Determination of optimum cutoff grades of multiple metal deposits by using the Golden Section search method

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Synopsis

In recent years several mine researchers have studied the optimization of cutoff grade with the purpose of maximizing Net Present Value (NPV). The best and most popular one is the Lane algorithm. Based upon the Lane algorithm it is possible to calculate the optimum cutoff grade for mine, mill, and refinery capacities for single metal deposits with variable grades. The Lane algorithm cannot be used in multiple metal deposits. The reason is that, while in single metal deposits six points are possible candidates for the optimum cutoff grade, in multiple metal deposits an infinite number points are possible candidates for the optimum cutoff grades and objective function evaluation of these infinite points is impossible. In this study the Golden Section search method was used to calculate optimum cutoff grades of multiple metal deposits for the same conditions as Lane assumed in single metal deposits. Based on this method, grade-tonnage distribution uncertainty space of problem is guessed. In the next step, by selecting test points in uncertainty space and evaluating the objective function at these points, a part of uncertainty space will be eliminated. The procedure is then repeated until the uncertainty space has been sufficiently reduced to ensure that the optimum cutoff grades have been located to the required accuracy.

Key words: Optimum cutoff grades, Optimization, Net Present Value (NPV), Golden Section search method

Introduction

In open pit mines, cutoff grade is used to discriminate ore from waste. It is one of the most crucial decisions that must be faced by mine engineers. If the mineral grade is equal to or above cutoff grade, the material is classified as ore and if the grade of mineral is less than the cutoff grade, the material is classified as waste. Depending upon the mining method, waste is either left *in situ* or sent to the waste dumps, whereas ore is sent to the treatment plant for further processing and eventual sale (Taylor 1985).

There are many theories for the determination of cutoff grades. But most of the research that has been done in the last three decades shows that determination of cutoff grades with the objective of maximizing net present value (NPV) is the most acceptable method. Maximizating NPV helps to reduce the risk of financial failure. Maximization of NPV also means that the capital invested is being used most efficiently. In addition, cash taken today is more certain than cash promised next year.

The basic algorithm to determine the cutoff grades which maximize the NPV of an operation subject to mining, milling, and refining capacities was proposed by Lane (Lane 1964; 1988). His theory takes into account the costs and capacities associated with these stages. Mine capacity is the maximum rate of mining the deposit, mill capacity is the maximum rate of processing ore, and refinery capacity is the maximum rate of production of final product. The determination of cutoff grade is based on the fact that either one of those stages will alone limit the total capacity of operation or a pair of stages may limit the entire operation. The theory also takes into account the grade distribution of the deposit and the opportunity cost (time costs) of mining low grade ore while high grade ore is still available in the deposit. The optimum cutoff grades theory introduced by Lane determines the cutoff grades year by year. This procedure depends upon the graphical approach for the determination of optimum cutoff grades. However, if only one of the capacities is limited, then analytical determination is also possible.

Deposits containing more than one metal are usually dealt with by converting all metals to their equivalent in terms of one basic metal, and aggregating several values (Liimatainen 1998; Zhang 1998). For example, lead and zinc often occur together. Assuming zinc to have twice the value of lead, the lead content can be divided by two and added to the zinc content in order to obtain total zinc content. Then any analysis can be conducted exactly as if mineralization consists of a single metal.

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The equivalent grades method has some flaws, but if minerals have fairly stable values, this procedure is valid and simplifies the problem. If one of the metals is subject to market limitation, this technique becomes invalid, because, the production in excess of the contracts for that metal cannot be sold and therefore ore cannot be valued on the basis of contract price. Therefore, it is the influence of capacities in both plant and market which invalidate the combined value criterion (Lane 1988). This method also has operational and economical flaws (Barid and Satchwell 2001).

Other methods for discrimination of ore/waste in multiple metal deposits are: Critical level method, Net Smelter Revenue (NSR) method, Single grade cutoff approach, Dollar value cutoff approach (Annels 1991;Barid and Satchwell 2001). None of these methods is an optimized technique, because the distribution of grade of mined material, mining operation capacity constraints, and the effect of time on money value are not considered. These methods usually lead to sub-optimal exploitation of the resource. In reality, there are potentially operational, economic and *logic serious* issues in the application of these methods. Therefore determination of optimum cutoff grades of multiple metal cutoff grade decision —making is formidable. In this paper, selecting cutoff grades with the purpose of maximizing NPV subject to the constraints of mining, concentrating, and refining capacities of two metals will be discussed.

