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Full Length Research Paper

Influence of some economic parameters on cut-off grade and ore reserve determination at Itakpe iron ore deposit, North central Nigeria

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Optimum determination of cut-off grade and ore reserve of a deposit is critical to a viable operation of an open-pit mine. The controlling variables in the determination of cut-off grade and ore reserve are the price of iron ore concentrate and its production cost. This paper studies the influence of changes in price and production cost of concentrate on cut-off grade and ore reserve determination of Itakpe Iron Ore Deposit, North Central Nigeria. The study utilizes graphical and mathematical models to show the relationship between cut-off grades and ore reserves at Itakpe Mine with changing price-cost ratios. It concludes that management of National Iron Ore Mining Company Limited Itakpe should promptly react to changes in price-cost ratios by lowering cut-off grades with increasing price-cost ratio or by increasing cut-off grade with decreasing price-cost ratio. This will subsequently determine the ore reserve of the deposit.

Keywords: Economic parameter, Ore reserve, Deposit, Cut-off grade, Ore concentrate, Cost ratio.

INTRODUCTION

Ct-off grade can be defined as the grade at which potential revenue balances all costs (Camisani *et al).* Alwyn (1991) observed that no profit margin is built in the above definition. However, if "all costs" may include the cost of capital, then the above definition can be justified. Further more, it is necessary to define or state succinctly the components of "all costs" in Camisani's definition. Consequently, in relation to open- pit mining, cut-off grade can be defined as the minimum grade at which the value of the ore balances all costs on mining, waste removal, mineral processing, and smelting, together with the administrative costs attached to the above unit operations, and leave the corporate organization with at least, a minimum corporate rate of return.

The above definition shows that cut-off grade depends on factors which are very susceptible to changes. The prices of mineral commodities have been volatile over the past years. So also are the cost of mining equipment, consumables, salaries and wages and even the cost of capital, which affect corporate acceptable rate of return on investment. On its own part, the cut-off grade affects the mineable ore reserve of a deposit. When cut-off grade increases, the tonnage of ore reserve that can be included as mineable ore reserve is reduced (Gerald, 1992). When cut-off grade decreases more tonnage of ore among the lower grade ores can now be regarded as mineable ore and thus ore reserve increases. Proper assessment and consideration of the above factors in mine planning and design will lead to the optimum operation of Itakpe mine. In particular, it is essential to foresee into the future how variability of economic factors will affect future operations of the mine. Knowledge of this will affect the mode of operation of the company, their strategic management plan, and the economy of the mining venture as a whole.

METHODOLOGY

The geologic reserve of Itakpe deposit is about 200mt. This geologic reserve is made up of 14 layers with varying tonnages and grades. Table 1 below, shows the various ore layers, their tonnages and grades.

In order to assess the influence of price and cost changes on grade-tonnage relationship, the mathematical

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Table 1. Ore layers, their tonnage and grade at Itakpe iron ore deposit

EAST PIT

Ore Layers	Ore Layer Index	Grade %	Tonnage mt
Northern	N_1	34.19	15.49
Northern	N_2	37.88	31.58
Northern	N_3	35.01	5.22
Intermediate	I_1	29.5	0.95
Intermediate	I_2	34.95	3.6
Intermediate	I_3	36.44	10.68
Central	C_1	40.95	6.2
Central	C_2	29.88	9.54
Central	C_3	34.42	20.1
Central	C_4	37.037	32
Southern	S_1	38.68	2.8
Southern	S_2	36.45	4.41
Southern	S_3	18.2	3.8
Total reserve of east pit			147.04mt

WEST PIT

Ore Layers	Ore Layer Index	Grade %	Tonnage mt
Northern	N_1	25.3	3.8
Northern	N_2	15.8	2.5
Northern	N_3	14.8	5.6
Intermediate	I_1	15.8	2.8
Intermediate	I_2	20.6	3.6
Intermediate	I_3	34.7	4.5
Central	C_1	20.5	2.27
Central	C_2	18.7	5.6
Central	C_3	17.8	7.6
Southern	S_1	20.8	2.6
Southern	S_2	28.6	3.6
Southern	S_3	24.4	4.6
Total reserve of east pit			49.27mt

(SOURCE: NIOMCO Project Report, 1980)

model for cut-off grade estimation will be utilized.

As defined above, cut-off grade is the minimum grade of ore at which the value of the smelted ore will balance all cost in mining, waste removal, mineral processing and smelting and leave the corporate output with at least a minimum acceptable level of profit.

