Ore Production Optimization for Constant Grade of Run-of-Mine Feed to the Beneficiation Plant of National Iron Ore Mining Company, Itakpe, Nigeria

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Abstract: The National Iron Ore Mining Company Ltd currently operates five mining faces with grades varying from 34.19%Fe to 36.44%Fe. Non-proportionate exploitation from the five ore faces of the pit has led to non-stable grade of ore being fed to the beneficiation plant. The result is that the concentrate being produced continues to vary from 62%Fe to 65%Fe. This variation can affect contractual obligation of the steel company that procures the iron ore concentrate from the National Iron Ore Mining Company. In this paper, mathematical and excel solution have been applied to estimate annual production from each mine face which when blended together will ensure a stable feed of 36%Fe to the beneficiation plant. This will in turn ensure stable grade of concentrate coming out of Itakpe beneficiation plant.

1. INTRODUCTION

For efficient operation of a metallurgical plant, it is necessary that the plant be fed with constant grade of the concentrate coming from beneficiation plant. This is necessary not only to ensure stable energy utilisation by the plant for its longevity but also to ensure that the steel products are of the specified quality that will meet contractual obligations.

For beneficiation plant to produce concentrate of constant grade, it is required that the run-of-mine ore going to the beneficiation plant be maintained at constant grade. If the run-of-mine ores vary in grade, then the concentrate from the beneficiation plant will also vary in grade. But the ores coming from various faces of ore bodies in the mine are of various grades. Thus, it becomes necessary that the ores coming from the faces be blended (homogenized) in a blending yard in order to have an ore of uniform grade. The question is, what tonnage from each face should be mined so that when blended together, an ore of constant grade will be fed to the beneficiation plant.

The National Iron Ore Company Ltd Itakpe mines iron ore from an open-pit mine. The mineable grades of ore vary from 24%Fe to 41%Fe (Table 1)

Table1. Ore grades and reserve at Itakpe

Grade %	Tonnage mt
34.19	15.49
37.88	31.58
35.01	5.22
29.5	0.95
34.95	3.6
36.44	10.68
40.95	6.2
29.88	9.54
34.42	20.1
37.037	32
38.68	2.8
36.45	4.41
25.3	3.8
34.7	4.5
28.6	3.6
24.4	4.6

Source: NIOMCO Project Report, 1980

The five ore faces being extracted have a grade of 34.19%Fe, 37.88%Fe, 35.01%Fe, 36.44%Fe, 34.42%Fe respectively with a weighted average of 36%Fe.

The grade of concentrate being fed to Ajaokuta plant varied from 62–65%Fe (NIOMCO 2000). The essence of this research is therefore to find out the tonnage of each grade of ore coming from each mine face which when blended together will form a constant average grade of 36%Fe. This will ensure that a concentrate of constant grade is supplied to Ajaokuta Steel Plant to ensure not only the efficient operation of the plant but will also enable the company to meet her contractual obligation in terms of quality of steel products.

2. METHODOLOGY

The variables to be estimated are the tonnages of ores coming from the various faces. Their values must be such that when blended together, they must provide the grade going to the beneficiation plant as well as provide the annual planned output of the mine.

This can be done by putting forward an objective function with constraints (Sharma J.K 2013), (Rzhesky 1985).

The constraints are to ensure the following:

1. That the tonnage of ore from each face is more than zero i.e all the faces being operated must be involved in the mining operation and blending process.
2. That the sum of ores produced from all the faces annually must provide the designed production rate of the mine.
3. That the ores from various faces when homogenized (blended) must provide the 36%Fe going to the beneficiation plant.

The objective function and the constraints are captured in the following equations

2.1. Objective Function

$$F = \frac{r_1 q_1 + r_2 q_2 + r_3 q_3 + r_4 q_4 + r_5 q_5}{q_1 + q_2 + q_3 + q_4 + q_5}$$

Where;

$$q_1, q_2, q_3, q_4, q_5 =$$

Tonnage of ores required to be mined from each face (variable)

$$r_1, r_2, r_3, r_4, r_5 =$$

The respective grades of ores q_1, q_2, q_3, q_4, q_5 from each face annually.

The objective function above represents the weighted grade of ores coming from the various faces and should be equal to 36%Fe i.e the grade of ore required to be fed to beneficiation plant. Consequently the objective function can be re-written as

$$F = \frac{r_1 q_1 + r_2 q_2 + r_3 q_3 + r_4 q_4 + r_5 q_5}{q_1 + q_2 + q_3 + q_4 + q_5} = 36\%Fe$$

The variables must satisfy the following conditions (constraints)

$$q_1 > 0$$

$$q_2 > 0$$

$$q_3 > 0$$

$$q_4 > 0$$

$$q_5 > 0$$

$$q_1 + q_2 + q_3 + q_4 + q_5 \geq 5\text{mt}$$

Where;

$$5\text{mt} = \text{the scheduled annual production rate of Itakpe mine.}$$

3. RESULTS AND DISCUSSION

The National Iron Ore Mining Company is currently operating five faces along five ore bodies with respective grades and reserve as tabulated below