Objective function

For an operating mine, there are typically three stages of production: (i) the mining stage, where units of various grade are extracted up to some capacity, (ii) the treatment stage, where ore is milled and concentrated, again up to some capacity constraint, and (iii) the refining stage, where the concentrate is smelted and/or refined to a final product which is shipped and sold. The latest stage is also subject to capacity constraints. For simplicity, assume a two metal deposit. In this deposit, ore is sent to a concentrator and the concentrator will produce two concentrates. Each concentrate for smelting and finally refining is sent to a refinery plant. Each stage has its own associated costs and a limiting capacity. The operation as a whole will incur continuing fixed costs. (See Figure 1).

By considering costs and revenues in this operation, the profit is determined by using following equation:

$$P = (s_1 - r_1)Q_{r1} + (s_2 - r_2)Q_{r2} - mQ_m - cQ_c - fT \quad [1]$$

Where m: mining cost ($/tonne of material mined), c: concentrating cost ($/tonne of material concentrated), r_1: refinery cost ($/unit of product 1), r_2: refinery cost ($/unit of product 2), f: fixed cost, s_1: selling price ($/unit of product 1), s_2: selling price ($/unit of product 2), T: the length of the production period being considered, Q_m: quantity of material to be mined, Q_c: quantity of ore sent to the concentrator, Q_{r1}: the amount of product 1 actually produced over this production period, Q_{r2}: the amount of product 2 actually produced over this production period.

If d is discount rate, the difference v between the present values of the remaining reserves at times t=0 and t=T is (Hustrulid and Kuchta 1995):

$$v = P - VdT \quad [2]$$

Where V is the present values at time t =0. Substituting Equation [1] into Equation [2] yields:

$$v = (s_1 - r_1)Q_{r1} + (s_2 - r_2)Q_{r2} - mQ_m - cQ_c - (f + Vd)T \quad [3]$$

The quantities refined Q_{r1} and Q_{r2} are related to that sent by the mine for concentration Q_c by:

$$Q_{r1} = \bar{g}_1 y_1 Q_c \quad [4]$$

$$Q_{r2} = \bar{g}_2 y_2 Q_c \quad [5]$$

Where: $\bar{g}_1$ is the average grade of metal 1 sent for concentration and $\bar{g}_2$ is the average grade of metal 2 sent for concentration.

Substituting Equations [4] and [5] into Equation [3] yields:

$$= \left[(s_1 - r_1)\bar{g}_1 y_1 + (s_2 - r_2)\bar{g}_2 y_2 - c\right] \\ Q_c = m\, Q_m - (f + Vd)T \quad [6]$$

One would now like to schedule the mining in such a way that the decline in remaining present value takes place as rapidly as possible. This is because later profits get discounted more than those captured earlier. In examining Equation [6], this means that v should be maximized.

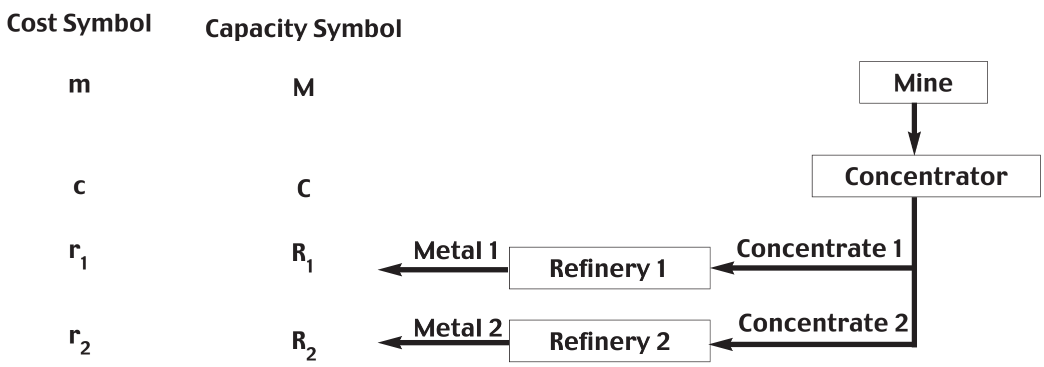

Figure 1—The flowchart of the mining operation in a two metal deposit

Equation [6] is the fundamental formula and all the cutoff grade optimum can be developed from it. The time taken T is related to the constraint capacity. Four cases arise depending upon which of the four capacities are actually limiting factors.