Value of smelted ore

$V = F_g \times M_R \times P_m$

Where

F_g - Grade of ore

M_R - Metallurgical recovery

P_m - Price per ton of smelted ore

Total production cost

$T = (C_m + (S_R \times W) + C_p + C_s)$

Where

C_m = Cost of mining per ton of ore including haulage and administrative costs.

S_R = Stripping ratio

W = Stripping cost per ton of waste including administrative cost.

C_p= Cost of mineral processing per ton of ore including administrative costs.

C_s = Cost of smelting per ton of ore including administrative costs.

If the corporate outfit is to make a minimum acceptable rate of return r%, then production cost plus profit margin:

$Tp = (1+r/100) (C_m + (S_R \times W) + C_p + C_s)$

By definition:

$F_c. M_R. P_m = (1+r/100) (C_m + (S_R \times W) + C_p + C_s)$

Where

F_c = Cut-off grade

Or

$$F_c = \frac{(1 + r/100)(C_m + (S_R \times W) + C_p + C_s)}{M_R \times P_m} \quad (4)$$

The above: formula is a modified form of the existing formula for cut-off ‘grade estimation (Alwyn, 1991). It

Table 2. Values of parameters for cut-off grade estimation of Itakpe deposit.

Parameter	r, %	YP_C,	₦	S_R, t/t	C_M, ₦	W, ₦	C_P, ₦
Value	25	0.48	12,000	4	300	200	280

Table 3. Decrease of cut-off grades with increasing prices of concentrates when yield and total production cost are constant.

Price N	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000	18,000	19,000	20,000
F_C, %	35.94	32.67	29.95	27.64	25.67	23.96	22.46	21.14	19.97	18.91	17.98

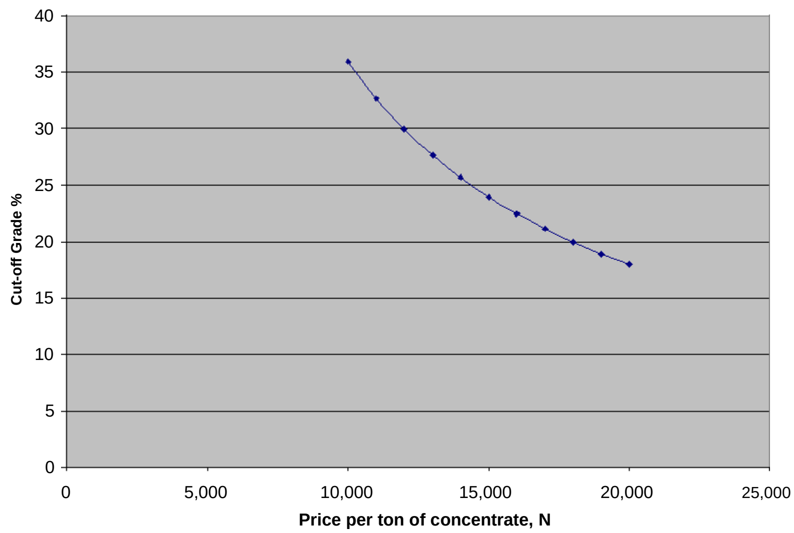

Figure 1. Lowering of cut-off grades with increasing price of concentrate when production cost and yield are constant

charges an acceptable rate of return on invested funds as well as separates mineral processing cost and smelting cost.

If a mining outfit does not own a smelting plant but merely exploits and beneficiates the run-of-mine ore and sells to smelting companies as it is the case with Itakpe, then formula (4) becomes:

$$F_C = \frac{(1 + r/100)\left(C_m + (S_R \; x \; W) + C_p + C_s\right)}{Y \, x \, P_c} \quad (5)$$

Where

Y = Concentrate yield per ton ore

P_c = Price per ton of concentrate

In both formula (4) and (5) the numerator represents the total production cost per ton of ore plus return on investment. Consequently, the cut-off grade can be re-written for formula (4) as:

$$F_C = \frac{Total \;\; production \;\; \cos t + \mathrm{RE}\, turn \;\; on \; Investment}{\mathrm{RE} \; \mathrm{cov} \; ery \;\; x \;\; \mathrm{PR} \; ice \;\; per \;\; ton \; of \;\; Smelted \;\; ore} \quad (6)$$

And for formula (5)

$$F_c = \frac{Total \;\; production \;\; \cos t + \mathrm{RE}\, turn \;\; on \; Investment}{Yield \; x \; \mathrm{PR} \; ice \; per \;\; ton \;\; of \, Concentrat \;\; e} \quad (7)$$

The return on investment component of the above formula means that the tonnage of ore that represent the cut-off grade must be exploited with a minimum corporate rate of return.