Table2. Grade and reserve of the five ore bodies being exploited

Grade %	Tonnage mt
34.19	15.49
37.88	31.58
35.01	5.22
36.44	10.68
34.42	20.1

Weighted grade of the five ore bodies is:

$$R = \frac{15.49 \times 34.19 + 31.58 \times 37.88 + 5.22 \times 35.01 + 10.68 \times 36.44 + 20.1 \times 34.42}{15.49 + 31.58 + 5.22 + 10.68 + 20.1} = 35.99 \approx 36\% \text{Fe}$$

This is the weighted grade of the five ore bodies which is the grade fed to beneficiation plant.

The objective function for blending the ores from the five ore bodies in Itakpe mine therefore becomes

$$F = \frac{34.19q_1 + 37.88q_2 + 35.01q_3 + 36.44q_4 + 34.42q_5}{q_1 + q_2 + q_3 + q_4 + q_5}$$

The objective function is not linear and contains five unknowns q_1, q_2, q_3, q_4, q_5 . Since the sum of all the ores coming from the five ore bodies must be equal to five million, the objective function can be made linear by transforming it as follows for excel solution

$$F = \frac{34.19q_1}{5} + \frac{37.88q_2}{5} + \frac{35.01q_3}{5} + \frac{36.44q_4}{5} + \frac{34.42q_5}{5}$$

$$F = 6.838q_1 + 7.576q_2 + 7.002q_3 + 7.288q_4 + 6.884q_5$$

The excel solution for the above is given in fig 1, in which

$$q_1 = 0.8\text{mt}, q_2 = 1.1\text{mt}, q_3 = 1\text{mt}, q_4 = 1.2\text{mt}, q_5 = 0.9\text{mt}$$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1		Q1	Q2	Q3	Q4	Q5	5				r1	r2	r3	r4	r5
2	Qty	0.8	1.1	1	1.2	0.9	Obj func.			Grade	34.19	37.88	35.01	36.44	34.42
3	Grade	6.838	7.576	7.002	7.288	6.884	35.7472								
4															
5	Constraint														
6		1	1	1	1	1	5	>=	5						
7	1	1					0.8	<=	0.8						
8	2		1				1.1	<=	1.1						
9	3			1			1	<=	1						
10	4				1		1.2	<=	1.2						
11	5					1	0.9	<=	0.9						
12	Non-neg														
13	Q1	1					0.8	>=	0						
14	Q2		1				1.1	>=	0						
15	Q3			1			1	>=	0						
16	Q4				1		1.2	>=	0						
17	Q5					1	0.9	>=	0						
18															
19															
20															
21															
22															
23															
24															

Fig1. Excel solution to the objective function

3.1. Verification

$$q_1 + q_2 + q_3 + q_4 + q_5 = 0.8 + 1.1 + 1 + 1.2 + 0.9 = 5\text{mt}$$

$$\text{Objective function} = \frac{34.19 \times 0.8 + 37.88 \times 1.1 + 35.01 \times 1 + 36.44 \times 1.2 + 34.42 \times 0.9}{0.8 + 1.1 + 1 + 1.2 + 0.9}$$

$$\frac{178.8}{5} = 35.76 \approx 36\% \text{Fe}$$

The weighted grade of ores required from each face is 35.76%Fe as against 35.99%Fe which is the weighted grade of the overall reserve from the five ore faces. The difference of 0.23%Fe can be explained in terms of the approximation of non-linear function to linear function. This can be corrected by setting $q_1=0.60\text{mt}$ and 1.3mt . The objective function can be verified again, that is;

$$F = \frac{34.19 \times 0.6 + 37.88 \times 1.3 + 35.01 \times 1 + 36.44 \times 1.2 + 34.42 \times 0.9}{0.8 + 1.1 + 1 + 1.2 + 0.9} = 35.9 \approx 36\% \text{Fe}$$

The table below summarise the required monthly, quarterly and annual tonnage coming from each face.

Table3. Summary of production requirement from each face to achieve 36%Fe

	q₁	q₂	q₃	q₄	q₅
Grade (%Fe)	34.19	37.88	35.01	36.44	34.42
Annual (mt)	0.6	1.3	1	1.2	0.9
Quarterly (mt)	0.15	0.325	0.25	0.3	0.225
Monthly (mt)	0.05	0.082	0.063	0.1	0.06

4. CONCLUSION

There should be proportionate exploitation of ores of various grades from the five faces representing five ore bodies currently being exploited. This is the only way to ensure 36%Fe ore grade as feed to beneficiation plant. Given the proportionate exploitation of the five ore bodies with various grades, proper blending at blending yard will ensure the supply of stable grade of 36%Fe to the beneficiation plant which in turn will ensure stable energy consumption regime and quality of steel products from Ajaokuta Steel Company Ltd, Nigeria.

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