If the mining rate is the limiting factor then the time T is given by:

$$T = \frac{Q_m}{M} \qquad [7]$$

If the concentrator rate is the limiting factor then the time T is controlled by the concentrator:

$$T = \frac{Q_c}{C} \qquad [8]$$

If the refinery output of metal 1 is the limiting factor then the time T is controlled by the refinery of metal 1:

$$T = \frac{Q_{r1}}{R_1} = \frac{\bar{g}_1 y_1 Q_c}{R_1} \qquad [9]$$

If the refinery output of metal 2 is the limiting factor then the time T is controlled by the refinery of metal 2:

$$T = \frac{Q_{r2}}{R2} = \frac{\bar{g}_2 y_2 Q_c}{R_2} \qquad [10]$$

Substituting Equations [7], [8], [9] and [10] into Equation [6] yields:

$$v_m = \left[(s_1 - r_1)\,\bar{g}_1\,y_1 + (s_2 - r_2)\bar{g}_2\,y_2 - c\right] Q_c - \left[m + \frac{f + Vd}{M}\right] Qm \qquad [11]$$

$$v_c = \left[(s_1 - r_1)\,\bar{g}_1\,y_1 + (s_2 - r_2)\,\bar{g}_2\,y_2 - \left(c + \frac{f + Vd}{C}\right)\right] Q_c - mQ_m \qquad [12]$$

$$v_{r1} = \left[\left(s_1 - r_1 - \frac{f + Vd}{R_1}\right)\bar{g}_1\,y_1 + (s_2 - r_2)\,\bar{g}_2\,y_2 - c\right] Q_c - m\,Q_m \qquad [13]$$

$$v_{r2} = \left[(s_1 - r_1)\,\bar{g}_1\,y_1 + \left(s_2 - r_2 - \frac{f + Vd}{R_2}\right)\bar{g}_2\,y_2 - c\right] Q_c - m\,Q_m \qquad [14]$$

Now, for any pair of cutoff grades, it is possible to calculate the corresponding V_m, V_c, V_{r1}, and V_{r2}. The controlling capacity is always the one corresponding to the least of these four equations. Therefore:

$$\max v_e = \max\left[\min\left(v_m, v_c, v_{r1}, v_{r2}\right)\right] \qquad [15]$$

In Equations [11] to [14], V is an unknown value because it depends upon the cutoff grades. Since the unknown V appears in these Equations an iterative process must be used. Equations [11] to [14] are known two dimensional and instead of a curve in one metal deposit , V_m, V_c, V_{r1}, V_{r2} and V_e are surface and may be represented in a series of contours . Figure 2 shows V_e for a two metal deposit.

If only one capacity is dominant, the limiting economic maximization may be accomplished analytically. To find the grades which maximize the NPV under different constraints, one first takes the derivative of Equations [11] to [14] with respect to g_1 and g_2. In the next step, setting derivatives of Equations [11] to [14] equal zero. It will obtain four line equations; the general form of these lines is:

$$\frac{g_1}{p} + \frac{g_2}{q} = 1 \qquad [16]$$

Where the p and q values of Equation [16] for different case are given in Table I. Equation [16] is useful when a single

