a nominal amount (say $0.002) and reduce the grade to reflect the remainder of the calculated treatment cost. So the equivalent grade would be given by the expression;

$$\frac{((\text{grade} \times \text{price} \times \text{rec}) - \text{treat cost})) + 0.002}{(\text{price} \times \text{rec})}$$

As a proof of the equivalence of the newly calculated grade let us consider the following example;

Grade = 2.0g/t Au	Recovery = 93%
Gold Price = $17/g	Treatment Cost = $17.50/t

Calculated conventionally the revenue would be given by ;

$$\text{Grade} \times \text{Price} \times \text{Recovery}$$

$$\text{That is} \quad 2.0 \times 17 \times 0.93 = \$31.62/t$$

Less the treatment cost of $14.50/t the block has a value of

$$\$31.62 - \$17.50 = \mathbf{\$14.12/t}$$

If we calculate an equivalent grade for the same block using the proposed formula;

$$\frac{(2.0 \times 17 \times 0.93) - 17.5 + 0.002}{(17 \times 0.93)} = \mathbf{0.89323}$$

If we now apply the same price and recovery but a treatment cost of $0.002/t to the equivalent grade;

$$\begin{aligned} \text{Revenue} &= 0.89323 \times 17 \times 0.93 \\ &= \$14.122/t \quad \text{less treatment at } \$0.002/t = \mathbf{\$14.12/t} \end{aligned}$$

The value of the block is the same either through a direct calculation or by developing an equivalent grade that incorporates the treatment costs. We can therefore use the recovered and treated grade as a means of deriving an equivalent grade for materials where a number of properties have an impact of the treatment costs and therefore the value of the material.

EQUIVALENT GRADES IN 3D

As the value can be recalculated and a new economic file generated for each run of LG3D the adoption of equivalent grades presents no real problems and is not necessary. It does however simplify the comparison of blocks and the presentation and interpretation of results.

EQUIVALENT GRADES IN 4D

As the equivalent grade is calculated once under a base set of circumstances and evaluated under a range of different economic circumstances we need to understand the implications of varying the MCOSTM through a set of 4D nested pits.

In order to understand the implications we must first remind ourselves what the relevant values used in 4D are;

- **MCOSTM** - metal cost of mining
- **CRATIO** - ratio of processing cost to mining cost
- **ROCK** - the amount of rock in a parcel
- **METAL** - the amount of metal contained within that parcel.
- **RECOVERY** - metallurgical recovery of the product.

The MCOSTM must be expressed in terms of the metal that the equivalence is expressed in terms of.

CRATIO should reflect the processing costs after any adjustments which occurred in the calculation of the equivalent grade.

ROCK is independent of the grade, this is a straight tonnage of rock within the parcel.

METAL is the amount of equivalent metal calculated as the product of the equivalent grade and the tonnage of rock in the parcel.

RECOVERY is the metallurgical recovery of the equivalent metal after any adjustment for the way in which the equivalent grade is expressed.

If we consider the implications for 4D optimizations in the three examples of equivalent grade presented earlier.

- <u>COPPER/COBALT CASE</u>

In this case a set of recoveries and relative prices are used to convert the cobalt grade to a copper equivalent grade. Therefore we would set the MCOSTM in terms of the copper price less the direct marketing costs that have been attributed to copper. The process to the concentrate stage is the same for either copper or cobalt and so the CRATIO is the ratio of the cost of processing to that stage relative to the mining cost. The RECOVERY would be set to the copper recovery as the equivalent grade relates to insitu copper.

The effect of varying the MCOSTM can be viewed as either increasing the mining and treatment costs or of reducing the metal prices. In the case of increasing the costs, as the treatment costs are expressed as the mining costs multiplied by a factor the two sets of costs rise and fall by the same proportion. In deriving the equivalent grade we have assumed a ratio of copper and cobalt prices with a small adjustment for smelting and marketing, a falling MCOSTM can be viewed as rising metal prices and the effect would be for the copper and cobalt prices (reduced by the marketing costs) to rise together maintaining the ratio used to establish the equivalent grade.

• POLYMETALLIC CASE

In this case the equivalent grade is denoted in terms of a recovered copper equivalent grade. The MCOSTM would therefore again be denominated in terms of copper metal. In this case the majority of the treatment costs were product specific and so the CRATIO will be small representing the ratio between the common treatment costs and the mining cost. The RECOVERY would be set to 100% as the grade is denominated in terms of recovered copper and so recovery has been taken into account in calculating the equivalent grade.

As the MCOSTM is increased the mining costs will increase but only a small proportion of the treatment costs are common are reflected in the CRATIO and so only that proportion will increase. The equivalence was established on the basis of the ratio between the metal prices less the direct costs attributed to the winning of that metal, therefore as the MCOSTM falls the metal prices less their direct costs can be viewed as increasing whilst maintaining the ratio used to establish the equivalence.

• PENALTY PROPERTIES

In this case the equivalent grade was expressed in terms of insitu gold and so the MCOSTM should be expressed in terms of grammes of gold. In this case in determining the equivalence we reduced the grade to reflect treatment cost and adopted a nominal treatment cost of $0.002, the CRATIO would therefore be very small being the ratio of $0.002 to the mining cost. The RECOVERY would be set to the gold recovery.

As the MCOSTM rises the mining costs can be viewed as rising but as the CRATIO is very small the treatment costs are negligible. The equivalent grade was set by assuming a relationship between gold price and the treatment cost and so as the MCOSTM falls both the gold price and the treatment cost can be seen as rising maintaining their relationships. However it must be remembered that in setting the equivalent grade any material where the revenue and treatment cost were equal would have a grade of zero, therefore cases where the MCOSTM is lower than the base circumstances are potentially misleading.

CONCLUSION

In determining a grade for cut off or optimization purposes it is often useful to combine many properties into one equivalent grade. However as the equivalence is calculated for a given set of cost, metal price and recovery relationships, should we wish to vary circumstances we must carefully consider the implications of what we do.

In forming an understanding of a deposit where many properties are of economic significance the reduction to a single equivalent grade is an invaluable step in understanding the deposits dynamics.

This page is intentionally blank