RESULTS AND DISCUSSIONS

Table 2 below shows the values of the parameters for Itakpe open-pit mire. The cost components were estimated as recommended by Alan *et al* (1992).

Using formula (5) cut-off grade of Itakpe deposit can be estimated as follows:

$$F_C = \frac{1.25(300 + (4 \, x \, 200) + 280)}{0.48 \, x \, 12{,}000} = 0.2995 \text{ or } 30\%$$

In general, cut-off grade varies with varying price-cost ratios. In special cases when either only the price varies or only the production cost varies, cut-off grade will vary accordingly. By utilizing formula (5) cutoff grades have been calculated for various price options when total cost of production and yield are constant. As can be seen from Table 3 and Figure 1 cut-off grade lowers with increasing price of concentrate. On the other hand, when price and yield are constant and total cost of production

Table 4. Increase of Fc with increasing total production cost when price and yield are constant

Cost N	1667	1692.3	1725	1742.6	1742	1748	1768	1983	1803	1853	1892
F_C, %	28.94	29	29.95	30.25	30.24	30.35	30.69	30.95	313	32.17	32.85

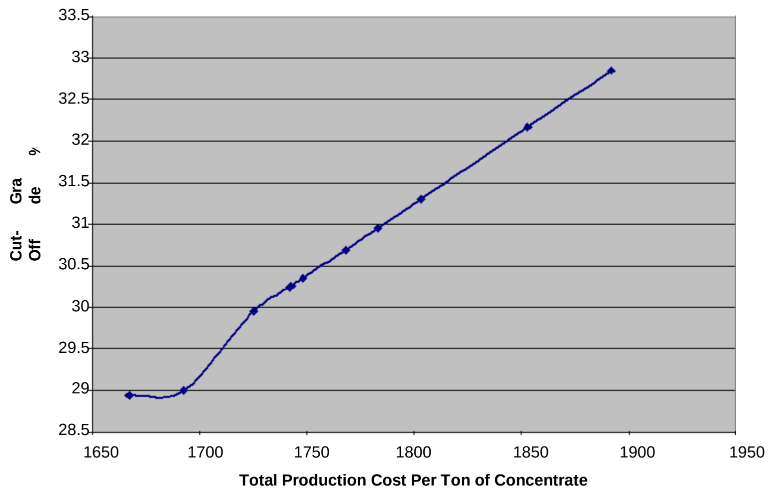

Figure 2. Increase of Fc with increasing total production cost when price of concentrate and yield are constant

Table 5. Showing varying prices and production costs but the same price-cost ratio

Price N	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000	18,000	19,000	20,000
Cost N	1333.38	1466.67	1600	1733.33	1866.67	2000	2133.33	2266.67	2400	2533.33	2666.67
P/C	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Fc,%	27.78	27.78	27.78	27.78	27.78	27.78	27.78	27.78	27.78	27.78	27.78

increases, cut-off grade increases (Table 4, Figure 2).

The more common situation is that both price and cost can change simultaneously. In such a case, (which is a more general case), it is more appropriate to calculate the cut-off grades for varying price-cost ratios. Provided that yield is constant, cut-off grades will lower with increasing price cost ratios and will increase with decreasing price-cost ratios. Irrespective of whatever value the price and total production cost may be, cut-off grade will be the same provided price-cost ratio does not change and yield is constant. The above statement can be proved using the mathematical model for cut-off grade estimation. Suppose the price per ton of concentrate is N15, 000 and total production cost is N2, 000 then price-cost ratio is 7.5. If the concentrate yield per ton of ore is 0.48; then, using formula 7, cut-off grade:

$$F_c = \frac{2000}{0.48x15000} x \frac{100}{1} = 27.28\%$$

If price per ton of concentrate changes to 4417,000 and total, production cost changes to N2, 267, (i.e. the price-cost ratio still remaining 7.5) while yields 0.48, then table 5 above shows the cut-off grade of ore at varying prices of concentrate and varying total production cost but the, same price-cost ratio. As can be seen, cut-off grade remains the same 27.78 %Fe even though prices and total production costs vary. The yield is constant as usual.

Since cut-off grade remains the same with varying prices and costs that generate the same price-cost ratio, then price-cost ratio can be plotted against cut-off grades and the plot can be used to ascertain graphically, the appropriate cut-off grade of the deposit by knowing the price-cost ratios. This is particularly useful when both price and cost of production are changing simultaneously. Table 6 below shows the cut-off grades at various price-cost ratios in the situation where both prices arid costs vary simultaneously.