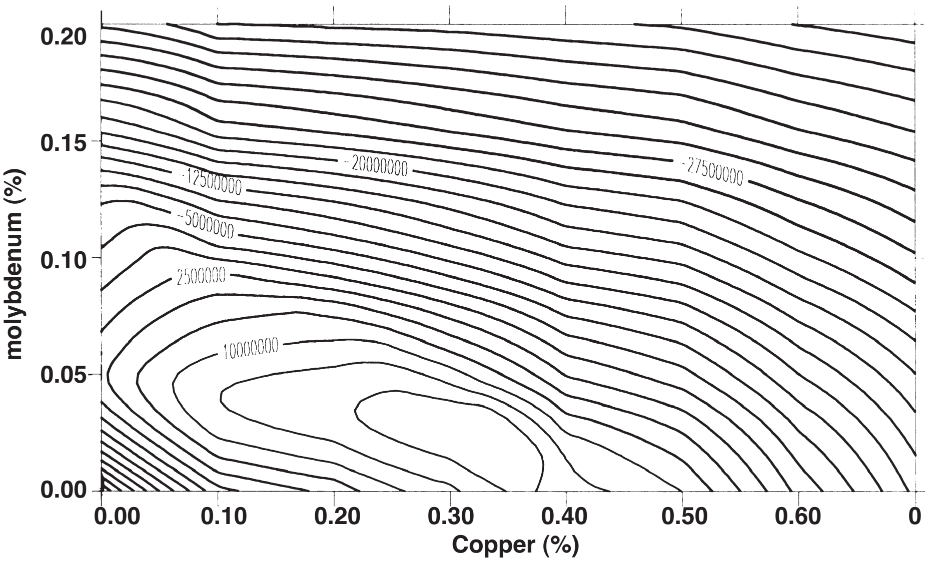

Figure 2—V_e for a two metal deposit

Table I

p and q values of Equation [16] for different cases

Limiting capacity	p	q
Mine	$\frac{c}{(s_1-r_1)\,y_1}$	$\frac{c}{(s_2-r_2)\,y_2}$
Concentrator	$\frac{c+\frac{f+Vd}{C}}{(s_1-r_1)\,y_1}$	$\frac{c+\frac{f+Vd}{C}}{(s_2-r_2)\,y_2}$
Refinery 1	$\frac{c}{(s_1-r_1-\frac{f+Vd}{R_1})\,y_1}$	$\frac{c}{(s_2-r_2)\,y_2}$
Refinery 2	$\frac{c}{(s_1-r_1)\,y_1}$	$\frac{c}{(s_2-r_2-\frac{f+Vd}{R_2})\,y_2}$

process is limiting; however, when the maximum occurs at a balancing point, where more than one capacity restricts throughput, no satisfactory analytical technique has been developed. The problem geometrically is one of four intersecting surfaces forming hills. The peaks are comparatively easy to locate but the ridges and valleys where they intersect are more difficult (Lane 1988). Infinite points are possible candidates for the optimum cutoff grades. For this reason, the maximum is best located by a search process. The Golden Section search technique to calculate the optimum cutoff grades of multiple metal deposits has been found quite effective.

Calculation of optimum cutoff grades

One of the fastest methods to calculate the optimum point of unimodal functions is the elimination method. In the first step of this method the uncertainty space of the problem is guessed. In the next step, by selecting test points in the uncertainty space and evaluating and comparing the objective function at these test points, a part of the uncertainty space will be eliminated. This reducing procedure is repeated until the uncertainty interval in each direction is less than a small specified positive value ε, where ε is the desirable accuracy for determining optimum cutoff grades (Rardin 1998).

The ratio of the remaining length, after the elimination process, to the initial length in each dimension is called the reduction ratio. The dichotomous search method, the Fibonacci search method, and the Golden Section search method are examples of elimination methods. Among these methods, the reduction ratio of the Golden Section search method is optimum and equals 0.618 (this number is called the golden number). In this method, the ratio of eliminated length to initial length will be equal to 0.382. In addition, using the Golden Section rule means that every stage of the uncertainty range reduction (except the first one), the objective function need only be evaluated at one new point (Chong and Zak 1996; Rao 1996; Bazarra, Hanif and Shetty 1993).

Figure 3 shows the Golden Section search method for a one dimensional function. In the first step, assume (L, U) to be the initial interval of uncertainty and note that the initial interval includes the optimum point. Then select two test points, g_1 and g_2 (Figure 3.a). The locations of these points are:

$$g_1 = L + (U - L) \times 0.382 \quad [17]$$

$$g_2 = L + (U - L) \times 0.618 \quad [18]$$

In the next step, the objective function will be evaluated in the g_1 and g_2 points. Depending on the objective function value of these points, the length of the new interval of uncertainty is successively reduced in each iteration

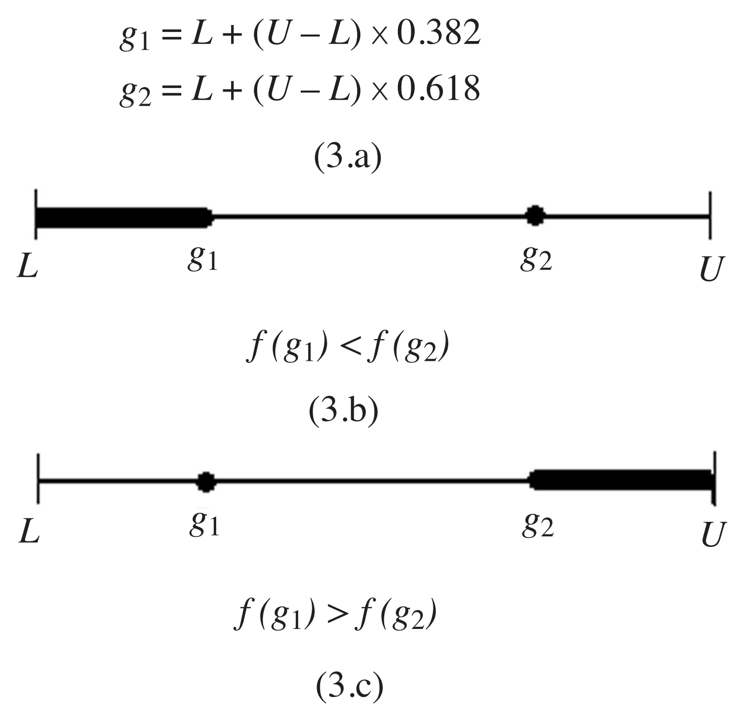

Figure 3—Golden Section search method for one dimensional function

(Figures 3.b and 3.c). The process is then repeated by placing a new observation. Repeating this in the new range will find the optimum point with desirable accuracy.

This procedure can be extended for multivariable problems. Applying the Golden Section search method for unimodal two-dimensional functions, in the first step the initial interval of uncertainty for each variable must be determined. Assume (L_1, U_1) to be the initial interval of uncertainty of variable 1 and (L_2, U_2) to be the initial interval of uncertainty of variable 2. Then select four test points (A, B, C, D) in the uncertainty space (Figure 4).

The locations of these points are:

$$a_1 = L_1 + (U_1 - L_1) \times 0.382 \quad [19]$$

$$a_2 = L_1 + (U_1 - L_1) \times 0.618 \quad [20]$$

$$b_1 = L_2 + (U_2 - L_2) \times 0.382 \quad [21]$$

$$b_2 = L_2 + (U_2 - L_2) \times 0.618 \quad [22]$$

In the next step, calculate the amount of the objective function for each four test points. By comparing the objective function values of these points, the optimum point in this iteration and a new space of uncertainty is determined:

- If point A is optimum then $U_1 = a_2$ and $U_2 = b_2$ and a part of the uncertainty space is eliminated. The remaining space is shown in Figure 5.a.
- If point B is optimum then $L_1 = a_1$ and $U_2 = b_2$ and a part of the uncertainty space is eliminated. The remaining space is shown in Figure 5.b.
- If point C is optimum then $U_1 = a_2$ and $L_2 = b_1$ and a part of the uncertainty space is eliminated. The remaining space is shown in Figure 5.c.
- If point D is optimum then $L_1 = a_1$ and $L_2 = b_1$ and a part of the uncertainty space is eliminated. The remaining space is shown in Figure 5.d.

In the remaining space for finding the optimum point, only one test point is left. In the next step, three new test points must be selected. This operation is repeated until the optimum point is found with desirable accuracy (Kim 1997).

Example

Consider a hypothetical condition that a final pit limit has been superimposed on a mineral inventory. The pit outline contains 15 million tonnes of material. The grade–tonnage distribution and average grade of ore for each metal are shown in Tables II, III and IV. The associated costs, prices, capacities, quantities and recoveries are demonstrated in Table V.

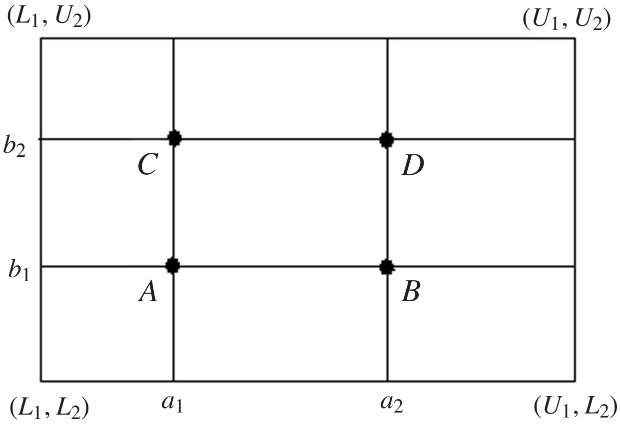

Figure 4—Golden Section search method for one-dimensional function

Table II

Grade-tonnage distribution of copper and molybdenum

Copper (%)	Molybdenum (%)				
	0–0.05	0.05–0.1	0.1–0.15	0.15–0.2	>0.2
0–0.1	1400000	900000	285000	315000	510000
0.1–0.2	400000	300000	250000	135000	60000
0.2–0.3	800000	530000	300000	210000	30000
0.3–0.4	1500000	570000	375000	135000	60000
0.4–0.5	410000	255000	75000	60000	60000
0.5–0.6	510000	300000	210000	105000	110000
0.6–0.7	375000	270000	210000	90000	90000
> 0.7	645000	690000	570000	500000	400000