In order to operate optimally, the National Iron Ore Mining Company Itakpe, needs to adjust its cut-off grade and mineable ore reserve with changing price-cost ratios. Table 7 shows the mineable ore reserves that Itakpe iron ore deposit can yield at the stated cut-off grades. When prices of concentrate and/or cost of production change to alter the existing price-cost ratio, the new

Table 6. Showing varying prices, cost, price-cost ratios and cut-off grades

Price N	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000	18,000	19,000	20,000
Cost N	1667	1692.3	1725	1742.6	1742	1748	1768	1783	1803	1853	1892
P/C	6.0	6.5	6.96	7.46	8.04	8.58	9.05	9.53	9.98	10.25	10.57
Fc,%	34.7	32.1	29.95	27.93	25.92	24.28	23.02	21.85	20.85	20.32	19.71

Table 7. Showing mineable ore reserves that can be generated by ore layers at Itakpe deposit, at various cut-off grades

FC%	34.19	29.88	29.5	28.6	25.3	24.4	20.8	20.6	20.5	18.7	18.2	17.8	15.8	14.8
Ore Reserve mt	137.25	146.79	147.74	151.34	155.14	159.94	162.54	166.14	168.41	174.01	177.81	185.41	190.71	196.31

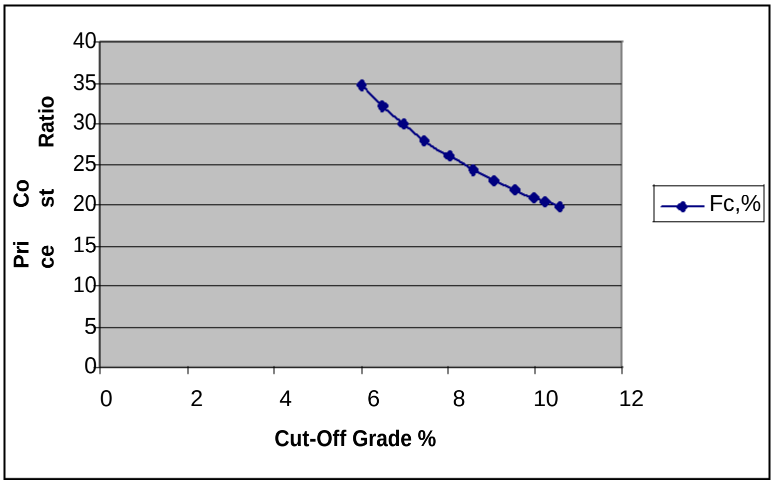

Figure 3. Cut-off grade at varying price-cost ratios

price- V cost ratio is used to ascertain the applicable cut-off grade in Figure 3. This applicable cut-off grade is used in Table 7 to obtain the new mineable ore reserve of Itakpe deposit that justifies investment. For example, suppose the price per ton of concentrate at Itakpe was N12, 000 and total production cost was N1725; at such economic indicators, Itakpe would be applying a cut-off grade of 29.95% (30%) as per Figure 3. If the price per ton of concentrates changes to N15, 000 and cost of production changes to N748, it means that price-cost ratio has changed from 6.96 to 8.58. From Figure 3, the new cut-off grade will be 24.28 %Fe. This can be established by tracing to the new cut-off grade that corresponds to a price-cost ratio of 8.58 in Figure 3. When the cut-off grade is established, this cut-off grade is used In Table 7 to obtain the new mineable ore reserve of Itakpe that will justify investment in the exploitation of the deposit. Care should be taken not to draw a graph with the data in Table 7 and attempt to interpolate to the exact ore reserve that corresponds to the new cut-off grade. This is because such an ore reserve may not be generated by the deposit given the tonnages and grades of the ore layers at Itakpe deposit. If the cut-off grade is not among those calculated in Table 7, then the ore reserve corresponding to the next higher cut-off grade in Table 7 should be chosen.

CONCLUSIONS

Increase in the price of concentrate lowers the cut-off grade of a deposit and increases the mineable ore reserve. On the other, hand increase in total: production cost increases the cut-off grade and decreases the mineable ore reserve of a deposit.

When the price of concentrate and total production cost change simultaneously (within a production period) to alter the existing price-cost ratio, the graph of price-cost ratio against cut-off grade is more suitable for estimating the new cut-off grade. In that case, the new price cost ratio is used to ascertain the applicable cut-off grade. The cut-off grade can then be used to determine the corresponding mineable ore reserve of the deposit. The Management of National Iron Ore Mining Company

Ltd, Itakpe can optimize their operations by reacting promptly to changes in price-cost ratios of iron ore concentrate. When price-cost ratio increases, cut-off grade should be lowered proportionately. When price-cost ratio decreases, cut-off grade should be increased.

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