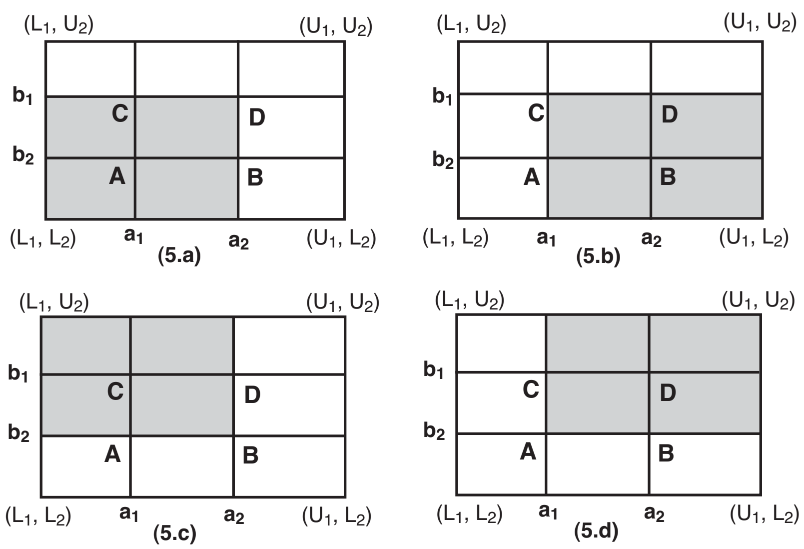

Figure 5—Elimination of a part of the uncertainty space by the Golden Section search method

Table III

Average grade of copper for different copper and molybdenum intervals

Copper (%)	Molybdenum (%)				
	0– 0.05	0.05–0.1	0.1–0.15	0.15–0.2	>0.2
0–0.1	0.02	0.03	0.02	0.03	0.05
0.1–0.2	0.12	0.17	0.16	0.19	0.14
0.2–0.3	0.25	0.27	0.25	0.22	0.26
0.3–0.4	0.33	0.32	0.35	0.34	0.37
0.4–0.5	0.44	0.47	0.45	0.48	0.46
0.5–0.6	0.53	0.55	0.57	0.54	0.55
0.6–0.7	0.67	0.63	0.65	0.64	0.66
> 0.7	0.98	1.04	1.02	1.09	1.01

Table IV

Average grade of molybdenum for different copper and molybdenum intervals

Copper (%)	Molybdenum (%)				
	0–0.05	0.05–0.1	0.1–0.15	0.15–0.2	>0.2
0-0.1	0.004	0.052	0.104	0.152	0.216
0.1-0.2	0.034	0.064	0.120	0.190	0.228
0.2-0.3	0.022	0.056	0.132	0.182	0.254
0.3-0.4	0.062	0.084	0.116	0.188	0.276
0.4-0.5	0.012	0.070	0.108	0.182	0.238
0.5-0.6	0.024	0.078	0.140	0.164	0.304
0.6-0.7	0.028	0.058	0.124	0.170	0.240
> 0.7	0.018	0.076	0.126	0.172	0.256

Table V

Economic parameters

Parameter	Unit	Quantity
Mine capacity	Tons per year	2500000
Mill capacity	Tons per year	1000000
Refining capacity (copper)	Tons per year	6000
Refining capacity (molybdenum)	Tons per year	1000
Mining cost	Dollars per tonne	1
Milling cost	Dollars per tonne	3.5
Refining cost (copper)	Dollars per tonne	88.5
Refining cost (molybdenum)	Dollars per tonne	254
Fixed costs	Dollars per year	790000
Price (copper)	Dollars per tonne	1700
Price (molybdenum)	Dollars per tonne	6700
Recovery (copper)	%	82
Recovery (molybdenum)	%	82
Discount rate	%	20

According to Figure 1, the objective function of this problem (v_e) is unimodal and the Golden Section search method can be used.

Based up on grade–tonnage distribution (Table II), the initial uncertainty interval for copper cutoff grade is 0,0.7 and initial uncertainty interval for molybdenum cutoff grade is 0,0.2 therefore:

$$L_1 = 0 \quad U_1 = 0.7 \quad L_2 = 0 \quad U_2 = 0.2$$

Considering Equations [19] to [22], the possible space for optimum point yield:

$$a_1 = 0 + (0.7 - 0) \times 0.382 = 0.2674$$
$$a_2 = 0 + (0.7 - 0) \times 0.618 = 0.4326$$
$$b_1 = 0 + (0.2 - 0) \times 0.382 = 0.0764$$
$$b_2 = 0 + (0.2 - 0) \times 0.618 = 0.1236$$

Thus the four test points in the first iteration are:

$$(0.2674,\ 0.0764),\ (0.2674,\ 0.1236),$$
$$(0.4326,\ 0.0764),\ (0.4326,\ 0.1236)$$

In the next step, calculate the amount of ore, the amount of waste, the average grade of ore for each metal, the amount of total mined material, the amount of mined material must be sent to the concentrator, the amount of metals product of refinery 1 and 2 and calculate the amount of V_m, V_c, V_{r1}, V_{r2} and V_e (objective function) for each four test points. Table VI shows the result of these calculations.

Among the four test points, point (0.2674, 0.0764) is the optimum point. Therefore the boundaries of the new search space are:

$$L_1 = 0 \quad U_1 = 0.4326 \quad L_2 = 0 \quad U_2 = 0.1236$$

By repeating this process, optimum cutoff grades can be found with desirable accuracy. In this example it is assumed that a cutoff grade with accuracy of 0.001% is desired. For finding cutoff grades with 0.001 per cent accuracy, the operation is repeated. Table VII shows the result of repeat operations for the first year of mine life. Optimum cutoff grades are obtained after 15 iterations (4 + 14 × 3 = 46 test points). According to these calculations, for the first year of mine life optimum the cutoff grades of copper will be 0.3441% and the optimum cutoff grade of molybdenum will be 0.0254%.

After doing calculations for the first year of mine life, the grade tonnage curve of the deposit must be adjusted. To do this, ore tonnes in the first year of mine life from the grade distribution intervals above optimum cutoff grades and waste tonnes in the first year of mine life from the grade distribution intervals below optimum cutoff grades should be subtracted. These calculations will be repeated until the end of mine life. The output obtained in these calculations gives the cutoff grade policy and the production schedule as shown in Table III.

Conclusion

One of the important parameters of open-pit mine design is determination of cutoff grade. The cutoff grade is used to find the destination of material to be mined. In multiple metal deposits none of the common methods such as critical level, equivalent grade and net smelter revenue methods is an optimized technique, because in these methods the distribution of grade of mined material, mining operation capacity and the effect of time on money value are not considered. The

Table VI

Objective function value (V_e) in four test points at first iteration

Test point	Objective function value
(0.2674, 0.0764)	13 400 582
(0.2674, 0.1236)	7 263 290
(0.4326, 0.0764)	10 043 473
(0.4326, 0.1236)	5 176 957

Table VII

Result of repeat operations for first year of mine life

Iteration	Cutoff grades		Objective function (v_e)
	Copper (%)	Molybdenum (%)	
1	0.2674	0.0764	13400582
	0.2674	0.1236	7263290
	0.4326	0.0764	10043473
	0.4326	0.1236	5176957
2	0.1652	0.0472	15609347
	0.1652	0.0764	14557106
	0.2674	0.0472	16886550
	0.2674	0.0764	13400582
3	0.2674	0.0292	16336005
	0.2674	0.0472	16886550
	0.3305	0.0292	18010784
	0.3305	0.0472	15404960
4	0.3305	0.0180	16949965
	0.3305	0.0292	18010784
	0.3695	0.0180	17467282
	0.3695	0.0292	16555937
5	0.3064	0.0292	17299971
	0.3064	0.0361	17904442
	0.3305	0.0292	18010784
	0.3305	0.0361	17167138
6	0.3305	0.0249	17637253
	0.3305	0.0292	18010784
	0.3454	0.0249	18026841
	0.3454	0.0292	17557996
7	0.3454	0.0223	17838465
	0.3454	0.0249	18026841
	0.3546	0.0223	17816747
	0.3546	0.0249	17679804
8	0.3397	0.0249	17905342
	0.3397	0.0265	18041904
	0.3454	0.0249	18026841
	0.3454	0.0265	17875922
9	0.3362	0.0265	17946174
	0.3362	0.0276	18030117
	0.3397	0.0265	18041904
	0.3397	0.0276	17978534
10	0.3397	0.0259	17990464
	0.3397	0.0265	18041904
	0.3419	0.0259	18049111
	0.3419	0.0265	18015664
11	0.3419	0.0255	18017498
	0.3419	0.0259	18049111
	0.3432	0.0255	18053530
	0.3432	0.0259	18036136
12	0.3432	0.0253	18034062
	0.3432	0.0255	18053530
	0.3441	0.0253	18056247
	0.3441	0.0255	18047846
13	0.3441	0.0252	18044244
	0.3441	0.0253	18056247
	0.3446	0.0252	1804554
	0.3446	0.0253	18052363
14	0.3437	0.0253	18047794
	0.3437	0.0254	18055211
	0.3441	0.0253	18056247
	0.3441	0.0254	18061286
15	0.3441	0.0254	18061286
	0.3441	0.0255	18058403
	0.3442	0.0254	18057018
	0.3442	0.0255	18050509

methodology outlined in this paper is Golden Section search method. This method provides a fast procedure to determine the optimum cutoff grades for multiple metal deposits. For this purpose hypothetical data of one Cu/Mo ore deposit was used to find the optimum cutoff grades and maximize the present value. The total deposit is assumed to be 15 million tonnes. Based on the Golden Section method and grade-tonnage distribution, the uncertainty space of problem was found. By selecting test points in the uncertainty space and calculating the amount of ore, amount of waste, average grade of ore for each metal, amount of total mined material, amount of mined material that must be sent to the concentrator, amount of metals product of refinery 1 and 2, amount of V_m, V_c, V_{r1}, V_{r2} and V_e (objective function) for each four test points were determined. Based on the result of the objective function at these points, a part of the uncertainty space can be eliminated. These operations were continued until the optimum cutoff grades (0.001%) were found with high desirable accuracy .

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Table VIII

Optimum cutoff grades for different years of mine life

Year	cutoff grade		Qm	Qc	Qr1	Qr2	Profit	NPV
	Copper (%)	Molybdenum (%)	(tonne)	(tonne)	(tonne)	(tonne)	($)	($)
1	0.3441	0.0254	2500000	1000000	5979	953	8990988	31058889
2	0.3382	0.0257	2462121	1000000	5945	948	8937434	28279583
3	0.3256	0.0218	2282898	1000000	5776	919	8657884	24998065
4	0.2683	0.0218	1986094	1000000	5324	900	8104657	21339794
5	0.2450	0.0172	1814563	1000000	5132	863	7729465	17503096
6	0.1242	0.0162	1523546	1000000	4577	838	6966054	13274251
7	0.0917	0.0104	1378169	1000000	4358	800	6512926	8963047
8	0.0714	0.0034	1052609	857348	3520	644	5091277	4242731

Sasol director appointed chairperson to the National Science and Technology Forum*

The NSTF Executive Committee and its stakeholders are proud to announce the appointment of John Marriott as the new chairperson of the NSTF from 1 June 2003. Marriott succeeds Dr S.J. Lennon, who successfully served as Chairperson of the NSTF for the past three years.

Marriott, is currently a director of Sasol Technology and is also the general manager of Sasol Ltd. A chemical engineer by training, he has spent several years at the highest level in the corporate world and has simultaneously maintained an outstanding reputation in the technical world. He has forged close associations with higher education institutions in South Africa, where his management skills and technical expertise helped provide marked insights into alliances between education and industry to ensure the provision of technical and scientific skills.

The NSTF welcomes Marriott as the chairperson of the NSTF and looks forward to his expertise in issues of science, engineering and technology to ensure continued growth of the discipline in South Africa. Marriott stated that he was honoured by the appointment and looked forward to being able to contribute to the activities of the NSTF.

The NSTF wishes both Lennon and Marriott success in their new challenges in uplifting the economic growth through science, engineering and technology. ◆

* *Issued by: Office of the Chief Executive Officer, National Science and Technology Forum (NSTF)*
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Thuthuka Project Managers commissions its first project with Outokumpu*

The recent commissioning of the cleaner flotation plant at Botswana's BCL Mine (Bamangwato Concessions Limited) near Selebi Phikwe marked several firsts for Thuthuka project managers.

Last year, Thuthuka was granted the tender for the upgrade of the cleaner flotation plant at the concentrator plant. BCL is a copper/nickel-mining complex and one of Botswana's largest private employers.

Gerhard Bezuidenhout was the Thuthuka project manager in charge of the upgrade to BLC's cleaner flotation plant. The full scope of the project involved the supply and installation of the cleaner flotation plant as part of a larger upgrade of the concentrator plant as a whole. The overall aim of the upgrade was to reduce spillage and increase economic mineral recovery within the concentrator plant.

Bezuidenhout says, 'This project was a very exciting one for Thuthuka for several reasons. Firstly, this is the first metallurgical processing plant of this nature that Thuthuka has managed as a turnkey project and secondly, this is Thuthuka's first venture with Outokumpu and we're very pleased to have established a good working relationship with one of South Africa's leading suppliers of flotation equipment.

'Outokumpu had previously supplied flotation cells to Tati Nickel, a Lin Ore and Botswanan company that owns BCL, so it was the natural extension of an existing relationship for them to partner us on this project.'

Thuthuka Project Managers won the tender to project manage the upgrade, while BCL Limited selected Outokumpu as the main process equipment supplier, sub-contracting to Thuthuka.

As the main turnkey contractor on the project, Thuthuka Project Managers was responsible for the civil, structural steel, piping, electrical and sections of the instrumentation contracts. As the project manager, Bezuidenhout carried overall responsibility for the project's execution. Other responsibilities included engineering and procurement, document control, progress control, scheduling, cost control, quality assurance and control, and reporting and liaising with BLC project personnel. 'It should be noted that the assistance of the BLC project personnel was of a high quality and contributed to the success of the project,' adds Bezuidenhout.

Bezuidenhout concludes, 'The BCL flotation plant represents the first association between Thuthuka and Outokumpu, and we're certain that the success achieved will result in future joint ventures. ◆

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